ISPRA
Istituto Superiore per la Protezione
e la Ricerca Ambientale

Sistema Nazionale
per la Protezione
dell'Ambiente

Italian Greenhouse Gas Inventory 1990-2022 National Inventory Document 2024

ISPRA
Istituto Superiore per la Protezione e la Ricerca Ambientale

Sistema Nazionale per la Protezione dell'Ambiente

ITALIAN GREENHOUSE GAS INVENTORY 1990-2022

NATIONAL INVENTORY DOCUMENT 2024

ISPRA - Institute for Environmental Protection and Research
Via Vitaliano Brancati, 48 – 00144 Rome
www.isprambiente.gov.it

Graphic design
Cover design: Luisa Mortola
Cover image: Graphic elaboration from NASA Johnson ISS047e125942 Flickr photo ISS047e125942 taken from the International Space Station on 21/05/2016. Creative Commons CC BY-NC 2.0 DEED by Angela Fiore and Luisa Mortola

November 2024

Annual Report for submission under the UN Framework Convention on Climate Change and the Paris Agreement

Authors

Daniela Romano, Chiara Arcarese, Antonella Bernetti, Antonio Caputo, Marco Cordella, Riccardo De Lauretis, Eleonora Di Cristofaro, Andrea Gagna, Barbara Gonella, Federica Moricci, Guido Pellis, Ernesto Taurino, Marina Vitullo

INTRODUCTION
Daniela Romano
Riccardo De Lauretis
Chiara Arcarese

TRENDS IN GREENHOUSE GAS EMISSIONS
Daniela Romano

ENERGY
Riccardo De Lauretis
Ernesto Taurino
Daniela Romano (§3.5.1, §3.5.4)
Antonella Bernetti (§3.5)
Antonio Caputo (§3.9)
Marco Cordella (§3.5, §3.6)

INDUSTRIAL PROCESSES AND PRODUCT USE
Andrea Gagna
Barbara Gonella
Ernesto Taurino
Federica Moricci
Daniela Romano (§4.5, §4.8)

AGRICULTURE
Eleonora Di Cristofaro
Angela Fiore

LAND USE, LAND USE CHANGE AND FORESTRY
Marina Vitullo
Guido Pellis

WASTE
Barbara Gonella
Ernesto Taurino

RECALCULATIONS AND IMPROVEMENTS
Daniela Romano

ANNEXES
KEY CATEGORIES AND UNCERTAINTY

Daniela Romano
Antonio Caputo
Marina Vitullo

ENERGY CONSUMPTION FOR POWER GENERATION
Riccardo De Lauretis
Ernesto Taurino

ESTIMATION OF CARBON CONTENT OF COALS USED IN INDUSTRY
Ernesto Taurino

CO_2 REFERENCE APPROACH
Ernesto Taurino
Riccardo De Lauretis

NATIONAL EMISSION FACTORS
Antonio Caputo
Riccardo De Lauretis
Ernesto Taurino

AGRICULTURE SECTOR
Eleonora Di Cristofaro
Angela Fiore

THE NATIONAL REGISTRY
Chiara Arcarese

FOR-EST MODEL
Guido Pellis
Marina Vitullo

FOR-FIRES MODEL
Guido Pellis
Marina Vitullo

Contact: Daniela Romano
Telephone +39 0650072541
E-mail daniela.romano@isprambiente.it

ISPRA- Institute for Environmental Protection and Research
Environmental Assessment, Control and Sustainability Department
Emissions, Prevention of Atmospheric Impacts and Climate Change Area
Air Emission Inventory Unit
Via V. Brancati, 48 00144 Rome – Italy

INDICE

PREMESSA

Nell'ambito degli strumenti e delle politiche per fronteggiare i cambiamenti climatici, un ruolo fondamentale è svolto dal monitoraggio delle emissioni dei gas-serra.

A garantire la predisposizione e l'aggiornamento annuale dell'inventario dei gas-serra secondo i formati richiesti, in Italia, è l'ISPRA su incarico del Ministero dell'Ambiente e della Sicurezza Energetica, attraverso le indicazioni del Decreto Legislativo n. 51 del 7 marzo 2008 e del Decreto Legislativo n. 30 del 13 marzo 2013, che prevedono l'istituzione di un Sistema Nazionale, *National System*, relativo all'inventario delle emissioni dei gas-serra.

In più, come è previsto dalla Convenzione-quadro sui cambiamenti climatici, l'ISPRA documenta in uno specifico rapporto, il *National Inventory Report*, le metodologie di stima utilizzate, unitamente ad una spiegazione degli andamenti osservati.

Il *National Inventory Report* facilita i processi internazionali di verifica cui le stime ufficiali di emissione dei gas serra sono sottoposte. In particolare, viene esaminata la rispondenza alle proprietà di trasparenza, consistenza, comparabilità, completezza e accuratezza nella realizzazione, qualità richieste esplicitamente dalla Convenzione suddetta. L'inventario delle emissioni è sottoposto ogni anno ad un esame (*review*) da parte di un organismo nominato dal Segretariato della Convenzione che analizza tutto il materiale presentato dal Paese e ne verifica in dettaglio le qualità su enunciate.

Questo rapporto, e le relative tabelle, è la prima comunicazione dell'Italia che adempie agli obblighi dell'Accordo di Parigi per quel che riguarda l'inventario nazionale dei gas serra.

Il presente documento rappresenta, inoltre, un riferimento fondamentale per la pianificazione e l'attuazione di tutte le politiche ambientali da parte delle istituzioni centrali e periferiche. Accanto all'inventario dei gas-serra, l'ISPRA realizza ogni anno l'inventario nazionale delle emissioni in atmosfera, richiesto dalla Convenzione di Ginevra sull'inquinamento atmosferico transfrontaliero (UNECE-CLRTAP) e dalle Direttive europee sulla limitazione delle emissioni. In più, tutto il territorio nazionale è attualmente coperto da inventari regionali sostanzialmente coerenti con l'inventario nazionale, realizzati principalmente dalle Agenzie Regionali e Provinciali per la Protezione dell'Ambiente.

Nonostante i progressi compiuti, l'attività di preparazione degli inventari affronta continuamente nuove sfide legate alla necessità di considerare nuove sorgenti e nuovi inquinanti e di armonizzare gli inventari prodotti per diverse finalità di *policy*. Il contesto internazionale al quale fa riferimento la preparazione dell'inventario nazionale costituisce una garanzia di qualità dei dati, per l'autorevolezza dei riferimenti metodologici, l'efficacia del processo internazionale di *review* e la flessibilità nell'adattamento alle nuove circostanze.

EXECUTIVE SUMMARY

ES.1. Background information on greenhouse gas inventories and climate change

The United Nations Framework Convention on Climate Change (FCCC) was ratified by Italy in the year 1994 through law no.65 of 15/01/1994.
The Kyoto Protocol, adopted in December 1997, has established emission reduction objectives for Annex B Parties (i.e., industrialised countries and countries with economy in transition): in particular, the European Union as a whole was committed to an 8% reduction within the period 2008-2012, in comparison with base year levels. For Italy, the EU burden sharing agreement, set out in Annex II to Decision 2002/358/EC and in accordance with Article 4 of the Kyoto Protocol, had established a reduction objective of 6.5% in the commitment period, in comparison with 1990 levels.

A new global agreement was reached in Paris in December 2015, for the period after 2020. The agreement aims to strengthen the global response to the threat of climate change by holding the increase in the global temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impact of climate change. On 5th October 2016, the threshold for entry into force of the Paris Agreement was achieved and the Paris Agreement entered into force on 4th November 2016.

To fulfil the gap 2013-2020, the 'Doha Amendment to the Kyoto Protocol' was adopted on 8th December 2012.

The EU and its Member States had committed to this second phase of the Kyoto Protocol and established to reduce their collective emissions to 20% below their levels in 1990 or other chosen base years; this was also reflected in the Doha Amendment. The target was to be fulfilled jointly with Iceland.

Italy was in compliance with the targets of both the Kyoto phases.

As a Party to the Convention and the Paris Agreement, Italy is committed to develop, publish and regularly update national emission inventories of greenhouse gases (GHGs) as well as formulate and implement programs to reduce these emissions.

In order to establish compliance with national and international commitments, the national GHG emission inventory is compiled and communicated annually by the Institute for Environmental Protection and Research (ISPRA) to the competent institutions, after endorsement by the Ministry of the Environment, (now, MASE). The submission is carried out through compilation of the Common Reporting Tables (CRT), according to the guidelines provided by the United Nations Framework Convention on Climate Change. As a whole, an annual GHG inventory submission shall consist of a national inventory report (NID) and the common reporting tables (CRTs) as specified in the Annex of Decision 18/CMA.1, Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement FCCC/PA/CMA/2018/3/Add.2.

Detailed information on emission figures and estimation procedures, including all the basic data needed to carry out the final estimates, is to be provided to improve the transparency, consistency, comparability, accuracy, and completeness of the inventory provided.
The national inventory is updated annually to reflect revisions and improvements in the methodology and use of the best information available. Adjustments are applied retrospectively to earlier years, which accounts for any difference in previously published data.

This report provides an analysis of the Italian GHG emission inventory from 1990 to 2022.

Emission estimates comprise the seven direct greenhouse gases under the Convention (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride, nitrogen trifluoride) which contribute directly to climate change owing to their positive radiative forcing effect and four indirect greenhouse gases (nitrogen oxides, carbon monoxide, non-methane volatile organic compounds, sulphur dioxide). Italy uses the 100-year time-horizon global warming potential values, excluding the value for fossil methane, listed in Table 8.A.1 in the contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change[1], following COP27 decision taken in 2022 on the 'Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention'.

This report, the CRT files and other related documents are available on website at the address http://emissioni.sina.isprambiente.it/serie-storiche-emissioni/.

The official inventory submissions, up to the last year, can be found at the UNFCCC website https://unfccc.int/ghg-inventories-annex-i-parties/2022.

The present submission has been communicated to the UNFCCC and the European Union according to the Governance Regulation of the Energy Union and Climate Action; it is part of the Biennial Transparency Report (BTR) under the Enhanced Transparency Framework, and under the Paris Agreement and available on https://unfccc.int/first-biennial-transparency-reports.

ES.2. Summary of national emission and removal related trends

Total greenhouse gas emissions, in CO_2 equivalent, excluding emissions and removals from land use, land use change and forestry, decreased by 20.9% between 1990 and 2022 (from 522 to 413 million CO_2 equivalent tons).

The most important greenhouse gas, CO_2, which accounted for 82.7% of total emissions in CO_2 equivalent in 2022, showed a decrease by 22.3% between 1990 and 2022. CH_4 and N_2O emissions were equal to 11.1% and 3.8%, respectively, of the total CO_2 equivalent greenhouse gas emissions in 2022. Both gases showed a decrease from 1990 to 2022, equal to 16.8% and 35.7% for CH_4 and N_2O, respectively. Other greenhouse gases, HFCs, PFCs, SF_6 and NF_3, ranged from less than 0.01% to 2.2% of total emissions.

Table ES.1 illustrates the national trend of greenhouse gases for 1990-2022, expressed in CO_2 equivalent terms, by substance and category.

[1] IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. TF Stocker, D Qin, G-K Plattner, et al. (eds.). Cambridge and New York: Cambridge University Press. Available at http://www.ipcc.ch/report/ar5/wg1.

Table ES.1. Total greenhouse gas emissions and removals in CO_2 equivalent [kt CO_2 eq]

GHG emissions	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
					kt CO_2 equivalent					
CO_2 excluding net CO_2 from LULUCF	438,208	448,596	469,598	501,366	435,701	361,246	339,641	302,614	335,920	340,904
CO_2 including net CO_2 from LULUCF	432,937	424,242	448,286	466,925	395,419	318,828	301,380	274,409	310,024	318,796
CH_4 excluding CH_4 from LULUCF	54,971	57,026	57,698	54,806	52,874	49,370	46,685	47,402	47,036	45,714
CH_4 including CH_4 from LULUCF	55,691	57,196	58,098	54,973	53,071	49,518	46,787	47,588	47,525	46,072
N_2O excluding N_2O from LULUCF	24,475	26,416	27,183	26,337	18,305	17,101	16,897	17,570	17,457	15,738
N_2O including N_2O from LULUCF	25,383	27,212	27,872	26,925	18,707	17,436	17,354	18,090	18,076	16,288
HFCs	372	1,100	3,747	9,666	12,805	12,082	11,089	9,971	9,411	9,085
PFCs	2,615	1,351	1,363	1,759	1,377	1,529	915	499	395	439
Unspecified mix of HFCs and PFCs	NO,NA	24	24	24	24	24	23	22	25	22
SF_6	421	700	621	565	405	483	438	252	282	390
NF_3	NA,NO	77	13	33	20	28	18	16	15	20
Indirect CO_2 emissions	1,311	1,211	1,073	1,041	860	692	786	705	740	728
Total (excluding LULUCF)	**522,373**	**536,500**	**561,322**	**595,598**	**522,371**	**442,557**	**416,493**	**379,051**	**411,282**	**413,041**
Total (including LULUCF)	**518,730**	**513,112**	**541,099**	**561,913**	**482,687**	**400,621**	**378,791**	**351,552**	**386,495**	**391,842**

GHG categories	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
					kt CO_2 equivalent					
1. Energy	426,167	438,670	460,484	488,344	429,916	359,981	336,404	300,064	332,164	337,877
2. Industrial Processes and Product Use	37,946	36,299	38,240	47,132	36,591	29,094	27,330	24,290	25,300	23,620
3. Agriculture	37,953	38,312	37,430	35,028	32,634	32,455	32,314	33,534	32,862	30,764
4. LULUCF	-3,643	-23,388	-20,223	-33,685	-39,684	-41,935	-37,702	-27,499	-24,787	-21,199
5. Waste	18,996	22,008	24,094	24,052	22,371	20,334	19,659	20,458	20,215	20,052
6. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Indirect CO_2 emissions	1,311	1,211	1,073	1,041	860	692	786	705	740	728
Total (including LULUCF)	**518,730**	**513,112**	**541,099**	**561,913**	**482,687**	**400,621**	**378,791**	**351,552**	**386,495**	**391,842**

ES.3. Overview of source and sink category emission estimates and trends

The energy sector is the largest contributor to national total GHG emissions with a share, in 2022, of 81.8%. Emissions from this sector decreased by 20.7% from 1990 to 2022. Substances with decrease rates were CO_2, whose levels reduced by 20% from 1990 to 2022 and accounts for 96.9% of the total in the energy sector, and CH_4 which showed a reduction of 50% but its share out of the sectoral total is only 1.9%; N_2O showed a decrease of 1.6% from 1990 to 2022, accounting for 1.2%. Specifically, in terms of total CO_2 equivalent, an increase in emissions was observed only in the transport sector (32.5% of the total energy emissions), equal to 7.4% from 1990 to 2022.

The industrial processes and process use sector accounts for 5.7% of total emissions excluding LULUCF. Emissions from the sector showed a decrease of 37.8% from 1990 to 2022. Specifically, by substance, CO_2 emissions account for 55.7% and showed a decrease by 53.0%, CH_4 decreased by 92.5%, but it accounts only for 2% in 2022, while N_2O, whose levels share 1.9% of total industrial emissions, decreased by 92.5%. The decrease in emissions is mostly due to a decrease in the chemical industry (due to the fully operational abatement technology in the adipic acid industry) and mineral and metal production emissions. A considerable increase was observed in F-gases emissions, whose level on total sectoral emissions is about 42.2%.

The agriculture sector accounts for 7.4% of total emissions excluding LULUCF. Emissions refer mainly to CH_4 and N_2O levels, which account for 67.7% and 31.5% of the sectoral total, respectively; CO_2, on the other hand, shares only 0.8% of the total. The decrease observed in the total level of emissions (-18.9%) is mostly due to the decrease of CH_4 emissions from enteric fermentation (-15.4%), which account for 47.1% of sectoral emissions and to the decrease of N_2O from agricultural soils (-22.5%), which accounts for 25.9% of sectoral emissions.

As regards land use, land-use change and forestry, from 1990 to 2022 total removals in CO_2 equivalent considerably increased; CO_2 accounts for almost the total emissions and removals of the sector (96.1%).

Finally, emissions from the waste sector, contributes to 4.9% to total emissions without LULUCF; their level increased by 5.6% from 1990 to 2022, mainly due to an increase in the emissions from solid waste disposal on land (13.9%), which account for 77.6% of waste emissions. The most important greenhouse gas in this sector is CH_4 which accounts for 91.8% of the sectoral emissions and shows an increase of 6.3% from 1990 to 2022. N_2O emission levels increased by 31.0%, whereas CO_2 decreased by 77.8%; these gases account for 7.6% and 0.6% in the sector, respectively.

Indirect CO_2 emissions refer to the atmospheric oxidation of NMVOC emissions from solvents and other products use. These emissions have decreased by 44.5% since 1990, the main reason being reduced use of solvent chemicals in industry.

Table ES.2 provides an overview of the CO_2 equivalent emission trends by IPCC source category.

Table ES.2. Summary of emission trends by source category and gas in CO_2 equivalent [kt CO_2 eq.]

Category	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
					kt CO_2 equivalent					
A. Energy: fuel combustion	**411,964**	**425,294**	**448,394**	**477,728**	**420,239**	**351,304**	**329,440**	**293,871**	**326,508**	**332,826**
CO_2: 1. Energy Industries	*136,941*	*139,941*	*144,273*	*159,227*	*136,885*	*105,486*	*91,235*	*81,213*	*86,009*	*94,410*
CO_2: 2. Manufacturing Industries and Construction	*90,773*	*88,970*	*94,894*	*90,787*	*68,890*	*54,542*	*48,972*	*44,907*	*53,491*	*53,701*
CO_2: 3. Transport	*100,319*	*111,531*	*121,642*	*126,780*	*114,626*	*105,589*	*105,234*	*85,639*	*101,847*	*108,654*
CO_2: 4. Other Sectors	*76,042*	*75,580*	*79,169*	*92,324*	*90,908*	*77,684*	*76,235*	*74,593*	*77,246*	*68,336*
CO_2: 5. Other	*1,071*	*1,496*	*837*	*1,233*	*652*	*459*	*453*	*625*	*314*	*511*
CH_4	*2,735*	*3,023*	*2,762*	*2,573*	*3,522*	*3,353*	*3,273*	*3,124*	*3,449*	*3,194*
N_2O	*4,083*	*4,753*	*4,817*	*4,804*	*4,756*	*4,190*	*4,037*	*3,770*	*4,152*	*4,021*
1B2. Energy: fugitives from oil & gas	**14,203**	**13,376**	**12,090**	**10,616**	**9,676**	**8,677**	**6,964**	**6,193**	**5,656**	**5,051**
CO_2	*4,048*	*4,002*	*3,262*	*2,557*	*2,377*	*2,574*	*2,756*	*2,112*	*1,816*	*1,799*
CH_4	*10,145*	*9,363*	*8,818*	*8,047*	*7,289*	*6,094*	*4,200*	*4,074*	*3,832*	*3,244*
N_2O	*11*	*10*	*11*	*12*	*11*	*9*	*8*	*7*	*8*	*8*
2. Industrial processes	**37,946**	**36,299**	**38,240**	**47,132**	**36,591**	**29,094**	**27,330**	**24,290**	**25,300**	**23,609**
CO_2	*27,992*	*26,049*	*24,743*	*27,663*	*20,804*	*14,355*	*14,230*	*12,932*	*14,621*	*13,134*
CH_4	*144*	*150*	*82*	*83*	*67*	*48*	*46*	*38*	*45*	*39*
N_2O	*6,402*	*6,848*	*7,646*	*7,338*	*1,088*	*545*	*570*	*559*	*505*	*480*

Category	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
					kt CO_2 equivalent					
HFCs	*372*	*1,100*	*3,747*	*9,666*	*12,805*	*12,082*	*11,089*	*9,971*	*9,411*	*9,085*
PFCs	*2,615*	*1,351*	*1,363*	*1,759*	*1,377*	*1,529*	*915*	*499*	*395*	*439*
Unspecified mix of HFCs and PFCs	*NO,NA*	*24*	*24*	*24*	*24*	*24*	*23.15*	*22.37*	*25.33*	*22.13*
SF_6	*421*	*700*	*621*	*565*	*405*	*483*	*438*	*252*	*282*	*390*
NF_3	*NA,NO*	*77*	*13*	*33*	*20*	*28*	*17.94*	*16.24*	*15.23*	*19.56*
3. Agriculture	**37,953**	**38,312**	**37,430**	**35,028**	**32,634**	**32,455**	**32,314**	**33,534**	**32,862**	**30,764**
CO_2: Liming	*1*	*1*	*2*	*14*	*18*	*14*	*16*	*10*	*26*	*4*
CO_2: Urea application	*465*	*512*	*525*	*507*	*335*	*425*	*396*	*472*	*414*	*218*
CO_2: Other carbon-containing fertilizers	*44*	*54*	*44*	*42*	*28*	*20*	*17*	*21*	*22*	*12*
CH_4: Enteric fermentation	*17,093*	*16,697*	*16,509*	*14,484*	*14,100*	*14,272*	*14,584*	*14,771*	*14,695*	*14,487*
CH_4: Manure management	*5,424*	*5,161*	*5,122*	*5,248*	*5,088*	*5,017*	*4,873*	*4,880*	*4,787*	*4,791*
CH_4: Rice Cultivation	*2,102*	*2,228*	*1,855*	*2,078*	*2,255*	*1,943*	*1,721*	*1,696*	*1,677*	*1,547*
CH_4: Field Burning of Agricultural Residues	*15*	*15*	*15*	*13*	*9*	*9*	*8*	*8*	*9*	*8*
N_2O: Manure management	*2,518*	*2,408*	*2,330*	*2,148*	*2,079*	*1,868*	*1,809*	*1,804*	*1,767*	*1,722*
N_2O: Agriculture soils	*10,288*	*11,233*	*11,024*	*10,490*	*8,720*	*8,886*	*8,888*	*9,868*	*9,463*	*7,972*
N_2O: Field Burning of Agricultural Residues	*4*	*4*	*4*	*3*	*2*	*2*	*2*	*2*	*2*	*2*
4A. Land-use change and forestry	**-3,643**	**-23,388**	**-20,223**	**-33,685**	**-39,684**	**-41,935**	**-37,702**	**-27,499**	**-24,787**	**-21,199**
CO_2	*-5,271*	*-24,353*	*-21,312*	*-34,440*	*-40,282*	*-42,418*	*-38,261*	*-28,205*	*-25,895*	*-22,108*
CH_4	*720*	*170*	*400*	*168*	*196*	*148*	*101*	*186*	*489*	*358*
N_2O	*908*	*796*	*689*	*587*	*402*	*335*	*457*	*520*	*619*	*550*
6. Waste	**18,996**	**22,008**	**24,094**	**24,052**	**22,371**	**20,334**	**19,659**	**20,458**	**20,215**	**20,052**
CO_2	*512*	*458*	*208*	*230*	*177*	*99*	*96*	*89*	*114*	*114*
CH_4	*17,313*	*20,390*	*22,536*	*22,279*	*20,545*	*18,634*	*17,980*	*18,810*	*18,540*	*18,404*
N_2O	*1,171*	*1,160*	*1,350*	*1,543*	*1,649*	*1,601*	*1,583*	*1,559*	*1,561*	*1,534*
Indirect CO_2 emissions	**1,311**	**1,211**	**1,073**	**1,041**	**860**	**692**	**786**	**705**	**740**	**728**
Total emissions (with LULUCF)	***518,730***	***513,112***	***541,099***	***561,913***	***482,687***	***400,621***	***378,791***	***351,552***	***386,495***	***391,842***
Total emissions (without LULUCF)	***522,373***	***536,500***	***561,322***	***595,598***	***522,371***	***442,557***	***416,493***	***379,051***	***411,282***	***413,041***

ES.4. Other information

In Table ES.3 NO_X, CO, NMVOC and SO_2 emission trends from 1990 to 2022 are summarised. All gases showed a significant reduction in 2022 as compared to 1990 levels. The highest reduction is observed for SO_2 (-95%), while NO_X and CO emissions reduced by about 70.7% and 72.2%, respectively; NMVOC levels showed a decrease by 58.2%.

Table ES.3. Total emissions of indirect greenhouse gases and SO_2 [kt]

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
					kt					
NO_X	2,128	1,992	1,522	1,296	958	749	670	598	611	624
CO	6,823	7,117	4,813	3,502	3,076	2,282	2,042	1,861	2,032	1,894
NMVOC	1,970	2,040	1,616	1,322	1,100	891	871	815	847	823

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
					kt					
SO_2	1,784	1,323	757	411	222	128	112	85	79	88

Sommario (Italian)

Nel documento "Italian Greenhouse Gas Inventory 1990-2022. National Inventory Document 2024" si descrive la comunicazione annuale italiana dell'inventario delle emissioni dei gas serra in accordo a quanto previsto nell'ambito della Convenzione Quadro sui Cambiamenti Climatici delle Nazioni Unite (UNFCCC) e all'Accordo di Parigi. Tale comunicazione è anche trasmessa all'Unione Europea nell'ambito del Regolamento 'Governance Regulation of the Energy Union and Climate Action'.

Ogni Paese che partecipa alla Convenzione, infatti, oltre a fornire annualmente l'inventario nazionale delle emissioni dei gas serra secondo i formati richiesti, deve documentare in un *report*, il *National Inventory Document*, la serie storica delle emissioni. La documentazione prevede una spiegazione degli andamenti osservati, una descrizione dell'analisi delle sorgenti principali, *key sources*, e dell'incertezza ad esse associata, un riferimento alle metodologie di stima e alle fonti dei dati di base e dei fattori di emissione utilizzati per le stime, un'illustrazione del sistema di *Quality Assurance/Quality Control* a cui è soggetto l'inventario e delle attività di verifica effettuate sui dati.

Il *National Inventory Document* facilita, inoltre, i processi internazionali di verifica cui le stime di emissione dei gas serra sono sottoposte al fine di esaminarne la rispondenza alle proprietà di trasparenza, consistenza, comparabilità, completezza e accuratezza nella realizzazione, qualità richieste esplicitamente dalla Convenzione suddetta. Nel caso in cui, durante il processo di *review*, siano identificati eventuali errori nel formato di trasmissione o stime non supportate da adeguata documentazione e giustificazione nella metodologia scelta, il Paese viene invitato ad una revisione delle stime di emissione.

I dati di emissione dei gas-serra, i rapporti *National Inventory Report*, così come i risultati dei processi di *review*, fino al 2023, sono pubblicati sul sito web del Segretariato della Convenzione sui Cambiamenti Climatici (https://unfccc.int/ghg-inventories-annex-i-parties/2023; https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/inventory-review-reports/inventory-review-reports-2022).

La presente comunicazione, completa del rapporto National Inventory Document e delle tabelle di stima dall'anno 1990 al 2022 (*Common Reporting Tables* – CRTs), è la prima sotto l'Accordo di Parigi. I documenti sono pubblicati sul sito https://unfccc.int/first-biennial-transparency-reports.

La serie storica nazionale delle emissioni è anche disponibile sul sito web all'indirizzo: http://emissioni.sina.isprambiente.it/serie-storiche-emissioni/.

Da un'analisi di sintesi della serie storica dei dati di emissione dal 1990 al 2022, si evidenzia che le emissioni nazionali totali dei sei gas serra, espresse in CO_2 equivalente, sono diminuite del 20.9% nel 2022 rispetto al 1990. In particolare, le emissioni complessive di CO_2 sono pari all'82.7% del totale e risultano nel 2022 inferiori del 22.3% rispetto al 1990. Le emissioni di metano e di protossido di azoto sono pari a circa l'11.1% e il 3.8% del totale, rispettivamente, e presentano andamenti in diminuzione sia per il metano (-16.8%) che per il protossido di azoto (-35.7%). Gli altri gas serra, HFC, PFC, SF_6 e NF_3, hanno un peso complessivo sul totale delle emissioni che varia tra lo 0.01% e il 2.2%; le emissioni degli HFC evidenziano una forte crescita, mentre le emissioni di PFC decrescono e quelle di SF_6 e NF_3 mostrano un incremento. Sebbene tali variazioni non siano risultate determinanti ai fini del conseguimento degli obiettivi di riduzione delle emissioni, la significatività del trend degli HFC potrebbe renderli sempre più importanti nei prossimi anni.

1 INTRODUCTION

1.1 Background information on greenhouse gas inventories and climate change

In 1988 the World Meteorological Organisation (WMO) and the United Nations Environment Program (UNEP) established a scientific Intergovernmental Panel on Climate Change (IPCC) to evaluate the available scientific information on climate variations, examine the social and economic influence on climate change and formulate suitable strategies for the prevention and the control of climate change.

The first IPCC report in 1990, although considering the high uncertainties in the evaluation of climate change, emphasised the risk of global warming due to an imbalance in the climate system originated by the increase of anthropogenic emissions of greenhouse gases (GHGs) caused by industrial development and use of fossil fuels. The scientific knowledge on climate change has firmed up considerably by the IPCC Fifth Assessment Report on global warming which states that "Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems." and "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen." Hence the need to reduce those emissions, particularly for the most industrialised countries.

The first initiative was taken by the European Union (EU) at the end of 1990, when the EU adopted the goal of stabilisation of carbon dioxide emissions by the year 2000 at the level of 1990 and requested Member States to plan and implement initiatives for environmental protection and energy efficiency. The contents of EU statement were the base for the negotiation of the United Nations Framework Convention on Climate Change (UNFCCC) which was approved in New York on 9th May 1992 and signed during the summit of the Earth in Rio de Janeiro in June 1992. Parties to the Convention are committed to develop, publish and regularly update national emission inventories of greenhouse gases (GHGs) as well as formulate and implement programs addressing anthropogenic GHG emissions. Specifically, Italy ratified the convention through law no.65 of 15/1/1994.

On 11/12/1997, Parties to the Convention adopted the Kyoto Protocol, which establishes emission reduction objectives for Annex B Parties (i.e., industrialised countries and countries with economy in transition) in the period 2008-2012. The European Union, as a whole, was committed to an 8% reduction within the period 2008-2012, in comparison with base year levels; for Italy, the EU burden sharing agreement, set out in Annex II to Decision 2002/358/EC and in accordance with Article 4 of the Kyoto Protocol, established a reduction objective of 6.5% in the commitment period, in comparison with the base 1990 levels.

Italy ratified the Kyoto Protocol on 1st June 2002 through law no.120 of 01/06/2002. The ratification law also prescribes the preparation of a National Action Plan to reduce greenhouse gas emission, which was adopted by the Interministerial Committee for Economic Planning (CIPE) on 19th December 2002 (deliberation n. 123 of 19/12/2002). The Kyoto Protocol entered into force on 16th February 2005.

The first commitment period ended in 2012, with an extension, for fulfilling commitments, to 18th November 2015, the so called *true-up period*.

In 2012 the 'Doha Amendment to the Kyoto Protocol was adopted in relation to the period 2013-2020, including new commitments for Annex I Parties to the Kyoto Protocol and a revised list of GHGs to be reported on by Parties in the second commitment period.

During the second commitment period, Parties committed to reduce GHG emissions by at least 18% below 1990 levels in the eight-year period from 2013 to 2020. The EU and its Member States had committed to the 'Doha Amendment to the Kyoto Protocol', pledging to reduce their collective emissions to 20% below their levels in 1990 during the period 2013-2020, as reflected in the Doha Amendment. The target was to be fulfilled jointly with Iceland. Italy deposited its instrument of ratification on 18 July 2016 and the amendment entered into force on 31 December 2020, following ratification by 147 Parties.

The EU had jointly fulfilled its UNFCCC target and implemented it internally through EU legislation in the 2020 Climate and Energy package, adopted in 2009. In the package, in order to achieve the 20% reduction in 2020 compared to 1990, the EU divided the effort between the sectors covered by the EU Emissions Trading System (EU ETS) and the sectors under the Effort Sharing Decision (ESD). Legally binding target trajectories for the period 2013-2020 were enshrined in both the EU-ETS Directive (Directive 2003/87/EC and respective amendments) and the Effort Sharing Decision. The Effort Sharing Decision had set annual national emission targets for all Member States for the period 2013-2020 for those sectors[2], excluding LULUCF, not covered by the EU emissions trading system (ETS). For Italy, the target included in the Effort Sharing Decision is equal to a GHG emissions reduction by 13% compared to 2005 levels.

The UNFCCC1/CMP.17 decision, adopted at the Sharm el Sheik Conference in December 2022, set the deadline for the conclusion of the fulfilment of the Doha commitments by 2023, considering that the UNFCCC expert review process (under Article 8 of the Protocol) of the emission inventories for the last year of the commitment period (2020) was to be completed by 1 June 2023. This timeline was met as all reviews were published by that date. In the same decision, a 100-day '*True-up period*' was foreseen, which ended on 9 September 2023. Italy has fulfilled its reduction commitments under the agreement. The final report on the review of the report upon expiration of the additional period for fulfilling commitments for the second commitment period of the Kyoto Protocol of Italy is published on the UNFCCC website: https://unfccc.int/documents/637791.

A global agreement was reached in Paris in December 2015, for the period after 2020. The Paris Agreement, entered into force in 2016, aims at strengthening the global response to the threat of climate change by holding the increase in the global temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase below 1.5°C above pre-industrial levels, as this would significantly reduce the risks and impact of climate change. To achieve this long-term temperature goal, Parties aim to reach global peaking of GHG emissions as soon as possible and undertake rapid reductions to achieve a balance between anthropogenic GHG emissions and removals in the second half of this century. In this framework, the European Union set a binding target to cut its emissions by at least 55% below 1990 levels by 2030, including the Land Use, Land-Use Change and Forestry (LULUCF) sector.

A part of the emission reduction target is divided among the sectors subject to the Emission Trading System (ETS), for which a 62% reduction from 2005 levels is required at European level. For the remaining, non-ETS share, new and more ambitious national targets were defined with the approval of the Fit for 55 package (Regulation (EU) 2023/857). Italy is required an overall reduction of 43.7% in emissions compared to 2005 levels for the sectors and categories included in the EU Effort Sharing Regulation (ESR, i.e., transport, residential, agriculture, waste and industry not included under ETS). Within this framework commitments for Land use, Land-Use Change, and Forestry (LULUCF) were also revised, defined in Regulation (EU) 839/2023 LULUCF: the target for 2030 is a net removal equal to, at least, -35.8Mt CO_2 eq. Annual binding national targets, both under ESR and LULUCF EU regulations will be fixed in 2025, following the EU review process of the 2025 GHG inventory submission.

As a Party to the Convention and the Paris Agreement, Italy is committed to develop, publish and regularly update national emission inventories as well as formulate and implement programs to reduce these emissions. In order to establish compliance with national and international commitments, air emission inventories are compiled and communicated annually to competent institutions.

[2] transport, buildings, agriculture, non-ETS industry and waste sectors

Specifically, the national GHG emission inventory is communicated through compilation of the Common Reporting Tables (CRTs), according to the guidelines provided by the United Nations Framework Convention on Climate Change.

The inventory is updated annually in order to reflect revisions and improvements in methodology and availability of new information. Recalculations are applied retrospectively to earlier years, which account for any difference in previously published data. The submission also provides for detailed information on emission figures and estimation methodologies in the annual National Inventory Report.

As follows, this report is compiled according to the guidelines on reporting as specified in the document FCCC/PA/CMA/2018/3/Add.2, Decision 18/CMA.1. Italy, as well as all EU Member States, uses the 100-year time-horizon global warming potential values, excluding the value for fossil methane, listed in table 8.A.1 in the contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change[3], following the COP27 decision taken in 2022 on the 'Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention'.

An analysis of the Italian GHG emission inventory for the year 2022, and a revision of the entire time series from 1990, communicated in the framework of the annual submission under the UNFCCC, is provided in the document.

Emission estimates comprise the six direct greenhouse gases (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride) plus nitrogen trifluoride (NF_3) which contribute directly to climate change owing to their positive radiative forcing effect and four indirect greenhouse gases (nitrogen oxides, carbon monoxide, non-methane volatile organic compounds, sulphur dioxide).

The CRT files, the national inventory document and other related documents are available at the address http://emissioni.sina.isprambiente.it/serie-storiche-emissioni/.

Information on accounts, legal entities, holdings and transactions is publicly available at: http://www.info-ets.isprambiente.it/index.php?p=publicinfo.

The internet address of the Italian registry is:

https://ets-registry.webgate.ec.europa.eu/euregistry/IT/index.xhtml.

The official inventory submissions can also be found at the UNFCCC website:

https://unfccc.int/first-biennial-transparency-reports.

The present document is the official submission, for the year 2024, both to the UNFCCC and to the European Union according to the Governance Regulation of the Energy Union and Climate Action; it is part of the Biennial Transparency Report (BTR) under the Enhanced Transparency Framework, under the Paris Agreement and available on https://unfccc.int/first-biennial-transparency-reports.

[3] IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. TF Stocker, D Qin, G-K Plattner, et al. (eds.). Cambridge and New York: Cambridge University Press. Available at http://www.ipcc.ch/report/ar5/wg1.

1.2 Description of the institutional arrangement for inventory preparation

1.2.1 National Inventory System

The National System for the Italian Greenhouse Gas Inventory was established by the Legislative Decree 51 of March 7th 2008 and confirmed by the Legislative Decree 30 of March 13th 2013.

Article 5.1 of the Kyoto Protocol established that Annex I Parties should have in place a National System from the end of 2006 for estimating anthropogenic greenhouse gas emissions by sources and removals by sinks and for reporting and archiving inventory information according to the guidelines specified in the UNFCCC Decision 20/COP.7. This decision is updated by Decision 24/CP19, which calls the system national inventory arrangements but does not change the basic requests of functionality and operability.

The 'National Registry for Carbon sinks', instituted by a Ministerial Decree on 1st April 2008, is part of the Italian National System. In agreement with the Ministerial decree art. 4, the Ministry for the Environment, Land and Sea is responsible for the management of the National Registry for Carbon sinks. The Decree also provides that ISPRA and the former State Forestry Service, now Carabinieri Forestali, are involved by the Ministry as technical scientific support for specific activities as defined in the relevant protocol. ISPRA is responsible for the preparation of emission and removals estimates for the LULUCF sector. Following an update of the abovementioned Ministerial Decree, in 2013, the Institute for Services on Agricultural and Agro-food Market (ISMEA[4]) has been designated for the technical coordination of the section related to cropland and grassland of the National Registry of Carbon Sinks.

In March 2006 Italy started operating a national registry under the European Emission Trading Scheme (EU ETS). Eventually, in June 2012 all national registries of the EU Member States as well as the national registries of Norway, Liechtenstein and Iceland were grouped in a single central software system managed by the European Commission.

According to Legislative Decree N. 47 of 9 June 2020, enforcing European Directive 2018/410/EC, ISPRA is responsible for the administration of the Italian part of the Union Registry; the Institute performs this task under the supervision of the National Competent Authority.

ISPRA is also responsible for the national system for policies, measures and emissions and, in cooperation with the Ministry of the Environment (MASE), collects all the information and data from the competent Ministries. Article 1 of the Decree implementing law N. 79 (9th December 2016), reports the list of information and data that are to be sent by the competent ministries to MASE and ISPRA and also the timing for providing such information. With the establishment of this system, there has been a strengthening of roles and obligations for statistical data flow, some of which are useful for the inventory scope.

The Italian National System, currently in place, is fully described in the document 'National Greenhouse Gas Inventory System in Italy' (ISPRA, 2018). A summary picture is reported herebelow.

As indicated by art. 14 bis of the Legislative Decree, the Institute for Environmental Protection and Research (ISPRA) is the single entity in charge of the preparation and compilation of the national greenhouse gas emission inventory. The MASE is responsible for the endorsement of the inventory and for communication to the Secretariat of the Framework Convention on Climate Change. The inventory is also submitted to the European Commission.

The Institute prepares a document which describes the national system including all updated information on institutional, legal and procedural arrangements for estimating emissions and removals of greenhouse gases and for reporting and archiving inventory information. The document is updated when there is the

[4] ISMEA is a public body, providing support to public and private sector. According to DPR 31 March 2001, n. 200, ISMEA is part of the National Statistical System – SISTAN and of the National Agricultural Information System – SIAN.

need to describe an annual change occurred in the system. The reports are publicly available at http://emissioni.sina.isprambiente.it/serie-storiche-emissioni/.

A specific unit of the Institute is responsible for the compilation of the Italian Greenhouse Gas Inventory and the Italian Atmospheric Emission Inventory in the framework of the Convention on Climate Change and the Convention on Long Range Transboundary Air Pollution, respectively. The whole inventory is compiled by the Institute.

ISPRA is responsible for the general administration of the inventory and all aspects related to its preparation, reporting and quality management. Activities include the collection and processing of data from different data sources, the selection of appropriate emissions factors and estimation methods consistent with the IPCC Guidelines, the compilation of the inventory following the QA/QC procedures, the assessment of uncertainty, the preparation of the National Inventory Document and the reporting through the Common Reporting Table, the response to the review process, the updating and data storage. Scientific and technical institutions and consultants may be engaged for ad hoc studies and research aimed at improving both activity data and emission factors, at country level, for some specific activities. Also, there are different institutions responsible for statistical basic information and data publication, primary to ISPRA for carrying out estimates. These institutions are part of the National Statistical System (Sistan), which periodically provides official statistics at national level; moreover, the National Statistical System ensures the homogeneity of the methods used for official statistics through a coordination plan, involving the entire public administration at central, regional and local levels.

The National Statistical System is coordinated by the Italian National Institute of Statistics (ISTAT); other bodies, joining the National Statistical System, are the statistical offices of ministries, national agencies, regions and autonomous provinces, provinces, municipalities, research institutes, chambers of commerce, local governmental offices, some private agencies and private subjects who have specific characteristics determined by law. The Italian statistical system was instituted on 6th September 1989 by the Legislative Decree n. 322/89, which established guiding principles and criteria for reforming public statistics. A national statistical plan which defines surveys, data elaborations and project studies for a three-year period is to be drawn up and updated annually. The plan is approved by a Prime Ministerial Decree after consideration of the Interministerial Committee for Economic Planning (CIPE). Statistical information and results deriving from the completion of the plan are of public domain and the system is responsible for wide circulation.

Ministries, public agencies and other bodies are obliged to provide the data and information specified in the annual statistical plan; the same obligations regard the private entities. All the data are protected by the principles of statistical disclosure control and can be distributed and communicated only at aggregate level even though microdata can circulate among the subjects of the Statistical System.

Sistan activity is supervised by the Commission for Guaranteeing Statistical Information (CGIS) which is an external and independent body. In particular, the Commission supervises: the impartiality and completeness of statistical information, the quality of methodologies, the compliance of surveys with EU and international directives. The Commission, established within the Presidency of the Council of Ministers, is composed of high-profile university professors, directors of statistical or research institutes and managers of public administrations and bodies, which do not participate at Sistan.

The main Sistan products, which are primarily necessary for inventory compilation, are:

- National Statistical Yearbooks, Monthly Statistical Bulletins, by ISTAT (National Institute of Statistics);
- Annual Report on the Energy and Environment, by ENEA (Agency for New Technologies, Energy and the Environment);
- National Energy Balance (annual), Petrochemical Bulletin (quarterly publication), by MASE (Ministry of Economic Development);

- Transport Statistics Yearbooks, by MIT (Ministry of Transportation);
- Annual Statistics on Electrical Energy in Italy, by TERNA (National Independent System Operator);
- Annual Report on Waste, by ISPRA;
- National Forestry Inventory, by "Carabinieri Forestali"[5] .

The national emission inventory is also a Sistan product.

Other information and data sources are used to carry out emission estimates, which are generally referred to in Table 1.1 of the following section 1.4.

1.3 Brief description of the process of inventory preparation

ISPRA has established fruitful cooperation with several governmental and research institutions as well as industrial associations, which helps improving the accuracy of the estimates of some leading categories of the inventory. These activities aim at the improvement of provision and collection of basic data and emission factors, through plant-specific data, and exchange of information on scientific studies and new sources. Moreover, when in depth investigation is needed and a high uncertainty in the estimates is present, ISPRA may commit specific sector studies to ad hoc research teams or consultants.

The final aim is for ISPRA to improve the implementation of country specific methodologies and use of national emission factors and parameters.

ISPRA also coordinates with different national and regional authorities and private institutions for the cross-checking of parameters and estimates as well as with ad hoc expert panels in order to improve the completeness and transparency of the inventory. The main basic data needed for the preparation of the GHG inventory are energy statistics published by the Ministry of the Environment, in the National Energy Balance (BEN), statistics on industrial and agricultural production published by the National Institute of Statistics (ISTAT), statistics on transportation provided by the Ministry of Transportation, and data supplied directly by the relevant professional associations.

Emission factors and methodologies used in the estimation process are consistent with the IPCC Guidelines and supported by national experiences and circumstances.

In addition to a new year, the entire time series from 1990 is checked and revised during the annual compilation of the inventory to meet the requirements of transparency, consistency, comparability, completeness and accuracy of the inventory. Measures to guarantee and improve these qualifications are undertaken and recalculations should be considered as a contribution to the overall improvement of the inventory.

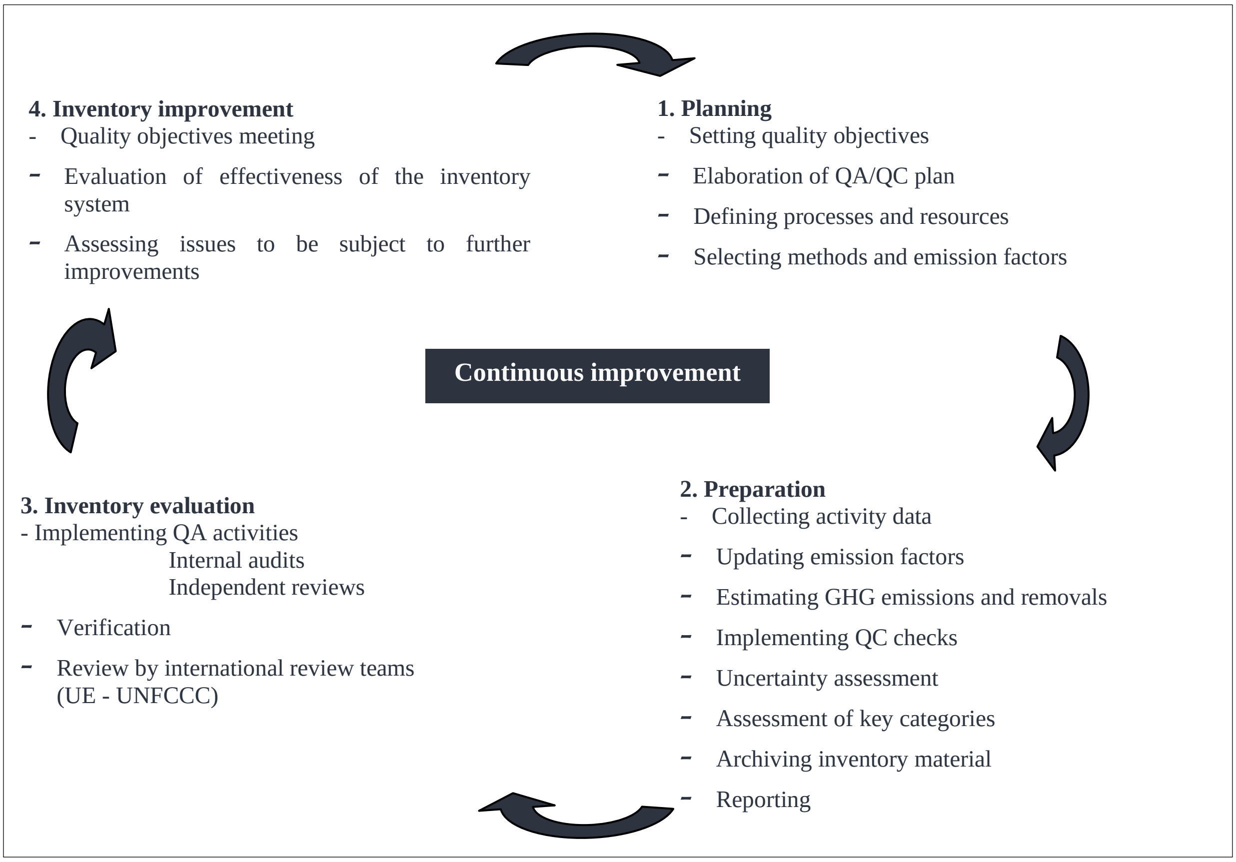
Recalculations are elaborated on account of changes in the methodologies used to carry out emission estimates, changes due to different allocation of emissions as compared to previous submissions and changes due to error corrections. The inventory may also be expanded by including categories not previously estimated if sufficient information on activity data and suitable emission factors have been identified and collected.

Information on the major recalculations is provided every year in the sectoral and general chapters of the national inventory reports.

In Figure 1.1 the most important steps to guarantee the continuous improvement of the national GHG emission inventory are outlined.

[5] http://www.carabinieri.it/arma/oggi/organizzazione/organizzazione-per-la-tutela-forestale-ambientale-e-agroalimentare

Figure 1.1 National Greenhouse Gas Inventory: annual inventory process



All the reference material, estimates and calculation sheets, as well as the documentation on scientific papers and the basic data needed for the inventory compilation, are stored and archived at the Institute. After each reporting cycle, all database files, spreadsheets and electronic documents are archived as 'read-only-files' so that the documentation and estimates could be traced back during the review process or the new inventory compilation year.

Technical reports and emission figures are publicly available on the website at the address:

https://emissioni.sina.isprambiente.it/inventario-nazionale/.

1.4 Brief general description of methodologies and data sources used

A detailed description of methodologies and data sources used in the preparation of the emission inventory for each sector is outlined in the relevant chapters. In Table 1.1, a summary of the activity data and sources used in the inventory compilation is reported.

Methodologies are consistent with the IPCC Guidelines and EMEP/EEA Guidebooks (IPCC, 2003; IPCC, 2006; EMEP/CORINAIR, 2007; EMEP/EEA, 2019); national emission factors are used as well as default emission factors from international guidebooks, when national data are not available. The development of national methodologies is supported by background documents.

In Table 1.2, a summary of the methods and emission factors used in the compilation of the Italian inventory is reported.

Table 1.1 Main activity data and sources for the Italian Emission Inventory

SECTOR	ACTIVITY DATA	SOURCE
1 Energy 1A1 Energy Industries	Fuel use	Energy Balance - Ministry of Environment Major national electricity producers European Emissions Trading Scheme
1A2 Manufacturing Industries and Construction	Fuel use	Energy Balance - Ministry of Environment Major National Industry Corporation European Emissions Trading Scheme
1A3 Transport	Fuel use Number of vehicles Aircraft landing and take-off cycles and maritime activities	Energy Balance - Ministry of Environment Statistical Yearbooks - National Statistical System Statistical Yearbooks - Ministry of Transportation Statistical Yearbooks - Italian Civil Aviation Authority (ENAC) Maritime and Airport local authorities
1A4 Residential-public-commercial sector	Fuel use	Energy Balance - Ministry of Environment
1B Fugitive Emissions from Fuel	Amount of fuel treated, stored, distributed	Energy Balance - Ministry of Environment Statistical Yearbooks - Ministry of Transportation Major National Industry Corporation
2 Industrial Processes and Product Use	Production data	National Statistical Yearbooks- National Institute of Statistics International Statistical Yearbooks-UN European Emissions Trading Scheme European Pollutant Release and Transfer Register Sectoral Industrial Associations
3 Agriculture	Agricultural surfaces Production data Number of animals Fertiliser consumption	Agriculture Statistical Yearbooks - National Institute of Statistics Sectoral Agriculture Associations
4 Land Use, Land Use Change and Forestry	Forest area, biomass increment and stock Biomass burnt	Carabinieri - National and Regional Forestry Inventory Statistical Yearbooks - National Institute of Statistics Universities and Research Institutes
5 Waste	Amount of waste	National Waste Cadastre - Institute for Environmental Protection and Research , National Waste Observatory

Table 1.2 Methods and emission factors used in inventory preparation

SUMMARY 3 SUMMARY REPORT FOR METHODS AND EMISSION FACTORS USED

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO_2		CH_4		N_2O		HFCs		PFCs		SF_6		Unspecified mix of HFCs and PFCs		NF_3	
	Meth	EF	Meth	EF	Meth	EF	Meth	EF	Meth	EF	Meth	EF	Meth	EF	Meth	EF
1. Energy	T1,T2,T3	CS,D,M	T1,T2, T3	CR,CS, D,M	T1,T2,T3	CR,D,M										
A. Fuel combustion	T1,T2,T3	CS,M	T1,T2, T3	CR,D, M	T1,T2,T3	CR,D,M										
1. Energy industries	T3	CS	T3	CR,D	T3	CR,D										
2. Manufacturing industries and construction	T2	CS	T2	CR,D	T2	CR,D										
3. Transport	T1,T2	CS,M	T1,T2, T3	CR,D, M	T1,T2,T3	CR,D,M										
4. Other sectors	T2	CS	T2	CR	T2	CR										

5. Other	T2	CS	T2	CR	T2	CR										
B. Fugitive emissions from fuels	T1,T2	CS,D	T1,T2	CR,CS,D	T1	D										
1. Solid fuels			T1,T2	CR,D												
2. Oil and natural gas	T1,T2	CS,D	T1,T2	CR,CS,D	T1	D										
C. CO_2 transport and storage																
2. Industrial processes	D,T1,T2,T3	CR,CS,D,M,PS	D,T1	CR,CS,D	CS,T3	CS,D,PS	CS,T2	CS,D,PS	CS,T2	CS,PS	CS,T2	CS,PS	CS	PS	T2	CS
A. Mineral industry	T2	CS,PS														
B. Chemical industry	D,T2,T3	CR,PS	D,T1	CR,CS,D	T3	D,PS	CS	PS	CS	PS						
C. Metal industry	T2	CR,CS,PS	D	CS,D			T2	PS								
D. Non-energy products from fuels and solvent use	T1,T2	D,M,PS														
E. Electronic industry							T2	CS	T2	CS	T2	CS	CS	PS	T2	CS
F. Product uses as ODS substitutes							T2	CS,D								
G. Other product manufacture and use					CS	CS					CS,T3	CS,PS				
H. Other																
3. Agriculture	T1	D	T1,T2	CS,D	D,T1,T2	CS,D										
A. Enteric fermentation			T1,T2	CS,D												
B. Manure management			T1,T2	CS,D	T2	CS,D										
C. Rice cultivation			T2	CS												
D. Agricultural soils[(3)]					T1	CS,D										
E. Prescribed burning of savannas																
F. Field burning of agricultural residues			T1	CS,D	T1	CS,D										
G. Liming	T1	D														
H. Urea application	T1	D														
I. Other carbon-containing fertilizers	T1	D														
J. Other																
4. Land use, land-use change and forestry	T1,T2,T3	CS,D	T1,T2	CS,D	T1,T2	CS,D										
A. Forest land	T1,T2,T3	CS,D	T2	CS,D	T2	CS,D										
B. Cropland	T1,T2	CS,D	T1	D	T1	D										
C. Grassland	T1,T2,T3	CS,D	T1	CS	T1	CS										

D. Wetlands																
E. Settlements	T1	D			T1	D										
F. Other land																
G. Harvested wood products	T2	CS														
H. Other																
5. Waste	D,T1	CS,D	D,T1 ,T2	CR,CS, D	D,T1	CR,CS,D										
A. Solid waste disposal			T2	CS												
B. Biological treatment of solid waste			D	CS,D	D	D										
C. Incineration and open burning of waste	D,T1	CS,D	D,T1	CR,CS, D	D,T1	CS,D										
D. Waste water treatment and discharge			T1	D	T1	CR,D										
E. Other																
6. Other (as specified in summary 1.A)																

Use the following notation keys to specify the method applied:

D (IPCC default) **T1a, T1b, T1c** (IPCC Tier 1a, Tier 1b and Tier 1c, respectively) **CR** (CORINAIR) **M** (model)

RA (Reference Approach) **T2** (IPCC Tier 2) **CS** (Country Specific)

T1 (IPCC Tier 1) **T3** (IPCC Tier 3) **OTH** (Other)

If using more than one method within one source category, list all the relevant methods. Explanations regarding country-specific methods, other methods or any modifications to the default IPCC methods, as well as information regarding the use of different methods per source category where more than one method is indicated, should be provided in the documentation box. Also use the documentation box to explain the use of notation OTH.

Use the following notation keys to specify the emission factor used:

D (IPCC default) **CS** (Country Specific) **OTH** (Other)

CR (CORINAIR) **PS** (Plant Specific) **M** (model)

Where a mix of emission factors has been used, list all the methods in the relevant cells and give further explanations in the documentation box. Also use the documentation box to explain the use of notation OTH.

Activity data used in emission calculations and their sources are briefly described here below.

In general, for the energy sector, basic statistics for estimating emissions are fuel consumptions provided in the Energy Balance by the Ministry of Environment. Additional information for electricity production is supplied by the major national electricity producers and by the major national industry corporation. On the other hand, basic information for road transport, maritime and aviation, such as the number of vehicles, harbour statistics and aircraft landing and take-off cycles are published by the National Institute of Statistics and the Ministry of Transportation in the relevant statistical yearbooks. Other data are communicated by different category associations.

A lot of information on productions, fuel consumptions, emission factors and emissions in specific energy and industrial sub sectors is obtained from data collected by operators under the European Emissions Trading Scheme (ETS).

The criteria of data reporting are defined by European Directive 2018/410/EC and adopted at national level by the Legislative Decree N. 47 of 9 June 2020. In compliance with the above-mentioned legislation, independent certifications and verifications of activity data, emission data and emission factors are required. At national level, data verification has to be carried out by verifiers accredited by the national ETS Committee according to the ministerial decree DEC/RAS/115/2006. The verification of data submissions ensures reliability, credibility, and precision/accuracy of monitoring systems for data and any information relating to emissions by plant.

Data from the Italian Emissions Trading Scheme database are incorporated into the national inventory whenever the sectoral coverage is complete; in fact, ETS data not always entirely cover energy categories whereas national statistics, such as the national energy balance and the energy production and consumption statistics, provide the complete basic data needed for the Italian emission inventory. Nevertheless, ETS data are entirely used to develop country-specific emission factors and check activity data levels.

For the industrial sector, the annual production data are provided by national sources and international statistical yearbooks, such as the FAO database on food balance.

Emission data collected through the National Pollutant Release and Transfer Register are also used in the development of emission estimates or considered as a verification of emission estimates for some specific categories. According to the Italian Decree of 23 November 2001, data (reporting period 2002-2006) included in the Italian pollutant emissions register were validated by competent authorities within 30 June each year and communicated by ISPRA to the Ministry of the Environment every year and to the European Commission every three years according to EC Decision 2000/479. Since 2008, the national pollutant emissions register has been replaced by the national pollutant release and transfer register (the Italian PRTR) to comply with Regulation EC n.166/2006; data are collected annually at facility level and sent, after validation, by competent authorities to European Commission within 31 March every year for data referring to the previous year. These data are used for the compilation of the inventory whenever they are complete in terms of sectoral information; in fact, industries communicate figures only if they exceed specific thresholds; furthermore, basic data such as fuel consumption are not supplied, and production data are not always split by product but reported as an overall figure. In any case, the Italian PRTR is a good basis for data checks and a way to facilitate contacts with industries which, in many cases, supply, under request, additional information as necessary for carrying out sectoral emission estimates.

In addition, final emissions are checked and verified also considering figures reported by industries in their annual environmental reports.

Both for energy and industrial processes, emissions of large industrial point sources are registered individually; communication also takes place in the framework of the European Directive on Large Combustion Plants, based upon detailed information such as fuel consumption. Other small plants voluntarily communicate their emissions which are also considered individually. For solvents, the amount of solvent use is provided by environmental publications of sectoral industries and associations.

ISPRA directly collects data from the industrial associations under the ETS and other European directives, Large Combustion Plant and PRTR, and makes use of these data in the preparation of the national inventory ensuring the consistency of time series.

For the other sectors, i.e. for agriculture, annual production data and the number of animals are provided by the National Institute of Statistics and other sectoral associations.

For land use, land use change and forestry, forest areas are derived from national forest inventories provided by the Ministry of Agriculture and Carabinieri; the Carabinieri is also the provider of official statistics related to the areas subject to fires.

For waste, the main activity data are provided by the Institute for Environmental Protection and Research and the Waste Observatory.

Unpublished data are used only if supported by personal communication and confidentiality of data is respected.

As for data disclosure, the inventory team is obliged to ensure confidentiality of sensitive information by legislation when data are communicated under specific directives or confidentiality is requested by data providers. In the case of data collection under the ETS, E-PRTR, large combustion plants and other directives, the database of the complete information is available only to a specific group of authorised people which has the legal responsibility for the respect of confidentiality issues. In other cases, each expert is responsible for the data received, and confidentiality. In any case, all data are placed on a password protected access environment at ISPRA and available only to authorised experts of the inventory team.

All the material and documents used for the inventory estimation process are stored at the Institute for Environmental Protection and Research. Activity data and emission factors as well as methodologies are referenced to their data sources. A 'reference' database has also been developed and used to increase the transparency of the inventory.

1.5 Brief description of key categories

A key category analysis of the Italian inventory is carried out according to the Approach 1 and Approach 2 described in the 2006 IPCC Guidelines (IPCC, 2006).

Following the IPCC guidelines, a key category is defined as an emission category that has a significant influence on a country's GHG inventory in terms of the absolute level and trend in emissions and removals, or both. Key categories are those which, when summed together in descending order of magnitude, add up to over 95% of the total emissions or 90% of total uncertainty.

National emissions have been disaggregated into the categories proposed in the IPCC guidelines and reflect specific national circumstances. Both level and trend analysis have been applied to the last submitted inventory; a key category analysis has also been carried out for the base year emission levels.

For the base year, 27 sources were individuated implementing Approach 1, whereas 30 sources were carried out by Approach 2. Including the LULUCF in the analysis, 35 categories were selected by Approach 1 and 38 by Approach 2. The description of these categories is shown in Table 1.3 and Table1.4.

Table 1.3 Key categories (excluding LULUCF) by the IPCC Approach 1 and Approach 2. Base year

Key categories (excluding the LULUCF sector)		
1.A.1	Energy industries - CO_2 gaseous fuels	L
1.A.1	Energy industries - CO_2 liquid fuels	L
1.A.1	Energy industries - CO_2 solid fuels	L
1.A.2	Manufacturing industries and construction - CO_2 gaseous fuels	L
1.A.2	Manufacturing industries and construction - CO_2 liquid fuels	L
1.A.2	Manufacturing industries and construction - CO_2 solid fuels	L1
1.A.3.b	Transport - CH_4 Road transportation	L2
1.A.3.b	Transport - CO_2 Road transportation	L
1.A.4	Other sectors - CH_4 commercial, residential, agriculture biomass	L2
1.A.4	Other sectors - CO_2 commercial, residential, agriculture gaseous fuels	L
1.A.4	Other sectors - CO_2 commercial, residential, agriculture liquid fuels	L
1.A.4	Other sectors - N_2O commercial, residential, agriculture liquid fuels	L2
1.A.4	Other sectors - N_2O commercial, residential, agriculture biomass	L2
1.B.2.a	Fugitive - CO_2 Oil and natural gas - Oil	L1
1.B.2.b	Fugitive - CH_4 Oil and natural gas - Natural gas	L
1.B.2.c	Fugitive - CO_2 Oil and natural gas - venting and flaring	L2
1.B.2.d	Fugitive - CO_2 Oil and natural gas - Other - flaring in refineries	L2
2.A.1	Mineral industry- CO_2 Cement production	L
2.A.2	Mineral industry- CO_2 Lime production	L1
2.A.4	Mineral industry- CO_2 Other processes uses of carbonates	L1
2.B.1	Chemical industry- CO_2 Ammonia production	L1
2.B.2	Chemical industry- N_2O Nitric acid production	L1
2.B.3	Chemical industry- N_2O Adipic acid production	L1
2.B.9	Chemical industry- PFCs Fluorochemical production	L2
2.C.1	Metal industry- CO_2 Iron and steel production	L1
2.F.1	Product uses as substitutes for ozone depleting substances - HFCs Refrigeration and Air conditioning	L2
2.F.3	Product uses as substitutes for ozone depleting substances - HFCs Fire protection	L2
3.A.1	Enteric Fermentation- CH_4	L
3.A.2	Manure Management - CH_4	L
3.A.2	Manure Management - N_2O	L
3.C	Rice Cultivation - CH_4	L1
3.D.a	Direct N_2O Emissions from Managed soils	L
3.D.b	Indirect N_2O Emissions from Managed soils	L
5.A	Solid waste disposal - CH_4	L
5.B	Biological treatment of Solid Waste – N_2O	L2
5.D	Wastewater treatment and discharge - CH_4	L
5.D	Wastewater treatment and discharge - N_2O	L2
	Indirect CO_2 emissions - CO_2	L2

L1 = level key category by Approach 1
T1 = trend key category by Approach 1
L2 = level key category by Approach 2
T2 = trend key category by Approach 2
L = level key category by Approach 1 and Approach 2
T = trend key category by Approach 1 and Approach 2

Table 1.4 Key categories (including LULUCF) by the IPCC Approach 1 and Approach 2. Base year

Key categories (excluding the LULUCF sector)		
1.A.1	Energy industries - CO2 gaseous fuels	L
1.A.1	Energy industries - CO2 liquid fuels	L
1.A.1	Energy industries - CO2 solid fuels	L
1.A.2	Manufacturing industries and construction - CO2 gaseous fuels	L

L1 = level key category by Approach 1
T1 = trend key category by Approach 1
L2 = level key category by Approach 2
T2 = trend key category by Approach 2
L = level key category by Approach 1 and Approach 2
T = trend key category by Approach 1 and Approach 2

Key categories (excluding the LULUCF sector)		
1.A.2	Manufacturing industries and construction - CO2 liquid fuels	L
1.A.2	Manufacturing industries and construction - CO2 solid fuels	L
1.A.2	Manufacturing industries and construction - N2O liquid fuels	L2
1.A.3.b	Transport - CH4 Road transportation	L2
1.A.3.b	Transport - CO2 Road transportation	L
1.A.3.c	Transport - CO2 Civil Aviation	L1
1.A.3.d	Transport - CO2 Waterborne navigation	L1
1.A.4	Other sectors - CH4 commercial, residential, agriculture biomass	L2
1.A.4	Other sectors - CO2 commercial, residential, agriculture gaseous fuels	L
1.A.4	Other sectors - CO2 commercial, residential, agriculture liquid fuels	L
1.A.4	Other sectors - N2O commercial, residential, agriculture liquid fuels	L2
1.B.2.a	Fugitive - CO2 Oil and natural gas - Oil	L1
1.B.2.b	Fugitive - CH4 Oil and natural gas - Natural gas	L
1.B.2.c	Fugitive - CO2 Oil and natural gas - venting and flaring	L2
	Fugitive - CO2 Oil and natural gas – flaring in refineries	L2
2.A.1	Mineral industry- CO2 Cement production	L
2.A.2	Mineral industry- CO2 Lime production	L1
2.A.4	Mineral industry- CO2 Other processes uses of carbonates	L1
2.B.1	Chemical industry- CO2 Ammonia production	L1
2.B.2	Chemical industry- N2O Nitric acid production	L1
2.B.3	Chemical industry- N2O Adipic acid production	L
2.B.9	Chemical industry- PFCs Fluorochemical production	L2
2.C.1	Metal industry- CO2 Iron and steel production	L1
2.C.3	Metal industry- PFCs Aluminium production	L
3.A.1	Enteric Fermentation- CH4	L
3.A.2	Manure Management - CH4	L
3.A.2	Manure Management - N2O	L
3.C	Rice cultivations - CH4	L1
3.D.a	Direct N2O Emissions from Managed soils	L
3.D.b	Indirect N2O Emissions from Managed soils	L
4.A.1	Forest Land remaining Forest Land -DOM (deadwood+litter) CO2	L2
4.A.1	Forest Land remaining Forest Land -Living biomass- CO2	L
4.A.2	Land Converted to Forest Land - CO2	L
4.B.1	Cropland remaining cropland – Living biomass -CO2	L1
4.B.1	Cropland remaining cropland – Organic soils -CO2	L2
4.B.2	Land Converted to Cropland – Soils -CO2	L2
	Land converted to Forest Land – Living biomass – CO2	L
	Land converted to Grassland – mineral soils – CO2	
4.C.1	Grassland Remaining Grassland – Living biomass- CO2	L
4.E.2	Land Converted to Settlements - CO2	L
4.E.2	Land Converted to Settlements - N2O	L2
5.A	Solid waste disposal - CH4	L
5.D	Wastewater treatment and discharge - CH4	L
5.D	Wastewater treatment and discharge - N2O	L2
	Indirect CO_2 emissions	L

Applying the analysis to the 2022 inventory, without the LULUCF sector, 47 key categories were totally individuated, both at level and trend. Results are reported in Table 1.5.

Table 1.5 Key categories (excluding LULUCF) by IPCC Approach 1 and Approach 2. Year 2022

Key categories (excluding the LULUCF sector)		
1.A.1	Energy industries - CO2 gaseous fuels	L, T
1.A.1	Energy industries - CO2 liquid fuels	L, T
1.A.1	Energy industries - CO2 solid fuels	L, T
1.A.2	Manufacturing industries and construction - CO2 gaseous fuels	L, T
1.A.2	Manufacturing industries and construction - CO2 liquid fuels	L, T
1.A.2	Manufacturing industries and construction - CO2 solid fuels	L1, T
1.A.2	Manufacturing industries and construction – CH4 biomass	T2
1.A.3.a	Transport – CO2 Civil aviation	L1, T1
1.A.3.b	Transport - CH4 Road transportation	T2
1.A.3.b	Transport – N2O Road transportation	T2
1.A.3.b	Transport - CO2 Road transportation	L, T
1.A.3.d	Transport - CO2 Waterborne navigation	L1, T1
1.A.3.e	Transport - CO2 Other transportation - pipelines	T1
1.A.4	Other sectors - CH4 commercial, residential, agriculture biomass	L, T
1.A.4	Other sectors - CO2 commercial, residential, agriculture gaseous fuels	L, T
1.A.4	Other sectors - CO2 commercial, residential, agriculture liquid fuels	L, T
1.A.4	Other sectors - CO2 commercial, residential, agriculture other fossil fuels	L1, T
1.A.4	Other sectors - CO2 commercial, residential, agriculture solid fuels	T1
1.A.4	Other sectors - N2O commercial, residential, agriculture biomass	L2, T
1.A.4	Other sectors - N2O commercial, residential, agriculture liquid fuels	L2
1.B.2.b	Fugitive - CH4 Oil and natural gas - Natural gas	L, T
1.B.2.c	Fugitive – CO2 Oil and natural gas - Other – venting and flaring	T2
1.B.2.d	Fugitive - CH4 Oil and natural gas - Other - flaring in refineries	L2, T2
1.B.2.d	Fugitive - CO2 Oil and natural gas - Other - flaring in refineries	T2
2.A.1	Mineral industry- CO2 Cement production	L, T
2.A.2	Mineral industry- CO2 Lime production	L1
2.A.4	Mineral industry- CO2 Other processes uses of carbonates	T
2.B.1	Chemical industry- CO2 Ammonia production	T
2.B.2	Chemical industry- N2O Nitric acid production	T
2.B.3	Chemical industry- N2O Adipic acid production	T
2.B.9	Chemical industry- HFCs Fluorochemical production	T2
2.B.9	Chemical industry- PFCs Fluorochemical production	T2
2.C.1	Metal industry- CO2 Iron and steel production	T1
2.C.3	Metal industry- PFCs Aluminium production	T
2.F.1	Product uses as substitutes for ozone depleting substances - HFCs Refrigeration and Air conditioning	L, T
2.F.2	Product uses as substitutes for ozone depleting substances - HFCs Foam blowing agents	T2
2.F.3	Product uses as substitutes for ozone depleting substances - HFCs Fire protection	L, T
3.A.1	Enteric Fermentation- CH4	L, T
3.A.2	Manure Management - CH4	L
3.A.2	Manure Management - N2O	L
3.D.a	Direct N2O Emissions from Managed soils	L
3.D.b	Indirect N2O Emissions from Managed soils	L
5.A	Solid waste disposal - CH4	L, T

L1 = level key category, Approach 1
T1 = trend key category, Approach 1
L2 = level key category, Approach 2
T2 = trend key category, Approach 2
L = level key category, Approach 1 and Approach 2
T = trend key category, Approach 1 and Approach 2

Key categories (excluding the LULUCF sector)		
5.B	Biological treatment of Solid waste - N2O	L2, T2
5.D	Wastewater treatment and discharge - CH4	L, T2
5.D	Wastewater treatment and discharge - N2O	L2, T2
	Indirect CO2 emissions	L2, T2

If considering emissions and removals from the LULUCF sector, 57 key categories were individuated as reported in Table 1.6.

Table 1.6 Key categories (including LULUCF) by IPCC Approach 1 and Approach 2. Year 2022

Key categories (including the LULUCF sector)		
1.A.1	Energy industries - CO2 gaseous fuels	L, T
1.A.1	Energy industries - CO2 liquid fuels	L, T
1.A.1	Energy industries - CO2 solid fuels	L, T
1.A.2	Manufacturing industries and construction - CO2 gaseous fuels	L, T
1.A.2	Manufacturing industries and construction - CO2 liquid fuels	L, T
1.A.2	Manufacturing industries and construction - CO2 solid fuels	L1, T
1.A.2	Manufacturing industries and construction – CH4 biomass	T2
1.A.3.a	Transport – CO2 Civil aviation	L1, T1
1.A.3.b	Transport - CO2 Road transportation	L, T
1.A.3.b	Transport – CH4 Road transportation	T
1.A.3.b	Transport – N2O Road transportation	L2
1.A.3.d	Transport - CO2 Waterborne navigation	L1, T1
1.A.3.e	Transport - CO2 Other transportation - pipelines	T1
1.A.4	Other sectors - CH4 commercial, residential, agriculture biomass	L, T
1.A.4	Other sectors - CO2 commercial, residential, agriculture gaseous fuels	L, T
1.A.4	Other sectors - CO2 commercial, residential, agriculture liquid fuels	L, T
1.A.4	Other sectors - CO2 commercial, residential, agriculture other fossil fuels	L1, T
1.A.4	Other sectors - CO2 commercial, residential, agriculture solid fuels	T1
1.A.4	Other sectors - N2O commercial, residential, agriculture biomass	L2, T
1.B.2.b	Fugitive - CH4 Oil and natural gas - Natural gas	L, T
1.B.2.b	Fugitive – CO2 Oil and natural gas - Oil	T1
1.B.2.c	Fugitive – CO2 Oil and natural gas - Other – venting and flaring	T2
1.B.2.d	Fugitive - CH4 Oil and natural gas - Other - flaring in refineries	L2, T2
1.B.2.d	Fugitive – CO2 Oil and natural gas - Other - flaring in refineries	T2
2.A.1	Mineral industry- CO2 Cement production	L, T
2.A.2	Mineral industry- CO2 Lime production	L1
2.A.4	Mineral industry- CO2 Other processes uses of carbonates	T
2.B.2	Chemical industry- CO2 Ammonia production	T
2.B.2	Chemical industry- N2O Nitric acid production	T
2.B.3	Chemical industry- N2O Adipic acid production	T
2.B.9	Chemical industry- HFCs Fluorochemical production	T2
2.B.9	Chemical industry- PFCs Fluorochemical production	T2
2.C.1	Metal industry- CO2 Iron and steel production	L1, T1
2.C.3	Metal industry- PFCs Aluminium production	T
2.F.1	Product uses as substitutes for ozone depleting substances - HFCs Refrigeration and Air conditioning	L, T
2.F.2	Product uses as substitutes for ozone depleting substances - HFCs Foam blowing agents	T2

L1 = level key category, Approach 1
T1 = trend key category, Approach 1
L2 = level key category, Approach 2
T2 = trend key category, Approach 2
L = level key category, Approach 1 and Approach 2
T = trend key category, Approach 1 and Approach 2

Key categories (including the LULUCF sector)		
2.F.3	Product uses as substitutes for ozone depleting substances - HFCs Fire protection	L, T
3.A.1	Enteric Fermentation- CH_4	L, T
3.A.2	Manure Management - CH_4	L, T
3.A.2	Manure Management - N_2O	L
3.C.4	Direct N_2O Emissions from Managed soils	L, T2
3.C.5	Indirect N_2O Emissions from Managed soils	L
3.C.7	Rice cultivations - CH_4	L1
4.A.1	Forest Land remaining Forest Land – DOM (deadwood+litter) - CO_2	T1
4.A.1	Forest Land remaining Forest Land – Living biomass - CO_2	L, T
4.A.2	Land Converted to Forest Land – soils - CO_2	L2, T1
4.A.2	Land Converted to Forest Land – living biomass - CO_2	L
4.B.1	Cropland Remaining Cropland – Living biomass - CO_2	L1, T
4.B.1	Cropland Remaining Cropland – Mineral soils - CO_2	L1, T1
4.C.1	Grassland Remaining Grassland – Living biomass - CO_2	L, T
4.C.2	Land Converted to Grassland – mineral soils CO_2	L1, T1
4.E.2	Land Converted to Settlements - CO_2	L, T2
5.A	Solid waste disposal - CH_4	L, T
5.B	Biological treatment of Solid waste - N_2O	L2, T2
5.D	Wastewater treatment and discharge - CH_4	L
5.D	Wastewater treatment and discharge - N_2O	L2, T2
	Indirect CO_2 emissions	L2, T2

The analysis of key categories is used to prioritize improvements that should be taken into account for the next inventory submissions. First of all, it is important that emissions of key categories, being the most significant in terms of absolute weight and/or combined uncertainty, are estimated with a high level of accuracy. For the Italian inventory, higher tiers are mostly used for calculating emissions from these categories as requested by the IPCC Guidelines and the use of country specific emission factors is extensive. As reported in Table A9.1, in the Annex, there are only a few key categories which estimates do not meet these quality objectives, in terms of the methodology and the application of default emission factors.

Among these categories, prioritization is made on account of the actual absolute weight, the expected future relevance, the level of uncertainty and a cost-effectiveness analysis. Therefore, improvements are planned for the LULUCF sector as well as for maritime navigation category, which emissions are estimated with a Tier1 and with Tier 2 for few years and has been selected as a priority after verification of the availability of annual detailed activity data, the evaluation of the resources and cost of the database to be implemented.

In addition to this evaluation, also categories estimated with higher tiers but affected by a high level of uncertainty are considered in the prioritization plan. For instance, activities were planned and are ongoing for HFC, PFC substitutes for ODS to improve the accuracy of the Italian inventory and reduce the overall uncertainty.

1.6 Information on the QA/QC plan including verification and treatment of confidentiality issues where relevant

ISPRA has elaborated an inventory QA/QC plan which describes specific QC procedures to be implemented during the inventory development process, facilitates the overall QA procedures to be conducted, to the extent possible, on the entire inventory and establishes quality objectives.

Particularly, an inventory QA/QC procedures manual (ISPRA, 2013) describes QA/QC procedures and verification activities to be followed during the inventory compilation and helps in the inventory improvement. Furthermore, specific QA/QC procedures and different verification activities implemented thoroughly the current inventory compilation, as part of the estimation process, are figured out in the annual QA/QC plan (ISPRA, 2024 [a]). These documents are publicly available at ISPRA website https://emissioni.sina.isprambiente.it/inventario-nazionale/.

Quality control checks and quality assurance procedures together with some verification activities are applied both to the national inventory as a whole and at sectoral level. Future planned improvements are prepared for each sector by the relevant inventory compiler; each expert identifies areas for sectoral improvement based on his own knowledge and in response to the UNFCCC inventory reviews and considering the result of the key category assessment.

The quality of the inventory has improved over the years and further investigations are planned for all those sectors relevant in terms of contribution to total CO_2 equivalent emissions and with high uncertainty.

In addition to *routine* general checks, source specific quality control procedures are applied on a case-by-case basis focusing on key categories and on categories where significant methodological and data revision have taken place or on new sources. Checklists are compiled annually by the inventory experts and collected by the QA/QC coordinator. These lists are also registered in the 'reference' database. General QC procedures also include data and documentation gathering. Specifically, the inventory analyst for a source category maintains a complete and separate project archive for that source category; the archive includes all the materials needed to develop the inventory for that year and is kept in a transparent manner.

All the information used for the inventory compilation is traceable back to its source. The inventory is composed of spreadsheets to calculate emission estimates; activity data and emission factors as well as methodologies are referenced to their data sources. Particular attention is paid to the archiving and storing of all inventory data, supporting information, inventory records as well as all the reference documents. To this end, a major improvement which increases the transparency of the inventory has been the development of a 'reference' database. After each reporting cycle, all database files, spreadsheets and official submissions are archived as 'read-only' mode in a master computer.

Quality assurance procedures regard some verification activities of the inventory as a whole and at a sectoral level. Feedback for the Italian inventory derive from communication of data to different institutions and/or at local level. For instance, the communication of the inventory to the European Community results in a pre-check of the GHG values before the submission to the UNFCCC and relevant inconsistencies may be highlighted.

Every year, emission figures are also subjected to a process of re-examination once the inventory, the inventory related publications and the national inventory reports are posted on website, specifically www.isprambiente.gov.it, and from the communication of data to different institutions and/or at local level. In some cases, sectoral major recalculations are presented and shared with the relevant stakeholders prior to the official submission.

For the energy and industrial sectors, different meetings have been held in the last years jointly with the industrial associations, the Ministries of the Environment and ISPRA in the framework of the European Emissions Trading Scheme (EU-ETS), for assessing carbon leakage in EU energy intensive industries and the definition of GHG emission benchmarks; also in this context, estimations of the emission inventory for different sectors have been presented.

ISPRA collects data from the industrial associations and industrial facilities under the EU- ETS and other European legislation such as Large Combustion Plant Directive and E-PRTR Regulation. The inventory team manages all these data and makes use of them in the preparation of the national inventory, ensuring the consistency of the time series by the comparison of the information collected under the directives with other sources available before the Regulations. Emissions and activity data submitted under the ETS are mandatorily subject to verification procedures, as requested and specified by the European Directive 2003/87/EC (art. 15 and Annex V). Also, the quality of the Italian PRTR data is guaranteed by art.9 of the Regulation 2006/166/EC and by art.3(3) of the Presidential Decree n.157/2011.

ISPRA manages all this information in an informative system to help in highlighting the main discrepancies among data and improving the time series consistency. The informative system is based on identification codes to trace back individual point sources in different databases.

Other specific activities relating to improvements in the inventory and QA/QC practices, in the last year, regarded the assessment of the information collected in the framework of different European legislation, Large Combustion Plant, PRTR and Emissions Trading. The actual figures are considered in an overall approach and used in the compilation of the inventory. In this regard the main progress is the updating of the administrative information to identify the facilities under the separate databases. Moreover, the so called "EU Business Registry" has been launched under the Industrial Emission Directive at European Union level; this new registry will include the administrative data for all the facilities in the scope of the Industrial Emission Directive as far as permitting procedures, site visit and site inspections, thematic data reporting are concerned. Thematic data (emissions, releases, waste quantities, activity data; number of site visits, infringements etc.) are also reported in compliance with the reporting decisions adopted by the EU Commission.

ISPRA is also responsible for the provincial inventory on the local scale; at now the provincial inventories at local scale for the years 1990, 1995, 2015 and 2019 are available. In fact, every 5 years, and now every 4 years, in the framework of the Protocol on Long-term Financing of the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP) under the Convention on Long-range Transboundary Air Pollution (CLTRAP), Parties have to report their national air emissions disaggregated on a 0.1°*0.1° grid. Specifically, ISPRA has applied a top-down approach to estimate emissions at provincial areas based on proxy variables. The results were checked out by regional and local environmental agencies and authorities; data are available at ISPRA web address https://emissioni.sina.isprambiente.it/inventario-nazionale/. The last report which describes detailed methodologies to carry out estimates is available (ISPRA, 2022). Comparisons between top-down and local inventories have been carried out during the last year and will continue in the next years; results are shared among the 'local inventories' expert group leading to an improvement in methodologies for both the inventories. ISPRA has also collaborated with local authorities to assess the participation of the Italian municipalities to the Covenant of Mayors (http://www.isprambiente.gov.it/it/pubblicazioni/rapporti/stato-di-attuazione-del-patto-dei-sindaci-in-italia).

A specific procedure undertaken for improving the inventory regards the establishment of national expert panels (in particular, in road transport, LULUCF and energy sectors) which involve, on a voluntary basis, different institutions, local agencies and industrial associations cooperating for improving activity data and emission factors accuracy.

The quality of the inventory has also improved through organization and participation in sector specific workshops. Follow-up processes are also set up in the framework of the WGI and WG5 under the EC Monitoring Mechanism, which addresses the improvement of different inventory sectors.

Especially in the last years, there has been an intensification of activities related to emission scenarios, and the importance of the emission inventory as a solid starting point is primary. The inventory is shared with the Ministry of the Environment, and all the relevant Ministries and local authorities.

In this context, from 2011, a report concerning the state of implementation of commitments to reduce greenhouse gases emissions, and describing emission trends and projections, is prepared by the MASE in consultation with other relevant Ministries. The report is annexed to the economy and financial document (DEF) to be annually approved by the Government.

Expert peer reviews of the national inventory occur annually within the UNFCCC process, whose results and suggestions can provide valuable feedback on areas where the inventory should be improved. The last review occurred in 2022. The final report will be available at the relevant UNFCCC web site address https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/inventory-review-reports-2022 and details on the review processes and implementation of the comments and potential recommendations are described in Annex 10 and in relevant sections.

At European level, reviews of the European inventory are undertaken by experts from different Member States for critical sectoral categories. Moreover, in the context of the European Effort Sharing Decision (EC, 2009), in 2021, a detailed review of the Italian inventory was conducted.

An official independent review of the entire Italian greenhouse gas inventory was undertaken by the Aether consultants in 2013. Main findings and recommendations regard mostly the transparency in the NIR, the improvement of QA/QC documentation.

The preparation of environmental reports where data are needed at different aggregation levels or refer to different contexts, such as environmental and economic accounting, is also a check for emission trends. At national level, for instance, emission time series are reported in the Environmental Data Yearbooks published by ISPRA. Emission data are also published by the Ministry of the Environment in the Reports on the State of the Environment and the National Communications as well as in the Demonstrable Progress Report. Moreover, figures are communicated to the National Institute of Statistics to be published in the relevant Environmental Statistics Yearbooks as well as used in the framework of the EUROSTAT NAMEA Project.

At European level, ISPRA also reports on indicators meeting the requirements of Article 13 of EU Regulation 1999/2018. Member States shall submit figures on specified indicators. These indicators are reported in the document 'Carbon Dioxide Intensity Indicators' (ISPRA, 2024 [b]).

Comparisons between emission estimates from industrial sectors and those published by the industry itself in their Environmental reports are carried out annually to assess the quality and the uncertainty of the estimates.

Additional consistency checks of data are carried out in the context of the European Regulation No 1999/2018. EU Member States shall report in textual and tabular format on data inconsistencies.

For example, data on air pollutants estimated under the UNECE Convention on Long-range Transboundary Air Pollution and those under the UNFCCC Convention should not exceed the difference of more than +/–5 % between the total emissions for a specific pollutant otherwise text and a tabular format should be compiled by the Member State. As shown in chapter 2, para 2.4, these differences for Italy are far under the threshold.

Other relevant articles of the EU Regulation are related to the consistency of reported GHG emissions under UNFCCC with data from the EU emissions trading system by category, and to consistency of energy statistics considering the apparent consumption calculated on the basis of the data included in the GHG inventory and the reference approach calculated on the basis of the energy data reported to Eurostat.

If these differences are higher than +/– 2 %, in the total national apparent fossil fuel consumption at aggregate level for all fossil fuel categories, a tabular format shall also be compiled. For Italy these differences are below the determined threshold.

The detailed tables are included in Annex 11 of the NID.

A summary of all the main QA/QC activities over the past years which ensure the continuous improvement of the inventory is presented in the document 'Quality Assurance/Quality Control plan for the Italian Emission Inventory. Year 2024' (ISPRA, 2024 [a]).

A proper archiving and reporting of the documentation related to the inventory compilation process is also part of the national QA/QC programme.

All the material and documents used for the inventory preparation are stored at ISPRA. Information relating to the planning, preparation, and management of inventory activities is documented and archived. The archive is organised so that any skilled analyst could obtain relevant data sources and spreadsheets, reproduce the inventory, and review all decisions about assumptions and methodologies undertaken. A master documentation catalogue is generated for each inventory year, and it is possible to track changes in data and methodologies over time. Specifically, the documentation includes:

- electronic copies of each of the draft and final inventory report, electronic copies of the draft and final CRT tables;
- electronic copies of all the final, linked source category spreadsheets for the inventory estimates (including all spreadsheets that feed the emission spreadsheets);
- results of the reviews and, in general, all documentation related to the corresponding inventory year submission.

After each reporting cycle, all database files, spreadsheets and electronic documents are archived as 'read-only' mode.

A 'reference' database is also compiled every year to increase the transparency of the inventory. This database consists of several records that reference all documentation used during the inventory compilation, for each sector and submission year, the link to the electronically available documents and the place where they are stored as well as internal documentation on QA/QC procedures.

1.7 General uncertainty evaluation, including data on the overall uncertainty for the inventory totals

The 2006 IPCC Guidelines (IPCC, 2006) define two approaches to estimating uncertainties in national greenhouse gas inventories: Approach 1, based on the error propagation equations, and Approach 2, corresponding to the application of Monte Carlo analysis.

For the Italian inventory, quantitative estimates of the uncertainties are calculated using Approach 1 which application is described in Annex 1, with or without emissions and removals from the LULUCF sector. Emission categories are disaggregated into a detailed level and uncertainties are therefore estimated for these categories.

For 2022, an uncertainty of 2.4% is estimated for total emission figures without LULUCF, whereas for the trend between the base year and 2022 the analysis assesses an uncertainty of 1.7%. Including the LULUCF sector into national figures, the uncertainty, according to Approach 1, is equal to 3.6% for the year 2022, whereas the uncertainty for the trend is estimated to be 2.5%. The small variation in the uncertainty levels, as compared to the previous submission, is mainly due to the recalculation process and consequent different weights of the categories and relevant uncertainties. The assessment of uncertainty has also been applied to the base year emission levels. The results show an uncertainty of 2.1% in the combined

GWP total emissions, excluding emissions and removals from LULUCF, whereas it increases to 2.8% including the LULUCF sector.

Approach 2, Montecarlo analysis[6], was implemented in previous submissions to estimate uncertainty of some of the key categories of the Italian inventory. Most of the results prove that both approaches (Approach 1 and 2) produce comparable results and that uncertainty values derived by Approach 2 are lower than those derived from the application of Approach 1. For details, please consult previous NIRs (e.g. NIR, 2022).

QC procedures are also undertaken on the calculations of uncertainties to confirm the correctness of the estimates and that there is sufficient documentation to duplicate the analysis. The assumptions which uncertainty estimations are based on are documented for each category. Figures used to draw up uncertainty analysis are checked both with the relevant analyst experts and literature references and are consistent with the IPCC Guidelines. More in details, facility level data are used to check and verify information from the industrial sector; these data also include information from the European Emissions Trading Scheme, the Italian PRTR register which is also collected and elaborated by the inventory team. Most of the time there is correspondence among activity data from different databases so that the level of uncertainty could be assumed lower than the one fixed at 3%; the same occurs for emission factors coming from measurements at plant level, and even in this case the uncertainty may be assumed lower than the predetermined level. Since the overall uncertainty of the Italian inventory is relatively low due to the prevalence of the energy sector sources, whose estimates derive from accurate parameters, out of the total, it has been decided to use conservative figures; this occurs especially for energy and industrial sectors. Details can be found at category level in the relevant sections.

The results of the uncertainty analysis, generally associated with a key category assessment by Approach 2, are used to prioritize improvements for the next inventory submissions. Emissions of key categories are usually estimated with a high level of accuracy in terms of the methodology used and characterised by a low uncertainty; some exceptions may occur and categories estimated with higher tiers may be affected by a high level of uncertainty. For instance, in the agriculture sector, direct N_2O emissions from agricultural soils and indirect N_2O from nitrogen used in agriculture are affected by a high level of uncertainty especially in the emission factors notwithstanding the advanced tiers used. For the categories with a high uncertainty, further improvements are planned whenever sectoral studies can be carried out.

1.8 General assessment of the completeness

The inventory covers all major sources and sinks, as well as direct and indirect gases, included in the IPCC guidelines.

Details are reported in Table 1.7 and Table 1.8. Sectoral and background tables of CRF sheets are complete as far as details of basic information are available. For instance, multilateral operations emissions are not estimated because no activity data are available.

Allocation of emissions is not consistent with the IPCC Guidelines only where there is no data available to split the information. For instance, for fugitive emissions, N_2O fugitive emissions from oil refining and storage activities are reported under category 1.B.2.d other, flaring in refineries. Further investigation will be carried out closely with industry about these figures.

[6] The description of the key categories to which the analysis was applied and the reference years are reported in 2022 NIR submission

Table 1.7 Source and sinks not estimated in the 2022 inventory

Sources and sinks not estimated (NE)[1]			
GHG	Sector[2]	Source/sink category [2]	Explanation
CH_4	Energy	1.A.1c Manufacture of solid fuel (biomass)	CH_4 emissions from charcoal production are not accounted for because of a lack of methodology in the 2006 IPCC Guidelines applicable to the type of furnace technology in use
N_2O	Energy	1.B Fugitive Emissions from Fuels/ 1.B.2 Oil and Natural Gas and Other Emissions from Energy Production/ 1.B.2.d Other /Geotherm	N_2O emissions are negligible
CO_2, CH_4, N_2O	Energy	1.D.2 Multilateral Operations	Information and statistical data are not available
CH_4	Agriculture	3.D Agricultural Soils	CH_4 emissions from managed soils have not been estimated because no methodology is available in the IPCC Guidelines.
CO_2, CH_4, N_2O	LULUCF	4.E Settlements/4(V) Biomass Burning 4.E Settlements	Emissions are considered insignificant, below 0.05% of the national total GHG emissions, and minor than 500 kt CO_2 eq.

Table 1.8 Source and sinks reported elsewhere in the 2022 inventory

GHG	Source/sink category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CO_2	1.AD Feedstocks, reductants and other non-energy use of fuels/Liquid Fuels/Gasoline	1.AD Liquid fuel/Gasoline/LPG/ Other Oil/Refinery feedstock/Residual oil	1.AD Liquid fuel/Naphta	National energy balances include only the input and output quantities from the petrochemical plants; so in the petrochemical transformation process the output quantity could be greater than the input quantity, in particular for light products as LPG, gasoline and refinery gas, due to chemical reactions. Therefore, it is possible to have negative values for some products (mainly gasoline, refinery gas, fuel oil). For this matter, for the reporting on CRF tables, these fuels have been added to naphtha.
N2O	1.B Fugitive Emissions from Fuels/ 1.B.2 Oil and Natural Gas and Other Emissions from Energy Production/ 1.B.2.a Oil/ 1.B.2.a.4 Refining / Storage	1.B.2.a.4 Refining/storage	1.B.2.d flaring in refineries	No information is available to split the emissions
CO_2	2.C Metal Industry/ 2.C.5 Lead Production	2.C.5. Lead Production	2.C.6 Zinc production	CO_2 emissions from the sole zinc and lead integrated plant in Italy have been estimated. The available data do not allow

GHG	Source/sink category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
				to distinguish between zinc and lead emissions.
HFC-125, HFC-134a, HFC-143a	2.F Product Uses as Substitutes for ODS/2.F.1 Refrigeration and air conditioning/ Transport Refrigeration	2.F.1 Refrigeration and air conditioning/ Transport Refrigeration	2.F.1 Refrigeration and air conditioning/ Commercial Refrigeration	Emissions from Transport Refrigeration are included in Commercial Refrigeration
CO_2	4.A Forest Land/4.A.1 Forest Land Remaining Forest Land/4(V) Biomass Burning/Wildfires	4.A.1 4(V) Biomass Burning/Wildfires	4.A.1, Carbon stock change in living biomass	CO_2 emissions due to wildfires in forest land remaining forest land are included in table 4.A.1, Carbon stock change in living biomass, Losses
CO_2	4.A Forest Land/4.A.2 Land Converted to Forest Land/4(V) Biomass Burning/Wildfires	4.A.2 4(V) Biomass Burning/Wildfires	4.A.2, Carbon stock change in living biomass	CO_2 emissions due to wildfires in forest land remaining forest land are included in table 4.A.2, Carbon stock change in living biomass, Losses
N_2O	4.A Forest Land/4.A.1 Forest Land Remaining Forest Land/4(I) Direct N2O Emissions from N Inputs to Managed Soils/Inorganic N Fertilizers	4(I) Direct N2O Emissions from N Inputs to Managed Soils/Inorganic N Fertilizers	3.D.1 Direct N2O emissions from managed soils	N inputs to managed soils are reported in the agriculture sector
CO_2	4.G Harvested Wood Products/Approach B/Approach B2/Total HWP from Domestic Harvest/HWP Produced and Exported/Solid Wood/Sawnwood and Wood panels	Solid Wood/Sawnwood and Wood panels in HWP Produced and exported	Solid Wood/Sawnwood and wood panels in HWP produced and consumed domestically	HWP produced and exported are included in the HWP produced and consumed domestically

2 TRENDS IN GREENHOUSE GAS EMISSIONS

2.1 Description and interpretation of emission trends for aggregate greenhouse gas emissions

Summary data of the Italian greenhouse gas emissions for the years 1990-2022 are reported in Tables A8.1.1- A8.1.5 of Annex 8.

Total greenhouse gas emissions, in CO_2 equivalent, excluding emissions and removals from LULUCF, have decreased by 19.9% between 1990 and 2022, varying from 522 to 413 CO_2 equivalent million tons (Mt). Table 1 shows the national greenhouse gases for 1990-2022, expressed in CO_2 equivalent terms and by substance; emissions are reported excluding and including emissions and removals from LULUCF and with indirect emissions which, for Italy, equals the total emissions.

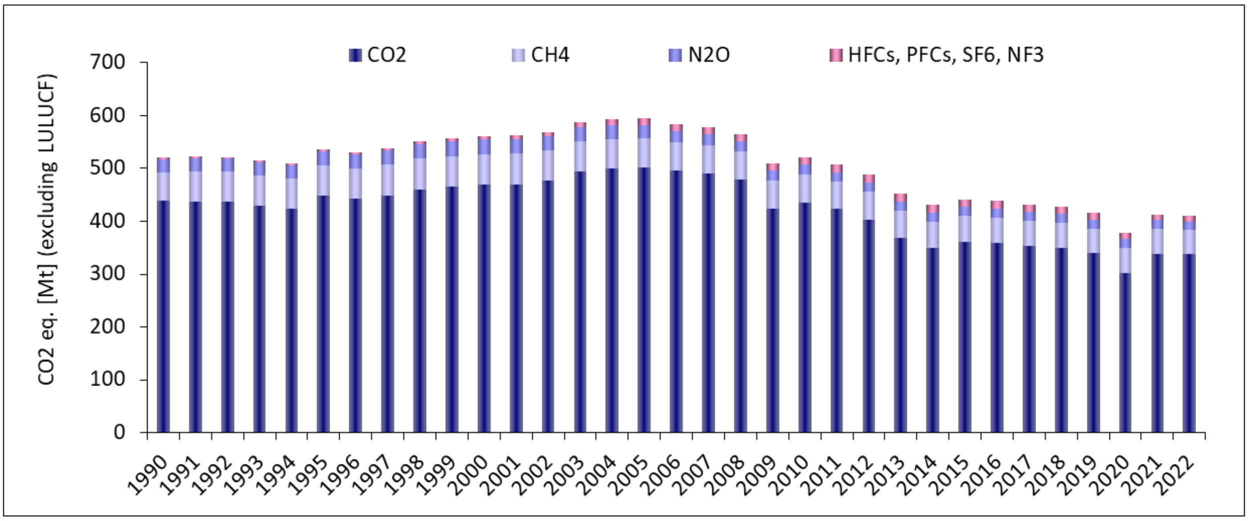
Table 2.1 Greenhouse gas emissions and removals from 1990 to 2022 by gas (kt CO_2 eq.)

GHG emissions	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
					kt CO_2 equivalent					
CO_2 excluding net CO_2 from LULUCF	438,208	448,596	469,598	501,366	435,701	361,246	339,641	302,614	335,920	340,904
CO_2 including net CO_2 from LULUCF	432,937	424,242	448,286	466,925	395,419	318,828	301,380	274,409	310,024	318,796
CH_4 excluding CH_4 from LULUCF	54,971	57,026	57,698	54,806	52,874	49,370	46,685	47,402	47,036	45,714
CH_4 including CH_4 from LULUCF	55,691	57,196	58,098	54,973	53,071	49,518	46,787	47,588	47,525	46,072
N_2O excluding N_2O from LULUCF	24,475	26,416	27,183	26,337	18,305	17,101	16,897	17,570	17,457	15,738
N_2O including N_2O from LULUCF	25,383	27,212	27,872	26,925	18,707	17,436	17,354	18,090	18,076	16,288
HFCs	372	1,100	3,747	9,666	12,805	12,082	11,089	9,971	9,411	9,085
PFCs	2,615	1,351	1,363	1,759	1,377	1,529	915	499	395	439
Unspecified mix of HFCs and PFCs	NO,NA	24	24	24	24	24	23	22	25	22
SF_6	421	700	621	565	405	483	438	252	282	390
NF_3	NA,NO	77	13	33	20	28	18	16	15	20
Indirect CO_2	1,311	1,211	1,073	1,041	860	692	786	705	740	728
Total (excluding LULUCF, with CO_2 indirect)	522,373	536,500	561,322	595,598	522,371	442,557	416,493	379,051	411,282	413,041
Total (including LULUCF, with CO_2 indirect)	518,730	513,112	541,099	561,913	482,687	400,621	378,791	351,552	386,495	391,842

The most important greenhouse gas, CO_2, which accounts for 82.7% of total emissions in CO_2 equivalent, shows a decrease of 22.3% between 1990 and 2022. In the energy sector, in particular CO_2 emissions in 2022 are 20.0% lower than in 1990. In 2022, CH_4 and N_2O emissions are equal to 11.1% and 3.8% of the total CO_2 equivalent greenhouse gas emissions, respectively. CH_4 emissions have decreased by 16.8% from 1990 to 2022, while N_2O emissions have decreased by 35.7%. As for other greenhouse gases, HFCs account for 2.2% of total emissions, PFCs and SF_6 are both equal to about 0.1% of total emissions; the weight of NF_3 is less than 0.01%.

Figure 2.1 illustrates the national trend of greenhouse gases for 1990-2022, expressed in CO_2 equivalent terms and by substance; total emissions do not include emissions and removals from land use, land use change and forestry.

Figure 2.1 National greenhouse gas emissions from 1990 to 2022 (without LULUCF) (Mt CO_2 eq.)

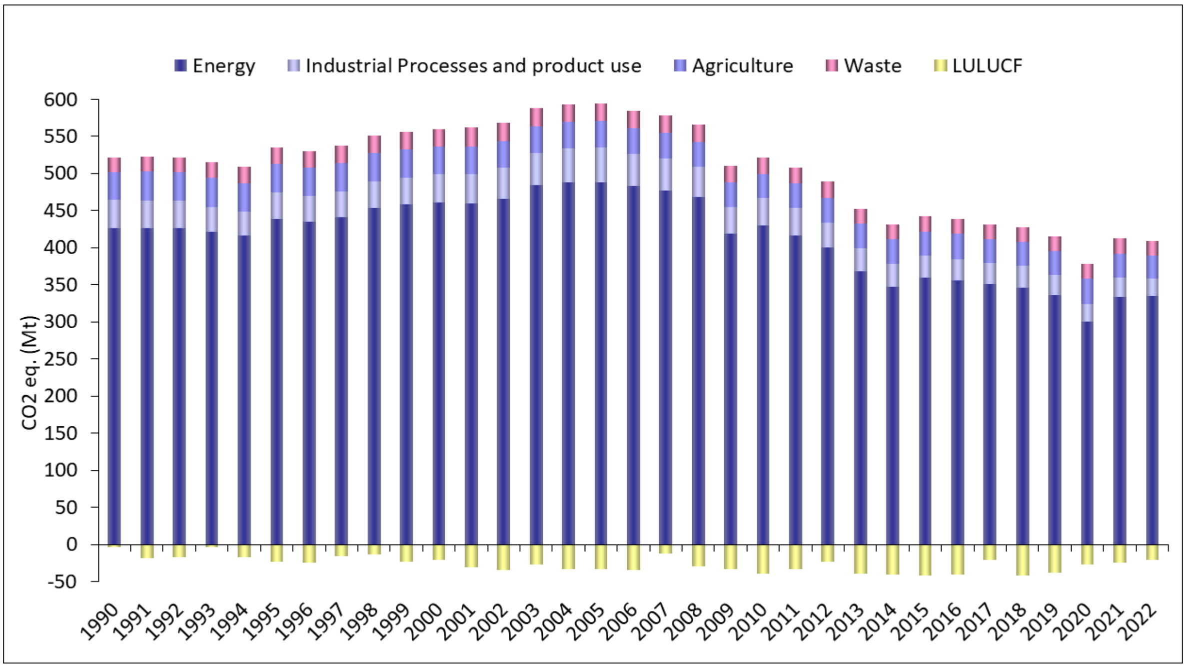


The share of the different sectors, in terms of total emissions, remains nearly unvaried over the period 1990-2022. Specifically, for the year 2022, the greatest part of the total greenhouse gas emissions is to be attributed to the energy sector, with a percentage of 81.8%, followed by agriculture and industrial processes and product use, accounting for 7.4% and 5.7%, respectively, and waste contributing with 4.9% to total emissions.

Total greenhouse gas emissions and removals, including LULUCF sector, are shown in Figure 2.2 subdivided by sector.

In 2022, considering the total GHG emissions (including the absolute value of net LULUCF emissions/ removals), the percentage contribution of the sectors is: 77.9% for energy, 7.1% for agriculture, 5.4% for industrial processes and product use, 4.9% for LULUCF and 4.6% for waste.

Figure 2.2 Greenhouse gas emissions and removals from 1990 to 2022 by sector (Mt CO_2 eq.)

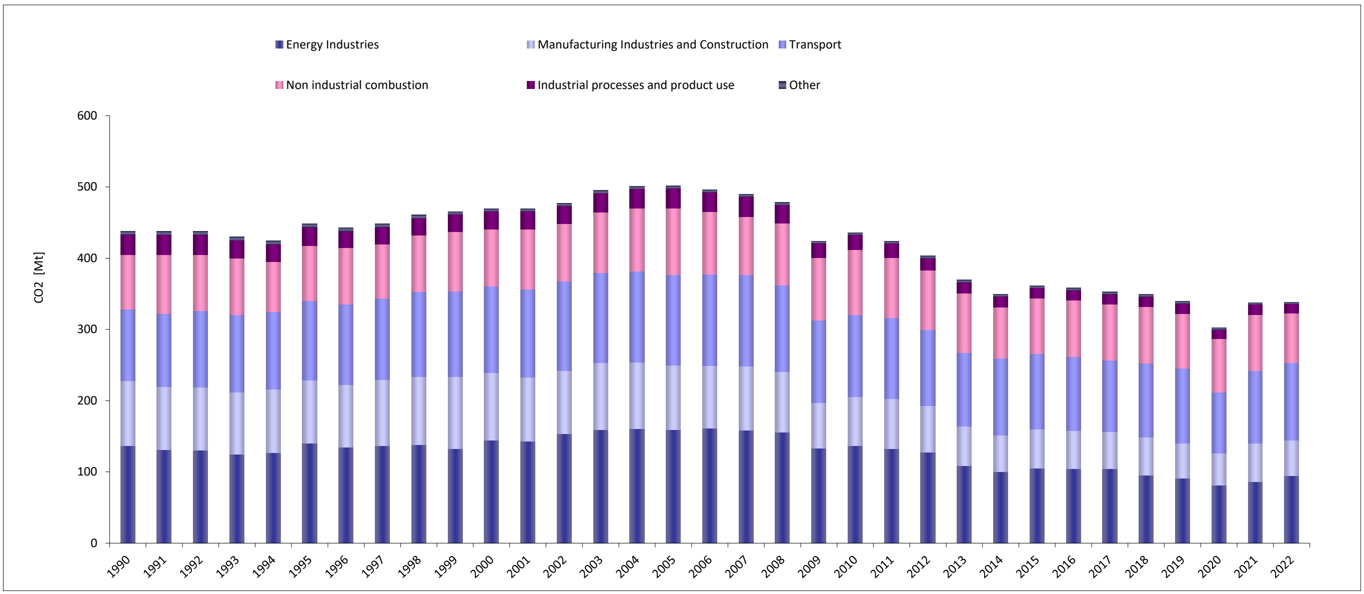


2.2 Description and interpretation of emission trends by gas

2.2.1 Carbon dioxide emissions

CO_2 emissions, without LULUCF, decreased by 22.3% from 1990 to 2022, ranging from 438 to 342 million tons. The most relevant emissions derive from transportation (31.9%) and energy industries (27.7%). Non-industrial combustion accounts for 20.0% and manufacturing and construction industries for 15.8%, while the remaining emissions derive from industrial processes (3.9%) and the other sectors (about 0.6%). The trend of CO_2 emissions by sector is shown in Figure 2.3. Indirect CO_2 emissions range from 1.3 Mt in 1990 to 0.7 Mt in 2022.

Figure 2.3 National CO_2 emissions by sector from 1990 to 2022 (Mt)



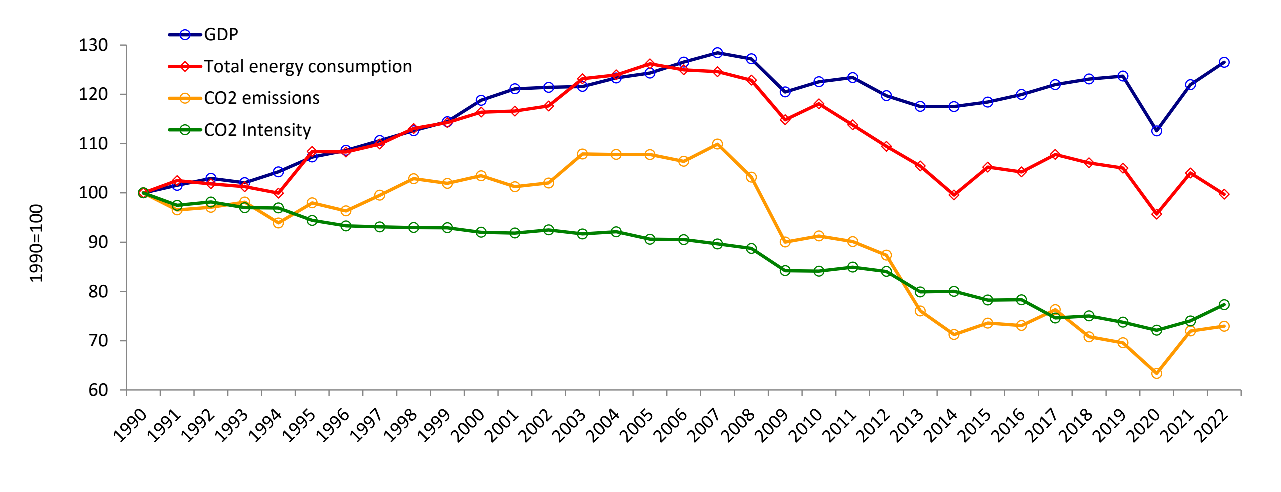
The main driver for the reduction of CO_2 emissions is the reduction in emissions observed in energy industries and manufacturing industries and construction; in the period 1990-2022, emissions from energy industries decreased by 31.1% while those from manufacturing industries and construction show a decrease of 40.8%. The transport sector has shown an increase in emissions until 2007 and then a decrease both for the economic recession and the penetration of vehicles with low fuel consumption. Non industrial combustion emission trend is driven by the annual climatic variation while emissions from industrial processes decreased by 53.0% mainly for the decrease in cement production.

Figure 2.4 illustrates the performance of the following economic and energy indicators:

- Gross Domestic Product (GDP) at market prices as of 2010 (base year 1990=100);
- Total Energy Consumption;
- CO_2 emissions, excluding emissions and removals from land-use change and forests;
- CO_2 *intensity*, which represents CO_2 emissions per unit of total energy consumption.

CO_2 emissions in the 1990s essentially mirrored energy consumption. A decoupling between the curves is observed only in recent years, mainly as a result of the substitution of fuels with high carbon contents by methane gas in the production of electric energy and in industry; in the last years, the increase in the use of renewable sources has led to a notable reduction in CO_2 intensity. The pandemic situation due to Covid-19 has led to a sharp fall in emissions and a slowdown in economic growth in 2020. The expected countertrend has been observed in the last two years.

Figure 2.4 Energy-related and economic indicators and CO_2 emissions



2.2.2 Methane emissions

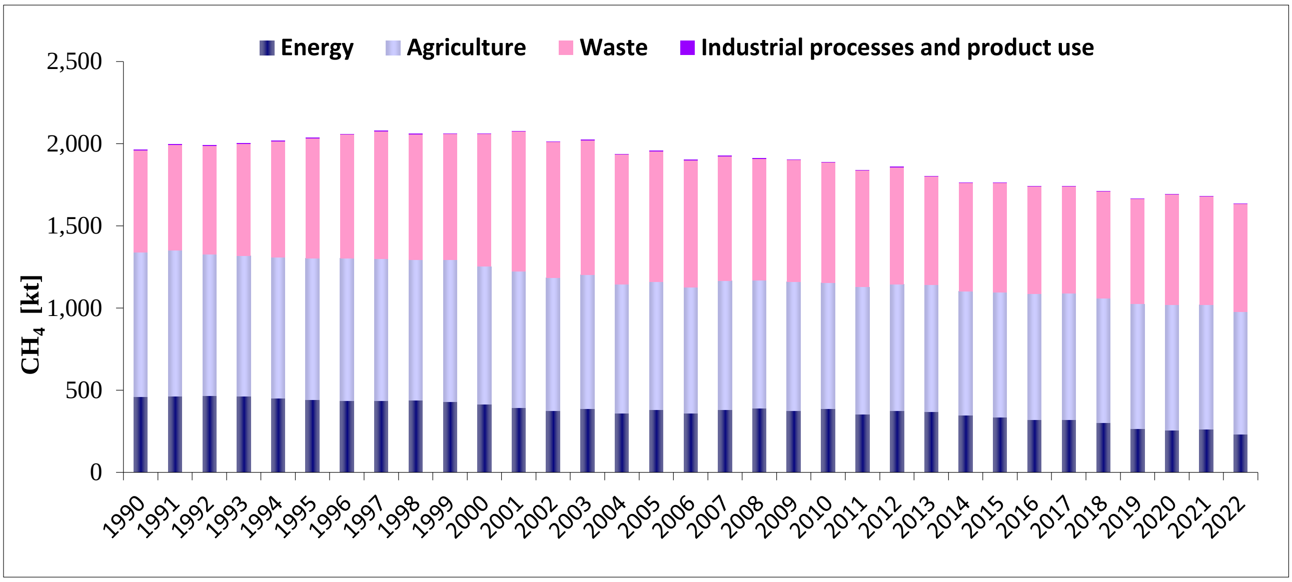
Methane emissions (excluding LULUCF) in 2022 represent 11.1% of total greenhouse gases, equal to 45.7 Mt in CO_2 equivalent, and show a decrease of 16.8% as compared to 1990 levels. CH_4 emissions, in 2022, mainly originated from the agriculture sector which accounts for 45.6% of total methane emissions, as well as from the waste (40.3%) and energy (14.1%) sectors.

Emissions in the agriculture sector regard mainly the enteric fermentation (69.5%) and manure management (23.0%) categories. The sector shows a decrease in emissions equal to 16.8% as compared to 1990, attributable widely to a reduction in livestock and the recovery of biogas for energy purposes (for swine and poultry).

Activities typically leading to emissions in the waste-management sector are the operation of dumping sites and the treatment of industrial wastewater. The waste sector shows an increase in CH_4 emission levels, equal to 6.3% compared to 1990; the largest sectoral shares of emissions are attributed to solid waste disposal on land (84.6%) and waste-water handling (14.5%), which show an increase equal to 13.9% and a decrease by 25.6%, respectively.

In the energy sector, the reduction of CH_4 emissions (-50.0%) is the result of two contrasting factors: on the one hand there has been a considerable reduction in emissions deriving from energy industries, transport, fugitive emissions from fuels (caused by leakage from the extraction and distribution of fossil fuels, due to the gradual replacement of natural-gas distribution networks), on the other hand a strong increase in the civil sector can be observed, as a result of the increased use of methane and biomass in heating systems. Figure 2.5 shows the emission figures by sector.

Figure 2.5 National CH_4 emissions by sector from 1990 to 2022 (kt)



2.2.3 Nitrous oxide emissions

In 2022, nitrous oxide emissions (excluding LULUCF) represent 3.8% of total greenhouse gases, with a decrease of 35.7% between 1990 and 2022, from 24.5 to 15.7 Mt CO_2 equivalent. The major source of N_2O emissions is the agricultural sector (61.6%), in particular the use of both chemical and organic fertilisers in agriculture, as well as the management of waste from the raising of animals. Emissions from the agriculture sector show a decrease of 24.3% during the period 1990-2022, due to a reduction in livestock number.

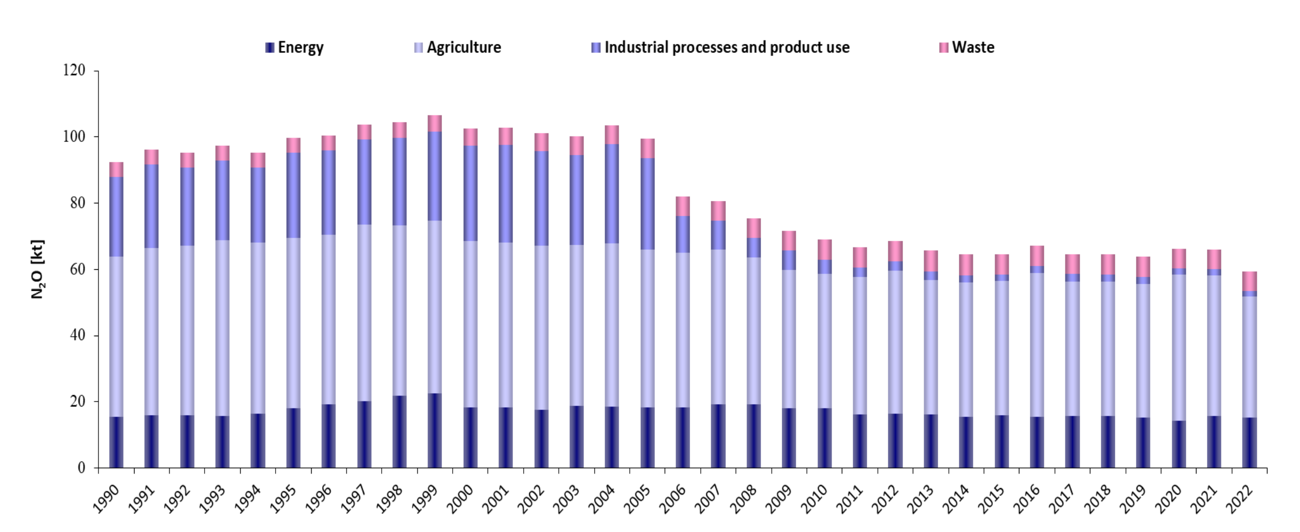
Emissions in the energy sector (25.6% of the total) show a decrease by 1.6% from 1990 to 2022; this trend can be traced primarily to the reduction of 40.2% in the manufacturing and construction industries (which account for 4.5% of the total N_2O emissions) due mainly to the reduction in the last years of cement production; the downward trend was counterbalanced by the increase of emissions by 32.0% in the other sectors category, which accounts for 13.0% of the total N_2O emissions, as a result of the increased use of biomass in heating systems.

For the industrial sector, N_2O emissions show a decrease of 92.5% from 1990 to 2022. The decrease is almost totally due to the introduction of abatement systems in the nitric and adipic acid production plants which drastically reduced emissions from these processes. A further component which has contributed to the reduction is the decreasing use of N_2O for medical purposes.

Other emissions in the waste sector (9.7% of national N_2O emissions) primarily regard the processing of industrial and domestic waste-water treatment and the biological treatment of solid waste.

Figure 2.6 shows national emission figures by sector.

Figure 2.6 National N_2O emissions by sector from 1990 to 2022 (kt)



2.2.4 Fluorinated gas emissions

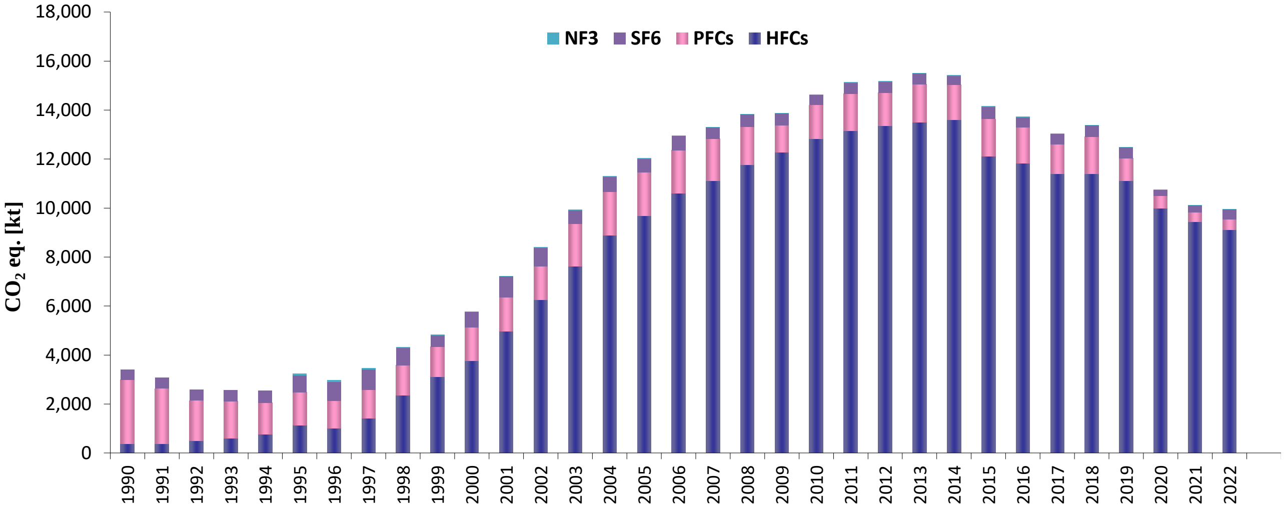
Taken altogether, the emissions of fluorinated gases represent 2.4% of total greenhouse gases in CO_2 equivalent in 2022 and they show a significant increase between 1990 and 2022. This increase is the result of different features for the different gases. HFCs, for instance, have increased considerably from 1990 to 2022, from 0.4 to 9.1 Mt in CO_2 equivalent. The main sources of emissions are the consumption of HFC-134a, HFC-125, HFC-32 and HFC-143a in refrigeration and air-conditioning devices, together with the use of HFC-134a in pharmaceutical aerosols. Increases during this period are due both to the use of these substances as substitutes for gases that destroy the ozone layer and to the greater use of air conditioners in automobiles.

Emissions of PFCs show a decrease of 83.2% from 1990 to 2022. The level of PFC emissions in 2022 is equal to 0.4 Mt in CO_2 equivalent, and it is due to by product emissions in fluorchemical production (66.1%), and the use of the gases in the production of semiconductors (33.9%).

Emissions of SF_6 are equal to 0.4 Mt in CO_2 equivalent in 2022, with a decrease of 7.3% as compared to 1990 levels. In 2022, 76.4% of SF_6 emissions derive from the gas contained in electrical equipment, 7.6% from the use of this substance in accelerators and 15.8% from the gas used in the semiconductors manufacture. NF_3 emissions account for 0.01 Mt in CO_2 equivalent in 2022 and derive from the semiconductors industry.

The national inventory of fluorinated gases has largely improved in terms of sources and gases identified and strict cooperation with the relevant industry has been established. Higher methods are applied to estimate these emissions; nevertheless, uncertainty still regards some activity data which are considered of strategic economic importance and therefore kept confidential.

Figure 2.7 National emissions of fluorinated gases by sector from 1990 to 2022 (kt CO_2 eq.)



2.3 Description and interpretation of emission trends by source

2.3.1 Energy

Emissions from the energy sector account for 81.8% of total national greenhouse gas emissions, excluding LULUCF, in 2022. Emissions in CO_2 equivalent from the energy sector are reported in Table 2.2 and Figure 2.8.

Table 2.2 Total emissions from the energy sector by source (1990-2022) (kt CO_2 eq.)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
		kt CO_2 eq.								
Total emissions	**426,167**	**438,670**	**460,484**	**488,344**	**429,916**	**359,981**	**336,404**	**300,064**	**332,164**	**337,877**
Fuel Combustion (Sectoral Approach)	411,964	425,294	448,394	477,728	420,239	351,304	329,440	293,871	326,508	332,826
Energy Industries	*137,620*	*140,603*	*144,874*	*159,890*	*137,467*	*106,052*	*91,693*	*81,634*	*86,428*	*94,871*
Manufacturing Industries and Construction	*92,151*	*90,204*	*96,245*	*92,299*	*70,048*	*55,569*	*49,958*	*45,839*	*54,561*	*54,728*
Transport	*102,190*	*114,215*	*123,954*	*128,358*	*115,902*	*106,716*	*106,347*	*86,561*	*102,926*	*109,774*
Other Sectors	*78,868*	*78,713*	*82,444*	*95,867*	*96,134*	*82,490*	*80,977*	*79,196*	*82,270*	*72,929*
Other	*1,136*	*1,559*	*877*	*1,314*	*688*	*477*	*466*	*640*	*324*	*523*
Fugitive Emissions from Fuels	14,203	13,376	12,090	10,616	9,676	8,677	6,964	6,193	5,656	5,051
Solid Fuels	*148*	*83*	*109*	*101*	*97*	*59*	*36*	*29*	*28*	*30*
Oil and Natural Gas	*14,055*	*13,293*	*11,982*	*10,515*	*9,580*	*8,618*	*6,928*	*6,165*	*5,628*	*5,022*

From 2005, GHG emissions from the energy sector have been decreasing because of the policies adopted at European and national level to implement the production of energy from renewable sources. From the same year, a further shift from petrol products to natural gas in producing energy has been observed as a consequence of the starting of the EU greenhouse gas Emission Trading Scheme (EU ETS) on January 1st, 2005. From 2009, a further drop in the sectoral emissions is due to the economic recession; an increase is observed only from 2009 to 2010 (+2.7%); since then, except for the increase of 3.5% between 2014 and 2015, the annual variations are always negative until 2019.

Total greenhouse gas emissions, in CO_2 equivalent, show a decrease of about 20.7% from 1990 to 2022; in particular, an upward trend is noted from 1990 to 2004, with an increase by 14.4%, while between 2005 and 2022 emissions decreased by 30.8%.

The GHG with the highest impact, in the energy sector, is CO_2, accounting for 96.9% of the sectoral total, in 2022, whose levels have decreased by 20.0% from 1990 to 2022.

In 2022, CH_4 emissions account for 1.9% of the sectoral total. Their trend shows a decrease of 50.0% from 1990 to 2022, and it is driven by the combined effect of technological improvements that limit volatile organic compounds (VOCs) from tail pipe and evaporative emissions (for cars) and the expansion of two-wheelers fleet.

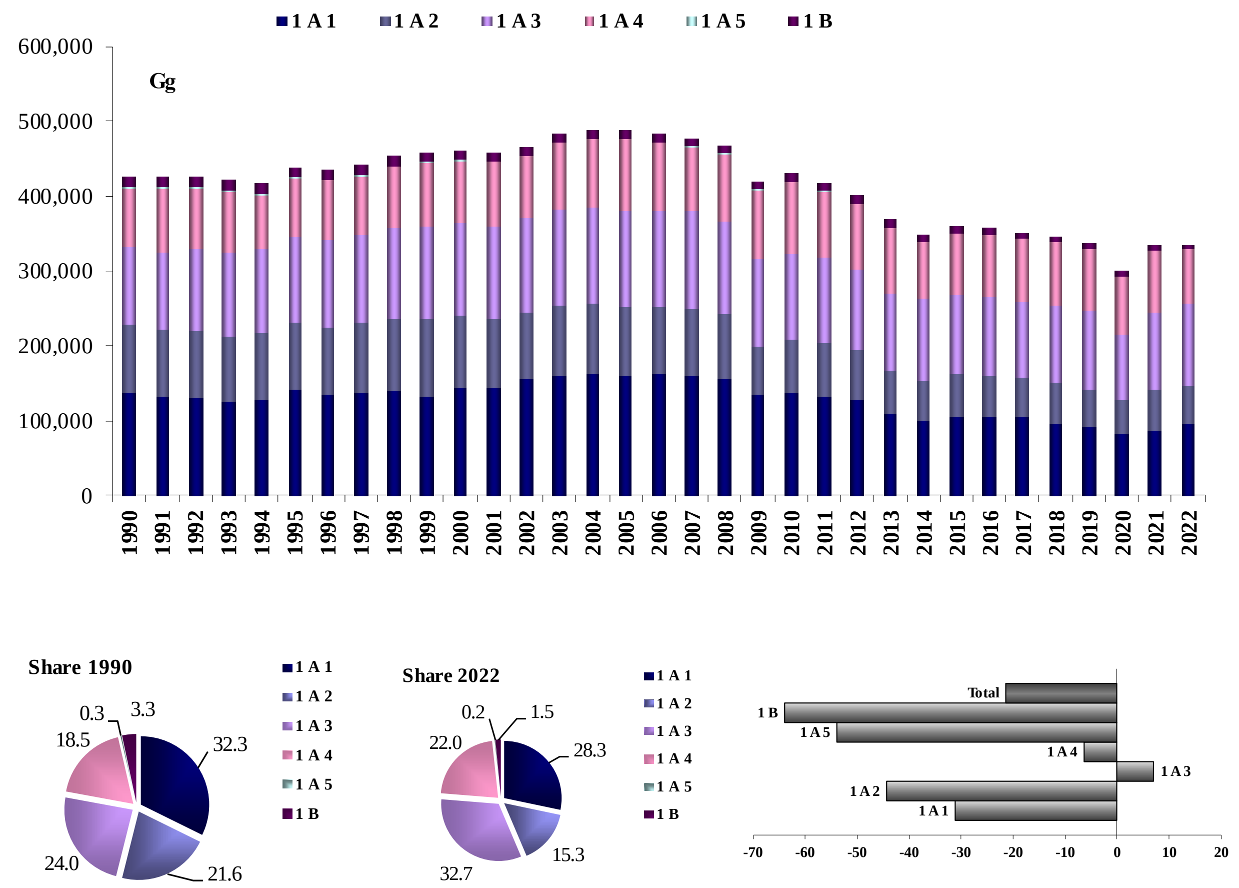
N_2O shows a decrease of 1.6% with a share out of the total equal to 1.2%, mainly driven by the technological development in road transport and to the switch from gasoline to diesel fuel consumption.

In general, for the sector, the decrease in emissions from 1990 to 2022 is driven by the reduction in the energy industries and manufacturing industries and construction, which, in 2022, account for 28.1% and 16.2% and reduced by 31.1% and 40.6%, respectively. Specifically, for the manufacturing industries and construction, the reason for the reduced emissions is the cut in production in some subsectors (e.g. chemical, construction and building materials, steel) due to the effects of the economic recession but also to an increase in efficiency, especially identified in the chemical sector. A decrease in emissions also occurs in other sectors subcategory (-7.5%), which account for 21.6% in 2022; the transport sector, accounting for 32.5%, in 2022, shows an increase of 7.4%.

Road transport is the most relevant source in the transport sector, accounting in 2022 for 24.3% of total national CO_2 equivalent emissions.

The increase in other sectors, which refer to emissions originated from energy use in the civil sector and from military mobile activities, is due, from 1990 to 2000, to the increase in numbers and size of building with heating, and to the trend in weather conditions, while from 2002, and especially in the last few years, to the increase in other greenhouse gas emissions than CO_2 for the growing use of woody biomass and biogas for heating. Details on these figures are described in the specific chapter.

Figure 2.8 Trend of total emissions from the energy sector (1990-2022) (kt CO_2 eq.)



2.3.2 Industrial processes and product use

Emissions from the industrial processes and product use sector account for 5.7% of total national greenhouse gas emissions, excluding LULUCF, in 2022. Emission trends from industrial processes are reported in Table 2.3 and Figure 2.9.

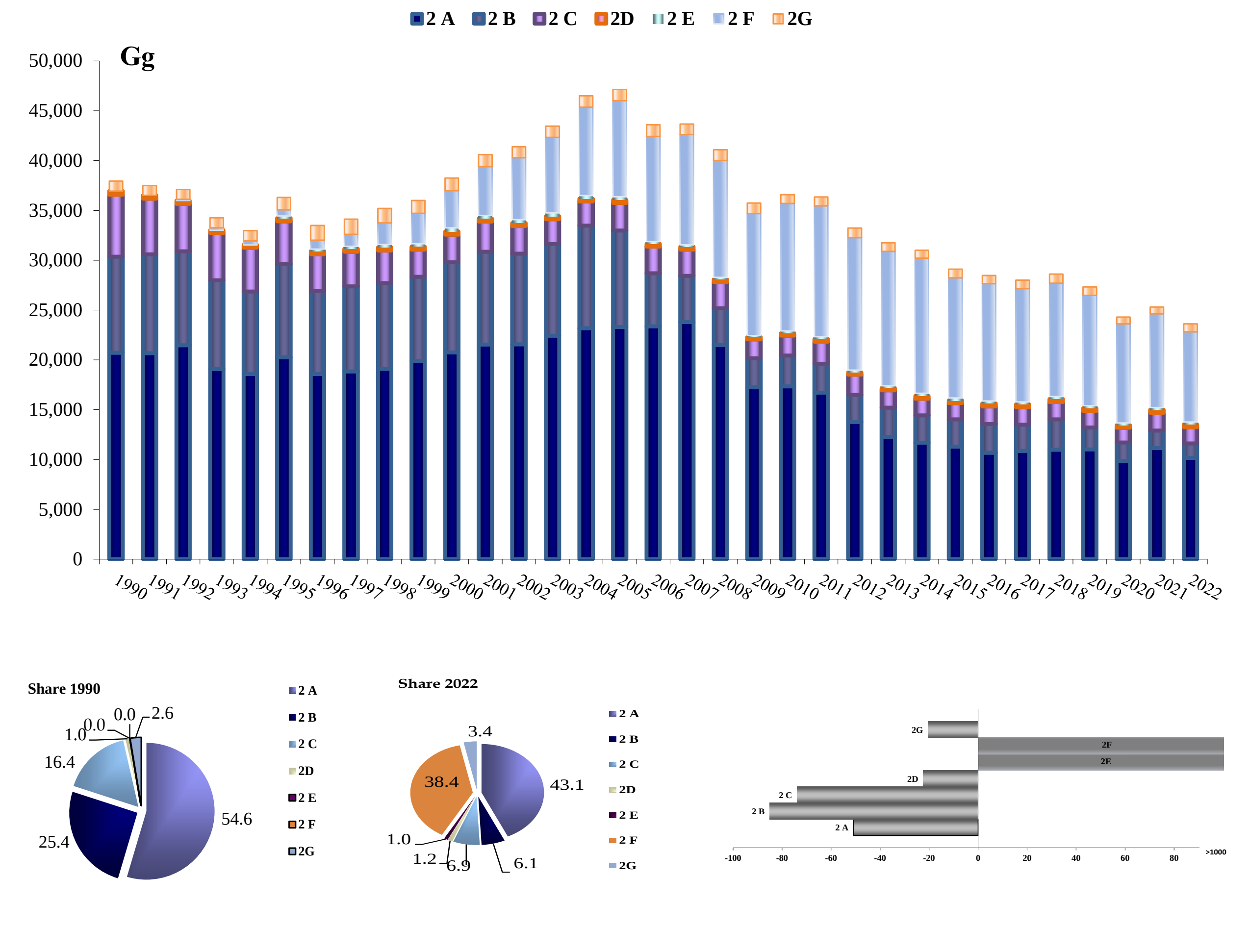
Total emissions, in CO_2 equivalent, show a decrease of 37.8%, from 1990 to 2022. Taking into account emissions by substance, CO_2 and N_2O decreased by 53.0% and 92.5%, respectively; in terms of their weight out of the sectoral total emissions, CO_2 accounts for 55.7% and N_2O for 2.0%. CH_4 decreased by 73.2% but it accounts for only 0.2%.

The decrease in emissions is mostly to be attributed to a decrease in the mineral and chemical industries. Emissions from mineral production decreased by 50.9%, mostly for the reduction of cement production. The decrease of GHG emissions in the chemical industry (-85.1%) is due to the decreasing trend of the emissions from nitric acid and adipic acid production (the last production process sharply reduced its emissions, due to a fully operational abatement technology). On the other hand, from 1990 to 2022, a considerable increase is observed in F-gas emissions (192.2%), whose share on total sectoral emissions is 66.4% in the last reporting year. The main drivers of the increase are the consumptions of HFCs in refrigeration and air-conditioning devices, together with their use in pharmaceutical aerosols (see section 2.2.4). Details for industrial processes and product use emissions can be found in the specific chapter.

Table 2.3 Total emissions from the industrial processes sector by gas (1990-2022) (kt CO_2 eq.)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
					kt CO_2 eq.					
Total emissions	**37,946**	**36,299**	**38,240**	**47,132**	**36,591**	**29,094**	**27,330**	**24,290**	**25,300**	**23,620**
CO_2	27,992	26,049	24,743	27,663	20,804	14,355	14,230	12,932	14,621	13,145
CH_4	144	150	82	83	67	48	46	38	45	39
N_2O	6,402	6,848	7,646	7,338	1,088	545	570	559	505	480
F-gases	3,408	3,252	5,769	12,049	14,631	14,147	12,484	10,760	10,129	9,957
HFCs	*372*	*1,100*	*3,747*	*9,666*	*12,805*	*12,082*	*11,089*	*9,971*	*9,411*	*9,085*
PFCs	*2,615*	*1,351*	*1,363*	*1,759*	*1,377*	*1,529*	*915*	*499*	*395*	*439*
Unspecified mix of HFCs and PFCs	-	*24*	*24*	*24*	*24*	*24*	*23*	*22*	*25*	*22*
SF_6	*421*	*700*	*621*	*565*	*405*	*483*	*438*	*252*	*282*	*390*
NF_3	-	*77*	*13*	*33*	*20*	*28*	*18*	*16*	*15*	*20*

Figure 2.9 Trend of total emissions from the industrial processes sector (1990-2022) (kt CO_2 eq.)



2.3.3 Agriculture

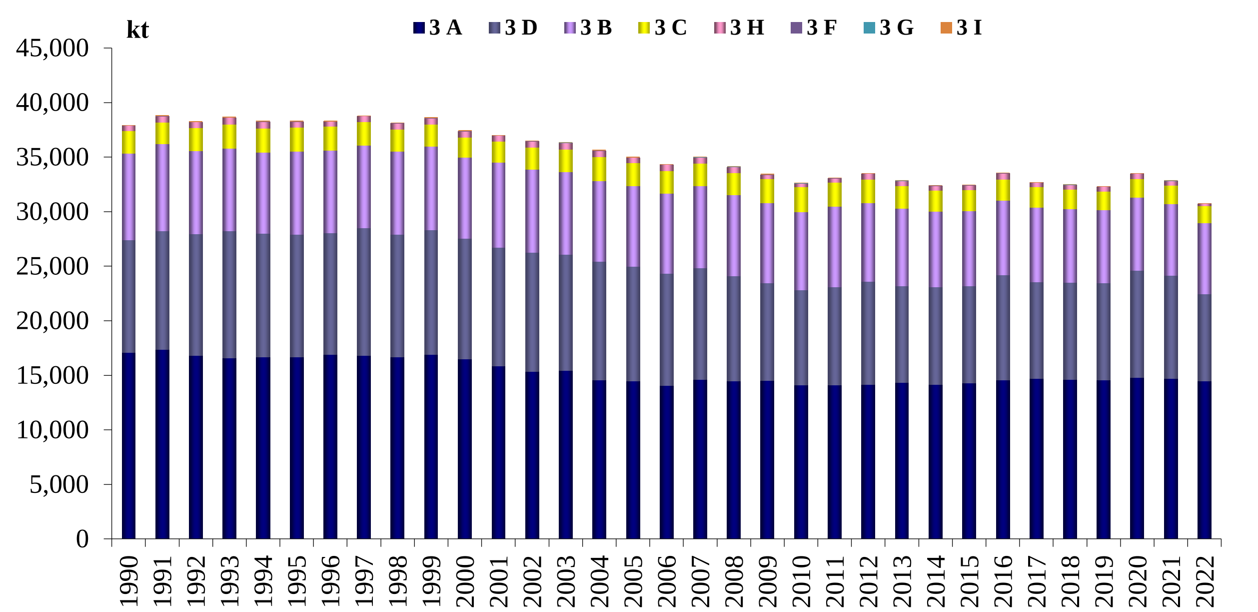
Emissions from the agriculture sector account for 7.4% of total national greenhouse gas emissions, in 2022, excluding LULUCF. Emissions from the agriculture sector are reported in Table 2.4 and Figure 2.10.

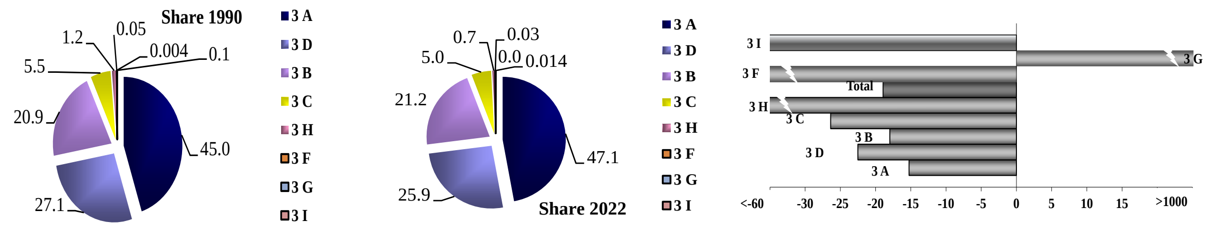
Table 2.4 Total emissions from the agriculture sector by source (1990-2022) (kt CO_2 eq.)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
					kt CO_2 eq.					
Total emissions	**37,953**	**38,312**	**37,430**	**35,028**	**32,634**	**32,455**	**32,314**	**33,534**	**32,862**	**30,764**
Enteric Fermentation	17,093	16,697	16,509	14,484	14,100	14,272	14,584	14,771	14,695	14,487
Manure Management	7,942	7,569	7,452	7,396	7,167	6,885	6,682	6,685	6,554	6,513
Rice Cultivation	2,102	2,228	1,855	2,078	2,255	1,943	1,721	1,696	1,677	1,547
Agricultural Soils	10,288	11,233	11,024	10,490	8,720	8,886	8,888	9,868	9,463	7,972
Field Burning of Agricultural Residues	19	18	18	17	12	11	10	10	11	10
Liming	1	1	2	14	18	14	16	10	26	4
Urea application	465	512	525	507	335	425	396	472	414	218
Other carbon-containing fertilizers	44	54	44	42	28	20	17	21	22	12

Emissions mostly refer to CH_4 and N_2O, which, in 2022, account for 67.7% and 31.5% of the total emissions of the sector, respectively. CO_2 accounts for the remaining 0.8% of total emissions. The decrease observed in total emissions (-18.9%) is mostly due to the decrease of CH_4 emissions from enteric fermentation (-15.2%) and to the decrease of N_2O (-22.5%) from agricultural soils; in 2022 these categories account for 47.1% and 25.9% of the total sectoral emissions, respectively.

Figure 2.10 Trend of total emissions from the agriculture sector (1990-2022) (kt CO_2 eq.)





Main drivers behind these downward trends are the reduction in the number of animals, especially cattle, in the whole period and the reduction of the use of nitrogen fertilizers. In addition, an increase in the recovery of the biogas produced from animal manure and used in the energy sector has occurred in the last years. This biogas has been used for electricity production and the combined electricity and heat production, thus contributing to the reduction of total emissions. Detailed comments can be found in the specific chapter.

2.3.4 LULUCF

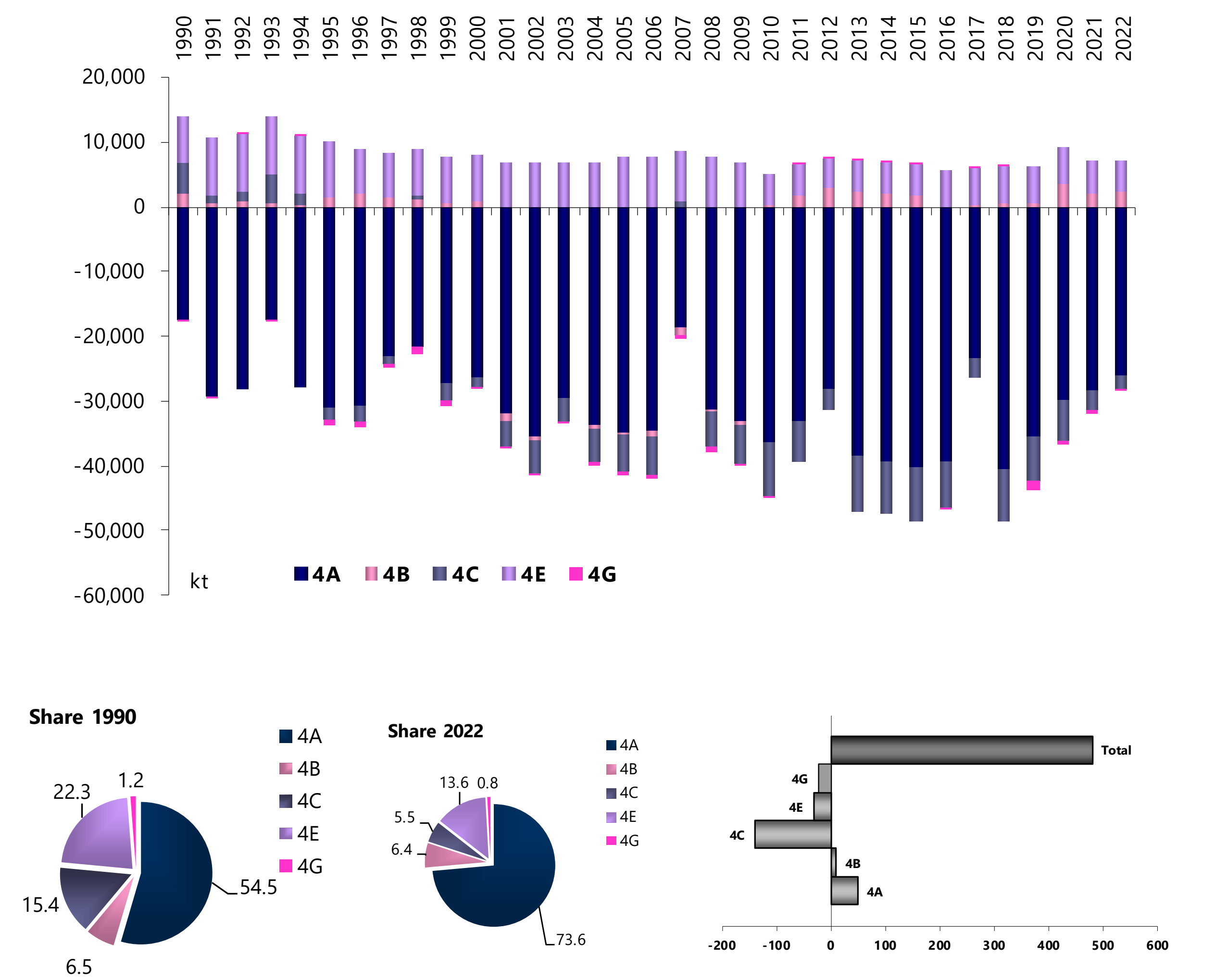
Emissions and removals from the LULUCF sector are reported in Table 2.5 and Figure 2.11.

Table 2.5 Total emissions from the LULUCF sector by source/sink (1990-2022) (kt CO_2 eq.)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
	kt CO_2 eq.									
Total emissions/removals	-3,586	-23,390	-20,190	-33,676	-39,669	-41,924	-20,384	-37,710	-27,509	-24,797
Forest land	-17,344	-31,019	-26,285	-34,943	-36,413	-40,278	-23,289	-35,391	-29,843	-28,440
Cropland	2,082	1,386	989	-410	375	1,742	336	674	3,707	2,220
Grassland	4,905	-1,941	-1,417	-5,594	-8,300	-8,326	-3,088	-7,095	-6,294	-3,038
Wetlands	NE,NO	5	8	8	130	130	32	32	32	NO,NE
Settlements	7,089	8,867	6,928	7,749	4,659	4,709	5,516	5,533	5,538	4,813
Other land	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Harvested wood products	-388	-706	-454	-503	-142	89	59	-1,469	-657	-361
Other (indirect N_2O soils)	70	18	40	17	23	11	50	8	9	9

LULUCF total removals, in CO_2 equivalent, show a high variability in the period, remarkably influenced by the annual fires' occurrence and the related GHG emissions. CO_2 accounts for 96.1% of total emissions and removals of the sector, as absolute weight. The key driver for the rise in removals is the increase of carbon stock in forest land. Further details for LULUCF emissions and removals can be found in the specific chapter.

Figure 2.11 Trend of total emissions and removals from the LULUCF sector (1990-2022) (kt CO_2 eq.)



2.3.5 Waste

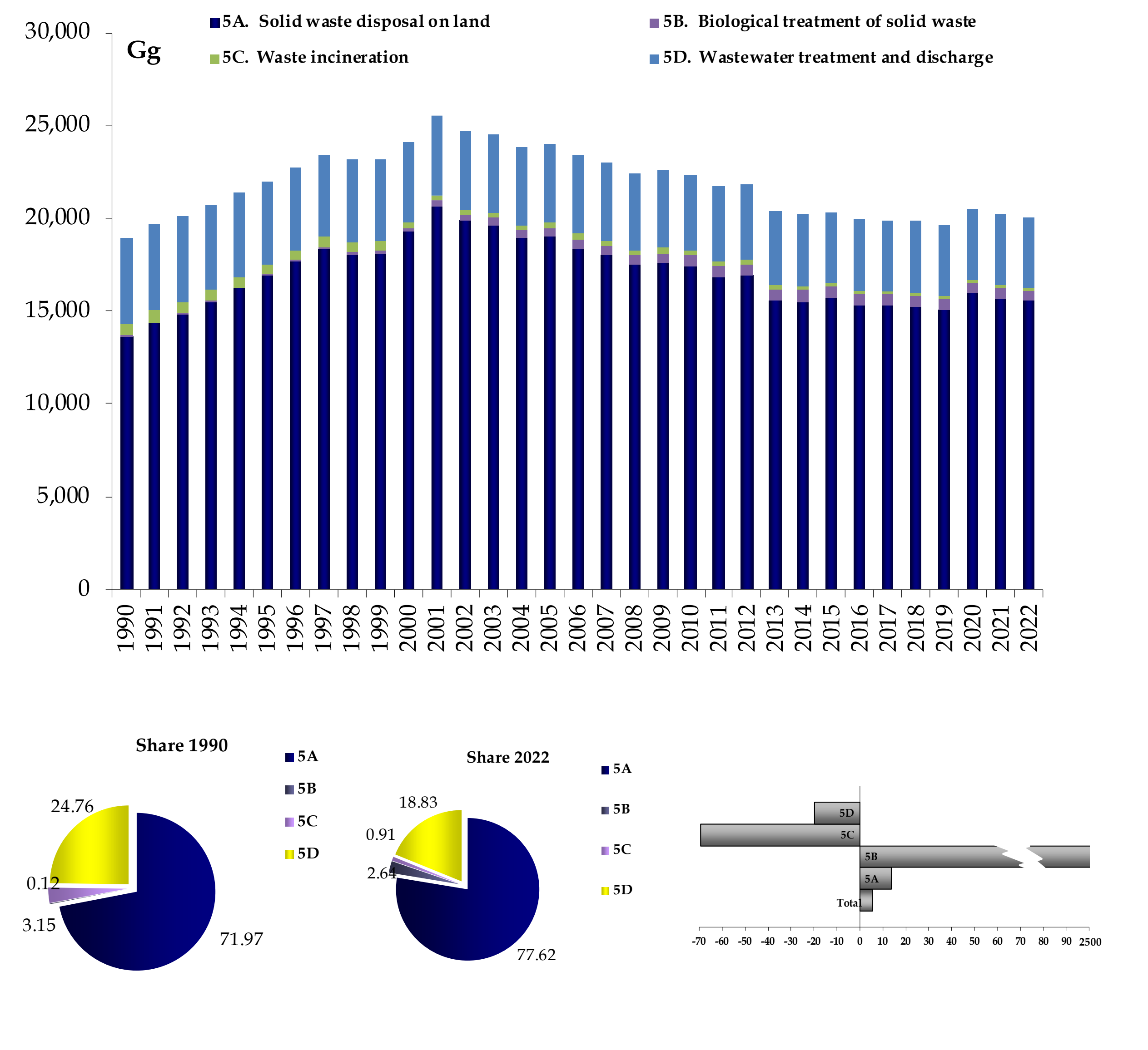
In 2022, emissions from the waste sector account for 4.9% of total national greenhouse gas emissions, excluding LULUCF. Emissions from the waste sector are shown in Table 2.6 and Figure 2.12.

Table 2.6 Total emissions from the waste sector by source (1990-2022) (kt CO_2 eq.)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
					kt CO_2 eq.					
Total emissions	**18,996**	**22,008**	**24,094**	**24,052**	**22,371**	**20,334**	**19,659**	**20,459**	**20,216**	**20,055**
Solid waste disposal	13,671	16,938	19,264	19,043	17,429	15,718	15,060	15,967	15,683	15,565
Biological treatment of solid waste	23	54	232	456	577	599	582	560	558	530
Incineration and open burning of waste	598	547	287	314	255	175	168	162	188	182
Waste-water treatment and discharge	4,703	4,469	4,311	4,240	4,110	3,843	3,849	3,770	3,787	3,778

Total sectoral emissions, in CO_2 equivalent, increased by 5.6% from 1990 to 2022. The trend is mainly driven by the increase in emissions from solid waste disposal (13.9%), accounting for 77.6% of the sectoral total in 2022, counterbalanced by the decrease of emissions from waste-water treatment (-19.7%), accounting for 18.8%. Considering emissions by gas, the most important greenhouse gas is CH_4 which accounts for 91.9% of the sectoral total and shows an increase of 6.3% from 1990 to 2022. N_2O levels have increased by 31.0% while CO_2 decreased by 77.8%; in 2022, these gases account for 7.6% and 0.6%, respectively. Further details can be found in the specific chapter.

Figure 2.12 Trend of total emissions from the waste sector (1990-2022) (kt CO_2 eq.)



2.3.6 Indirect CO_2 emissions

The contribution of indirect CO_2 emissions from atmospheric oxidation of NMVOCs to the greenhouse gas emissions is small, about 0.2% of the total greenhouse gas emissions.

2.4 Description and interpretation of emission trends for indirect greenhouse gases and SO_2

Emission trends of NO_X, CO, NMVOC and SO_2 from 1990 to 2022 are presented in Table 2.7 and Figure 2.13.

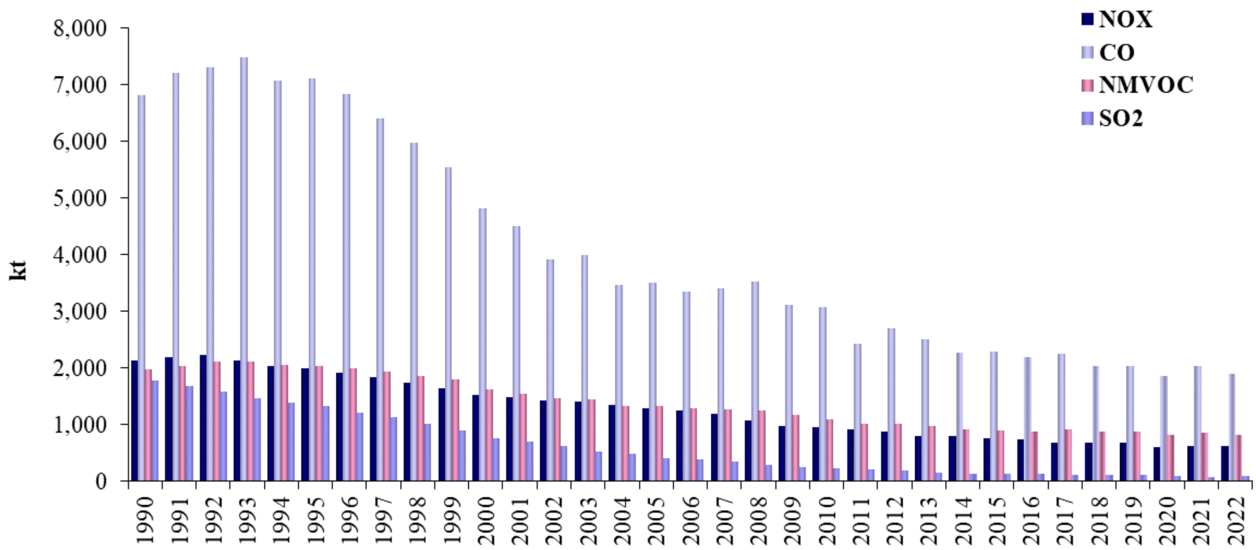
Table 2.7 Total emissions without LULUCF for indirect greenhouse gases and SO_2 (1990-2022) (kt)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
	kt									
NO_X	2,128	1,992	1,522	1,296	958	749	670	598	611	624
CO	6,823	7,117	4,813	3,502	3,076	2,282	2,042	1,861	2,032	1,894
NMVOC	1,970	2,040	1,616	1,322	1,100	891	871	815	847	823
SO_2	1,784	1,323	757	411	222	128	112	85	79	88

All gases show a significant reduction in 2022 as compared to 1990 levels. The highest reduction is observed for SO_2 (- 95.0%), NO_X levels have reduced by 70.7%, while CO and NMVOC show a decrease by 72.2% and 58.2%, respectively. A detailed description of the trend by gas and sector as well as the main reduction plans can be found in the Italian National Programme for the progressive reduction of the annual national emissions of SO_2, NO_X, NMVOC and NH_3, as requested by the Directive 2001/81/EC.

The most relevant reductions occurred because of the Directive 75/716/EC, and successive ones related to the transport sector, and of other European Directives which established maximum levels for sulphur content in liquid fuels and introduced emission standards for combustion installations. Therefore, in the combustion processes, oil with high sulphur content and coal have been substituted with oil with low sulphur content and natural gas.

Figure 2.13 Trend of total emissions for indirect greenhouse gases and SO_2 (1990-2022) (kt)



It should be noted that these figures differ from the national totals reported under the *United Nations Economic Commission for Europe* (UNECE) *Convention on Long Range Transboundary Air Pollution* (CLRTAP). If considering total emissions excluding the LULUCF sector, differences are to be attributed to the different accounting of emissions from the civil aviation sector and from fires. In the national totals under CLRTAP, in fact, emissions from aviation are calculated considering all LTO cycles, both domestic and international, excluding entirely the cruise phase. If national figures comprise LULUCF, on the other hand, differences are also to be attributed to fires; under the UNFCCC national total with LULUCF includes emissions from fires from forest, grassland, and cropland whereas they are not considered in the national total for CLRTAP. Emission trends of NO_X, CO, NMVOC and SO_2, excluding LULUCF, communicated under UNECE CLRTAP are presented in Table 2.8.

In the context of the European Regulation No 525/2013, Art. 7(1)(m)(i), EU Member States shall report on the consistency of data on air pollutants under the UNECE Convention on Long-range Transboundary Air Pollution and those under the UNFCCC. Differences in percentage terms between figures, without LULUCF, between the two Conventions are illustrated in Table 2.9.

Table 2.8 Total emissions for indirect greenhouse gases and SO_2 (1990-2022) (kt) under UNECE CLRTAP

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
					kt					
NO_X	2,125	1,988	1,516	1,291	952	745	667	596	608	620
CO	6,824	7,118	4,814	3,502	3,076	2,283	2,043	1,861	2,031	1,894
NMVOC	1,970	2,040	1,616	1,322	1,100	891	871	815	847	823
SO_2	1,784	1,322	756	411	222	127	112	85	79	88

Table 2.9 Percentage differences between total emissions for indirect greenhouse gases and SO_2 under the UNFCCC and UNECE CLRTAP Conventions (1990-2022)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
NO_X	0.17%	0.17%	0.41%	0.40%	0.64%	0.47%	0.47%	0.40%	0.55%	0.68%
CO	-0.01%	-0.01%	-0.02%	-0.01%	0.00%	-0.04%	-0.06%	0.01%	0.03%	0.01%
NMVOC	0.00%	0.00%	-0.01%	-0.01%	-0.01%	-0.02%	-0.02%	0.00%	0.01%	0.00%
SO_2	0.01%	0.02%	0.05%	0.10%	0.18%	0.16%	0.16%	0.19%	0.33%	0.36%

2.5 Indirect CO_2 and nitrous oxide emissions

Indirect emissions originate from the atmospheric oxidation of CH_4, CO and NMVOCs.

Following different UNFCCC review recommendations, from this year's submission, Italy has reported CO_2 emissions from the oxidation of NMVOCs from solvent use not in the relevant categories but, separately and all together, as indirect CO_2 emissions.

Details on how they are converted into indirect CO_2 can be found in the sections on indirect CO_2 emissions from non-energy-related products from fuels and solvents in Section 4.5.

Indirect emissions of N_2O take place because of two different nitrogen loss pathways. These pathways are the volatilization/emission of nitrogen as NH_3 and NO_X and the subsequent deposition of these forms of nitrogen as ammonium (NH_4+) and oxidised nitrogen (NO_X) on soils and waters, and the leaching and runoff of nitrogen from synthetic and organic nitrogen fertilizer inputs, crop residues, mineralization of nitrogen through land use change or management practices, and urine and dung deposition from grazing animals, into groundwater, riparian areas and wetlands, rivers. All NH_3 or NO_X anthropogenic emissions are potential sources of N_2O emissions.

Indirect N_2O emissions are estimated according to Equation 7.1 of the 2006 IPCC Guidelines (IPCC, 2006) based on NO_X and NH_3 national emissions disaggregated at sectoral level (ISPRA, 2021 [a]) and reported as memo item in the relevant sectors, except for the agriculture sector where emissions are already included in the national totals. This method assumes that N_2O emissions from atmospheric deposition are reported by the country that produced the original NO_X and NH_3 emissions. The ultimate formation of N_2O may occur in another country due to atmospheric transport of emissions. Also, the method does not account for the probable lag time between NO_X and NH_3 emissions and subsequent production of N_2O in soils and surface waters. This time lag is expected to be small related to an annual reporting cycle.

Total GHG emissions include indirect CO_2 emissions for Italy.

3 ENERGY

3.1 Sector overview

For the pollutants and sources discussed in this section, emissions result from the combustion of fuel. The pollutants estimated are: carbon dioxide (CO_2), NO_X as nitrogen dioxide, nitrous oxide (N_2O), methane (CH_4), non-methane volatile organic compounds (NMVOC), carbon monoxide (CO), and sulphur dioxide (SO_2). The sources covered are:

- Energy industries (public electricity and heat production, petroleum refining, manufacture of solid fuels and other energy industries);
- Manufacturing industries and construction (iron and steel, non-ferrous metals, chemicals, pulp, paper and print, food processing, beverages and tobacco, non-metallic minerals and other);
- Transport (aviation, road transportation, railways, navigation and other transportation);
- Other sectors (commercial/institutional, residential and agriculture/forestry/fishing);
- Fugitive emissions from fuels.

The national emission inventory is prepared using energy consumption information available from national statistics and an estimate of the use of the fuels.

Estimates for a particular source sector are calculated by applying an emission factor to an appropriate statistic. That is:

Total Emission = Emission Factor x Activity Data

Emission factors are typically derived from measurements on several representative sources and the resulting factor applied to the whole country.

For some categories, emissions data are available at individual sites. Hence, emissions for a specific category can be calculated as the sum of the emissions from these point sources. That is:

Emission = Σ Point Source Emissions

However, it is necessary to carry out an estimate of the fuel consumption associated with these point sources, so that emissions from non-point sources can be estimated from fuel consumption data without double counting. In general, a point source approach is applied to specific point sources (e.g. power stations, cement kilns, refineries). Most non-industrial sources are estimated using emission factors.

For most of the combustion source categories, emissions are estimated from fuel consumption data reported in the National Energy Balance (BEN) and in the joint questionnaire IEA/EUROSTAT/UNECE and from an emission factor appropriate to the type of combustion.

Thus, the estimate from fuel consumption emission factors refers to stationary combustion in boilers and heaters. The other categories are estimated by more complex methods discussed in the relevant sections. However, for these processes, where emissions arise from fuel combustion for energy production, these are reported under IPCC Table 1A. The fuel consumption of Other Industry is estimated so that the total fuel consumption of these sources is consistent with the national energy balance.

Fugitive emissions are estimated and reported under 1B category and the relevant information is provided in paragraph 3.9.

Emissions from CO_2 storage and distribution category do not occur in Italy, yet.

According to the IPCC 2006 Guidelines (IPCC, 2006), electricity generation by companies primarily for their own use is auto-generation, and the emissions produced should be reported under the industry concerned. However, most national energy statistics (including Italy) report emissions from electricity generation as a separate category. The Italian inventory makes an overall calculation and then attempts to report as far as possible according to the IPCC methodology:

- auto-generators are reported in the relevant industrial sectors of section "1.A.2 Manufacturing Industries and Construction", including sector "1.A.2.g Other";
- refineries auto-generation is included in section 1.A.1.b;
- iron and steel auto-generation is included in section 1.A.1.c;
- autogeneration of energy and heat in the incinerators is reported in 1.A.4.a.

These reports are based on TERNA estimates of fuel used for steam generation connected with electricity production (TERNA, several years).

Emissions from waste incineration facilities with energy recovery are reported under category 1.A.4.a (Combustion activity, commercial/institutional sector), for the fossil and biomass fraction of waste incinerated in the other fuel and biomass subcategories respectively, whereas emissions from other types of waste incineration facilities are reported under category 5.C (Waste incineration). In fact, energy recovered by these plants is mainly used for district heating of commercial buildings or is auto consumed in the plant. For 2022, almost 99% of the total amount of waste incinerated is treated in plants with an energy recovery system. The available literature (ENEA-federAmbiente, 2012) provides that in 2010 the gross electricity production by urban waste incinerators was equal to 3887 GWh (net 3190 GWh) and the amount sent to the network was equal to only 121 GWh. To estimate CO_2 emissions, considering the total amount of waste incinerated in plants with energy recovery, carbon content is calculated, as described in paragraph 7.4.2, in the waste chapter. Different emission factors for municipal, industrial and oils, hospital waste, and sewage sludge are applied, as reported in the waste chapter, Tables 7.19-7.23. Waste amount is then converted in energy content applying the conversion factor resulting from data provided by TERNA and equal in 2022 to 11.3 GJ/t of waste. In 2022, the resulting average emission factor for the fossil part of waste is equal to 96.9 kg CO_2/GJ while for the biomass is equal to 83.0 kg CO_2/GJ.

Landfill gas recovered is used for heating and power in commercial facilities, the resulting emissions are reported under 1.A.4.a in biomass. In 2022, the resulting average emission factor is equal to 50.6 kg CO_2/GJ. Biogas recovered from the anaerobic digester of animal waste is used for utilities in the agriculture sector and relative emissions are reported under 1.A.4.c in biomass. In 2022, the resulting average emission factor is equal to 53.9 kg CO_2/GJ. Italy allocates these emissions to the 1.A.4 category because the energy produced in these plants, incinerators or landfills, as well as energy produced by biogas collection from manure and agriculture residue, is prevalently auto-consumed for heating and electricity of the buildings or animal recoveries, and only a few amount of energy produced goes to the electrical grid.

Emission trends

In 2022, the energy sector accounts for 96.0% of CO_2 emissions, 14.1% of CH_4 and 25.6% of N_2O. In terms of CO_2 equivalent, the energy sector shares 81.8% of total national greenhouse gas emissions excluding LULUCF. Emission trends of greenhouse gases from the energy sector are reported in Table 3.1.

Table 3.1 GHG emission trends in the energy sector 1990-2022 (Mt CO_2 eq.)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Total Energy	426.2	438.7	460.5	488.3	429.9	360.0	336.4	300.1	332.2	337.9
CO_2	409.2	421.5	444.1	472.9	414.3	346.3	324.9	289.1	320.7	327.4
CH_4	12.9	12.4	11.6	10.6	10.8	9.4	7.5	7.2	7.3	6.4
N_2O	4.1	4.8	4.8	4.8	4.8	4.2	4.0	3.8	4.2	4.0

The emission trend is generally driven by economic indicators as already shown in chapter 2. From 2005, GHG emissions from the sector are decreasing because of the policies adopted at European and national level to implement the production of energy from renewable sources. From the same year, a further shift from petrol products to natural gas in producing energy has been observed as a consequence of the starting of the EU greenhouse gas Emission Trading Scheme (EU ETS) on January 1st 2005. From 2009, a further drop in the sectoral emissions is due to the economic recession. In general, from 2005 adecrease is observed in total GHG emissions and annual variations are always negative except for 2010, for the recovery of the economy after the economic recession, and 2015, where emissions increased of 3.5% with respect to 2014 due to a reduction in energy production by hydroelectric which resulted in an increase of energy production from thermoelectric plants to satisfy the energy demand. From 2016 the main driver of the decrease of emissions is the shift from coal to natural gas fuel consumption for energy production. In 2020 there is a further significant decrease in emissions due to the pandemic and the consequent lock-down regime to which the country has been subjected. In 2021 the end of the pandemic and recovery of economy resulted in an increase of emissions with respect to the previous year but the political crisis and the outbreak of conflict in Europe have strongly affected some production sectors.

In Table 3.2, the electricity production distinguished by source for the whole time series is reported based on data supplied by the national grid operator (ENEL, several years; TERNA, several years). From 2010 to 2014 a drop in electricity generation from fossil fuels has been observed in Italy. The drop has been driven both by the economic recession and by the increase of renewable sources for energy production. The use of natural gas and coal is generally driven by the market; in 2011, from one side there was a minor availability (and higher prices) of natural gas imported by pipelines from Algeria and Libya, due to the "spring revolutions" occurring in these countries in that year, on the other side a new coal power plant, one of the largest in Italy, was fully operative with a production of around 12500 GWh explaining the increasing trend of electricity production from solid fuels. In "other fuels" a multitude of fuels are included, as biomass, waste, biogas from agriculture residues and waste and synthesis gases from heavy residual or chemical processes. The breakdown is available to the inventory expert allowing emission estimations, but it is confidential and not published by the owner of the information, TERNA.

Table 3.2 Production of electricity by sources 1990-2022 (GWh)

Source	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
	GWh									
Hydroelectric	35,079	41,907	50,900	42,927	54,407	46,970	48,154	49,495	47,478	30,291
Thermoelectric	178,590	196,123	220,455	253,073	231,248	192,054	195,734	181,307	189,711	199,210
- solid fuels	32,042	24,122	26,272	43,606	39,734	43,201	18,839	13,380	14,022	22,607
- natural gas	39,082	46,442	97,607	149,259	152,737	110,860	141,687	133,683	143,998	141,445
- derivated gases	3,552	3,443	4,252	5,837	4,731	2,220	2,452	1,697	1,947	1,614
- oil products	102,718	120,783	85,878	35,846	9,908	5,620	3,453	3,175	3,851	4,953
- other fuels	1,196	1,333	6,446	18,525	24,138	30,151	29,302	29,373	25,893	28,591
Geothermic	3,222	3,436	4,705	5,325	5,376	6,185	6,075	6,026	5,914	5,837
Eolic and Photovoltaic	0	14	569	2,347	11,032	37,786	43,891	43,703	45,966	48,616
Total	**216,891**	**241,480**	**276,629**	**303,672**	**302,062**	**282,994**	**293,853**	**280,531**	**289,069**	**283,954**

Source: TERNA

More in general, the share of the total energy consumption by primary sources in the period 1990- 2022, reported in Table 3.3, shows an evident change from oil products and solid fuels to natural gas and renewable while the share of consumption of electricity is variable and driven by the market.

Table 3.3 Total energy consumptions by primary sources 1990-2022 (%)

Sources	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
	%									
renewable	0.7	0.9	1.1	2.0	4.3	8.8	10.6	11.5	11.0	10.7
solid fuels	9.6	7.9	6.9	8.6	8.0	8.0	4.2	3.6	3.6	5.1
natural gas	23.7	25.7	31.4	36.0	36.2	35.8	39.5	41.5	40.9	38.3
crude oil	56.2	54.9	49.5	43.1	38.5	36.7	35.0	32.0	33.4	35.2
primary electricity	9.8	10.5	11.1	10.3	13.1	10.8	10.7	11.4	11.1	10.8

Source: Ministry of Environment

Further analysis on the electricity generation time series and CO_2 emission factors are available at the following web address: https://emissioni.sina.isprambiente.it/inventario-nazionale/ .

Recalculations

In 2024 submission some recalculations occurred as in the following.

Currently, a review process of the national energy balance is underway with Eurostat and involves the various interested parties (TERNA, GSE, MASE) in Italy. In a first step, those responsible for the National Energy Balance implemented methodological changes for 2022 and subsequently applied these changes to 2021 to make it consistent. ISPRA is following this process closely in order to know the details and optimize the estimates. This change in methodology has caused a break in the series for some fuels and it is necessary further work to improve the time series consistency and it will probably take a few years to also reconstruct the historical series of fuels according to the new definitions. In conclusion, this has determined recalculations in 2021.

Updated time series of the national energy balance regarded kerosene for residential for the whole time series.

Minor recalculations occur because of the update of the whole time series of CO_2 EFs of residual gas of chemical processes and only in 2010 and 2013-2020 because of the update of data about synthesis gas not applied in the previous submission.

As regards emissions from fuels delivered to water-borne navigation, natural gas emissions factor has been corrected for year 2021. Minor corrections on the figures of the gasoline engines split between 2 strokes and 4 strokes from 2014 onwards. The corrections lead to any relevant impact on the distribution of the ratio of 2 strokes 4 strokes in the time series.

The recalculations that affect the whole fugitive emission sector regard the update of the country specific emission factors (for oil production, gas production and processing and oil venting and flaring), the update of data of natural gas imported and of a leakage data by one of the main distribution operators.

The road transport historical series has been revised mainly as a result of the upgrade of Copert model version used (from version 5.6.1 in last submission to 5.7.3 in submission 2024), which resulted in various methodological updates. Detailed information is reported in paragraph 3.5.2.

Waste fuel consumption for commercial heating activity data has been updated from 2020 because of the update of activity data for some industrial waste plants. Detailed information is reported in paragraph 3.6.

Recalculations affected the whole time series 1990-2021 for all gases. The following table shows the percentage differences between the 2024 and 2023 submissions for the total energy sector and by gas. Recalculation resulted for the energy sector in an increase of GHG emissions in 1990 of 0.15% and a reduction in 2021 of 0.20%.

Table 3.4 Emission recalculations in the energy sector 1990-2021 (%)

Year	GHG	CO_2	CH_4	N_2O
1990	0.15	0.15	0.00	0.11
1991	0.16	0.17	0.00	0.12
1992	0.12	0.13	-0.01	0.09
1993	0.10	0.10	-0.01	0.07
1994	0.08	0.09	-0.01	0.06
1995	0.09	0.09	-0.01	0.06
1996	0.08	0.08	-0.02	0.05
1997	0.07	0.07	-0.02	0.04
1998	0.06	0.07	-0.02	0.04
1999	0.05	0.05	-0.02	0.03
2000	0.03	0.03	-0.02	0.29
2001	0.04	0.04	-0.03	0.03
2002	0.03	0.04	-0.03	0.04
2003	0.03	0.03	-0.03	0.04
2004	0.02	0.02	-0.04	0.04
2005	0.01	0.01	-0.04	0.06
2006	0.04	0.04	-0.11	0.01
2007	0.04	0.04	-0.12	0.13
2008	0.01	0.01	-0.14	0.17
2009	0.01	0.01	-0.16	0.36
2010	0.00	0.00	-0.17	0.28
2011	0.01	0.01	-0.18	0.39
2012	0.00	0.00	-0.17	0.40
2013	0.00	0.00	-0.17	0.52
2014	0.00	0.00	-0.15	0.81
2015	0.00	0.00	-0.14	0.82
2016	0.00	0.00	-0.20	0.70
2017	0.00	0.00	-0.20	0.58
2018	0.00	0.00	-0.22	0.50
2019	0.00	0.00	-0.27	0.59
2020	0.01	0.00	-0.27	0.59
2021	-0.20	-0.23	0.15	1.46

Key categories

Key category analysis, for 2022, identified 24 categories at level or trend assessment with Approach 1 and Approach 2 in the energy related emissions.

In the case of the energy sector in Italy, a sector-by-sector analysis instead of a source-by-source analysis will better illustrate the accuracy and reliability of the emission data, given the interconnection between the underlying data of most key categories.

In the following box, key categories for 2022 are listed, referring to the section of the text where they are quoted.

Key-categories identification in the energy sector with the IPCC Approach 1 and Approach 2 for 2022

KEY CATEGORIES	without LULUCF	with LULUCF	Relevant paragraphs	Notes
1 Transport - CO_2 Road transportation	L,T	L,T	3.5.2	Tables 3.21-3.29
2 Other sectors - CO_2 commercial, residential, agriculture gaseous fuels	L,T	L,T	3.6	Tables 3.32-3.35
3 Energy industries - CO_2 solid fuels	L,T	L,T	3.3	Tables 3.6-3.9
4 Energy industries - CO_2 gaseous fuels	L,T	L,T	3.3	Tables 3.6-3.9
5 Manufacturing industries and construction - CO_2 gaseous fuels	L,T	L,T	3.4	Tables 3.10-3.13
6 Energy industries - CO_2 liquid fuels	L,T	L,T	3.3	Tables 3.6-3.9
7 Other sectors - CO_2 commercial, residential, agriculture liquid fuels	L,T	L,T	3.9	Tables 3.32-3.35
8 Manufacturing industries and construction - CO_2 liquid fuels	L,T	L,T	3.4	Tables 3.10-3.13
9 Fugitive - CH_4 Oil and natural gas - Natural gas	L,T	L,T	3.9	Tables 3.40-3.46
10 Other sectors - CH_4 commercial, residential, agriculture biomass	L,T	L,T	3.6	Tables 3.32-3.35
11 Manufacturing industries and construction - CO_2 solid fuels	L1,T	L1,T	3.4	Tables 3.10-3.13
12 Other sectors - CO_2 commercial, residential, agriculture other fossil fuels	L1,T	L1,T	3.6	Tables 3.32-3.35
13 Other sectors - N_2O commercial, residential, agriculture biomass	L2,T	L2,T	3.6	Tables 3.32-3.35
14 Transport - CO_2 Waterborne navigation	L1, T1	L1, T1	3.5.4	Table 3.30
15 Fugitive - CO_2 Oil and natural gas – venting and flaring	T2	T2		Tables 3.40-3.46
16 Other sectors - N_2O commercial, residential, agriculture liquid fuels	L2		3.6	Tables 3.32-3.35
17 Other sectors - CO_2 commercial, residential, agriculture solid fuels	T1	T1	3.6	Tables 3.32-3.35
18 Transport - CH_4 Road transportation	T2	T	3.5.2	Tables 3.21-3.29
19 Fugitive - CH_4 Oil and natural gas - Other - flaring in refineries	L2, T2	L2, T2	3.9	Tables 3.40-3.46
20 Fugitive - CO_2 Oil and natural gas - Other - flaring in refineries	T2	T2	3.9	Tables 3.40-3.46
21 Transport – CO_2 Civil aviation	L1, T1	L1, T1	3.5.1	Tables 3.15-3.19
22 Transport - CO_2 Other transportation - pipelines	T1	T1	3.5.5	Table 3.31
23 Transport - N_2O Road transportation	L2		3.5.2	Tables 3.21-3.29
24 Manufacturing industries and construction - CH_4 biomass		T2	3.4	Tables 3.10-3.13

With reference to the box, fourteen key categories (n. 2-8, 10-13, 16-17, 24) are linked to stationary combustion and to the same set of energy data: the energy sector CRT Table 1.A.1, the industrial sector, Table 1.A.2 and the civil sector Tables 1.A.4a and 1.A.4b.

Ten out of fourteen key categories refer to CO_2 emissions, two categories refer to CH_4 and N_2O emissions from the use of biomass in the residential sector, one to CH_4 emissions from manufacturing industries using biomass and the last category refers to N_2O emissions from liquid fuels in other sectors.

All these sectors refer to the national energy balance (MASE, several years [a]) for the basic energy data and the distribution among various subsectors, even if more accurate data for the electricity production sector can be found in TERNA publications (TERNA, several years). Evolution of energy consumptions/emissions is linked to the activity data of each sector; see paragraph 3.3, 3.4 and 3.6 and Annex 2 for the detailed analysis of those sectors. Electricity production is the most "dynamic" sector and the energy emissions trend, for CO_2, N_2O and CH_4, is mainly driven by thermoelectric production, see Tables A2.1 and A2.4 for more details.

In the following table emissions in kt of CO_2 equivalent for stationary combustion key categories at level assessment are summarized. From 1990 to 2022, an increase in use of natural gas instead of fuel oil and gas oil in stationary combustion plants is observed; it results in a decrease of CO_2 emissions from combustion of liquid fuels and an increase of emissions from gaseous fuels used in the different sectors. Coal and coke for residential heating has been banned and reduced to 0. The increase of CH_4 emissions from other sectors reflects the increase of the use of biomass for residential heating.

Table 3.5 Stationary combustion, GHG emissions in 1990 and 2022 (kt CO_2 eq)

	1990	2022
Energy industries - CO2 liquid fuels	81,197	18,299
Energy industries - CO2 solid fuels	38,647	23,427
Other sectors - CO2 commercial, residential, agriculture liquid fuels	38,274	12,592
Other sectors - CO2 commercial, residential, agriculture gaseous fuels	36,338	50,221
Manufacturing industries and construction - CO2 liquid fuels	32,806	15,518
Manufacturing industries and construction - CO2 gaseous fuels	32,234	31,746
Manufacturing industries and construction - CO2 solid fuels	25,732	6,034
Energy industries - CO2 gaseous fuels	16,954	52,566
Other sectors - CH4 commercial, residential, agriculture biomass	1,116	2,465
Other sectors - CO2 commercial, residential, agriculture other fossil fuels	530	5,523

Source: ISPRA elaborations

Another group of key categories (n. 1, 14, 18, 21-23) referred to the transport sector, with basic total energy consumption reported in the national energy balance and then subdivided in the different subsectors with activity data taken from various statistical sources; see paragraph 3.5, transport, for an accurate analysis of these key sources. This sector also shows a remarkable increase in emissions in the '90s, in particular CO_2 from air transport and road transport, as can be seen in Table 3.19 and Table 3.28, respectively. In the last years CO_2 emissions from road transport started to decrease as a consequence of the economic crisis and the reduction of the average fuel consumption per kilometer of the new vehicles. The trend of N_2O and CH_4 emissions is linked to technological changes occurred in the period.

Finally, the last four key categories (n. 9, 15, 19 and 20) refer to oil and gas operations. For this sector basic overall production data are reported in the national balance but emissions are calculated with more accurate data published or delivered to ISPRA by the relevant operators, see paragraph 3.9.

Most of the categories described are also key categories for the years 1990 and 2022 considering LULUCF emissions and removals.

3.2 Methodology description

Emissions are calculated by the equation:

$$E(p,s,f) = A(s,f) \times e(p,s,f)$$

where

E(p,s,f) = Emission of pollutant p from source s from fuel f (kg)

A(s,f) = Consumption of fuel f by source s (TJ-t)

e(p,s,f) = Emission factor of pollutant p from source s from fuel f (kg/TJ-kg/t)

The fuels covered are listed in Table A2.2 in Annex 2, though not all fuels occur in all sources. Sector specific tables specify the emission factors used. Emission factors are expressed in terms of kg pollutant/ TJ based on the net calorific value of the fuel. The carbon factors used are based on national sources and are appropriate for Italy. Most of the CO_2 emission factors have been crosschecked with the results of specific studies that evaluate the carbon content of the imported/produced fossil fuels at national level. A comparison of the current national factors with the IPCC ones has been carried out; the results suggest quite limited variations in liquid fuels and some differences in natural gas, explained by basic hydrocarbon composition, and in solid fuels.

Monitoring of the carbon content of the fuels nationally used is an ongoing activity at ISPRA. The principle is to analyse regularly the chemical composition of the used fuel or relevant activity statistics, to estimate the carbon content and the emission factor. National emission factors are reported in Table 3.12 and Table 3.21. The specific procedure followed for each primary fuel (natural gas, oil, coal) is reported in Annex 6.

In particular:

- transportation fuels have shown a significant variation around the year 2000 due to the reformulation of gasoline and diesel to comply with the EU directive, see Table 3.21;
- the most important imported fuels, natural gas, fuel oil and coal show variations of carbon content from year to year, due to changes in the origin of imported fuel supply; a methodology has been set up to evaluate annually the carbon content of the average fuel used in Italy, see Annex 6 for details;
- derived gases produced in refineries, as petcoke, refinery gas and synthesis gas from heavy residual fuel, in iron and steel integrated plants, as coke oven gas, blast furnaces gas and oxygen converter gas, and in chemical and petrochemical plants have been calculated from 2005 on the basis of the analysis of information collected by the plants in the framework of EU ETS, see Annex 6 for details.

The activity statistics used to calculate emissions are fuel consumptions provided annually by the Ministry of Environment (MASE) in the National Energy Balance (MASE, several years [a]), by TERNA (TERNA, several years) for the power sector and some additional data sources to characterize the technologies used at sectoral level, quoted in the relevant sections.

Activity data collected in the framework of the EU ETS scheme do not cover the overall energy sector, whereas the official statistics available at national level, such as the National Energy Balance (BEN) and the energy production and consumption statistics supplied by TERNA, provide the complete basic data needed for the emission inventory. Italian energy statistics are mainly based on the National Energy Balance thanks to the transmission of the joint questionnaires IEA/EUROSTAT/UNECE. The report is reliable, by international standards, and it may be useful to summarize its main features:

- it is a balance, every year national experts from the Ministry of the Environment carry out the exercise balancing final consumption data with import-export information;
- the balance is made on the energy value of energy carriers, taking into account transformations that may occur in the energy industries (refineries, coke plants, electricity production);
- data are collected regularly by the Ministry of Environment, on a monthly basis, from industrial subjects;
- oil products, natural gas and electricity used by industry, civil or transport sectors are taxed with excise duties linked to the physical quantities of the energy carriers; excise duties are differentiated in products and final consumption sectors (i.e. diesel oil for industrial use pays duties lower than for transportation use and higher than for electricity production);
- concerning energy consumption information, this scheme produces highly reliable data: BEN is based on registered quantities of energy consumption and not on estimates;

- coal is an exception to this rule, it is not subject to excise duties; consumption information is estimated; anyway, it is nearly all imported and a limited number of operators use it and the Ministry of Environment monitors all of them on a monthly basis.

The energy balances of fuels used in Italy, published by the Ministry of Environment (MASE, several years [a]), compare total supply based on production, exports, imports, stock changes and known losses with the total demand; the difference between total supply and demand is reported as "statistical difference". 2022 data communicated by Italy to the Joint Questionnaire IEA/EUROSTAT/UNECE in the format revisited by EUROSTAT are available on website: https://sisen.mase.gov.it/dgsaie/ . Some differences between data communicated to the international organizations and EUROSTAT publication have been observed and are under investigation; they should mainly be due to the use of default instead of country specific energy conversion factors and different classification criteria of fuels.

Data submitted by the Ministry of Environment to the Joint Questionnaire IEA/ EUROSTAT/UNECE have been used for solid, liquid and gaseous fuel consumptions.

Some inconsistencies have been found in data communicated at Eurostat and referring to the ninety years, especially in the sectoral distribution of fuels; in these cases, the information already available in the national energy balances has been maintained because of considered more reliable and consistent in the time series.

Additionally, to fossil fuel, the Joint Questionnaire reports commercial wood and straw combustion estimates for energy use, biodiesel and biogas. Carbon dioxide emissions from biomass combustion are not included in the national total as suggested in the IPCC Guidelines (IPCC, 2006) but emissions of other GHGs and other pollutants are included. CORINAIR methodology (EMEP/EEA, 2023) includes emissions from the combustion of wood in the industrial and domestic sectors as well as the combustion of biomass in agriculture.

The inventory also includes emissions from the combustion of lubricants based on data collected from waste oil recyclers and quoted in the energy balance. According to the IPCC 2006 Guidelines (IPCC, 2006), only emissions from the combustion of lubricants in two strokes engines are reported in the energy sector while the other emissions are reported in the IPPU sector.

Currently, a review process of the national energy balance is underway with Eurostat and involves the various interested parties (TERNA, GSE, MASE) in Italy. In a first step, those responsible for the National Energy Balance implemented methodological changes for 2022 and subsequently applied these changes to 2021 to make it consistent. ISPRA is following this process closely in order to know the details and optimize the estimates. This change in methodology has caused a break in the series for some fuels and it is necessary further work to improve the time series consistency and it will probably take a few years to also reconstruct the historical series of fuels according to the new definitions.

3.3 Energy industries

A detailed description of the methodology used to estimate greenhouse gas emissions from electricity production under 1.A.1.a, 1.A.1.b and 1.A.1.c is reported in Annex 2. Basic data, methodology and emission factors used to estimate emissions are derived from the same sources. In the following sub-paragraphs additional information on the specific categories is supplied.

In this category, gaseous fuels refer to natural gas while solid fuels mainly to coal used to produce energy and derived gases used in the integrated iron and steel plants; liquid fuels include residual oil fuel consumption used for energy production in power plants and different fuels used in refineries. The CO_2 implied emission factor trend for the sector is driven by the liquid fuel consumption in the petroleum refining industry (95% of the total of liquid) where many fuels, with very different emission factors, are used, such as refinery gas, that have an average emission factor value equal to 56.5 t/TJ, and petroleum coke with an average emission factor equal to 96.9 t/TJ. In the last years, a reduction in the consumption of synthesis gas from heavy residual fuels (in 2022 the average emission factors t CO_2/TJ values are about 80.5 and 99.1 for heavy residual fuels and synthesis gas respectively) is observed, resulting in the interannual variations. Emission factors time series for these fuels are reported in Annex 6.

3.3.1 Public Electricity and Heat Production

3.3.1.1 Source category description

This paragraph refers to the main electricity producers that produce electricity for the national grid. From 1998 onwards, the expansion of the industrial cogeneration of electricity and the split of the national monopoly have transformed many industrial producers into "independent producers", regularly supplying the national grid. These producers account in 2022 for 89.4% of all electricity produced with combustion processes in Italy (TERNA, several years).

In Italy, only limited data do exist about producers working for district heating grids; most of the cogenerated heat is produced and used on the same site by industrial operators. Therefore, data on heat production is prevalently reported in Table1.A(a)s2 for industry and Table1.A(a)s4 for district heating. In TERNA yearly publication, heat cogenerated while producing electricity is reported separately. Unfortunately, no details are reported on the final use of cogenerated heat, so it can be used in the inventory preparation just to cross check the total fuel amount with other sources, such as EU ETS or the consumption of fuels in the industry reported in the national energy balance.

Under biomass, wood and charcoal consumption and relevant emissions are reported until 2007; CO_2 emission factor is shown in Table 3.12 while CH_4 and N_2O emission factors are equal to 30 g/GJ and 4 g/GJ respectively. From 2008 also bioliquid fuel is used and included under biomass (CH_4 and N_2O emission factors equal to 12 g/GJ and 2 g/GJ respectively), resulting in the decrease of the average emission factor.

Other fuels subcategory refers mainly to fuel consumptions of other liquid, solid and gaseous fuels such as industrial wastes (89.8 tCO_2/TJ), that are more than half of the total TJ of the subcategory, as plastics, rubber, and solvents, synthesis gas from heavy residual (99.1 tCO_2/TJ in 2022) and other liquid fuels (76.6 tCO_2/TJ in 2022); the average CO_2 emission factor has been calculated for the whole time series and it is equal to 90.5 t/TJ in 2022.

CO_2 implied emission factor trend of liquid fuels for this category is driven by the mix of high and low sulfur fuel oil consumptions that is changed in the years as a consequence of the adoption of air quality European Directives introducing air pollutants ceilings at the stacks, and the policies at national level which established stringent ceiling for new and old plants and a timing scheduled for their implementation. The CH_4 implied emission factor is the weighted average of gasoil and residual oil emission factors equal to 1.5 g/GJ and 3 g/GJ respectively. The general decreasing trend is due to the minor use of fuel oil for energy production, at the minimum in the last years, while the amount of gasoil, which is related to the start up of power plants and to the gasoil used in stationary engines, has a more stable trend.

3.3.1.2 Methodological issues

The data source on fuel consumption is the annual report "Statistical data on electricity in Italy - Production" ("Dati statistici sull'energia elettrica in Italia - Produzione"), edited from 1999 by the Italian Independent System Operator (TERNA, several years). The reports refer to the total of producers and the estimate of the part belonging to public electricity production is made by the inventory team on the basis of detailed electricity production statistics by industrial operators. Data on total electricity production for the year 2022 are reported in Annex 2. For the time series, see previous NIR reports. The emission factors used are listed in Table 3.12.

Another source of information is the National Energy Balance (MASE, several years [a]), which contains data on the total electricity producing sector. The data of the national energy balance (BEN) are also used to address the statistical survey of international organizations, IEA, Eurostat and UNECE. Both BEN and TERNA publications could be used for the inventory preparation, as they are part of the national statistical system and published regularly. Currently, a review process of the national energy balance is underway with Eurostat and involves the various interested parties (TERNA, GSE, MASE) in Italy.

A detailed analysis of both sources is reported in Annex 2. From the year 2005 onwards, a valuable source of information is given by the reports prepared for each industrial installation subject to EU ETS scheme. These reports are prepared by independent qualified verifiers and concern the CO_2 emissions, emission factors and activity data, including fuel used. ISPRA receives copies of the reports from the competent authority (Ministry of Environment) and can extract the information relative to electricity production. The information available is very useful but does not fully cover the electricity production sector or the public electricity production. The EU ETS does not include all installations, only those above 20 MWt, it is made on a point source basis so the data include electricity and heat production while the corresponding data from TERNA, concerning only the fuel used for electricity production, are commercially sensitive, confidential and they are not available to the inventory team. Anyway, the comparison of data collected by TERNA with those submitted to the EU ETS allows identifying possible discrepancies in the different datasets and thus providing the Ministry of Environment experts with useful suggestions to improve the energy balance.

In Table 3.6, fuel consumptions and emissions of 1.A.1.a category are reported for the time series. Table 3.6 shows a decrease in fuel consumption and an overall decrease in GHG emissions. However, a slower increase is observed in CH_4 emissions due to the increase in use of natural gas and biomass.

Table 3.6 Public electricity and heat production: Energy data (TJ) and GHG emissions, 1990-2022

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Fuel consumption (TJ)	1,441,741	1,472,753	1,554,810	1,709,208	1,480,778	1,205,336	1,146,779	1,056,626	1,120,719	1,166,759
GHG (Gg CO_2 eq.)	109,050	110,709	109,527	115,827	97,534	79,317	67,342	60,209	65,093	71,696
CO_2 (Gg)	108,670	110,335	109,193	115,445	97,195	78,922	67,034	59,922	64,807	71,388
CH_4 (Gg)	3.8	4.0	3.6	4.0	3.6	4.2	4.1	4.1	4.0	3.9
N_2O (Gg)	1.0	1.0	0.9	1.0	0.9	1.0	0.7	0.7	0.7	0.7

Source: ISPRA elaborations

In 2022, consumption is fairly in line with the previous year's data before the pandemic. Moreover, it has been possible to observe a shift from coal to natural gas for energy production in the last years. As the main data source refers to the whole electricity production sector, the uncertainty and time-series consistency, source-specific QA/QC and verification, recalculations and planned improvements are all addressed in Annex 2.

3.3.2 Refineries

3.3.2.1 Source category description

This subsector covers the energy emissions from the national refineries (13 plants operational in 2022), including the energy used to generate electricity for internal use and exported to the national grid by power plants that directly use off-gases or other residues of the refineries. These power plants are generally owned by other companies but are located inside the refinery premises or just sideways. In 2022 the power plants included in this source category have generated 6.6% of all electricity produced with combustion processes in Italy. Energy consumption and emissions are reported in CRT Table 1.A.1.b. Parts of refinery losses, flares, are reported in CRT Table 1.B.2.a and c, using IPCC emission factors.

3.3.2.2 Methodological issues

The consumption data used for refineries come from BEN (MASE, several years [a]); the same data are also reported by Unione Energia per la Mobilità, the industrial category association (UNEM, several years). From 2005 onwards, also the EU ETS "verified reports" cover almost the entire sector, for energy consumptions, combustion emissions and process emissions. Other sources of information are the annual reporting requirements for the large combustion plants under the European Directive (LCP) and the E-PRTR Regulation; both data sets include most refineries, but not all the emission sources.

For the part of the energy and related emissions due to the power plants, the source is TERNA (see Annex 2 for further details). The quota of total energy consumption from electricity production included in category 1.A.1.b is estimated by the electricity production model on the basis of fuels used and plant location.

All the fuel used in boilers and processes, the refinery "losses" and the reported losses of crude oil and other fuels (that are mostly due to statistical discrepancies) are considered to calculate emissions. Fuel lost in the distribution network is accounted for here and not in the individual end use sector. From 2002 particular attention has been paid to avoid double counting of CO_2 emissions checking if the refinery reports of emissions already include losses in their energy balances. IPCC Tier 2 emission factors and national emission factors are used as reported in Table 3.12.

From 2008, TERNA modified the detailed table of fuel consumption and related energy production introducing a more complete list of fuels. The aim of the change was to revise the consumption values of waste fuels which are very important for estimating the contribution of renewable to electricity production and consequently greenhouse gases.

In Table 3.7, a sample calculation for the year 2022 is reported, with energy and emission data.

Table 3.7 Refineries, CO_2 emission calculation, year 2022

	Consumption, TJ				CO_2 emissions, Gg			
REFINERIES	Petroleum coke	Ref. gas	Liquid fuels	Natural gas	Petroleum coke	Ref. gas	Liquid fuels	Natural gas
energy		11,562	55,398	46,148		654	4,810	2,719
furnaces	28,241	115,344	16,209		2,735	6,520	1,157	
TOTAL				272,902				18,594

Source: ISPRA elaborations

From 2005, the weighted average of CO_2 emission factor reported by operators in the context of the EU ETS scheme is used for petroleum coke, refinery gas and synthesis gas from heavy residual fuels. The trend of the implied emission factor is driven by the mix of the fuels used in the sector. The main fuels used are refinery gases, fuel oil and petroleum coke, which have very different emission factors, and every year their amount used changes resulting in an annual variation of the IEF. The increase in the last years, with respect to the nineties, of the consumption of fuels with higher carbon content, as petroleum coke and synthesis gas obtained from heavy residual fuels, explains the general growth of the IEF for liquid fuel reported in the CRT for this sector.

In the following box, liquid fuel consumptions of 1.A.1.b category disaggregated by fuel are reported.

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Refinery gas	119,123	136,305	124,549	153,036	153,739	132,688	128,601	111,499	112,318	126,906
Naphta	218	784	4,441	2,613	3,353	87	0	3	0	0
Pet coke	28,495	28,634	40,623	50,180	49,415	30,094	26,736	20,427	28,200	28,241
Synthesis gas	0	0	36,425	65,021	78,628	61,763	51,096	56,735	42,353	55,217
Fuel oil	76,881	89,310	84,589	75,301	49,442	16,435	3,657	3,684	5,380	8,162
LPG	1,243	1,151	2,026	3,408	2,717	1,704	3,346	2,497	3,463	7,812
Gasoil	43	43	5,338	11,317	897	0	0	0	7	416
Gasoline	0	0	0	0	0	0	0	0	0	0
Total	226,003	256,228	297,992	360,875	338,191	242,771	213,436	194,846	191,720	226,754

Liquid fuel consumptions in petroleum refining (TJ), 1990-2022

3.3.2.3 Uncertainty and time-series consistency

The combined uncertainty in CO_2 emissions from refineries is estimated to be about 4.2% in annual emissions; a higher uncertainty, equal to 50.1%, is calculated for CH_4 and N_2O emissions because of the uncertainty levels attributed to the related emission factors. Montecarlo analysis has been carried out to estimate uncertainty of CO_2 emissions from stationary combustion of solid, liquid and gaseous fuels emissions, resulting in 5.1%, 3.3% and 5.8%, respectively. Normal distributions were assumed for all the parameters. A summary of the results is reported in Annex 1. In Table 3.8 GHG emissions from the sector in the years 1990, 1995, 2000, 2005, 2010, 2015, 2019-2022 are reported.

Table 3.8 Refineries, GHG emission time series

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
CO_2 emissions, Mt	15.8	18.0	22.2	27.9	28.3	20.9	19.0	17.4	16.5	19.0
CH_4 emissions, Gg	0.40	0.46	0.59	0.69	0.69	0.48	0.41	0.39	0.36	0.43
N_2O emissions, Gg	0.45	0.51	0.60	0.73	0.69	0.51	0.45	0.41	0.40	0.48
Refinery, total, Mt CO_2eq	16.0	18.1	22.4	28.1	28.5	21.1	19.1	17.6	16.7	19.2

Source: ISPRA elaborations

An upward trend in emission levels is observed from 1990 to 2010 explained by the increasing quantities of crude oil processed and the complexity of process used to produce more environmentally friendly transportation fuels. Liquid fuel consumptions have reached a plateau in 2010 and they are now in a downward trend that is expected to continue, due to the reduced quantities of crude oil processed and electricity produced and to the gradual substitution with natural gas fuel consumption.

3.3.2.4 Source-specific QA/QC and verification

Basic data to estimate emissions have been reported by the national energy balance and the national grid administrator. Data collected under other reporting obligations that include refineries (EU ETS, LCP and E-PRTR databases) have been used to cross-check the energy balance data, fuels used and emission factors. Differences and problems have been analysed in detail and solved together with the experts of the Ministry of Environment, who are in charge of preparing the National Energy Balance.

3.3.2.5 Source-specific recalculations

Recalculations occur because of the update of synthesis gas CO_2 emission factors and activity data for 2010 and 2013-2020 not applied in the previous submission. In 2021 recalculations occur because of the National Energy balance review process.

3.3.2.6 *Source-specific planned improvements*

For the next submissions, the adaptation of the estimation methodologies to the changes in the energy balance is planned.

3.3.3 Manufacture of Solid Fuels and Other Energy Industries

3.3.3.1 *Source category description*

In Italy, all the iron and steel plants are integrated, therefore there is no separated reporting for the different part of the process. A few coke and "manufactured gas" producing plants were operating in the early nineties and they have been reported here. Only one manufactured gas producing plant is still in operation from 2002.

In this section, emissions from power plants, which use coal gases, are also reported. In 2022 the power plants included in this source category have generated about 1.4% of all electricity produced with combustion processes in Italy.

With regard to the manufacture of other solid fuels, in Italy, charcoal was produced in the traditional way until the sixties while now it is prevalently produced in modern furnaces (e.g with the VMR system) where exhaust gases are collected and recycled to produce the energy for the furnace itself. This system ensures good management of the exhausts and the temperature, so that any waste of energy is prevented, and emissions are kept to a minimum. So CH_4 emissions from the production of charcoal are not accounted for, and the notation key NE is used in the reporting, also considering that the emission factor available in the Revised 1996 IPCC Guidelines, in Table 1-14 vol.3 (IPCC, 1997), refers to production processes in developing countries not applicable to our country anymore. Moreover, in the IPCC Good Practice Guidance as well as in the IPCC 2006 Guidelines no guidance is supplied for charcoal production. Analysing the issue with the 2019 IPCC Refinements results in an available methodology (IPCC, 2029) and Italy plans to make an estimate for the next submission.

3.3.3.2 *Methodological issues*

Fuel consumption data for the sector are reported in the BEN (MASE, several years [a]). Fuels used to produce energy are also reported with more detail as for fuel disaggregation level by TERNA (TERNA, several years). From 2005 onwards, also the EU ETS "verifier's reports" cover almost the entire sector, for energy consumptions, combustion emissions and process emissions. Other sources of information are the yearly reporting obligations for the large combustion plants under European Directive (LCP) and for facilities under the E-PRTR Regulation; both reporting obligations include most of the iron and steel integrated plants and the only coke producing plant but not all the emission sources.

A carbon balance is done, as suggested by the IPCC good practice guidance, to avoid over or under estimation from the sector. In Annex 3 further details on carbon balances of solid fuels and derived gases used are reported.

The high-implied emission factor for solid fuels is due to the large use of derived steel gases and in particular blast furnace gas to produce energy. These gases have been assimilated to the renewable sources and incentives are still provided for their use.

Other fuels are used in co-combustion with coal gases to produce electricity and they are reported by TERNA, see Annex 2. From 2008, natural gas and fuel oil consumptions reported in the CRT for this sector, are those communicated by the operators of the plants included in the sector in the framework of the EU ETS scheme. The consumptions of these fuels, especially for natural gas, are higher than those reported for the previous years. Fuel consumption reported in the sector is subtracted from the total fuel consumption to produce energy, guaranteeing that over and under estimation are avoided.

CH_4 emissions from coke ovens are estimated on the basis of production data to take into account additional volatile emissions due to the specific process. Average emission factors are calculated on the basis of information communicated by the four (two in the last years) plants under the E-PRTR registry.

3.3.3.3 Uncertainty and time-series consistency

The combined uncertainty in CO_2 emissions from integrated iron and steel plants is estimated to be about 4.2% in annual emissions; a higher uncertainty, equal to 50.1%, is calculated for CH_4 and N_2O emissions on account of the uncertainty levels attributed to the related emission factors. Montecarlo analysis has been carried out to estimate uncertainty of CO_2 emissions from stationary combustion of solid, liquid and gaseous fuels emissions, resulting in 5.1%, 3.3% and 5.8%, respectively. Normal distributions have been assumed for all the parameters. A summary of the results is reported in Annex 1. In Table 3.9 GHG emissions from the sector are reported.

Table 3.9 Manufacture of solid fuels, GHG emission time series

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
CO_2 emissions, Mt	12.5	11.6	12.9	15.9	11.4	5.6	5.2	3.8	4.7	4.0
CH_4 emissions, Gg	4.9	3.8	2.4	1.3	0.6	0.5	0.4	0.3	0.3	0.3
N_2O emissions, Gg	0.12	0.10	0.09	0.12	0.08	0.04	0.04	0.03	0.03	0.03
Total, Mt CO_2eq	12.6	11.8	12.9	16.0	11.5	5.6	5.2	3.9	4.7	4.0

Source: ISPRA elaborations

The trend of CO_2 and N_2O emissions is driven by the production trends combined with an increase in energy consumption required by more energy intensive products. In 2009 a strong reduction of emissions is observed due to the effects of the economic recession that in 2010 and 2011 has partially recovered. In 2012 a further drop occurred for the economic crisis and for environmental constrains of the main iron and steel integrated plants that should reduce its productions. In 2015 a drop is still observed (around 1.7 Mt CO_2) consistently with the production activities reduction of the main iron and steel integrated plants.

The trend of CH_4 emissions is driven by the coke production trend, decreased from 6.4 Mt in 1990 to less than 2 Mt in 2022 and by the renewal of the production plants. In particular, the strong reduction of CH_4 emissions in the last years is the result of the renewal of the coke production plants in Taranto, started in 2005, and the implementation of best available technologies to reduce volatile organic compounds. In 2009, as well as in 2013, national coke production has reduced of about 40% with respect to the previous year, determining a loss in efficiency of the production plants and an increase of emissions by product unit (IEF) for those years.

3.3.3.4 Source-specific QA/QC and verification

Basic data to estimate emissions have been reported by the national energy balance and the national grid administrator. Data collected under other reporting obligations that include integrated iron and steel plants, such as EU ETS Directive, LCP and E-PRTR databases, have been used to cross-check the energy balance data, fuels used and emission factors. Differences and problems have been analysed in detail and solved together with Ministry of Environment experts, which are in charge of preparing the National Energy Balance. In particular, in the national PRTR register the integrated plants report every year the CO_2 emitted at each stage of the process, coke production, sinter production and iron and steel production, which result from separate carbon balances calculated in each phase of the production process. Moreover, total CO_2 emissions reported in the E-PRTR by the operators are equal to those reported under the EU ETS scheme.

The detailed analysis and comparison of the different data reported improved the allocation of fuel consumption and CO_2 emissions between 1.A.1.c and 1.A.2.a sectors. From the 2010 submission, in fact, coking coal losses for transformation process and related emissions have been reallocated under 1.A.1.c instead of 1.A.2.a.

3.3.3.5 Source-specific recalculations

Minor recalculations because of the update of CO_2 emission factor.

3.3.3.6 Source-specific planned improvements

No specific improvements are planned for the next submission.

3.4 Manufacturing industries and construction

3.4.1 Sector overview

Included in this category are emissions which originate from energy use in the manufacturing industries included in category 1.A.2. Where emissions are released simultaneously from the production process and from combustion, as in the cement, lime and glass industry, these are estimated separately and included in category 2.A. All greenhouse gases as well as CO, NO_X, NMVOC and SO_2 emissions are estimated.

In 2022, energy use in industry account for 15.8% of total national CO_2 emissions, 0.7% of CH_4, 4.5% of N_2O. In terms of CO_2 equivalent, the manufacturing industry shares 13.3 % of total national greenhouse gas emissions.

Three key categories have been identified for this sector in 2022, for level and trend assessment, using both the IPCC Approach 1 and Approach 2:

Manufacturing industries and construction - CO_2 gaseous fuels (L, T);

Manufacturing industries and construction - CO_2 solid fuels (L1, T);

Manufacturing industries and construction - CO_2 liquid fuels (L, T).

All these categories are key categories for 1990 at level assessment, with and without LULUCF, to which a new category is added: Manufacturing industries and construction - CH_4 biomass key category at trend assessment but only with the uncertainty and considering LULUCF. N_2O from liquid fuels, is key category for 1990 only including the uncertainty estimates.

In the following Table 3.10, GHG emissions connected to the use of fossil fuels, excluded process emissions, are reported. Industrial emissions show oscillations related to economic cycles.

Table 3.10 Manufacturing industry, GHG emission time series

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
CO_2 emissions, Gg	90,773	88,970	94,894	90,787	68,890	54,542	48,972	44,907	53,491	53,701
CH_4 emissions, Gg	6.69	6.92	6.01	6.48	5.68	11.21	11.46	11.01	11.60	11.26
N_2O emissions, Gg	4.49	3.92	4.46	5.02	3.77	2.69	2.51	2.36	2.81	2.69
Industry, total, Gg CO_2 eq	92,151	90,204	96,245	92,299	70,048	55,569	49,958	45,839	54,561	54,728

In Table 3.11 emissions are reported by pollutant for all the subsectors included in the sector.

Table 3.11 Trend in greenhouse gas emissions from the manufacturing industry sector, 1990-2022

GAS/SUBSOURCE	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
CO_2 (Gg)										
1.A.2.a Iron and Steel	25,255	24,201	22,537	19,289	15,708	10,629	9,825	8,004	9,429	8,758
1.A.2.b Non-Ferrous Metals	735	879	1,249	1,176	1,105	999	1,114	1,036	1,326	1,133
1.A.2.c Chemicals	21,429	18,659	18,104	17,241	16,395	11,132	9,088	9,137	9,813	10,080
1.A.2.d Pulp, Paper and Print	3,108	4,185	4,253	5,457	5,148	4,872	4,975	4,665	5,011	4,535
1.A.2.e Food	3,891	5,095	6,282	6,017	4,132	3,444	3,455	3,472	3,651	3,377
1.A.2.f Non-metallic minerals	21,045	17,461	21,407	25,271	18,099	14,007	10,915	10,348	11,017	11,389
1.A.2.g Other	15,310	18,490	21,062	16,338	8,303	9,460	9,600	8,245	13,245	14,428
CH_4 (Mg)										
1.A.2.a Iron and Steel	3,795	4,226	3,093	3,304	2,880	2,062	1,797	1,449	1,593	1,394
1.A.2.b Non-Ferrous Metals	13	15	26	24	19	18	19	18	23	19
1.A.2.c Chemicals	876	725	643	533	542	327	239	237	266	331
1.A.2.d Pulp, Paper and Print	77	93	115	154	92	107	109	98	121	121
1.A.2.e Food	105	127	174	429	731	7,639	8,239	8,238	8,389	8,173
1.A.2.f Non-metallic minerals	1,412	1,276	1,463	1,624	1,197	842	832	779	890	850
1.A.2.g Other	408	461	493	412	219	215	225	191	317	375
N_2O (Mg)										
1.A.2.a Iron and Steel	411	414	366	396	294	200	177	148	183	160
1.A.2.b Non-Ferrous Metals	13	16	24	23	20	18	19	18	23	19
1.A.2.c Chemicals	404	322	314	317	328	207	134	134	147	198
1.A.2.d Pulp, Paper and Print	64	82	80	102	90	86	87	81	86	78
1.A.2.e Food	52	53	76	87	47	172	180	180	184	178
1.A.2.f Non-metallic minerals	2,644	2,285	2,630	2,986	2,183	1,427	1,368	1,286	1,464	1,369
1.A.2.g Other	906	751	974	1,110	807	579	544	508	725	685

Source: ISPRA elaborations

A general trend of reduction in emissions is observed from 1990 to 2022; some sub sectors reduced sharply (iron and steel, non-metallic minerals), other sub sectors (non-ferrous metals, pulp and paper) increased their emissions. In 2009 an overall reduction of emissions for all the sectors occurred due to the effects of the economic recession. In 2010 production levels restored for iron and steel, but a further significant drop is noted in 2013 due to environmental constraints of the main integrated iron and steel plant in Italy, located in Taranto, which had to reduce its steel production level. Non-metallic minerals emission trend is driven by the cement industry which strongly reduced its production levels in 2009 and further in 2013, in relation to the economic recession and the crisis of building construction sector; a further decrease of this sector is observed in 2016 and 2017. The increasing trend of CH_4 emissions in the last years especially for food industry is driven by the increase of biomass used as a fuel in this sector with a peak in 2014 and in 2019-2021. The decreasing trend of CO_2 and N_2O in the last years is driven by the trend of non-metallic minerals industry emissions due to the reduction trend of cement productions.

3.4.2 Source category description

The category 1.A.2 comprises seven sources: 1.A.2.a Iron and Steel, 1.A.2.b Non-Ferrous Metals, 1.A.2.c Chemicals, 1.A.2.d Pulp, Paper and Print, 1.A.2.e Food, 1.A.2.f Non-metallic minerals, 1.A.2.g Other.

Iron and steel. The main processes involved in iron and steel production are those related to sinter and blast furnace plants, to basic oxygen and electric arc furnaces and to rolling mills.

Most of emissions are connected to the integrated steel plants, while for the other plants, the main energy source is electricity (accounted for in 1.A.1.a) and the direct use of fossil fuels is limited to heating – re heating of steel in the intermediate part of the process.

There were four integrated steel plants in 1990 that from 2005 are reduced to two, with another plant that still has a limited production of pig iron. Nevertheless, the steel production in integrated plants did not change significantly in the 1990-2008 period due to an expansion in capacity of the two operating plants. From 2015 only one integrated plant remains in operation. The maximum production was around 11 Mt/y in 1995 and in 2005-2008, with lower values in other years and the lowest of 3.4 Mt in 2020, just lower than 2022.

It has to be underlined that the integrated steel plants include also the cogeneration of heat and electricity using the recovered "coal gases" from various steps of the process, including steel furnace gas, BOF gas and coke oven gas. All emissions due to the "coal gases" used to produce electricity are included in the electricity grid operator's yearly reports and are accounted in the category 1.A.1.c. No detailed information is available for the heat produced, so the emissions are included in source category 1.A.2.a.

With the aim of avoiding double counting process emissions resulting from the iron and steel subcategory are reported in the industrial processes sector. CH_4 emissions are estimated for each emitting activities according to the classification of activities described in the EMEP/EEA guidebook and consequently allocated at the combustion or industrial processes sector in consideration of the relevant methodological issues. More in details, CH_4 process emissions for pig iron and steel production are already allocated to the industrial processes sector as well as fugitive CH_4 emissions from coke production that are reported under fugitive emissions while CH_4 emissions from the combustion of fuels are allocated to the energy sector.

This subsector is one of the most important of 1.A.2 category and accounts, in 2022, for 16.2% of total 1.A.2 GHG emissions, and 2.1% of total national emissions.

Non-Ferrous Metals

In Italy, the production of primary aluminium stopped in 2013 (and was 232 Gg in 1990) while secondary aluminium accounts for 350 Gg in 1990 and 717 Gg in 2022. These productions, however, use electricity as the primary energy source so the emissions due to the direct use of fossil fuels are limited. The sub sector comprises also the production of other non-ferrous metals, both primary and secondary copper, lead, zinc and others; but those productions have also a limited share of emissions. Magnesium production is not occurring. The bulk of emissions are due to foundries that prepare mechanical pieces for the engineering industry or the market, using all kinds of alloys, including aluminum, steel and iron.

Chemicals

CO_2, CH_4 and N_2O emissions from chemical and petrochemical plants are included in this sector.

In Italy there are petrochemical plants integrated with a nearby refinery and stand-alone plants that get the inputs from the market. Main products are Ethylene, Propylene, Styrene. In particular, ethylene and propylene are produced in petrochemical industry by steam cracking. Ethylene is used to manufacture ethylene oxide, styrene monomer and polyethylene. Propylene is used to manufacture polypropylene but also acetone and phenol. Styrene, also known as vinyl benzene, is produced on an industrial scale by catalytic dehydrogenation of ethyl benzene. Styrene is used in the rubber and plastic industry to manufacture through polymerization processes such products as polystyrene, ABS, SBR rubber, SBR latex.

Except for ethylene oxide, whose production has stopped in 2002, the other productions of the above-mentioned chemicals still occur in Italy. Activity data are stable from 1990 to 2012, with limited yearly variations along the time series and a reduction in the last years.

Chemical industry includes non-organic chemicals as chlorine/soda, sulfuric acid, nitric acid, ammonia. A limited production of fertilizers is also present in Italy. From 1990 to 2022 the sum of production of this source category has greatly reduced: in 2022 it was less than half of the production in 1990.

This source category does include some emissions from the cogeneration of electricity. Due to the transformation of some of those plants in power plants directly connected to the grid, and so reported in category 1.A.1.a, the percentage of the category 1.A.2.c CO_2 emissions due to electricity generation has reduced from 1990 to 2022. This subsector accounts, in 2022, for 18.5% of total 1.A.2 GHG emissions, and 2.5% of total national emissions.

Pulp, Paper and Print

Emissions from the manufacturing of paper are included in this source category. In Italy the manufacture of virgin paper pulp is rather limited, with a production feeding less than 5% of the paper produced in 2019. Most of the pulp was imported in 1990, while in 2022 half of the pulp used is produced locally from recycled paper. Paper production is expanding, and activity data (total paper produced) were 6.2 Mt in 1990 and 8.7 Mt in 2022. The printing industry represents a minor part of the source category emissions.

This source category includes also emissions from the cogeneration of electricity. Due to the transformation of some of those plants in power plants directly connected to the grid (and so reported in category 1.A.1.a), the percentage of the category 1.A.2.d CO_2 emissions due to electricity generation has strongly reduced from 1990 to 2022.

Food

Emissions from food production are included in this source category. In Italy the food production industry is expanding. A comprehensive activity data for this sector is not available; more in detail while energy data are those reported in the national energy balance for this sector, information at subsector and technological level is not available and only few plants are part of the ETS; energy fuel consumption was estimated to be 62 PJ in 1990 and 117 PJ in 2022, almost half of energy consumptions derives from biomass. Value added at constant prices has increased by 0.6% per year from 1990 to 2003 and almost constant from 2004.

This source category also includes emissions from the cogeneration of electricity. Due to the transformation of those plants into power plants directly connected to the grid, and so reported in category 1.A.1.a, the percentage of the category 1.A.2.e CO_2 emissions due to electricity generation has reduced from 1990 to 2022.

Non-metallic minerals

This sector, which refers to construction materials, is quite significant in terms of emissions due to the energy intensity of the processes involved. Construction materials subsector includes the production of cement, lime, bricks, tiles and glass. It comprises thousands of small and medium size enterprises, with only a few large operators, mainly related to cement production. Some of the products are also exported. The description of the process used to produce cement, lime and glass is reported in chapter 4, industrial processes.

The fabrication of bricks is a rather standard practice in most countries and does not need additional description; fossil source is mainly natural gas. A peculiar national circumstance is the fabrication of tiles, in which are involved many specialised “industrial districts” where many different independent small size enterprises are able to manufacture world level products for both quality and style, exported everywhere. The processes implemented are efficient with reference to the average European level and use mostly natural gas as the main fossil source since the year 2000.

The activity data of industries oriented to so many different markets are, of course, peculiar to each subsector and it is difficult to identify a common trend. The productions of cement, lime and glass are the most relevant from the emissions point of view.

This subsector is the most important of 1.A.2 category and accounts, in 2022, for 21.5% of total 1.A.2 GHG emissions, and 2.9% of total national emissions.

Other

This sector comprises emissions from many different industrial subsectors, some of which are quite significant in Italy in terms of both value added and export capacity.

In particular, engineering sector (vehicles and machines manufacturing) is the main industrial sub sector in terms of value added and revenues from export and textiles was the second subsector up to year 2000.

The remaining "other industries" include furniture and other various "made in Italy" products that produce not negligible amounts of emissions.

This source category also includes emissions from the cogeneration of electricity. Due to the transformation of some of those plants into power plants directly connected to the grid, reported in category 1.A.1.a, the percentage of the category 1.A.2.g CO_2 emissions due to electricity generation has reduced in the last years. This subsector accounts, in 2022, for 20.6% of total 1.A.2 GHG emissions, and 2.6% of total national emissions.

3.4.3 Methodological issues

Energy consumption data comprise specification of consumption for 13 sub-sectors and more than 25 fuels. These very detailed data, combined with industrial production data, allow for a good estimation of all the fuel used by most industrial sectors, with the details required by CRT format. With reference to coal used in the integrated steel production plants the quantities reported in BEN are not used as such, but a procedure has been elaborated to estimate the carbon emissions linked to steel production and those attributable to the coal gases recovered for electricity generation, as already mentioned in paragraph 3.4.1. The detailed calculation procedure is described in Annex 3. Moreover, a part of the fuel input is considered in the estimation of process emissions, see chapter 4 for further details.

The balance of fuel (total consumption minus industrial processes consumption) is considered in the emission estimate; CO_2 emission factors used for 2022 are listed in Table 3.12. The procedure used to estimate the national emission factors is described in Annex 6. These factors account for the fraction of carbon oxidised equal to 1.00 for solid, liquid and gaseous fuels, as suggested by the IPCC 2006 guidelines (IPCC, 2006).

For some fuels such as natural gas, coal and residual oil, country specific emission factors are available for the whole time series; so, their time series considers different oxidation factors according to the improvement of combustion efficiency occurred in the nineties but considering the value equal to 1.00 from 2005.

For petroleum coke, synthesis gas from heavy residual, refinery gases, iron and steel derived gases, coking coal, anthracite, coke oven coke from 2005, and for residual gases from chemical processes, from 2007, CO_2 emission factors have been calculated based on the data reported by operators under the EU ETS scheme. See Annex 6 for further details. For the other fuels, where national information was not available, default emission factors provided by the IPCC 2006 Guidelines have been used (IPCC, 2006).

Table 3.12 Emission Factors for Power, Industry and Civil sector

	t CO_2 / TJ	t CO_2 / t	t CO_2 / toe
Liquid fuels			
Crude oil	73.300	3.101	3.069
Jet gasoline	70.000	3.101	2.931
Jet kerosene	71.500	3.153	2.994
Petroleum Coke in industry*	92.968	3.120	3.892
Petroleum Coke in refineries*	96.855	3.435	4.055
Gasoil	74.100	3.186	3.102
Orimulsion	77.000	2.118	3.224
Fuel oil*	76.609	3.144	3.207
Heavy residual in refineries*	80.480	3.134	3.370
Synthesis gas from heavy residual*	99.071	0.926	4.148
Residual gases from chemical processes*	48.785	2.211	2.043
Other chemical gases*	53.394	2.301	2.235
Gaseous fuels			
Natural gas*	58.918	2.020 (sm^3)	2.467
Solid fuels			
Steam coal*	93.233	2.310	3.903
"sub-bituminous" coal	96.100	1.816	4.024
Lignite	101.000	1.202	4.229
Coking coal*	94.447	2.953	3.954
Anthracite*	104.643	3.044	4.381
Coke oven coke*	108.216	3.189	4.531
Biomass			
Solid Biomass*	(94.600)	(0.962)	(3.961)
Derived Gases			
Refinery Gas*	56.531	2.665 (sm^3)	2.367
Coke Oven Gas*	45.925	0.805 (sm^3)	1.881
Oxygen converter Gas*	191.486	1.414 (sm^3)	8.017
Blast furnace*	250.750	0.911 (sm^3)	10.498
Other fuels (fossil)			
Municipal solid waste*	96.931	1.092	4.572
Industrial solid waste*	81.504	2.054	3.412
*country specific emission factors			

Source: ISPRA elaborations

Other sources of information are the yearly survey performed for the E-PRTR, since 2003, and the EU ETS; both surveys include main industrial operators, but not all emission sources. In particular from 2005 onwards the detailed reports by operators subject to EU ETS constitute a valuable source of data, as already said above, with reference to oxidation factors and average emission factors.

In general, in the industrial sector, the ETS data source is used for cross checking BEN data. Energy/emissions data from the EU ETS survey of industrial sectors should be normally lower than the corresponding BEN data because only part of the installations / sources of a certain industrial sub sector are subject to EU ETS. In case of missing sources or lower figures in the BEN than ETS, at fuel level, a verification procedure is carried out.

Since 2007 data, ISPRA verifies data from both sources and communicates potential discrepancies to MASE. Thus, a verification procedure has started that could lead to a change of data in the energy balance. However, it is necessary to underline that EU ETS data does not include all industrial installations and cannot be used directly to estimate sectoral emissions for a series of reasons that will be analyzed in the following, sector by sector.

Biomass fuel consumption in the sector is driven by the use of wood in the non-metallic subcategory and biogas from agriculture residues in the food subcategory. The trend of the implied emission factors is driven in the last years by the exponential increase of the biogas fuel consumption, observed mainly in the food processing industry, and the strong decrease of wood consumption in industry, as supplied by the national energy balance (MASE, several years [a]).

Other fuels include industrial waste fuel consumption reported in the non-metallic mineral subcategory. The use of industrial waste in manufacturing industries is linked to the use in the last 10 years in cement production plants and refers to the consumption of RDF (Refuse-derived Fuel), plastics, tyres, waste oils and solvents. The average emission factor time series is reported in Table A6.12 of Annex 6 and it has been derived from data reported to the ETS by the plants using that fuel.

Iron and steel

For this sector, all main installations are included in EU ETS, but only from 2013 all sources of emissions are included. In the previous years, only part of the processes of integrated steel making was subject to EU ETS, in particular the manufacturing process after the production of row steel was excluded up to 2007 and only the lamination processes have been included from 2008.

So, the EU ETS data has been of limited use for this subsector and the procedure set up starting from the total carbon input to the steel making process, is the most comprehensive one to estimate the emissions to be reported in 1.A.2.a, see Annex 3 for further details. Of course, data available from EU ETS are used for cross-checking the national energy balance data, with an aim to improve the consistency of the data set. These plants are also reported in E-PRTR, but not all sources are included.

The low implied emission factors and annual variations in the average CO_2 emission factor for solid fuel are due to the fact that both activity data and emissions reported under this category include the results of the carbon balance (see Annex 3 for further details). The implied emission factor for 2022 is equal to 56.3 t/TJ. CH_4 implied emission factor is equal to 15.0 kg/TJ in 2022 and it is higher than the default emission factors because of the specificities of the in-process combustion activities. The sintering process is a pre-treatment step in the production of iron in which metal ores, coke and other materials are roasted under burners, involving the mixing of combustion products and/or the fuel with the product or raw materials (EMEP/EEA, 2019). Apart from combustion emissions, the heating of plant feedstock and product can lead to substantial CH_4 emissions which are to be accounted for in the combustion process.

Non-Ferrous Metals

These plants are mostly excluded from EU ETS; primary aluminum producing plants should have been included from 2013, but the only Italian plant closed in the same year. These production processes are also in the scope of the E-PRTR survey, which collects also information concerning emissions to air, but since these facilities usually do not exceed the emission thresholds for mandatory reporting the information regarding emissions to air is not reported by the operators.

Chemicals

The use of EU ETS data for this subsector is rather complex because generally chemical plants are excluded from EU ETS while petrochemical plants, which report also under the E-PRTR, are included from 2013. In this case, the data set is used for cross checking BEN data. As mentioned in paragraph 3.4.1, also a small amount of emissions connected to the production of electricity for the onsite use is reported in source 1.A.2.c, basic data are taken from TERNA reports and the relative subsector amount is estimated with a model.

In this category, biomass refers to the steam wood fuel consumption as available in the BEN. The relevant CO_2 emission factor is reported in Table 3.12 above.

Fuel consumptions of derived chemical and petrochemical fuels, which could be considered as petrol derived fuels, were reported in the past in the "other fossil fuels" category for chemicals industries. With the aim of improving the comparison between reference and sectoral approaches, these fuels have been reported under the liquid fuel category. The average CO_2 emission factor at sectoral level for liquid fuels is driven by the weight of synthesis gases from chemical processes fuel consumptions. The relevant CO_2 emission factor is reported in Table 3.12 above.

Pulp, Paper and Print

Most of the operators in the paper and pulp sector are included in EU ETS, while only a few of the printing installations are included.

CH_4 and N_2O emissions from biomass fuel consumption in the sector, are included in the inventory on the basis of the biomass fuel consumption reported in the annual environmental report by the industrial association (ASSOCARTA, several years) and to the EU ETS. Statistics on biomass fuel consumption appear from 1998. According to the information supplied by the industrial association of the sector, ASSOCARTA, a few plants started to use biomass in 1998. The use of biomass has an increasing trend till 2008 while in 2009 the use of biomass sharply reduced with a further reduction in the following years to return in the last years to the same level of 2009. From 2008 information is directly reported by the production plants in the framework of the EU ETS and a reduction in the IEF is observed as a consequence of increase in energy efficiency of the biomass fuel used. For the years from 1990 to 1997 the use of biomass for energy purposes in the pulp and paper industry has been assumed not occurring. Biomass fuel consumption includes especially black liquor, from 1998 to 2007, but also industrial sludge and biogas from industrial organic wastes. From 2013 only biogas is included and, in 2022, CO_2 emission factor is equal to 55.5 t/TJ.

Food

Emissions from food production are included in this source category. Comprehensive activity data for this sector is not available; the subsector comprises many small and medium size enterprises, with thousands of different products. Only limited info on this sector can be found in the ETS survey, the sector is not included in the scope of ETS.

Liquid fuel refers to fuel oil and LPG fuel consumption driving the variability of the average emission factors.

For the years up to 2002, solid fuel consumption was mainly related to the consumption of coke and small amount of lignite. From 2012 the fuel consumption and relevant emission factors refers only to anthracite.

Biomass includes fuel consumption of steam wood and biogas from food industrial residual. The CH_4 implied emission factor time series is driven by the mix of these fuels. In this sector emissions are prevalent from biogas from food industry residual or in the paper industry, with an EF of CH_4 equal to 153 kg/TJ, while in the other manufacturing industries biomass refers to wood and similar with an emission factor for CH_4 equal to 28 kg/TJ.

CH_4 emissions from biogas fuel combustion take into account the technology used to produce energy and heat from biogas combustion, usually stationary engines, which is not fully efficient and results in higher emissions of VOC, CO and PM. The emission factor is reported in the EMEP/CORINAIR Guidebook (EMEP/CORINAIR, 2007) as the maximum for stationary engines. The relevant information is planned to be collected at plant level to update this emission factor considering the improvement in technology in the last years with respect to the nineties. Biogas has an emission factor for N_2O, equal to 3 kg/TJ.

Non-metallic minerals

This sector comprises emissions from many different industrial subsectors, some of which are subject to EU ETS and some not. Construction material subsector is energy intensive, and it is subject to EU ETS. In the national energy database, the data for construction material are reported separately and they can be cross checked with ETS survey. However, in the construction material subsector, there are many small and medium size enterprises, so the operators subject to ETS are only a part of the total.

Biomass includes wood fuel consumption and other non-conventional fuels especially used in the construction material subsector. CH_4 emission factor is equal to 28 kg/TJ and refers to the use of these non-conventional fuels for cement production (EMEP/EEA, 2009).

Industrial waste fuel consumption is also included in this subcategory; CH_4 and N_2O emission factors are equal to 3 kg/TJ and 15 kg/TJ respectively.

Other

This sector comprises emissions from many different industrial subsectors, mainly not subject to EU ETS.

3.4.4 Uncertainty and time-series consistency

The combined uncertainty in CO_2 emissions for this category is estimated to be about 4% in annual emissions; a higher uncertainty is calculated for CH_4 and N_2O emissions on account of the uncertainty levels attributed to the related emission factors and the difference in emission factors between the industrial subsectors, sources 1.a.2.a-g.

Time series of the industrial energy consumption data are contained in the BEN time series and in the CRTs and are reported in the following table.

Table 3.13 Fuel consumptions for Manufacturing Industry sector, 1990-2022 (TJ)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
1.A.2 Manufacturing Industries and Construction	**1,367,598**	**1,393,148**	**1,506,841**	**1,464,862**	**1,116,067**	**913,182**	**859,303**	**794,893**	**932,427**	**913,577**
a. Iron and Steel	397,841	378,482	373,499	371,192	299,536	182,846	169,942	139,913	171,024	152,361
b. Non-Ferrous Metals	11,916	14,708	20,276	19,774	18,537	16,968	18,240	17,309	22,225	18,847
c. Chemicals	320,112	288,273	279,930	257,657	241,530	169,118	142,626	144,585	151,693	162,941
d. Pulp, Paper and Print	50,730	70,189	73,713	94,498	88,256	83,986	86,227	80,591	85,866	77,214
e. Food Processing, Beverages and Tobacco	62,370	84,987	103,004	99,007	73,493	108,704	113,370	113,441	116,959	110,551
f. Non-metallic minerals	278,929	255,293	306,930	363,170	261,735	201,447	172,083	163,314	171,884	172,503
g. Other	245,699	301,216	349,489	259,564	132,980	150,113	156,816	135,741	212,776	219,161

Source: ISPRA elaborations

Emission levels observed from 1990 to 2005 are nearly constant with some oscillations, linked to the economic cycles and reflecting the development of national sectoral industries, as paper and food. After the year 2005 the general trend is downward, with oscillations due to the economic cycles industries but also reflecting the delocalization of production in some specific sectors as chemicals and textile industry, see Table 3.11 above. The underlining reason for the reduced emissions is the reduced industrial output, and the increase in energy efficiency. For the iron and steel sector as well as for the non-metallic minerals sector, a drop is observed in the last years coherent with the reduction of the production activities in the main national iron and steel integrated plants and in the cement production industry respectively.

3.4.5 Source-specific QA/QC and verification

Basic data to estimate emissions have been reported by the national energy balance and the national grid administrator. Data collected by other surveys that include EU-ETS and E-PRTR surveys have been used to cross – check the energy balance data, fuels used and EFs. Differences and problems have been analyzed in detail and solved together with MASE experts.

The energy data used to estimate emissions reported in Table 1.A.2 have two different levels of accuracy:

- in general, they are quite reliable, and their uncertainty is the same of the BEN; as reported in Annex 4 the BEN survey covers 100% of import, export and production of energy; the total industrial consumption estimate is obtained subtracting from the total the known energy quantities (obtained by specialized surveys) used in electricity production, refineries and the civil sector.
- the energy consumption at sub sectoral level (sources 1.A.2.a-g) is estimated by MASE on the basis of sample surveys, actual production and economic data; therefore, the internal distribution on energy consumption has not the same grade of accuracy of the total data.

3.4.6 Source-specific recalculations

Recalculations occur because of the update of the whole time series of the residual chemical gas CO_2 emission factors. In 2021 recalculations occur because of the National Energy balance review process.

3.4.7 Source-specific planned improvements

With the aim to improve the comparison with the international statistics and the relevant definition and classification of fuels we are progressively updating the emission inventory adopting the energy balance activity data provided by the Italian Ministry of Environment to the international organization after verification that these time series data reflect the relevant emission inventory categories.

A revision of biomass and waste fuel consumption time series is planned for the next submission on the basis of energy data communicated by the Ministry of Environment to the Joint Questionnaire IEA/EUROSTAT/UNECE, after a verification and comparison with data up to now used and available in the National Energy Balance reports (MASE, several years [a]). National Energy Balances are available in Italy from 1970 with the same format and comparable data. The submissions to the international questionnaire in some cases follow different rules and different allocation of fuel consumptions. The comparison is oriented to avoid that the use of international statistics results in a loss of information already used for the emission inventory.

3.5 Transport

This sector shows an increase in emissions, reflecting the trend observed in fuel consumption for road transportation, which in 2022 accounts for about 91.5% of GHG sectoral emissions. The mobility demand and, particularly, the road transportation share keeps above 90% over the years. A growth is observed, although since 2008 emissions from transport begin to decrease. Due to the pandemic during the year 2020, the mobility demand sharply lowered, mainly corresponding to the lockdown periods. Since 2021 the sector has shown a recovery and in 2022 it is responsible for 26.6% of total national GHG emissions and 32.5% of the GHG energy sector emissions.

In 2022 the GHG emission shares of the different transport modes are: 2.3% for domestic aviation, 91.5% for road transportation, 0.04% for railways (diesel oil), 5.3% for domestic navigation, 0.9% for pipeline transport.

Emissions increase of about 26.8% from 1990 to 2007 and show a decrease of about 18.0% from 2007 to 2019; despite an inversion of the trend between 2013 and 2014, a further reduction is observed between 2015 and 2017, while 2018-2019 emissions show an upward trend because of a general growth of economy. Year 2022 shows an increase of 6.7% and 7.4% in comparison with the years 2021 and 1990 respectively. Year 2022 has an increase of 3.2% in comparison to 2019, before the pandemic occurred. In 2012 a drop is observed in CO_2 emissions due to a sharp reduction of gasoline and diesel fuel consumption for road transport, explained mainly by the economic crisis, contributing to the reduction of movements of passengers and goods, and in a minor way the penetration in the market of low consumption vehicles.

The time series of CO_2, CH_4 and N_2O emissions, in Mt CO_2 equivalent, is reported in Table 3.14; figures comprise all the emissions reported in table 1.A.(a)s3 of the CRT. Emission estimates are discussed below for each sub sector. The trend of CH_4 and N_2O emissions is impacted by the evolution of the technologies in the road transport sector and the distribution between the different fuels consumption.

Table 3.14 GHG emissions for the transport sector (Mt CO_2 eq.)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
CO_2 Mt CO_2eq	100.32	111.53	121.64	126.78	114.63	105.59	105.23	85.64	101.85	108.65
CH_4 Mt CO_2eq	1.01	1.13	0.86	0.56	0.33	0.24	0.21	0.18	0.19	0.20
N_2O Mt CO_2eq	0.86	1.55	1.45	1.01	0.95	0.89	0.90	0.75	0.89	0.92
Total, Mt CO_2 eq.	**102.19**	**114.22**	**123.95**	**128.36**	**115.90**	**106.72**	**106.35**	**86.56**	**102.93**	**109.77**

Source: ISPRA elaborations

CO_2 from road vehicles is key category both in 1990 and 2022, in level and trend (Tier 1 and Tier 2) with and without LULUCF. CO_2 from waterborne navigation is key category both in 1990 and 2022, in level (Tier 1) with and without LULUCF and in trend (Tier 1) with and without LULUCF. CO_2 from civil aviation is key category in level (Tier 1) in 1990 with LULUCF, in 2022 in level (Tier 1) with and without LULUCF, in trend (Tier 1) with and without LULUCF. CO_2 from pipelines is key category in trend (Tier 1) with and without LULUCF.

3.5.1 Aviation

3.5.1.1 Source category description

The IPCC methodology requires the estimation of emissions for category 1.A.3.a.i International Aviation and 1.A.3.a.ii Domestic Aviation, including figures both for the cruise phase of the flight and the landing and take-off cycles (LTO). Emissions from international aviation are reported as a memo item and are not included in national totals.

Civil aviation contributes mainly to CO_2 emissions. CH_4 and N_2O emissions also occur and are estimated in this category but their contribution is insignificant. In 2022, total GHG emissions from this source category were about 2.3% of the national total emissions from transport, and about 0.6% of the GHG national total (in terms of CO_2 only, the share is almost the same).

GHG emissions from aviation from 1990 to 2022 show an increase of about 66.4%. From 1990 to 2019, GHG emissions from the sector increased by 59.3%, due to the expansion of the aviation transport mode. Considering the sharp reduction of movements that occurred in 2020 due to the global pandemic, the aviation sector decreased by 20% in comparison with 1990. From 2010 to 2019 a reduction is observed in GHG emissions, equal to -19.6% due both to the reduction of domestic flights and to an increase of energy efficiency in new aircrafts. Considering the year 2022, the total reduction amounts to -16.0%, in comparison with 2010 emissions. Focusing on the period 2010-2022, after the minimum GHGs emissions registered in the years 2015-2016, there is a rise in the emissions from aviation in the years 2017-2019, related to the growth rates in the number of domestic flights. The year 2020 is thus to be considered apart because of the exceptional global conditions. GHG emissions in 2022 are 108% higher in comparison to 2020: there is a full recovery from the first year of pandemic, and emissions are 4.4% higher than in 2019. CO_2 emissions deriving from civil aviation represent a key category in level (Tier 1) in 1990 with LULUCF, in 2022 in level (Tier 1) with and without LULUCF, in trend (Tier 1) with and without LULUCF.

3.5.1.2 Methodological issues

The methodology to estimate emissions is in line with the IPCC Guidelines (IPCC, 2006) and the EMEP/EEA Guidebook (EMEP/EEA, 2023).

Activity data comprise both fuel consumptions and aircraft movements, which are available in different level of aggregation and derive from different sources as specified here below:

- Total inland deliveries of aviation gasoline and jet fuel are provided in the national energy balance (MASE, several years [a]). This figure is the best approximation of aviation fuel consumption, for international and domestic use, but it is reported as a total and not split between domestic and international and include fuel used for engines and airframe testing;
- Data on annual arrivals and departures of domestic and international landing and take-off cycles at Italian airports are reported by different sources: National Institute of Statistics in the statistics yearbooks (ISTAT, several years [a]), Ministry of Transport in the national transport statistics yearbooks (MIT, several years), the Italian civil aviation in the national aviation statistics yearbooks (ENAC/MIT, several years), which report total national and international commercial air traffic, scheduled and not scheduled flights including charter and air taxi, EUROCONTROL flights data time series 2002 – 2022 (EUROCONTROL, several years). Along the time series, data from ENAC have been used (ENAC/MIT, several years) from 1990 to 2001, whereas, EUROCONTROL flights data are used from 2002, considering departures from and arrivals to all airports in Italy, regarding flights flying under instrument flight rules (IFR), including civil helicopters flights and excluding flights flagged as military.

As for the emission and consumption factors, values, from 1990 to 1999, are derived by the EMEP/CORINAIR guidebook (EMEP/CORINAIR, 2007), both for LTO cycles and cruise phases, considering national specificities. These specificities derived from the results of a national study which, taking into account detailed information on the Italian air fleet and the origin-destination flights for the year 1999, calculated national average values for both domestic and international flights (Romano et al., 1999; ANPA,

2001) on the basis of the default EMEP/CORINAIR emission and consumption factors (EMEP/CORINAIR, 2007). The resulting national average emission and consumption factors were therefore used to estimate emissions for LTO cycles and cruise both for domestic and international flights from 1990 to 1999.

Specifically, for the year 1999, a Tier 3 method was applied. In fact, figures on the number of flights, destination, aircraft fleet and engines were provided by the local airport authorities, national airlines and EUROCONTROL, covering about 80% of the national official statistics on aircraft movements for the relevant year. Data on 'Times in mode' were also supplied by the four principal airports and estimates for the other minor airports have been carried out based on previous sectoral studies at local level.

Emissions were estimated from the number of aircraft movements broken down by aircraft and engine type (derived from ICAO database if not specified) at each of the principal Italian airports; information about whether the flight is international or domestic and the related distance travelled was also considered.

Based on sample information, estimates have been carried out at national level from 1990 to 1999 considering the official statistics on movements of the aviation sector (ENAC/MIT, several years) and applying the national average consumption and emission factors, as previously described.

From 2005, EUROCONTROL provides emission estimates from the aviation sector of each EU Member State under both the UNFCCC and LRTAP conventions, both for LTO cycles and cruise phases, domestic and international, including data on fuel consumption and emission factors, and the number of flights which are also available for 2002-2004. The Advanced Emissions Model (AEM) was applied by EUROCONTROL to derive these figures, according to a Tier 3 methodology (EMEP/EEA, 2023).

For the period between 1999 and 2005, linear interpolation was applied to calculate consumption and emission parameters. In general, to carry out national estimates of greenhouse gases and other pollutants for LTO cycles, both domestic and international, consumption and emissions are calculated using the average consumption and emission factors multiplied by the total number of flights. The same method is used to estimate emissions for domestic cruise.

On the other hand, for international cruise, consumption is derived by difference from the total fuel consumption reported in the national energy balance and the estimated values as described above and emissions are therefore calculated.

Data on domestic and international aircraft movements from 1990 to 2022 are shown in Table 3.15 where domestic flights are those entirely within Italy.

Table 3.15 Aircraft Movement Data (LTO cycles)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Domestic flights	172,148	185,220	319,748	350,140	354,520	280,645	288,470	151,156	209,721	286,496
International flights	147,875	198,848	303,608	381,206	406,990	425,410	502,764	172,835	232,750	419,862

Source: ISTAT, several years [a]; ENAC/MIT, several years; Eurocontrol, several years.

Emission factors are reported in Table 3.16 and Table 3.17. CO_2 and SO_2, emission factors (in kg/TJ) depend on the fuel quality, and according to the information available in literature it has been assumed that the quality of jet fuel does not change in the period. CO_2 emission factors are those in the 2006 IPCC Guidelines (IPCC, 2006), while SO_2 emission factor is equal to 1 kg/t of fuel. For N_2O, because of emission factors are not available at engine/airplane level in the relevant EMEP and IPCC Guidelines which are based on the ICAO database, the 2006 IPCC Guidelines default value has been used, equal to 2 kg/TJ (IPCC, 2006). For the other gases, including CH_4, emission factors depend on the technologies and vary in the time series according to the surveys as already described in this paragraph.

Table 3.16 CO_2 and SO_2 emission factors for Aviation (kg/t) 1990-2022

	CO_2[a]	SO_2
Aviation jet fuel	849	1.0
Aviation gasoline	839	1.0

a Emission factor as kg carbon/t.

Table 3.17 Non-CO_2 emission factors for Aviation (2022)

	Units	CH_4	N_2O	NO_x	CO	NMVOC	Fuel
Domestic LTO	kg/LTO	0.132	0.054	8.247	6,041	0.863	615.707
International LTO	kg/LTO	0.153	0.062	10.283	6.487	0.858	716.376
Domestic Cruise	kg/t fuel	-	0.087	15.106	4.559	0.635	-
International Cruise	kg/t fuel	-	0.095	15.994	2.643	0.267	-
Aircraft Military[a]	kg/t fuel	0.400	0.200	15.800	126.000	3.600	-

Source: (a)EMEP/CORINAIR, 2007; EMEP/EEA 2023; Eurocontrol, several years

Total fuel consumption, both domestic and international, is reported by LTO and cruise in Table 3.18.

Table 3.18 Aviation jet fuel consumptions for domestic and international flights (Gg)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
	Gg									
Domestic LTO	111	120	208	233	227	168	180	89	123	146
International LTO	130	175	258	269	296	328	399	130	162	301
Domestic cruise	357	384	654	666	704	526	580	291	421	620
International cruise	1,246	1,688	2,297	2,456	2,534	2,745	3,584	1,087	1,432	2,625

Source: ISPRA elaborations

Emissions from military aircrafts are also estimated and reported under category 1.A.5.b Other. The methodology to estimate military aviation emissions is simpler than the one described for civil aviation since LTO data are not available in this case. As for activity data, total consumption for military aviation is published in the petrochemical bulletin (MASE, several years [b]) by fuel. Emission factors are those provided in the EMEP/CORINAIR guidebook (EMEP/CORINAIR, 2007). CO_2 and SO_2 emission factors depend on fuel properties; as regards CO_2, emission factors have been calculated assuming that 100% of the fuel carbon is oxidized to CO_2. Therefore, emissions are calculated by multiplying military fuel consumption data for the EMEP/CORINAIR default emission factors shown in Table 3.17.

3.5.1.3 Uncertainty and time-series consistency

The combined uncertainty in CO_2 emissions from aviation is estimated to be about 3% in annual emissions; a higher uncertainty is calculated for CH_4 and N_2O emissions on account of the uncertainty levels attributed to the related emission factors.

Time series of domestic emissions from the aviation sector is reported in Table 3.19. An upward trend in emission levels is observed from 1990 to 2019 which is explained by the increasing number of LTO cycles. Nevertheless, the propagation of more modern aircrafts in the fleet slows down the trend in the most recent years. In 2020, the lowest emissions level due to the pandemic is observed. By the year 2022, emissions increased and reached higher levels in comparison with 2019.

Table 3.19 GHG emissions from domestic aviation

		1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
CO_2	*Gg*	1,493.1	1,588.5	2,718.2	2,839.4	2,958.5	2,166.8	2,378.8	1,194.8	1,703.4	2,484.6
CH_4	*Mg*	26. 9	27.7	47.9	52.8	52.7	36.5	39.4	19.8	27.1	38.1
N_2O	*Mg*	41.8	44.4	76.0	79.4	82.8	60.6	66.5	33.4	47.7	69.5

Source: ISPRA elaborations

3.5.1.4 Source-specific QA/QC and verification

Data used for estimating emissions from the aviation sector derive from different sources: local airport authorities, national airlines operators, EUROCONTROL and official statistics by different Ministries and national authorities. Different QA/QC and verification activities are carried out for this category.

As regards past years, the results of the national studies and methodologies, applied at national and airport level, were shared with national experts in the framework of an *ad hoc* working group on air emissions instituted by the National Aviation Authority (ENAC). The group, chaired by ISPRA, included participants from ENAC, Ministry of Environment, Ministry of Transport, national airlines and local airport authorities. The results reflected differences between airports, aircrafts used and times in mode spent for each operation. Currently, verification and comparison activities regard activity data and emission factors. In particular, the number of flights has been compared considering different sources: ENAC, ASSAEROPORTI, ISTAT, EUROCONTROL and verification activities have been performed on the basis of the updated EUROCONTROL data on fuel consumption and emission factors resulting in an update and improving of the national inventory. Furthermore, there is an ongoing collaboration and data exchange with regional environmental agencies on this issue.

3.5.1.5 Source-specific recalculations

No recalculations occurred respect to the last submission.

3.5.1.6 Source-specific planned improvements

Improvements for the next submissions are planned based on the outcome of the ongoing quality assurance and quality control activities, regarding the results of investigation about data and information deriving from different sources, in particular further assessment of EUROCONTROL data, and comparison with ISTAT information.

3.5.2 Road Transport

3.5.2.1 Source category description

This section addresses the estimation of emissions related to category 1.A.3.b Road transportation. In 2022, total GHG emissions from this category were about 91.5% of the total national emissions from transport, 29.7% of the energy sector and about 24.3% of the GHG national total.

From 1990 to 2022, GHG emissions from the sector increased by 6.8%. This trend is explained by multiple factors: on one side a strong increase starting from 1990 until 2007 (27.7%), due to the increase of vehicle fleet, total mileage and consequently fuel consumptions and on the other side, in the last years, from 2007 onwards, a decrease in fuel consumption and emissions basically due to the economic crisis (emissions from 2007 to 2019 decrease of about -18.7%); then from 2019 to 2020, there has been a sharp reduction in emissions, amounting to approximately -19.4%, as a result of the pandemic crisis; the post pandemic recovery in mobility and consumption from 2020 to 2021 has led to an increase in GHG emissions of about 21.6%. Finally, during last year, an increase in emissions of about 5.1% has been observed.

CO_2 emissions from road transport are key category, both in 1990 and in 2022, with approach 1 and approach 2, with and without LULUCF, at level and trend assessment.

CH_4 emissions are key category: in 1990 in level with approach 2 with and without LULUCF; in trend with approach 1 with LULUCF; in trend with approach 2 with and without LULUCF.

N_2O emissions are key categories in 2022 in level with approach 2 with and without LULUCF.

Emissions from road transport are calculated either from a combination of total fuel consumption data and fuel properties or from a combination of drive related emission factors and road traffic data.

Emissions from biomass fuel consumption are included and reported: as regards biodiesel, under diesel fuel category, as regards bioethanol under gasoline fuel category and as regards biogas under natural gas fuel category. Biomass fuel refers prevalently to the use of biodiesel, which is mixed with diesel fuel, to the use of bioethanol mixed with gasoline fuel and to the use of biogas mixed with natural gas.

CO_2 emissions are calculated based on the amount of carbon in the fuel. In the model used to calculate emissions, the fuel consumption input, which is balanced with the fuel consumption estimated by the model, includes both fossil and bio fuels; then CO_2 emissions related to biomass are subtracted to the total with the aim to be reported under biomass. CH_4 and N_2O emissions depend on the technology of vehicles and have been calculated on the basis of more detailed information regarding the type and technology of vehicles and the associated fuel consumption. Methane emission trend is due to the combined effect of technological improvements that limit VOCs from tail pipe and the expansion of the fleet. It has to be underlined that in Italy there is a remarkable fleet of motorbikes and mopeds (about 10 million vehicles in 2022) that use gasoline and it increased of about 56.5% since 1990 (this fleet not completely complies with strict VOC emissions controls).

3.5.2.2 Methodological issues

According to the IPCC Guidelines (IPCC, 2006) and the EMEP/EEA air pollutant emission inventory guidebook 2023 (EMEP/EEA, 2023), a national methodology has been developed and applied to estimate emissions; COPERT methodology is used and country specificities are taken into account according to Tier 3 of IPCC Guidelines, such as the physic-chemical characterization of fossil fuels used in Italy and the peculiar structure of the circulating fleet.

The model COPERT 5 (updated version 5.7.3, January 2024) has been used and applied for the whole time series in 2024 submission. COPERT 5 introduced over the years upgrades both from software and methodological point of view (https://www.emisia.com/utilities/copert/versions/).

As regards fuel, updates concerned: fuel energy instead of fuel mass calculations; distinction between primary and end (blends) fuels, automated energy balance. Regarding vehicle types, updated vehicle category naming, new vehicle types and emission control technology level, have been introduced. As regards emission factors, one function type and the possibility to distinguish between peak/off-peak urban, have been implemented.

Main methodological innovations introduced in version 5.7.3 respect to version 5.6.1, used in last submission, relate: updating emission factors of Euro 6 CNG passenger cars, Euro VI diesel buses, Euro VI diesel hybrid buses, non-exhaust emission factors.
As regards the software, revisions relate: the removal of CO_2 correction, capability of alternative HDVs classification based on REG EU 2017/2400, improved labels of forms and headers.
Furthermore various bugs have been corrected regarding: the correction of the calculation for cold emissions of CO, NO_X, VOC for petrol and diesel PCs and LCVs, the correction of cold start ratio of diesel Euro 6 cars for NO_X and CO, the correction of cold start ratio of petrol-fueled cars and vans for VOC and CO, the correction of cold emissions of Euro 6 CNG passenger cars for SPN23, the correction of bug when importing stock of HDVs in VECTO groups from excel to COPERT.

In addition, software update issues and minor corrections have been implemented.

Italian road vehicles electricity consumption data, introduced recently in COPERT in relation to the evolution of the fleet, derive from Eurostat database (https://ec.europa.eu/eurostat/data/database).

As regards CO_2 emissions from catalytic converters using urea (reported under category 2.D.3), Italian road transport emissions estimation about CO_2 from urea-based catalysts is implemented in the model used. For diesel passenger cars Euro 6 and light duty trucks Euro 6, the consumption of urea is assumed to be equal to 2% of fuel consumption; for diesel heavy duty trucks and buses, the consumption of urea is assumed to be equal to 6% of fuel consumption at Euro 4 and Euro 5 level and equal to 3.5% at Euro 6 level. Regarding the purity (the mass fraction of urea in the urea-based additive), the default value of thirty-two and half percent has been used (IPCC, 2006).

Methodologies are described in the following, distinguishing emissions calculated from fuel consumption and traffic data.

Fuel-based emissions

Emissions of carbon dioxide and sulphur dioxide from road transport are calculated from the consumption of gasoline, diesel, liquefied petroleum gas (LPG) and natural gas and the carbon or sulphur content of the fuels consumed. Consumption data have been updated according to data officially communicated to the Joint Questionnaire OECD/IEA/EUROSTAT.

Consumption data for the fuel consumed by road transport in Italy are taken from the national energy balance (MASE, several years [a]), in physical units (considering the use in road transportation, in machinery as regards gasoline, in commercial and public service, and subtracting the quantities for military use in diesel oil and off-road uses in petrol).

Monitoring of the carbon content of the fuels used in Italy is an ongoing activity at ISPRA (Italian Institute for Environmental Protection and Research). The purpose is to regularly analyse the chemical composition of the used fuels or relevant commercial statistics to estimate the carbon content/emission factor (EF) of the fuels.

With reference to the whole inventory, for each primary fuel, a specific procedure has been established.

As regards road transport, Italy country-specific CO_2 emission factors values for gasoline, diesel fuel and LPG, derive from ad hoc studies about the properties of transportation fuels sold in Italy and whose results are representative and applicable with reference to four different time phases: 1990 – 1999; 2000 – 2012; 2013 – 2019; since 2020 (Innovhub – Fuel Experimental Station surveys, several years).

As regards natural gas, the national market is characterized by the commercialisation of gases with different chemical composition in variable quantities from one year to the other. The methodology used to estimate the average EF for natural gas per year is based on the available consumption data, referring to the lower heat value (each year the quantities of natural gas imported or produced in Italy are published on https://sisen.mase.gov.it/dgsaie/ (MASE, several years).

Emissions of CO_2, expressed as kg carbon per ton of fuel, are based on the H/C and O/C ratios of the fuel. The increase in fuel consumption due to air conditioning use implies that extra CO_2 emissions in g/km are calculated as a function of temperature and relative humidity; nevertheless because of CO_2 emissions depend on total statistical fuel consumption, there is no impact on the CO_2 officially reported but instead on other pollutants.

Emissions of SO_2 are based on the sulphur content of the fuel, on the assumption that all the sulphur in the fuel is transformed completely into SO_2. As regards heavy metals (exhaust emissions of lead have been dropped because of the introduction of unleaded gasoline), apparent fuel metal contents (COPERT default) are used in the emissions calculation; for the non-exhaust share, values consider also of lubricant content and engine wear (EMEP/EEA, 2023).

Fuel consumption data derive basically from the national energy balance (MASE, several years [a]); supplementary information is taken from the Oil Bulletin (MASE, several years [b]). As regards biofuels, the consumption has increased in view of the targets to be respected by Italy and set in the framework of the European directive 20-20-20. The trend of biodiesel is explained by the fact that this biofuel has been tested from 1994 to 1996 before entering in production since 1998. Country specific values obtained for biodiesel in 2020 National survey have been used to update the entire fuel specifications historical series (previously, in the absence of country specific parameters, Eurostat Energy Balance parameters were used). The consumption of bioethanol has been introduced since 2008, according to data resulting in the energy balance. Values of the fuel-based emission factors for CO_2 from consumption of petrol and diesel fuels are shown in Table 3.21. These factors account for the fraction of carbon oxidised for liquid fuels equal to 1, as suggested by the 2006 IPCC guidelines (IPCC, 2006). From the nineties, different directives regulating the fuel quality in Europe have been implemented (Directive 93/12/EC, Directive 98/70/EC, Directive 2003/17/EC and Directive 2009/30/EC), in parallel with the evolution of vehicle fleet technologies; this resulted in remarkable differences in the characteristics of the fuels, including the content of carbon, hydrogen and oxygenates, parameters needed to derive the CO_2 emission factors.

The final reports on the physic-chemical characterization of fossil fuels used in Italy, carried out by the Fuel Experimental Station, that is an Italian Institute operating in the framework of the Department of Industry, are used, with the aim to improve fuel quality specifications. Fuel information is also updated based on the annual reports published by ISPRA about the fuel quality in Italy.

In consequence of the removal of CO_2 correction tool in COPERT model, previously aimed at CO_2 correction based on type approval CO_2 emission factors, referred to gasoline and diesel passenger cars from Euro 4 onwards. Country specific hot energy consumption factors have been applied (CNR STEMS, Innovhub SSI, 2020).

A specific survey was also conducted to characterize the national fuel used in 2000-2001.

Regarding 1990-1999, a study was carried out to evaluate the use of the default emission factors reported in the IPCC Guidelines 1996 in consideration of the available information on national fuels. Emission factors from the Guidelines have been considered representative for diesel and LPG while for gasoline a country specific emission factor has been calculated considering the IPCC default values and the specific energy content of the national fuels. For further details see the relevant paragraph in Annex 6.

Values for SO_2 vary annually as the sulphur-content of fuels change and are calculated every year for gasoline and gas oil and officially communicated to the European Commission in the framework of European Directives on fuel quality (ISPRA, several years); these figures are also published by the refinery's industrial association (UNEM, several years). The Directive 2003/17/EC introduced for 2005 new limit for S content in the fuels, both gasoline and diesel, 50% lower than the previous ones.

Table 3.20 Fuel-Based Emission Factors for Road Transport

National emission factors	Mg CO_2 /TJ	Mg CO_2/Mg
Mtbe	73.072	-
Gasoline, 1990-'99, interpolated emission factor	71.034	3.123
Gasoline, test data, 2000-2012[b, c]	71.864	3.143
Gasoline, test data, 2013-2019[c]	73.338	3.140
Gasoline, test data, since 2020[c]	73.081	3.152
Gas oil, 1990-'99, IPCC OECD[a]	73.274	3.129
Gas oil, engines, test data, 2000-2012[b,c]	73.892	3.171
Gas oil, engines, test data, 2013-2019[c]	73.648	3.151
Gas oil, engines, test data, since 2020[c]	73.510	3.150
LPG, 1990-'99, IPCC[a] Europe	64.350	3.000
LPG, test data, 2000-2019[b, c]	65.592	3.026
LPG, test data, since 2020[c]	65.984	3.026
Natural gas (dry) 1990	55.822	-
Natural gas (dry) 2022	58.918	-

a IPCC, 1997. Revised 1996 IPCC Guidelines for National GHG Inventories, Reference Manual, ch1, tables 1-36 to 1-42
b APAT, 2003
c Emission factor in kg carbon/ton, based on Fuel Experimental Station (Innovhub, several years)

Emissions of CO_2 and SO_2 can be broken down by vehicle type based on estimated fuel consumption factors and traffic data in a manner similar to the traffic-based emissions described below for other pollutants. The current inventory used fuel consumption factors expressed as grams of fuel per kilometer for each vehicle type and average speed calculated from the emission functions and speed-coefficients provided by the model COPERT 5 (EMISIA SA, 2024). Mileage and fuel consumptions calculated from COPERT functions are shown in Table 3.21 for each vehicle, fuel and road type in Italy in 2022.

Table 3.21 Average fuel consumption and mileage for main vehicle category and road type, year 2022

		Fuel Consumption (TJ)				Mileage (kveh_km)			
		Urban	Rural	Highway	TOTAL	Urban	Rural	Highway	TOTAL
Passenger Cars	Petrol	90,914	126,777	53,084	270,775	23,319,908	64,294,358	23,259,582	110,873,848
Passenger Cars	Petrol Hybrid	10,826	9,613	5,495	25,933	4,202,643	6,724,230	3,081,939	14,008,811
Passenger Cars	Petrol PHEV	1,840	1,530	1,055	4,425	724,429	1,159,087	531,248	2,414,764
Passenger Cars	Diesel	124,194	253,894	134,576	512,665	38,922,565	132,793,507	67,745,666	239,461,739
Passenger Cars	Diesel Hybrid	1,219	2,620	2,464	6,303	459,812	1,624,668	980,931	3,065,411
Passenger Cars	LPG Bifuel	25,564	27,026	17,816	70,405	7,049,867	13,943,655	7,087,475	28,080,997
Passenger Cars	CNG Bifuel	11,895	8,556	5,811	26,262	2,682,819	3,845,374	2,414,537	8,942,731
Passenger Cars	Battery Electric	220	437	307	964	408,294	653,271	299,416	1,360,981
						-	-	-	-
Light Commercial Vehicles	Petrol	1,930	1,793	635	4,358	330,846	727,861	264,677	1,323,384
Light Commercial Vehicles	Diesel	51,758	71,636	33,526	156,920	11,941,180	26,270,595	9,552,944	47,764,719
						-	-	-	-
Heavy Duty Trucks	Petrol	2	5	2	9	255	766	255	1,277
Heavy Duty Trucks	Diesel	33,387	68,870	169,221	271,478	2,561,277	8,210,860	19,224,468	29,996,605
						-	-	-	-
Buses	Diesel	11,516	9,133	23,775	44,424	783,083	943,796	2,937,955	4,664,834

		Fuel Consumption (TJ)				Mileage (kveh_km)			
		Urban	Rural	Highway	TOTAL	Urban	Rural	Highway	TOTAL
Buses	Diesel Hybrid	252	17	-	270	23,592	2,621	-	26,213
Buses	CNG	3,007	218	-	3,225	155,635	17,293	-	172,928
						-	-	-	-
Mopeds	Petrol	2,094	897	-	2,991	2,846,103	1,219,758	-	4,065,861
Motorcycles	Petrol	20,681	9,939	1,753	32,373	13,085,331	7,633,110	1,090,444	21,808,884

Source: ISPRA elaborations

Notes: Biodiesel included in diesel; bioethanol included in gasoline; biogas included in natural gas.

Biofuels used and fossil fuel fraction in biodiesel

In Italy, biodiesel, biogasoline and biogas are used in road transportation and the respective emissions have been estimated in the inventory. As regards biodiesel and biogasoline, almost all the commercial gasoline is practically still substantially an E0 (in 2022 the share of biogasoline is 0.4%, respect to the total road gasoline consumption), while the distributed diesel reaches up to 5-7% by volume of biodiesel in diesel fuel (in 2022 the share of biodiesel is 5.8%, respect to the total road diesel consumption). That is because Italian producers/refineries have decided since the beginning of the introduction of the obligations on biofuels to focus on biodiesel rather than on ethanol to comply with the European/Italian obligations to introduce biofuels on the market.

Biogasoline represents to date a minimum percentage out of the total gasoline including biogasoline consumption. According to the Renewable energy Directive (2009/28/EC) the amount of biogasoline reported in the Energy balance is equal to the renewable part of the fuel, calculated as 37% of the total volume placed on the market.

Biodiesel has been tested since 1994 to 1996 before entering in production since 1998.

CO_2 emissions from fossil fuel content of biofuels in Italy have been estimated by the implementation of the COPERT tool "fossil fuel fraction in biodiesel". In particular, the estimation is based on the country specific data regarding the share of FAME in biodiesel (equal to 90.1% in 2022), deriving from data and information reported by Italy under Council Directive (EU) 2015/652 laying down calculation methods and reporting requirements pursuant to Directive 98/70/EC of the European Parliament and of the Council relating to the quality of petrol and diesel fuels.

Moreover, biogas road consumption has been considered, representing about 26% of total road natural gas consumption in 2022. It is reported since 2020 in the IEA - Eurostat – UNECE Energy Questionnaire.

The fuel balance process

An automatic fuel balancing procedure is implemented in COPERT 5 to ensure that the breakdown of fuel consumption by each vehicle type calculated on the basis of the fuel consumption factors once added up matches the BEN figures for total fuel consumption in Italy (adjusted for off-road consumption).

This simulation is started up having the target to equalize calculated and statistical consumptions, separately for fuel, at national level, with the aim to obtain final estimates as accurate as possible. Once all data and input parameters have been inserted and all options have been set reflecting the peculiar situation of the Country, emissions and consumptions are calculated by the model in the detail of the vehicle category legislation standard; then the aggregated consumption values so calculated are compared with the input statistical national aggregated values (deriving basically from the National Energy Balance, as described above), with the aim to minimize the deviation.

Traffic-based emissions

Emissions of NMVOC, NO_X, CO, CH_4 and N_2O are calculated from emission factors expressed in grams per kilometer and road traffic statistics estimated by ISPRA on the basis of data released from: Ministry of Transport (MIT, several years), the Automobile Club of Italy (ACI, several years), the National Association of Cycle-Motorcycle Accessories (ANCMA, several years), the National Institute of Statistics (ISTAT, several years [b]), the National Association of concessionaries of motorways and tunnels (AISCAT, several years).

The emission factors are based on experimental measurements of emissions from in-service vehicles of different types driven under test cycles with different average speeds calculated from the emission functions and speed-coefficients provided by COPERT 5 (EMISIA SA, 2024). This source provides emission functions and coefficients relating emission factors (in g/km) to average speed for each vehicle type and Euro emission standard derived by fitting experimental measurements to polynomial functions. These functions were then used to calculate emission factor values for each vehicle type and Euro emission standard at each of the average speeds of the road and area types.

Country specific hot emission factors for Euro 6 Small and Medium LPG passenger cars, deriving from tests on five Euro 6 b/c bifuel LPG passenger cars (national survey carried out by Innovhub (Innovhub, 2018), are implemented in COPERT 5.

N_2O emission factors derive from the application of COPERT 5 v.5.7.3 model (EMISIA SA, 2024). Tier 3 is implemented, according to which N_2O is connected to the aftertreatment devices, such as catalytic converters and diesel particle filters. N_2O emissions are significant for catalyst vehicles, in particular when the catalyst is under partially oxidizing conditions, when the catalyst has not reached its light-off temperature yet or when the catalyst is aged. So N_2O emissions depend on the vehicle age or cumulative mileage. Moreover, aftertreatment ageing depends upon the fuel sulphur level. Hence, different emission factors are explained by the variation in fuel sulphur content and in the driving conditions (EMEP/EEA, 2023). COPERT model version 5.7.3 reports an emission factor equal to 0 for conventional LPG passenger cars, for conventional diesel passenger cars and light duty vehicles, while for the other vehicle categories, emission factors are available in the model. Because of those zero values, noticeable variations may appear between IEF referred to consecutive years where the fleet consists just of conventional vehicles and Euro 1 vehicles; such differences are then explained by the different share of Euro 1 vehicles out of the total. As regards newer vehicles, N_2O emissions may derive as a byproduct from SCR systems, this issue needs to be monitored to reveal how much this is could be a problem in real world conditions (EMEP/EEA, 2023).

The road traffic data used are vehicle kilometer estimates for the different vehicle types and different road classifications in the national road network. These data have to be further broken down by composition of each vehicle fleet in terms of the fraction of vehicles on the road powered by different fuels and in terms of the fraction of vehicles on the road relating to the different emission regulations which applied when the vehicle was first registered. These are related to the age profile of the vehicle fleet.

In brief, the emissions from motor vehicles fall into three different types calculated as hot exhaust emissions, cold-start emissions, and evaporative emissions for NMVOC; in addition, not exhaust emissions for PM, BC and heavy metals deriving from road vehicle tyre and brake wear and road abrasion are contemplated.

Hot exhaust emissions are emissions from the vehicle exhaust when the engine has warmed up to its normal operating temperature. Emissions depend on the type of vehicle, type of fuel the engine runs on, the driving profile of the vehicle on a journey and the emission regulations applied when the vehicle was first registered as this defines the type of technology the vehicle is equipped with.

For a particular vehicle, the drive cycle over a journey is the key factor which determines the amount of pollutant emitted.

Key parameters affecting emissions are acceleration, deceleration, steady speed and idling characteristics of the journey, as well as other factors affecting load on the engine such as road gradient and vehicle weight. However, studies have shown that for modelling vehicle emissions over a road network at national scale, it is sufficient to calculate emissions from emission factors in g/km related to the average speed of the vehicle in the drive cycle (EMISIA, 2024). Emission factors for average speeds on the road network are then combined with national road traffic data. Emissions are calculated from vehicles of the following types:

- Gasoline passenger cars
- Diesel passenger cars
- LPG passenger cars
- CNG passenger cars
- Petrol Hybrid passenger cars
- Petrol PHEV passenger cars
- Diesel Hybrid passenger cars
- Battery electric passenger cars
- Gasoline Light Commercial Vehicles (Gross Vehicle Weight (GVW) <= 3.5 tonnes)
- Diesel Light Commercial Vehicles (Gross Vehicle Weight (GVW) <= 3.5 tonnes)
- Rigid-axle Heavy Duty Trucks (GVW > 3.5 tonnes)
- Articulated Heavy Duty Trucks (GVW > 3.5 tonnes)
- Diesel Buses and coaches
- Diesel Hybrid Buses
- CNG Buses
- Mopeds and motorcycles.

Basic data derive from different sources. Detailed data on the national fleet composition are found in the yearly report from ACI (ACI, several years), used from 1990 to 2006, except for mopeds for which estimates have been elaborated based on National Association of Cycle-Motorcycle Accessories data on mopeds fleet composition and mileages (ANCMA, several years).

Specific fleet composition data were provided by the Ministry of Transport for all vehicle categories from 2007 onwards. The Ministry of Transport in the national transport yearbook (MIT, several years) reports mileages time series. Furthermore, since 2015 the Ministry of Transport supplies information on the distribution of old gasoline cars over the detailed vehicles categories (PRE ECE; ECE 15/00-01; ECE 15/02; ECE 15/03; ECE 15/04; information obtained from the registration year; data used for the updating of the time series since 2007).

Since 2014, the Ministry of Transport supplies updated information on the reallocation of not defined vehicles categories (data used for the updating of the time series since 2007). Ministry of Transport data have been used for: the passenger cars ("Petrol Hybrid" passenger cars category are introduced from 2007 onwards, the mini petrol (Gasoline < 0.8 l) passenger cars subsector is introduced since 2012 and diesel small (Diesel<1.4 l) subsector since 2007 onwards, in addition to the gasoline, diesel, LPG, CNG traditional ones); the diesel and gasoline light commercial vehicles; the breakdown of the heavy duty trucks, buses and coaches fleet according to the different weight classes and fuels (for HDT almost exclusively diesel, a negligible share consists of gasoline HDT vehicles; diesel for coaches; diesel, diesel hybrid and CNG for buses); the motorcycles fleet in the detail of subsector and legislation standard of both 2-stroke and 4-stroke categories.

Fleet values for urban buses have been updated according to the updating of the data on urban public buses, published on CNIT (MIT, several years). The National Institute of Statistics carries out annually a survey on heavy goods vehicles, including annual mileages (ISTAT, several years [b]). The National Association of concessionaries of motorways and tunnels produces monthly statistics on highway mileages by light and heavy vehicles (AISCAT, several years). The National General Confederation of

Transport and Logistics (CONFETRA, several years) and the national Central Committee of road transporters (Giordano, 2007) supplied useful information and statistics about heavy goods vehicles fleet composition and mileages.

In Tables 3.22, 3.23, 3.24 and 3.25 detailed data on the relevant vehicle mileages in the circulating fleet are reported, subdivided according to the main emission regulations.

Table 3.22 Passenger Cars technological evolution: circulating fleet calculated as stock data multiplied by effective mileage (%)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
a. Gasoline cars technological evolution										
PRE ECE, pre-1973	0.04	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
ECE 15/00-01, 1973-1978	0.10	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ECE 15/02-03, 1978-1984	0.30	0.15	0.03	0.01	0.01	0.01	0.01	0.01	0.00	0.00
ECE 15/04, 1985-1992	0.55	0.55	0.28	0.10	0.04	0.03	0.02	0.02	0.02	0.02
PC Euro 1 - 91/441/EEC, from 1/1/93	0.00	0.24	0.27	0.17	0.05	0.02	0.01	0.01	0.01	0.01
PC Euro 2 - 94/12/EEC, from 1/1/97	-	-	0.39	0.32	0.21	0.11	0.07	0.06	0.05	0.04
PC Euro 3 - 98/69/EC Stage2000, from 1/1/2001	-	-	-	0.31	0.20	0.15	0.09	0.08	0.07	0.07
PC Euro 4 - 98/69/EC Stage2005, from 1/1/2006	-	-	-	0.09	0.44	0.41	0.28	0.27	0.25	0.24
PC Euro 5 - EC 715/2007, from 1/1/2011	-	-	-	-	0.04	0.21	0.18	0.17	0.17	0.17
PC Euro 6 (Since EC 715/2007, from 9/1/2015)										
- Euro 6 a/b/c	-	-	-	-	-	0.06	0.25	0.24	0.23	0.23
- Euro 6 d-temp (2019 - 2020)	-	-	-	-	-	-	0.09	0.14	0.14	0.13
- Euro 6 d (since 2021)	-	-	-	-	-	-	-	-	0.05	0.09
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1990	**1995**	**2000**	**2005**	**2010**	**2015**	**2019**	**2020**	**2021**	**2022**
b. Diesel cars technological evolution										
Conventional, pre-1993	1.00	0.92	0.35	0.06	0.01	0.00	0.00	0.00	0.00	0.00
PC Euro 1 - 91/441/EEC, from 1/1/93	-	0.08	0.10	0.03	0.01	0.00	0.00	0.00	0.00	0.00
PC Euro 2 - 94/12/EEC, from 1/1/97	-	-	0.55	0.22	0.05	0.02	0.01	0.01	0.01	0.01
PC Euro 3 - 98/69/EC Stage2000, from 1/1/2001	-	-	-	0.57	0.31	0.16	0.08	0.08	0.06	0.07
PC Euro 4 - 98/69/EC Stage2005, from 1/1/2006	-	-	-	0.12	0.55	0.43	0.28	0.26	0.21	0.24
PC Euro 5 - EC 715/2007, from 1/1/2011	-	-	-	-	0.07	0.35	0.28	0.27	0.28	0.27
PC Euro 6 (Since EC 715/2007, from 9/1/2015)										
- Euro 6 a/b/c	-	-	-	-	0.00	0.05	0.28	0.28	0.29	0.27
- Euro 6 d-temp (2019 - 2020)	-	-	-	-	-	-	0.06	0.10	0.11	0.10
- Euro 6 d (since 2021)	-	-	-	-	-	-	-	-	0.03	0.05
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1990	**1995**	**2000**	**2005**	**2010**	**2015**	**2019**	**2020**	**2021**	**2022**
c. Lpg cars technological evolution										
Conventional, pre-1993	1.00	0.90	0.71	0.47	0.04	0.01	0.01	0.01	0.01	0.01
PC Euro 1 - 91/441/EEC, from 1/1/93	-	0.10	0.20	0.26	0.02	0.01	0.00	0.00	0.00	0.00
PC Euro 2 - 94/12/EEC, from 1/1/97	-	-	0.09	0.19	0.08	0.03	0.02	0.01	0.01	0.01
PC Euro 3 - 98/69/EC Stage2000, from 1/1/2001	-	-	-	0.06	0.08	0.05	0.03	0.02	0.02	0.02

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
PC Euro 4 - 98/69/EC Stage2005, from 1/1/2006	-	-	-	0.01	0.75	0.46	0.31	0.29	0.26	0.24
PC Euro 5 - EC 715/2007, from 1/1/2011	-	-	-	-	0.03	0.36	0.28	0.26	0.25	0.24
PC Euro 6 (Since EC 715/2007, from 9/1/2015)										
- Euro 6 a/b/c	-	-	-	-	-	0.08	0.13	0.13	0.12	0.12
- Euro 6 d-temp (2017-2019)	-	-	-	-	-	-	0.23	0.22	0.21	0.21
- Euro 6 d (2020 and later)	-	-	-	-	-	-	-	0.05	0.10	0.15
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1990	**1995**	**2000**	**2005**	**2010**	**2015**	**2019**	**2020**	**2021**	**2022**
d. CNG cars technological evolution										
PC Conventional - Euro 4	1.00	1.00	1.00	1.00	0.91	0.58	0.44	0.42	0.39	0.37
PC Euro 5 - EC 715/2007, from 1/1/2011	-	-	-	-	0.09	0.32	0.29	0.29	0.28	0.28
PC Euro 6 (Since EC 715/2007, from 9/1/2015)										
- Euro 6 a/b/c	-	-	-	-	-	0.10	0.14	0.14	0.13	0.14
- Euro 6 d-temp (2017-2019)	-	-	-	-	-	-	0.13	0.12	0.12	0.12
- Euro 6 d (2020 and later)	-	-	-	-	-	-	-	0.04	0.07	0.09
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		2007	**2008**	**2009**	**2010**	**2015**	**2019**	**2020**	**2021**	**2022**
e. Hybrid Gasoline cars technological evolution (from 2007 onwards)										
PC Euro 4 - 98/69/EC Stage2005, from 1/1/2006		1.00	1.00	0.65	0.54	0.11	0.02	0.01	0.01	0.00
PC Euro 5 - EC 715/2007, from 1/1/2011		-	-	0.35	0.46	0.74	0.12	0.07	0.04	0.03
PC Euro 6 (Since EC 715/2007, from 9/1/2015)										
- Euro 6 a/b/c		-	-	-	-	0.15	0.16	0.09	0.05	0.03
- Euro 6 d-temp (2017-2019)		-	-	-	-	-	0.71	0.44	0.24	0.16
- Euro 6 d (2020 and later)		-	-	-	-	-	-	0.38	0.66	0.77
Total		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
				2013	**2014**	**2015**	**2019**	**2020**	**2021**	**2022**
f. Petrol PHEV cars technological evolution (from 2013 onwards)										
- Euro 6 a/b/c				1.00	1.00	1.00	0.14	0.08	0.05	0.03
- Euro 6 d-temp (2017-2019)				-	-	-	0.86	0.41	0.24	0.16
- Euro 6 d (2020 and later)				-	-	-	-	0.50	0.71	0.81
Total				1.00	1.00	1.00	1.00	1.00	1.00	1.00
		2007	**2008**	**2009**	**2010**	**2015**	**2019**	**2020**	**2021**	**2022**
g. Hybrid Diesel cars technological evolution (from 2007 onwards)										
PC Euro 6 (Since EC 715/2007, from 9/1/2015)										
- Euro 6 a/b/c		1.00	1.00	1.00	1.00	1.00	0.11	0.04	0.02	0.01
- Euro 6 d-temp (2017-2019)		-	-	-	-	-	0.89	0.37	0.17	0.11
- Euro 6 d (2020 and later)		-	-	-	-	-	-	0.59	0.81	0.88
Total		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Source: ISPRA elaborations on ACI and Ministry of Transport data

Table 3.23 Light Duty Vehicles technological evolution: circulating fleet calculated as stock data multiplied by effective mileage (%)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
a. Gasoline Light Commercial Vehicles technological evolution										
Conventional, pre 10/1/94	1.00	0.93	0.63	0.35	0.08	0.05	0.03	0.03	0.03	0.03
LCV Euro 1 - 93/59/EEC, from 10/1/94	-	0.07	0.21	0.17	0.10	0.05	0.02	0.02	0.02	0.02
LCV Euro 2 - 96/69/EEC, from 10/1/98	-	-	0.16	0.15	0.30	0.17	0.06	0.05	0.04	0.04
LCV Euro 3 - 98/69/EC Stage2000, from 1/1/2002	-	-	-	0.31	0.26	0.20	0.11	0.10	0.07	0.08
LCV Euro 4 - 98/69/EC Stage2005, from 1/1/2007	-	-	-	0.01	0.25	0.31	0.24	0.23	0.20	0.17
LCV Euro 5 - 2008 Standards 715/2007/EC, from 1/1/2012	-	-	-	-	0.00	0.21	0.17	0.16	0.15	0.13
LCV Euro 6 (Since 2007/715/EC, from 9/1/2016)										
- Euro 6 a/b/c	-	-	-	-	-	0.02	0.11	0.10	0.09	0.08
- Euro 6 d-temp (2018 - 2020)	-	-	-	-	-	-	0.25	0.30	0.31	0.26
- Euro 6 d (since 2021)	-	-	-	-	-	-	-	-	0.09	0.20
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1990	**1995**	**2000**	**2005**	**2010**	**2015**	**2019**	**2020**	**2021**	**2022**
b. Diesel Light Commercial Vehicles technological evolution										
Conventional, pre 10/1/94	1.00	0.92	0.54	0.23	0.07	0.03	0.01	0.01	0.01	0.01
LCV Euro 1 - 93/59/EEC, from 10/1/94	-	0.08	0.22	0.11	0.05	0.03	0.01	0.01	0.00	0.00
LCV Euro 2 - 96/69/EEC, from 10/1/98	-	-	0.24	0.20	0.18	0.09	0.02	0.01	0.01	0.01
LCV Euro 3 - 98/69/EC Stage2000, from 1/1/2002	-	-	-	0.45	0.34	0.22	0.06	0.05	0.05	0.04
LCV Euro 4 - 98/69/EC Stage2005, from 1/1/2007	-	-	-	0.01	0.34	0.33	0.19	0.18	0.18	0.16
LCV Euro 5 - 2008 Standards 715/2007/EC, from 1/1/2012	-	-	-	-	0.01	0.30	0.32	0.29	0.26	0.24
LCV Euro 6 (Since 2007/715/EC, from 9/1/2016)										
- Euro 6 a/b/c	-	-	-	-	0.00	0.01	0.17	0.16	0.14	0.13
- Euro 6 d-temp (2018 - 2020)	-	-	-	-	-	-	0.22	0.29	0.26	0.25
- Euro 6 d (since 2021)	-	-	-	-	-	-	-	-	0.09	0.16
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Source: ISPRA elaborations on ACI and Ministry of Transport data

Table 3.24 Heavy Duty Trucks and Buses technological evolution: circulating fleet calculated as stock data multiplied by effective mileage (%)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
a. Heavy Duty Trucks technological evolution										
Conventional, pre 10/1/93	1.00	0.90	0.68	0.39	0.20	0.02	0.02	0.01	0.01	0.01
HDT Euro I - 91/542/EEC Stage I, from 10/1/93	-	0.10	0.10	0.06	0.04	0.01	0.01	0.00	0.00	0.00
HDT Euro II - 91/542/EEC Stage II, from 10/1/96	-	-	0.22	0.27	0.15	0.08	0.05	0.04	0.04	0.04
HDT Euro III - 2000 Standards, 99/96/EC, from 10/1/2001	-	-	-	0.27	0.36	0.34	0.23	0.20	0.18	0.17
HDT Euro IV - 2005 Standards, 99/96/EC, from 10/1/2006	-	-	-	-	0.07	0.09	0.07	0.07	0.06	0.06
HDT Euro V - 2008 Standards, 99/96/EC, from 10/1/2009	-	-	-	-	0.18	0.39	0.33	0.32	0.30	0.28
HDT Euro VI (Since 2009/595/EC, from 12/31/2013)										
- Euro VI A/B/C	-	-	-	-	-	0.07	0.24	0.24	0.22	0.21
- Euro VI D/E (2019 and later)	-	-	-	-	-	-	0.06	0.12	0.18	0.24

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
b. Diesel Buses technological evolution										
	1990	**1995**	**2000**	**2005**	**2010**	**2015**	**2019**	**2020**	**2021**	**2022**
Conventional, pre 10/1/93	1.00	0.93	0.65	0.34	0.13	0.01	0.00	0.00	0.00	0.00
Buses Euro I - 91/542/EEC Stage I, from 10/1/93	-	0.07	0.07	0.08	0.04	0.01	0.00	0.01	0.00	0.00
Buses Euro II - 91/542/EEC Stage II, from 10/1/96	-	-	0.28	0.32	0.27	0.14	0.09	0.07	0.06	0.05
Buses Euro III - 2000 Standards, 99/96/EC, from 10/1/2001	-	-	-	0.26	0.34	0.38	0.25	0.26	0.21	0.20
Buses Euro IV - 2005 Standards, 99/96/EC, from 10/1/2006	-	-	-	-	0.12	0.13	0.11	0.11	0.10	0.09
Buses Euro V - 2008 Standards, 99/96/EC, from 10/1/2009	-	-	-	-	0.11	0.28	0.26	0.25	0.26	0.26
Buses Euro VI (Since 2009/595/EC, from 12/31/2013)	-	-	-	-	-	0.05	0.21	0.20	0.21	0.20
- Euro VI A/B/C	-	-	-	-	-	-	0.06	0.10	0.15	0.19
- Euro VI D/E (2019 and later)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
c. CNG Buses technological evolution										
	1990	**1995**	**2000**	**2005**	**2010**	**2015**	**2019**	**2020**	**2021**	**2022**
Urban CNG Buses Conventional, pre 10/1/93; Urban CNG Buses Euro I - 91/542/EEC Stage I, from 10/1/93	1.00	1.00	0.11	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Urban CNG Buses Euro II - 91/542/EEC Stage II, from 10/1/96	-	-	0.89	0.20	0.10	0.05	0.03	0.02	0.01	0.01
Urban CNG Buses Euro III - 2000 Standards, 99/96/EC, from 10/1/2001; Urban CNG Buses Euro IV - 2005 Standards, 99/96/EC, from 10/1/2006	-	-	-	0.79	0.09	0.07	0.06	0.05	0.04	0.04
Euro V - 2008 Standards, 99/96/EC, from 10/1/2009; EEV (Enhanced environmentally friendly vehicle; ref. 2001/27/EC and 1999/96/EC line C, optional limit emission values); Urban CNG Buses Euro VI – EC 595/2009, from 12/31/2013	-	-	-	-	0.81	0.88	0.91	0.93	0.94	0.95
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
d. Diesel Hybrid Buses technological evolution (from 2007 onwards)										
		2007	**2008**	**2009**	**2010**	**2015**	**2019**	**2020**	**2021**	**2022**
Buses Euro VI (Since 2009/595/EC, from 12/31/2013)										
- Euro VI A/B/C		1.00	1.00	1.00	1.00	1.00	0.21	0.16	0.10	0.08
- Euro VI D/E		-	-	-	-	-	0.79	0.84	0.90	0.92
Total		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Source: ISPRA elaborations on ACI and Ministry of Transport data

Table 3.25 Mopeds and motorcycles technological evolution: circulating fleet calculated as stock data multiplied by effective mileage (%)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Mopeds and motorcycles – Conventional	1.00	1.00	0.88	0.43	0.18	0.12	0.11	0.09	0.09	0.09
Mopeds and motorcycles - Euro 1	-	-	0.12	0.30	0.20	0.14	0.11	0.10	0.09	0.09
Mopeds and motorcycles - Euro 2	-	-	-	0.22	0.35	0.32	0.23	0.22	0.20	0.19
Mopeds and motorcycles - Euro 3	-	-	-	0.04	0.27	0.41	0.41	0.40	0.38	0.36
Mopeds and motorcycles - Euro 4	-	-	-	-	-	-	0.14	0.18	0.18	0.17
Mopeds and motorcycles - Euro 5	-	-	-	-	-	-	0.00	0.01	0.05	0.10
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Source: ISPRA elaborations on ACI, ANCMA and Ministry of Transport data

Average emission factors are calculated for average speeds by three driving modes: urban, rural and motorway, combined with the vehicle kilometres travelled and vehicle categories. ISPRA estimates total annual vehicle kilometres for the road network in Italy by vehicle type, see Table 3.26, based on data from various sources:

- Ministry of Transport (several years) for rural roads and on other motorways; the latter estimates are based on traffic counts from the rotating census and core census surveys of ANAS (ANAS, several years);
- highway industrial association for fee-motorway (AISCAT, several years);
- local authorities for built-up areas (urban).

Table 3.26 Evolution of fleet consistency and mileage

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
All passenger vehicles (including moto), total mileage (10^9 veh-km/y)	350	412	454	453	447	443	442	341	422	439
Car fleet (10^6)	27	30	32	34	36	37	40	40	40	40
Moto, total mileage (10^9 veh-km/y)	30	41	42	42	34	32	26	24	25	26
Moto fleet (10^6)	7	7	9	9	9	10	10	10	10	10.
Goods transport, total mileage (10^9 veh-km/y)	69	76	81	104	85	70	65	63	72	79
Truck fleet (10^6), including LDV	2	3	3	4	5	5	5	5	5	5

Source: ISPRA elaborations

Notes: The passenger vehicles include passenger cars, buses and moto; the moto fleet includes mopeds and motorcycles; in the goods transport light commercial vehicles and heavy duty trucks are included.

When a vehicle engine is cold, it emits at a higher rate than when it has warmed up to its designed operating temperature. This is particularly true for gasoline engines and the effect is even more severe for cars fitted with three-way catalysts, as the catalyst does not function properly until the catalyst is also warmed up. Emission factors have been derived for cars and LCVs from tests performed with the engine starting cold and warmed up. The difference between the two measurements can be regarded as an additional cold-start penalty paid on each trip a vehicle is started with the engine (and catalyst) cold.

Evaporative emissions of gasoline fuel vapour from the tank and fuel delivery system in vehicles constitute a significant fraction of total NMVOC and methane emissions from road transport. Nevertheless, the contribution of evaporative emissions to total NMVOC emissions decreased significantly since the introduction of carbon canisters. Breathing losses through the tank vent and fuel permeations and leakages are considered the most important sources of evaporative emissions. The estimation of evaporative emissions considers three different mechanisms: diurnal emissions (depending on daily temperature variations), running losses (during the vehicles use) and hot soak emissions (following the vehicles use). The process of fuelling of vehicles is not considered here. The procedure for estimating evaporative emissions of NMVOCs takes account of gasoline volatility, the absolute ambient temperature and temperature changes, the characteristics of vehicles design; the driving pattern is also significant for hot soak emissions and running losses (EMEP/EEA, 2023).

3.5.2.3 Uncertainty and time-series consistency

The combined uncertainty in CO_2 emissions from road transport is estimated to be about 4% in annual emissions; a higher uncertainty is calculated for CH_4 and N_2O emissions because of the uncertainty levels attributed to the related emission factors.

The following Table 3.27 summarizes the time series of GHG emissions in CO_2 equivalent from road transport, highlighting the evolution of this source, characterized by an upward trend in CO_2 emission levels from 1990 to 2007, which is explained by the increasing of the fleet, total mileages, and fuel consumptions and by a decreasing trend from 2007 onwards, due, on one side, to the economic crisis, and on another side, to the propagation of the number of vehicles with low fuel consumption per kilometre. In subsequent years, with respect to 2007, a reduction in total mileages, fuel consumptions (gasoline and diesel) and consequently CO_2 emissions has been noted. Since 2017 emissions increase until 2019. Then from 2019 to 2020 there has been a sharp reduction in emissions, amounting to approximately -19.4% as a result of the pandemic crisis. Then from 2020 to 2021 a recovery of about +21.6%. Finally, during last year 2021 – 2022 GHG emissions increase of about 5.1%.

CH_4 and N_2O emission trends are consequence of the penetration of new technologies according to the main emission regulations. Specifically, CH_4 and more in general VOC emissions have reduced along the time series due to the introduction of VOC abatement devices on vehicles, in agreement with the legislation emission limits, and the rate of penetration of the new vehicles into the national fleet. The time series of N_2O emissions and implied emission factors are prevalently driven by the fleet composition and the penetration rate of the new vehicles/technologies. Moreover, in the COPERT model, N_2O emission factors depend also on the sulphur content of the fuel. Significant drops of emissions and implied emission factors are observed in 1999-2000 and in 2004-2005 which are explained by the different fuel specifications in those years due to the application of the relevant European Directives on fuel quality. The sulphur content (%wt) in gasoline was 0.04 and 0.007 respectively in 1999 and 2000, 0.0055 and 0.0025 respectively in 2004 and 2005, 0.0012 and 0.0005 in 2008 and 2009 and for diesel oil changed from 0.0226 in 2004 to 0.0035 in 2005 and from 0.0028 in 2008 to 0.0008 in 2009.

Table 3.27 GHG emissions from road transport (kt CO_2 equivalent)

		1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
CO_2	Gg	92,331.7	103,532.1	111,523.9	117,111.9	104,656.9	98,348.2	96,607.7	77,836.2	94,635.0	99,435.4
CH_4	Gg CO_2 eq	969.1	1,090.1	814.6	521.5	294.1	219.3	188.5	151.2	168.9	175.8
N_2O	Gg CO_2 eq	745.3	1,433.9	1,336.6	914.4	852.4	826.0	823.2	676.4	823.4	849.6
Total	Gg CO_2 eq	94,046.1	106,056.2	113,675.0	118,547.7	105,803.4	99,393.5	97,619.4	78,663.8	95,627.2	100,460.7

Source: ISPRA elaborations

3.5.2.4 Source-specific QA/QC and verification

Data used for estimating emissions from the road transport sector derive from different sources, including official statistics providers and industrial associations. A specific procedure undertaken for improving the inventory in the sector regards the establishment of a national expert panel in road transport which involves, on a voluntary basis, different institutions, local agencies and industrial associations cooperating for improving activity data and emission factors accuracy. In this group, emission estimates are presented annually, and new methodologies are shared and discussed. Reports and data of the meetings can be found at the following address: http://groupware.sinanet.isprambiente.it/expert_panel/library. 2023 meeting has been held in Livorno (https://www.snpambiente.it/snpa/arpa-lombardia/expert-panel-for-polluting-emissions-reduction/).
In addition, road transport emission factors are shared and publicly available on the website https://fetransp.isprambiente.it/#/.

Besides, time series resulting from the recalculation due to the application of COPERT have been discussed over time with national experts in the framework of an ad hoc working group on air emissions inventories.

The group is chaired by ISPRA and includes participants from the local authorities responsible for the preparation of local inventories, sectoral experts, the Ministry of Environment, and air quality model experts. Recalculations are comparable with those resulting from application of the model at local level. Top-down and bottom-up approaches have been compared with the aim to identify the major problems and future possible improvements in the methodology to be addressed (emission estimates at the link: https://emissioni.sina.isprambiente.it/inventario-nazionale/).

3.5.2.5 Source-specific recalculations

The annual update of the emissions time series from road transport implies a periodic review process.

In 2024 submission, the historical series has been revised mainly as a result of the upgrade of COPERT model version used (from version 5.6.1 in last submission to 5.7.3 in submission 2024), which resulted in various methodological updates.
Emission factors of Euro 6 CNG passenger cars, Euro VI diesel buses, Euro VI diesel hybrid buses, non-exhaust emission factors have been updated.
As regards the software, revisions relate: the removal of CO2 correction tool, capability of alternative HDVs classification based on REG EU 2017/2400, improved labels of forms and headers.

Furthermore various bugs have been corrected regarding: the correction of the calculation for cold emissions of CO, NO_X, VOC for petrol and diesel PCs and LCVs, the correction of cold start ratio of diesel Euro 6 cars for NO_X and CO, the correction of cold start ratio of petrol-fueled cars and vans for VOC and CO, the correction of cold emissions of Euro 6 CNG passenger cars for SPN23, the correction of bug when importing stock of HDVs in VECTO groups from excel to COPERT. Software update issues and minor corrections have been also implemented.

Country specific emission factors for Euro 6 LPG passenger cars, deriving from Innovhub survey, until 2022 submission inserted in the model as user values, are now implemented in COPERT model.

N_2O emission factors for urban CNG buses have been introduced in COPERT model version 5.7.3, respect to the version 5.6.1 applied in last submission.

In consequence of the removal of CO_2 correction tool in COPERT model, previously referred to gasoline and diesel passenger cars from Euro 4 onwards, Country specific hot energy consumption factors have been applied (CNR STEMS, Innovhub SSI, 2020).

Italian road vehicles electricity consumption data derive from Eurostat database (https://ec.europa.eu/eurostat/data/database). COPERT input road electricity consumption data have been calibrated on the basis of the vehicles categories using electricity actually included in COPERT classification. In 2024 submission, updated electricity consumption factors have been applied, deriving from Appendix 4 of the 2023 EMEP/EEA air pollutant emission inventory guidebook, resulting in a different balance of mileage and in a revision of estimated electricity consumption since 2007, respect to previous submission.

Revisions affected also the annual balances and, as a consequence, adjustments of mileages were applied in the historical series.

Natural gas estimates have been revised since 2021 according to the revision of road consumption data reported in the National Energy Balance and of parameters applied for the estimation of emissions from this fuel for the whole Inventory. In particular, in the National Energy Balance, road natural gas final consumption has been revised for 2021 respect to last submission; moreover, because of additional data availability for natural gas, density data for 2021 and H:C ratio since 2019 have been also updated.

Biogas road consumption, included in COPERT model in the total road natural gas consumption, has been considered in the Inventory, reported only since 2020 in the IEA - Eurostat – UNECE Energy Questionnaire (about 11%, 15% and 26% of total road natural gas consumption in 2020, 2021 and 2022 respectively).

A revision of the road transport natural gas national consumption data, published on the IEA Eurostat UNECE Energy Questionnaire, affected the years 2021 and 2022. In particular, natural gas consumption data increased for 2021 and 2022. The revisions affect the estimates related to the fleet categories CNG passenger cars and CNG urban buses. The resulting final revision with respect to the 2023 submission for the natural gas road consumption data in 2021 was a decrease of about -17.0%.

Estimate of the mopeds circulating fleet in 2021 has been revised consistently with 2022 data supplied by the Ministry of Transport.

Mileage balance has been also revised in consequence of a revision of transport statistics data published by the Ministry of Transport regarding: the circulating urban buses fleet and the passengers-km since 2020; the tons-km as regards freight transport since 2021. In particular, the most recent estimate of total on road freight transport data published for 2021, has been revised upwards from the Ministry of Transport respect to last submission and the estimate for 2022 results further higher, being the highest value than in last decade.

According to the 2006 IPCC Guidelines, emission estimates from lubricants have been reported under IPPU except lubricants used in two stroke engines in road transport; so, CO_2 emissions from lubricants have been detailed and attributed just to the two stroke engines in road transport ("1.A.3.b.iv, Other liquid fuels"), calculated by COPERT model, while the remaining share has been considered in the IPPU sector.

Differences between 2024 and previous submission, for road transport GHG emissions, account for 0.00% in 1990 and -0.38% in 2021; the recalculations registered for the driver carbon dioxide values are 0.00% in 1990 and -0.38% in 2021; as regards methane, discrepancies vary from -0.22% in 1990 to -14.20% in 2021; emissions of nitrous oxide show variations of 0.00% in 1990 and +3.42% in 2021. In Table 3.28 the recalculation time series is reported for all gases.

Table 3.28 Emission recalculations in road transport 1990 - 2021 (%)

Year	GHG	CO_2	CH_4	N_2O
1990	0.00%	0.00%	-0.22%	0.00%
1991	0.00%	0.00%	-0.22%	0.00%
1992	0.00%	0.00%	-0.20%	0.00%
1993	0.00%	0.00%	-0.20%	0.00%
1994	0.00%	0.00%	-0.20%	0.00%
1995	0.00%	0.00%	-0.24%	0.00%
1996	0.00%	0.00%	-0.27%	0.00%
1997	0.00%	0.00%	-0.28%	0.00%
1998	0.00%	0.00%	-0.30%	0.00%
1999	0.00%	0.00%	-0.30%	0.00%
2000	0.01%	0.00%	-0.35%	0.97%
2001	0.00%	0.00%	-0.50%	0.03%
2002	0.00%	0.00%	-0.53%	0.05%
2003	0.00%	0.00%	-0.56%	0.08%
2004	0.00%	0.00%	-0.64%	0.11%
2005	0.00%	0.00%	-0.87%	0.30%
2006	-0.01%	0.00%	-2.50%	-0.10%
2007	-0.01%	0.00%	-3.25%	0.57%
2008	-0.01%	0.00%	-4.03%	0.97%
2009	0.00%	0.00%	-5.16%	2.00%
2010	-0.01%	0.00%	-5.77%	1.58%
2011	0.00%	0.00%	-5.96%	1.95%
2012	0.00%	0.00%	-6.21%	2.23%
2013	0.00%	0.00%	-7.01%	2.85%
2014	0.02%	0.00%	-5.77%	4.08%

Year	GHG	CO_2	CH_4	N_2O
2015	0.02%	0.00%	-5.89%	4.28%
2016	0.01%	0.00%	-8.42%	3.58%
2017	0.00%	0.00%	-8.95%	3.13%
2018	0.00%	0.00%	-9.21%	2.60%
2019	0.01%	0.00%	-9.72%	2.95%
2020	0.00%	0.00%	-11.40%	3.38%
2021	-0.38%	-0.38%	-14.20%	3.42%

3.5.2.6 Source-specific planned improvements

Improvements for the next submission will be connected to the possible new availability of data and information regarding activity data, calculation factors and parameters, new developments of the methodology and the update of the software.

3.5.3 Railways

The electricity used by the railways for electric traction is supplied by the public distribution system, so the emissions arising from its generation are reported under category 1.A.1.a Public Electricity.

Emissions from diesel trains are reported under the category 1.A.3.c Railways. Estimates are based on the gasoil consumption for railways reported in BEN (MASE, several years [a]), and on the methodology Tier1, and emission factors from the EMEP/EEA Emission Inventory Guidebook 2023 (EMEP/EEA, 2023).

As regards the use of lubricants in diesel locomotives in railways, emission estimates from lubricants are reported under IPPU, except for lubricants related to the use in two stroke engines in road transport which are under the energy sector.

Fuel consumption data are collected by the Ministry of Economic Development, responsible for the energy balance, from the companies with diesel railways. The activity is present only in those areas without electrified railways, which are limited in the national territory. The trend reflects the decrease in the use of these railways. Because of low values, emissions from railways do not represent a key category.

Carbon dioxide and sulphur dioxide emissions are calculated on fuel-based emission factors using fuel consumption data from the energy balance. The CO_2 emission factors for diesel fuel derive from ad hoc studies about the properties of transportation fuels sold in Italy, performed by ISPRA since the nineties, and whose results are representative and applicable with reference to three different time phases: 1990 – 1999; 2000 – 2011; 2012 – 2019; since 2020 (Innovhub, several years).

Values for SO_2 vary annually according to the variation of the Sulphur-content of fuels produced, imported and commercialized, and it is yearly monitored according to legislative constraints; moreover, it is officially communicated to the European Commission in the framework of European Directives on fuel quality (ISPRA, several years). Emissions of CO, NMVOC, NO_x, N_2O and methane are based on the EMEP/EEA methodology (EMEP/EEA, 2023) considering the implementation of the relevant European Directives to reduce atmospheric pollutants. The emission factors shown in Table 3.29 are aggregate factors so that all factors are reported on the common basis of fuel consumption.

Table 3.29 Emission factors for railway in 2022 (kg/t)

	CO_2	CH_4	N_2O	NO_x *kg/t*	CO	NMVOC	SO_2
Diesel trains	3,140	0.18	1.24	52.4	10.7	4.65	0.015

Source: EMEP/EEA,2023; IPCC, 2006

GHG emissions from railways accounted in 2022 for about 0.04% of the total transport sector emissions. No recalculation occurred in this submission. No specific improvements are planned for the next submission.

3.5.4 Navigation

3.5.4.1 Source category description

This source category includes all emissions from fuels delivered to water-borne navigation. Mainly CO_2 emissions derive from this category, whereas CH_4 and N_2O emissions are less important. Emissions from navigation constituted 5.3% of the total GHG in the transport sector in 2022 and about 1.4% of the national total (considering CO_2 only, the share of emissions from navigation out of the total is almost the same). GHG emissions increased by 4.2% from 1990 to 2022, after a temporary drop in emissions in 2021. GHGs emissions from national navigation are 25.8% higher in 2022 than in the year 2021. CO_2 from waterborne navigation is key category both in 1990 and 2022, in level (Tier 1) with and without LULUCF and in trend (Tier 1) with and without LULUCF.

3.5.4.2 Methodological issues

Emissions of the Italian inventory from the navigation sector are carried out according to the IPCC Guidelines (IPCC 2006) and the EMEP/EEA Guidebook (EMEP/EEA, 2023). A national methodology has been developed following the EMEP/EEA Guidebook which provides details to estimate emissions from domestic navigation, specifying recreational craft and inland waterways, ocean-going ships by cruise and harbour activities; emissions from international navigation are also estimated and included as memo item (EMEP/EEA, 2023). Inland, coastal, and deep-sea fishing are estimated and reported under 1.A.4.c. International inland waterways do not occur in Italy.

The methodology developed to estimate emissions is based on the following assumptions and information.

Activity data comprise both fuel consumptions and ship movements, which are available in different level of aggregation and derive from different sources as specified here below:

- Total deliveries of fuel oil, gas oil and marine diesel oil to marine transport are given in national energy balance (MASE, several years (a)) but the split between domestic and international is not provided;
- Naval fuel consumption for inland waterways, ferries connecting mainland to islands and leisure boats, is also reported in the national energy balance as it is the fuel for shipping (MASE, several years (a));
- Data on annual arrivals and departures of domestic and international shipping calling at Italian harbours are reported by the National Institute of Statistics in the statistics yearbooks (ISTAT, several years (a)) and Ministry of Transport in the national transport statistics yearbooks (MIT, several years).

As for emission and consumption factors, figures are derived from national studies.

The first study assessed detailed information on the Italian marine fleet and the origin-destination movement matrix for the year 1997, and calculated national average values, both for recreational and harbour activities and national cruise, considering specificities of national harbours including typical times for manoeuvring and time spent in the harbour as well as the distribution of ships in terms of ferries, container ships, cargo (ANPA, 2001). On the basis of this information and the default emission and consumption factors reported in the EMEP/CORINAIR guidebook (EMEP/CORINAIR, 2007), national average figures were estimated for harbour and cruise activities both for domestic and international shipping from 1990 to 1999.

The study was repeated for the years 2004, 2005 and 2006 to consider more recent trends in the maritime sector both in terms of modelling between domestic and international consumption and improvements of operational activities in harbour (TECHNE, 2009). Based on the results, national average emissions and consumption factors were updated and applied from 2000.

Specifically, for the years referred to in the surveys, the current method estimates emissions from the number of ships movements broken down by ship type at each of the principal Italian ports considering the information of whether the ship movement is international or domestic, the average tonnage and the relevant distance travelled. For those years, in fact, figures on the number of arrivals, destination, and fleet composition were provided by the local port authorities and by the National Institute of Statistics, covering about 90% of the official national statistics on ship movements. Consumption and emission factors are those derived from the EMEP/CORINAIR guidebook (EMEP/CORINAIR, 2007) and refer to the Tier 3 ship movement methodology that takes into account origin-destination ship movements matrices as well as technical information on the ships, as engine size, gross tonnage of ships and operational times in harbours. Based on sample information, estimates have been carried out at national level for the relevant years considering the official statistics of the maritime sector.

Moreover, a recent study has been conducted in some Italian ports, which allows to update emission factors in ports, where hoteling emission factors have been updated from year 2008 (ISPRA, 2023).

In general, to carry out national estimates of greenhouse gases and other pollutants in the Italian inventory for harbour and domestic cruise activities, consumptions and emissions are calculated for the complete time series using the average consumption and emission factors multiplied by the total number of movements. On the other hand, for international cruise, consumption is derived by difference from the total fuel consumption reported in the national energy balance and the estimated values as described above and emissions are therefore calculated.

The composition of the fleet of gasoline-fueled recreational craft distinguished in two strokes and four strokes engine distribution is provided by the industrial category association (UCINA, several years); the trend of the average emission factors considers the switch from two strokes to four strokes engines of the national fleet due to the introduction in the market of new models. In 2000, the composition of the fleet was 90% two stroke engines equipped and 10% four stroke while in the last year four strokes engines are about 53% of the fleet. Gasoline fuel consumption for recreational crafts is not available on the National Energy balance for the last years so it is estimated based on the fleet which has not significantly changed in the last years.

3.5.4.3 Uncertainty and time-series consistency

The combined uncertainty in CO_2 emissions from maritime is estimated to be about 3% in annual emissions; a higher uncertainty is calculated for CH_4 and N_2O emissions on account of the uncertainty levels attributed to the related emission factors. Estimates of fuel consumption for domestic use, in the national harbours or for travel within two Italian destinations, and bunker fuels used for international travels are reported in Table 3.30. Time series of domestic GHG emissions for waterborne navigation are also shown in the same table. An upward trend in emission levels is observed from 1990 to 2000, explained by the increasing number of ship movements. Nevertheless, the operational improvements in harbour activities and a reduction in ship domestic movements inverted the tendency in the last years.

Table 3.30 Marine fuel consumptions in domestic navigation and international bunkers (Gg) and GHG emissions from domestic navigation (Gg CO_2 eq.)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Gasoline for recreational craft (Gg)	182	210	213	199	169	90	87	86	84	67
Diesel oil for inland waterways (Gg)	20	23	20	77	62	54	24	19	22	21
Fuels used in domestic cruise navigation (Gg)	778	706	811	740	725	525	621	667	511	664
Fuel in harbours (dom+int ships) (Gg)	748	693	818	759	844	733	981	1,054	807	1,049
Fuel in international Bunkers (Gg)	1,348	1,241	1,214	2,095	2,562	1,563	1,702	1,321	1,774	1,331
Emissions from National Navigation (Gg)										
CO_2 (Gg)	5,470	5,163	6,103	5,623	5,705	4,448	5,435	5,798	4,540	5,717
CH_4 (Gg CO_2 eq.)	39	42	43	38	33	20	22	22	19	19
N_2O (Gg CO_2 eq.)	34	31	37	35	36	29	36	38	30	38
Total (Gg CO_2 eq.)	**5,543**	**5,236**	**6,183**	**5,696**	**5,774**	**4,497**	**5,492**	**5,858**	**4,588**	**5,774**

Source: ISPRA elaborations

3.5.4.4 Source-specific QA/QC and verification

Basic data to estimate emissions are reconstructed starting from information on ship movements and fleet composition coming from different sources. Data collected from the local port authorities were compared with the official statistics supplied by ISTAT, collected from maritime operators with a yearly survey and communicated at international level to EUROSTAT. Differences and problems were analyzed in details and solved together with ISTAT experts. Different sources of data are usually used and compared during the compilation of the annual inventory. Besides, time series resulting from the recalculation have been presented to the national experts and regional environmental agencies in the framework of an ad hoc working group on air emissions inventories. Top-down and bottom-up approaches have been compared with the aim to identify the potential problems and future improvements to be addressed.

3.5.4.5 Source-specific recalculations

Recalculations, with respect to the previous submission, occurred. CO_2 natural gas emission factor has been corrected for the year 2021. Minor corrections on the figures of the gasoline engines split between 2 stroke and 4 stroke from 2014 onwards. Minor recalculations affected activity data of diesel oil consumption for 2021, avio gasoline for 2020 and jet fuel for 2021 for military offroad as well as distribution of gasoline fuel consumption between agricultural and forestry activities for 2020.

3.5.4.6 Source-specific planned improvements

Further, improvements will regard verification of activity data on ship movements and emission estimates with regional environmental agencies, especially with those more affected by maritime pollution. In particular, we plan to build a tool which calculate every year emissions at harbor level taking in account of the information officially provided by Italy to Eurostat per type of ship, class of tonnage and movement statistics.

3.5.5 Other transportation

3.5.5.1 Source category description

This category includes all emissions from fuels delivered to the transportation by pipelines and storage of natural gas. Mainly CO_2 emissions derive from this category, as well as the other relevant pollutants typical of a combustion process, such as SO_X, NO_X, CO and PM. CH_4 and N_2O emissions are also estimated. CO_2 from pipelines is a key category in trend (Tier 1) with and without LULUCF.

3.5.5.2 Methodological issues

Emissions from pipeline compressors are carried out according to the IPCC Guidelines and are estimated on the basis of natural gas fuel consumption used for the compressors and the relevant emission factors. The amount of fuel consumption is estimated on the basis of data supplied for the whole time series by the national operators of natural gas distribution (SNAM, several years; STOGIT, several years) and refers to the fuel consumption for the gas storage and transportation; this consumption is part of the fuel consumption reported in the national energy balance in the consumption and losses sheet (MASE, several years [a]). Emission factors are those reported in the EMEP/EEA Guidebook for gas turbines (EMEP/CORINAIR, 2007), except for CO_2 for natural gas which is the country specific value used for the whole energy sector reported in Table 3.12. Emissions communicated by the national operators in their environmental reports are also considered to estimate air pollutants.

3.5.5.3 Uncertainty and time-series consistency

The combined uncertainty is estimated to be about 3% in annual emissions; a higher uncertainty is calculated for CH_4 and N_2O emissions on account of the uncertainty levels attributed to the related emission factors. Fluctuations and time series are driven both by the general trend of total natural gas fuel consumed (and transported) and by the annual fluctuation of the storage activities, which are driven by the price fluctuation of the natural gas. Natural gas fuel consumption for pipeline compressors increased from 7,359 TJ in 1990 to 16,664 TJ in 2022 with a peak of 19,098 TJ in 2010. GHG emissions follow the same trend of fuel consumption.

Table 3.31 Pipelines transport consumptions (Tj) and GHG emissions (Gg CO_2 eq.)

Pipeline transport	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Consumption (TJ)	7,359	11,556	15,367	15,940	19,098	9,662	11,739	11,646	14,549	16,664
Emissions from Pipelines (Gg)										
CO2 (Gg CO2 eq.)	410.78	646.63	864.51	900.21	1,106.63	556.84	677.87	674.45	851.19	981.68
CH4 (Gg CO2 eq.)	0.52	0.81	1.08	1.12	1.34	0.68	0.82	0.82	1.02	1.17
N2O (Gg CO2 eq.)	5.85	9.19	12.22	12.67	15.18	7.68	9.33	9.26	11.57	13.25
Total (Gg CO2 eq.)	**417.15**	**656.62**	**877.80**	**914.00**	**1,123.15**	**565.20**	**688.03**	**684.52**	**863.78**	**996.09**

Source: ISPRA elaborations

3.5.5.4 Source-specific QA/QC and verification

Basic data to estimate emissions are reconstructed starting from information on fuel consumptions coming from different sources. Fuel consumption reported by the national operators for this activity are compared with the amount of natural gas internal consumption and losses reported in the energy balance. Starting from the length of pipelines, the average energy consumptions by kilometer are calculated and used for verification of data collected by the operators. Energy consumption and emissions by kilometer calculated on the basis of data supplied by the main national operator (SNAM, several years) are used to estimate the figures for the other operators when their annual data are not available.

3.5.5.5 Source-specific recalculations

No specific recalculations were made concerning this source.

3.5.5.6 Source-specific planned improvements

No further improvements are planned.

3.6 Other sectors

3.6.1 Sector overview

In this paragraph sectoral emissions are reported, which originate from energy use in the civil sector included in category 1.A.4. Commercial, institutional, residential, agriculture/forestry/fisheries, and emissions from military mobile activities which are also included in category 1.A.5. All greenhouse gases as well as CO, NO_X, NMVOC and SO_2 emissions are estimated.

In 2022, energy use in other sectors accounts for 20.2% of CO_2, 5.6% of CH_4, 13.1% of N_2O of total national emissions. In terms of CO_2 equivalent, other sectors share 17.8% of total national greenhouse gas emissions and 21.7% of total GHG emissions of the energy sector.

The trend of greenhouse gas emissions is summarized in Table 3.32. A general increase in emissions is observed from 1990 to 2000, due to the increase in activity data (number and size of building with heating); a sharp increase of CO_2 emissions is observed in 2005 due to exceptionally cold weather conditions. CH_4 and N_2O emissions increase in the period is due to the growing use of woody biomass and biogas for heating. CH_4 and N_2O emissions of category 1.A.4.c are driven by the use of biomass in the agriculture sector, both wood and biogas, for heating of greenhouse and aquaculture plants; according to the national energy balance, wood biomass fuel started to be consumed in 2000 while biogas from agriculture residues sharply increased in the last years. Details on the total amount of crop residues generated and the share of the crop residue amounts used for different purposes (for energy referring to permanent crops residues) are reported in Annex 7, Figure A.7.1.

Table 3.32 Trend in greenhouse gas emissions from the other sectors, 1990-2022

GAS/SUBSOURCE	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
CO_2 (Gg)										
1.A.4a. Commercial/ Institutional	11,902	14,070	17,230	23,424	28,296	22,766	24,471	23,459	21,708	19,315
1.A.4b. Residential	55,788	52,756	53,824	60,441	55,267	47,982	44,735	44,069	48,073	41,775
1.A.4c. Agriculture/ Forestry/Fisheries	8,352	8,754	8,115	8,459	7,345	6,935	7,029	7,065	7,465	7,246
1.A.5 Other (Not elsewhere specified)	1,071	1,496	837	1,233	652	459	453	625	314	511
CH_4 (Mg)										
1.A.4a. Commercial/ Institutional	604	879	1,993	3,068	3,978	4,473	4,559	4,226	4,174	3,903
1.A.4b. Residential	43,781	50,032	52,554	55,508	98,593	87,873	85,635	82,508	93,107	84,420
1.A.4c. Agriculture/ Forestry/ Fisheries	1,264	946	669	592	774	2,383	2,710	2,792	2,839	2,752
1.A.5 Other (Not elsewhere specified)	173	223	126	160	65	54	56	79	39	65
N_2O (Mg)										
1.A.4a. Commercial/ Institutional	311	413	614	911	1,167	1,143	1,184	1,147	1,118	1,048
1.A.4b. Residential	3,014	3,172	3,303	3,521	5,261	4,659	4,501	4,348	4,868	4,382
1.A.4c. Agriculture/ Forestry/ Fisheries	2,515	2,757	2,610	2,685	2,373	2,327	2,391	2,413	2,393	2,282

1.A.5 Other (Not elsewhere specified)	225	215	135	291	131	59	43	49	31	39

Source: ISPRA elaborations

Seven key categories have been identified for this sector in 2022, for level and trend assessment, using both the IPCC Approach 1 and Approach 2:

- Other sectors - CO_2 commercial, residential, agriculture gaseous fuels (L, T);
- Other sectors - CO_2 commercial, residential, agriculture liquid fuels (L, T);
- Other sectors - CO_2 commercial, residential, agriculture other fossil fuels (L1, T);
- Other sectors - CH_4 commercial, residential, agriculture biomass (L, T);
- Other sectors - N_2O commercial, residential, agriculture biomass (L2, T);
- Other sectors - N_2O commercial, residential, agriculture liquid fuels (L2);
- Other sectors - CO_2 commercial, residential, agriculture solid fuels (T1).

All these categories, except N_2O commercial, residential, agriculture liquid fuels, are also key categories including the LULUCF estimates in the key category assessment.

3.6.2 Source category description

This category includes four sources: 1.A.4.a. Commercial/ Institutional, 1.A.4.b. Residential, 1.A.4.c. Agriculture/ Forestry/ Fisheries and 1.A.5 Other (Military). The estimation procedure follows that of the basic combustion data sheet. Emissions are estimated from the energy consumption data and the emission factor illustrated in Table 3.12. Emissions from off-road sources are estimated and they are reported under the relevant sectors. The methodology of these estimates is discussed in the next paragraph 3.6.3 *Others*.

Commercial/ Institutional

Emissions from this sector arise from the energy used directly in the institutional, service and commercial buildings, mainly for heating. Additionally, this category includes all emissions due to the non-renewable part of waste used in electricity generation.

In the other fuel subcategory, the amount of fossil waste burnt in incinerators with energy recovery is reported. Emissions from these plants are allocated in the commercial/institutional category because of the final use of heat and electricity production which is mainly used for district heating of commercial buildings or is auto consumed in the plant. In fact, until the early 2000s, electricity and heat produced by incinerators have been prevalently used to satisfy the energy demand from connected activities: heating of buildings, domestic hot water, and electricity for offices. This is still true for industrial and hospital incinerators, meanwhile municipal solid waste incinerators have increased the amount of energy provided to the grid from the early 2000s until now. Although there are no data or a robust estimate of the share of waste used to produce electricity, the available literature (ENEA-federAmbiente, 2012) provides that in 2010 the gross electricity production by urban waste incinerators was equal to 3,887 GWh (net 3,190 GWh) and the amount sent to the network was equal to only 121 GWh.

Biomass refers to the consumption of biomass waste, biogas recovered for energy purposes from landfill and sludge treatments and wood and steam wood; from 2002 to 2005 minor amounts of biodiesel fuel consumption are also included. In Table 7.12 of the waste sector chapter, the amount of waste and biogas fuel consumptions for 2022 are reported. In 2022, this sector has a share of 4.8% of total GHG national emissions excluding LULUCF.

Residential

Emissions from this sector arise from the energy used directly in residential buildings, mainly for heating. The sector includes emission from households and gardening machinery. Biomass refers to wood and steam wood fuel consumption. In 2022, this sector has a share of 11.0% of total GHG national emissions, excluding LULUCF.

Agriculture/ Forestry/ Fisheries

This subsector includes all emissions due to the direct fossil fuel use in agriculture, mainly to produce mechanical energy, the fuel used in fisheries and for the machinery used in the forestry sector.

Up to 1999, biomass included only biogas recovered for energy purposes from the storage of animal manure and agriculture residuals, while from 2000, as reported in the National Energy Balance, a huge amount of wood has been consumed affecting implied emission factors. In 2022, this sector has a share of 1.9% of total GHG national emissions, excluding LULUCF.

Others

Emissions from military aircraft and naval vessels are reported under 1A.5.b Mobile. The methods of estimation are discussed in paragraphs 3.5.1 and 3.5.4 for aviation and maritime respectively. In 2022, this sector has a share of 0.1% of total GHG national emissions, excluding LULUCF.

3.6.3 Methodological issues

For this sector, energy consumption is reported in the national energy balance separating commercial and public services, residential and agriculture-fisheries.

Emissions from 1.A.4.b Residential and 1.A.4.c Agriculture/Forestry/Fishing are disaggregated into those arising from stationary combustion and those from off-road vehicles and other machinery. Emissions estimations from off-road sources are discussed later in this paragraph. Emissions from fishing vessels are estimated from fuel consumption data (MASE, several years [a]). Emission factors are shown in Table 3.12.

In the solid fuel subcategory, the following fuels are included: steam coal, coke oven coke and gas work gas. Since the eighties, there has been a sharp reduction in the use of these fuels due to air quality national legislation (in 1990 they accounted for about 1.1 % of total energy consumption of 1.A.4 category) and a further decrease is observed between 1997 and 1998 in consequence of the banning of coal used in residential heating in urban areas.

CH_4 emission factors used are those reported in the 1996 CORINAIR handbook, vol.1, for coal, equal to 200 kg/TJ (EMEP/CORINAIR, 1996), and in the EMEP/CORINAIR Guidebook for coke oven coke, equal to 15 kg/TJ (EMEP/CORINAIR, 2007) which is the maximum value of emission factor for solid fuels without specification, and gas work gas, equal to 5 kg/TJ (IPCC, 2006). No more solid fuels are used for heating purposes from 2013.

For non-CO_2 GHG emissions, at the detailed level of fuel and technology, EMEP/EEA remains the best source of information.

For liquid fuel, the average emission factors are driven by the mix of fuel consumptions used in heating boilers, prevalently LPG, but also gasoil and fuel oil which was used especially in the past.

For these fuels the respective CH_4 emission factors have been used: LPG 1 kg/TJ, fuel oil 3 kg/TJ and gasoil 7 kg/TJ. Regarding natural gas, the country specific CH_4 emission factor is equal to 2.5 kg/TJ.

All these emission factors have been calculated on the basis of the default and range emission factors published in the Guidebook EMEP/CORINAIR 2007, taking into account country specific circumstances by means of the type of boilers where these fuels are burnt. In the 2006 IPCC Guidelines emission factors for residential/commercial/institutional boilers are equal to those reported for manufacturing industrial boilers (e.g., natural gas default emission factor is equal to 1 for all the sources of combustion) while it is assumed that these emissions should be different according to the technology and size of the boilers.

In the following box the default emission factors reported in the Guidebook EMEP/CORINAIR 2007 are shown and compared with the national ones.

Liquid and gaseous fuel CH_4 default emission factors(kg/TJ) (EMEP/CORINAIR, 2007)

Fuel	EMEP/CORINAIR default EF	Range	IPCC default EF	National EF
LPG	-	1 - 2.5	1	1
Gasoil	0.6	0.1 - 8	3	7
Fuel oil	1.6	0.1 - 10	3	3
Natural gas	1.2	0.3 - 4	1	2.5

Average implied emission factors for other fuels, which refer to fossil waste, vary on an annual basis. For CO_2, the variation occurs from 1990, as a consequence of the mix of wastes used in incinerators, such as urban wastes, industrial, hospital, and oil wastes; for non-CO_2 gases, emission factors reported in EMEP/EEA (EMEP/EEA, 2016) applied at plant level have been considered, but specifically for CH_4 and N_2O this use does not result in changes of the implied emission factors because values are the same for the different kind of wastes, and emission factors are equal to 5.3 kg/TJ and 8.8 kg/TJ, respectively. In 2022 CO_2 average emission factor was equal to 96.9 kg/GJ.

Regarding biomass fuel consumption, CO_2, CH_4 and N_2O emission factors used in the national inventory for the different type of fuels are reported in the following box. CH_4 and N_2O emission factors derive from the EMEP/CORINAIR Guidebook (EMEP/CORINAIR, 2007), and the implied emission factors fluctuate as a function of the mix of fuels (wood, biogas, waste and biodiesel).

Regarding CO_2 from waste, fossil fraction emissions are distinguished by biomass to include them in the national totals. CO_2 emission factors are built based on carbon content in each type of waste: municipal waste, industrial waste, oil, sludge and hospital. Biogas emission factors are calculated starting from the stoichiometric carbon value equal to 750 kg C/t and annual energy efficiencies provided by Terna (Terna, several years) for the respective use in commercial and agriculture sectors. Wood and steam wood average CO_2 emission factor is derived taking in account the typical national wood used and it is applied for the whole timeseries. Implied emission factors result from the mix of biomass fuels used for each category (1A4a, 1A4b, 1A4c).

Biomass CO_2, CH_4 and N_2O emission factor for 2022 (kg/TJ)

Fuel	CO_2	CH_4	N_2O
Wood	94,600	320	14
Biogas landfills and sludge treatment	50,611	153	3
Biogas agriculture residues	53,929	153	3
Waste	83,000	5	9
Biodiesel	79,600	12	2

3.7 Other

In this paragraph, the methodology used to estimate emissions vehicles and mobile machinery used within the agriculture, forestry, industry (including construction and maintenance), residential, and sectors, such as airport ground support equipment, agricultural tractors, chain saws, forklifts, snowmobiles. Engine types typically used in this off-road equipment include compression-ignition (diesel) engines, spark-ignition (motor gasoline), 2-stroke engines, and motor gasoline 4-stroke engines. Estimates are calculated basedon the Tier 3 method (equation 3.3.3 of the 2006 IPCC Guidelines (IPCC, 2006). This involves the estimation of emissions from different classes of off-road sources using the following equation for each class:

$$Ej = Nj \cdot Hj \cdot Pj \cdot Lj \cdot Wj \cdot (1 + Yj \cdot aj /2) \cdot ej$$

where

Ej =	Emission of pollutant from class j	(kg/y)
Nj =	Population of class j	
Hj =	Annual usage of class j	(hours/year)
Pj =	Average power rating of class j	(kW)
Lj =	Load factor of class j	
Yj =	Lifetime of class j	(years)
Wj =	Engine design factor of class j	
aj =	Age factor of class j	(y^{-1})
ej =	Emission factor of class j	(kg/kWh)

For gasoline engine sources, evaporative NMVOC emissions are also estimated as:

$$Evj = Nj \cdot Hj \cdot evj$$

where

Evj =	Evaporative emission from class j	kg
evj =	Evaporative emission factor for class j	kg/h

Population data are based on a survey of machinery sales (Frustaci, 1999). Machinery lifetime is estimated on the European averages, see EMEP/CORINAIR (EMEP/CORINAIR, 2007), the annual usage data were taken either from industry or published data (EEA, 2000). The emission factors used came mostly from EMEP/CORINAIR and from Samaras (EEA, 2000). The load factors were taken from Samaras (EEA, 2000). It was possible to calculate fuel consumptions for each class based on fuel consumption factors given in EMEP/CORINAIR (EMEP/CORINAIR, 2007).

Estimates were derived for fuel consumption for the years 1990-2022 for each of the main categories:

A. Agricultural power units: gas oil consumption was taken from the energy balance (MASE, several years [a]). The consumption of gasoline was estimated using the energy balance (MASE, several years [a]) and subtracting the amount of fuel estimated for domestic house & garden on the basis of the population approach for 1995.

B. Industrial off-road: gas oil consumption was calculated from the Ministry of Environment data (MASE, several years [a]).

C. Domestic house & garden: gasoline consumption was estimated from the population approach for 1995. Time series is reconstructed in relation to the fuel use in agriculture.

3.7.1 Uncertainty and time-series consistency

The combined uncertainty in CO_2 emissions in "Other sectors" is estimated to be about 3% in annual emissions; a higher uncertainty is calculated for CH_4 and N_2O emissions on account of the uncertainty levels attributed to the related emission factors. Estimates of fuel consumption used by other sectors in 2022 are reported in Table 3.33.

Table 3.33 Trend in fuel consumption for the other sector, 1990-2022 (TJ)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
					TJ					
1.A.4a. Commercial/ Institutional	206,427	247,440	306,088	419,507	489,018	400,595	422,663	402,497	370,464	326,781
1.A.4b. Residential	1,002,597	1,004,192	1,037,175	1,172,398	1,222,588	1,078,886	1,019,775	997,341	1,091,945	955,381
1.A.4c. Agriculture/ Forestry/ Fisheries	114,638	121,163	111,486	116,933	103,172	107,101	110,434	111,540	118,784	115,695
1.A.5 Other	14,840	20,814	11,595	16,947	9,001	6,388	6,317	8,733	4,385	7,139

Source: ISPRA elaborations

In the following Table 3.34, total GHG emissions connected to the use of fossil fuels and waste derived fuels are reported for the whole time series. An increase in emissions is observed from 1990 to 2000, due to the increase in activity data (numbers and size of buildings with heating); a sharp increase can be observed in 2005 due to exceptionally cold weather conditions. CH_4 and N_2O emissions increased in the period due to the growing use of woody biomass for heating.

Table 3.34 Other sectors, GHG emission time series 1990-2022

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
CO_2 (Gg)	77,113	77,076	80,006	93,557	91,560	78,143	76,688	75,218	77,561	68,847
CH_4 (Mg)	45,822	52,079	55,342	59,329	103,409	94,784	92,960	89,605	100,158	91,140
N_2O (Mg)	6,065	6,557	6,662	7,408	8,931	8,188	8,119	7,958	8,410	7,751
GHG (Gg CO_2 eq)	80,003	80,272	83,321	97,181	96,822	82,967	81,442	79,836	82,594	73,453

Source: ISPRA elaborations

In Table 3.35, other sectors emissions are summarized according to main categories. From 1990 to 2022, an increase in the use of natural gas instead of fuel oil and gas oil in stationary combustion plants is observed; it results in a decrease of CO_2 emissions from combustion of liquid fuels and an increase of emissions from gaseous fuels. CH_4 and N_2O emissions increased in the period due to the increasing use of woody biomass for heating.

Table 3.35 Other sectors, GHG emissions in 1990 and 2022

		1990	2022
CO_2 other sectors liquid fuels	Gg	39,346	13,103
CO_2 other sectors solid fuels	Gg	899	0
CO_2 other sectors gaseous fuels	Gg	36,338	50,221
CO_2 other sectors other fuels	Gg	530	5,523
CH_4 other sectors	Mg	45,822	91,140
N_2O other sectors	Mg	6,065	7,751

Source: ISPRA elaborations

3.7.2 Source-specific QA/QC and verification

Basic data to estimate emissions are reported in the national energy balance and the national grid administrator (for the waste used to generate electricity). The energy data used to estimate emissions reported in table 1.A.4 have different levels of accuracy:

- the overall sum of residential and institutional/service/commercial energy consumption is quite reliable, and their uncertainty is the same of the BEN; the quantities of fuels used for those economic sectors are routinely reported by main suppliers and the data are well documented;
- the energy consumption for agriculture and fisheries is also routinely reported by energy statistics and the underlying data are quite reliable because the energy use for those sectors has special taxation regimes and they are accounted for separately;
- the energy use for military and off roads is instead partly reported and partly estimated with models, as described in paragraph 3.6.3 others.

3.7.3 Source-specific recalculations

Recalculations occur because of the update of kerosene activity data for the whole time series.

Currently, a review process of the national energy balance is underway with Eurostat and involves the various interested parties (TERNA, GSE, MASE) in Italy. In a first step, those responsible for the National Energy Balance implemented methodological changes for 2022 and subsequently applied these changes to 2021 to make it consistent and giving rise to recalculations.

In 2020 recalculations occur because of the correction of an error in biogas activity data.

Minor recalculations occur since 2013 because of the update of incineration with energy recovery activity data.

3.7.4 Source-specific planned improvements

The implementation of updated emission factors from small combustion of biomass is planned.

3.8 International bunkers

The methodology used to estimate the quantity of fuels used by international bunkers in aviation and maritime navigation has been illustrated in the relevant transport paragraphs, 3.5.1 and 3.5.4. The methodology implements the IPCC guidelines according to the available statistical data.

3.9 Feedstock and non-energy use of fuels

3.9.1 Source category description

In Table 3.36 and 3.37, detailed data on petrochemical and other non-energy use for the year 2022 are given. The tables refer to all products produced starting from fossil fuels, solid, gas or liquid, and used for "non energy" purposes. A national methodology is used for the reporting and estimation of avoided emissions.

3.9.2 Methodological issues

The quantities of fuels stored in products in petrochemical plants are calculated on the basis of information contained in a detailed yearly report, the petrochemical bulletin, by the Ministry of Environment (MASE, several years [b]).

The national petrochemical balance includes information on petrochemical input entering the process and used for the production of petrochemical products, and petrochemical plants output, returns to the market, losses and internal consumption. Due to chemical reactions in the petrochemical transformation process, the output quantity of some fuels could be greater than the input quantity; in particular, it occurs for light products such as LPG, gasoline and refinery gas, and for fuel oil. Therefore, for these fuels it is possible to have negative values of the balance. For this matter, with the aim of allowing the reporting on CRT tables, these fuels have been added to naphtha. The amount of fuels recovered from the petrochemical processes and returning on the market are considered as an output, because consumed for transportation or in the industrial sectors, and no carbon is stored.

In Table 3.36 and Table 3.37 the overall results and details by product are reported respectively. In Table 3.36 the breakdown of total petrochemical process is reported; the percentages referring to the "net" input are calculated on the basis of the total input subtracting the quantity of fuels as gasoil, LPG, fuel oil and gasoline which return on the market because produced from the petrochemical processes. In Table 3.37 the input to the petrochemical processes in petrochemical plants and the relevant losses, internal consumption and return to the market are reported, at fuel level, allowing the calculation of the quantity stored in products, subtracting the output (returns to the market, losses and internal consumption) from the input (petrochemical input). Carbon stored, for all the fuels, is therefore calculated from the amounts of fuels stored (in tonnes) multiplied by the relevant emission factors (tC/t) reported in Table 3.37.

An assessment was made to estimate the quantities stored in products according to the IPCC 1996 Guidelines, Reference Manual, ch1, tables 1-5 (IPCC, 1997), multiplying the IPCC percentage values in tables 1-5 of the Guidelines by the amount of fuels reported as "petrochemical input" in Table 3.37. The resulting estimate of about 4,193 Gg of products, for the year 2022, is 24% larger than the quantities reported, 3,384 Gg.

Non-energy products amount stored from refineries, and other manufacturers, are reported in the national energy balance (MASE, several years [a]) and the carbon stored is estimated with emission factors reported in Table 3.38. For lubricants the net carbon stored results from the difference between the amount of lubricants and the amount of recovered lubricant oils. The energy content has been calculated on the basis of the IPCC default values. Minor differences in the overall energy content of these products occur if the calculation is based on national parameters instead of IPCC default values.

In the CRT tables the fuel input amount is reported so that the fractions of carbon stored could be derived. As these fractions are derived from actual measurements, they do not correspond to any default values and may vary over time.

Table 3.36 Other non-energy uses, year 2022

Breakdown of total petrochemical flow				
	Petrochemical Input	Returns to refinery/market	Internal consumption / losses	Quantity stored in products
ALL ENERGY CARRIERS, Gg	7,640	2,826	1,430	3,384
% of total input		37.0%	18.7%	44.3%
% of net input			29.7%	70.3%

Source: ISPRA elaborations

Table 3.37 Petrochemical, detailed data from MASE, year 2022 (MASE, detailed petrochemical breakdown)

FUEL TYPE	Petroch. Input	Returns to refinery/ market	Internal consumption / losses	Quantity stored in products	% on total input	% on net input	Emission factor (IPCC)
	Gg	Gg	Gg	Gg			t C / t
LPG	253	319	8	-74			0.8146
Refinery gas	272	202	587	-516			0.7781
Virgin naphtha	3,986	0	0	3,986			0.8900
Gasoline	971	1,452	3	-484			0.8379
Kerosene	474	339	0	135			0.8606
Gas oil	362	273	11	78			0.8696
Fuel oil	323	110	110	103			0.8534
Petroleum coke	0	0	0	0			0.8666
Others (feedstock)	335	132	57	147			0.8462
Losses	0	0	0	0			0.8462
Natural gas	665	0	654	11			0.7732
total	7,640	2,826	1,430	3,384	44%	70%	

Source: ISPRA elaborations

Table 3.38 Other non-energy uses, year 2022, MASE several years [a]

NON ENERGY FROM REFINERIES	Quantity stored in products	Energy content IPCC '96	Total energy content	Emission factor
	Gg	TJ/Gg	PJ	Gg C / Gg
Bitumen + tar	2,671	40.19	107.3	0.8841
lubricants	665	40.19	26.7	0.8038
recovered lubricant oils	118	40.19	4.7	0.8038
paraffin	63	40.19	2.5	0.8368
others (benzene, others)	676	40.19	27.2	0.8368
Totals	4,193		168.5	

Source: ISPRA elaborations

At national level, this methodology seems the most accurate according to the available data.

3.9.3 Uncertainty and time-series consistency

In Annex 4, the time series for comparison between reference and sectoral approaches are reported showing percentage differences in a limited range.

3.9.4 Source-specific QA/QC and verification

Basic data to estimate emissions are directly provided to ISPRA by MASE. The energy data used to estimate emissions have a high level of accuracy because they summarize the results of a 100% legally binding monthly survey of all the operators concerned.

3.9.5 Source-specific recalculations

Recalculations occur because of the implementation of the updated national energy balance data.

3.10 Fugitive emissions from solid fuels, oil and natural gas

3.10.1 Source category description

Fugitive emissions of GHGs arise during the stages of fuel production, from extraction of fossil fuels to their final use. Emissions are mainly due to leaks or other irregular releases of gases from the production and transformation of solid fuels, the production of oil and gas, the transmission and distribution of gas and from oil refining. Solid fuels category implies mainly methane emissions, while oil and natural gas categories include carbon dioxide and nitrous oxide too.

In 2022, GHG emissions from this source category account for 1.2% out of the total emissions and 1.5% of emissions in the energy sector. Trends in fugitive emissions are summarized in Table 3.46. The results of key category analysis are shown in the following box.

Key-category identification in the fugitive sector with the IPCC Approach 1 and Approach 2

Year		IPCC category	without LULUCF	with LULUCF
2022	CH_4	Oil and natural gas - Natural gas	L, T	L, T
	CH_4	Oil and natural gas – Flaring in refineries	L2, T2	L2, T2
	CO_2	Oil and natural gas – Venting and flaring	T2	T2
	CO_2	Oil and natural gas – Flaring in refineries	T2	T2
	CO_2	Oil and natural gas – Oil	-	T1
1990	CH_4	Oil and natural gas - Natural gas	L	L
	CO_2	Oil and natural gas – Oil	L1	L1
	CO_2	Oil and natural gas - Venting and flaring	L2	L2
	CO_2	Oil and natural gas – Flaring in refineries	L2	L2

As for 2022, CH_4 emissions are key categories for natural gas according to level and trend assessment with Approach 1 and Approach 2, with and without LULUCF; CH_4 emissions for flaring in refineries are key categories according to level and trend assessment with Approach 2, with and without LULUCF; CO_2 emissions for venting and flaring as well as for flaring in refineries are key categories for trend with Approach 1, with LULUCF.

As for the base year, CH_4 emissions are key categories for natural gas following both the Approaches, with and without LULUCF; CO_2 emissions are key categories for oil only with Approach 1, while CO_2 emissions are key categories from venting and flaring and from flaring in refineries with Approach 2, with and without LULUCF.

Fugitive CH_4 and CO_2 emissions reported in 1.B.1 refer to coal mining for only two mines with very low production in the last ten years. One mine is underground and produces coal and the other one, a surface mine, produces lignite. The underground mine stopped the extraction activities between 1994 and 1999, whereas the surface mine stopped the activity in 2001.

CH_4 emissions from solid fuel transformation refer to fugitive emission from coke production in the iron and steel industry, which is also decreasing in the last years. N_2O emissions from 1.B.1 are not occurring.

Fugitive CO_2 emissions reported in 1.B.2 refer prevalently to fugitive emissions in refineries during petroleum production processes, e.g. fluid catalytic cracking and sulphur recovery plants and flaring, but also include emissions from the exploration, production, transport and distribution of oil and natural gas.

CH_4 emissions reported in 1.B.2 refer mainly to the production of oil and natural gas and to the transmission in pipelines and distribution of natural gas, while N_2O emissions refer to flaring in the production of oil and natural gas and in refineries and emission from exploration.

For the completeness of the related CRF tables, particularly 1.B.2, the N_2O emissions in refining and storage are reported under flaring in refineries as shown in the following Table 3.39.

Table 3.39 Completeness of N_2O fugitive emissions

1.B. 2.a. Oil		
iv. Refining/storage	N_2O	Included in 1.B.2.d flaring in refineries

3.10.2 Methodological issues

Coal mining and handling

CH_4 emissions from coal mining have been estimated on the basis of activity data published on the national energy balance (MASE, several years [a]) and emission factors provided by the IPCC guidelines (IPCC, 2006). Mining and post mining emissions have been calculated. As for CH_4 emissions from mining and post mining the average emission factors of the 2006 IPCC Guidelines (IPCC, 2006) have been selected, 18m^3/t and 2.5m^3/t, respectively. As concerns CO_2 emissions, the calculations have been carried out considering the species profile in coal mine gas by literature data (EMEP/CORINAIR, 2007). The coal gas composition considered is 80% of CH_4 and 6% of CO_2 by volume (Williams, 1993).

As for closed or abandoned mines, there are no methods for estimating emissions from surface mines at present (IPCC, 2006). As for the only one underground mine closed from 1994 to 1999, there are no data for a country-based approach to estimate fugitive emissions during the closure period. The emission estimations are carried out applying Tier 2 of the 2006 IPCC Guidelines for bituminous mines with 100% of gassy parameter.

Solid fuel transformation

CH_4 emissions from coke production have been estimated on the basis of activity data published in the national statistical yearbooks (ISTAT, several years [a]) and emission factors reported in the EMEP/CORINAIR Guidebook (EMEP/CORINAIR, 2007) taking in account the information provided by the relevant operators in the framework of the EPRTR registry and the ETS, as addressed in paragraph 3.3.3 of this chapter.

With regard to the manufacture of other solid fuels, in Italy charcoal was produced in the traditional way until the sixties while now it is prevalently produced in modern furnaces (e.g with the VMR system) where exhaust gases are collected and recycled to produce the energy for the furnace itself. This system ensures good management of the exhausts and the temperature, so that any waste of energy is prevented and emissions are kept to a minimum. So CH_4 emissions from the production of charcoal are not accounted for also considering that the emission factor available in the Revised 1996 IPCC Guidelines, in Table 1-14 vol.3 (IPCC, 1997), refers to production processes in developing countries not applicable to our country anymore. Moreover, in the IPCC Good Practice Guidance as well as in the IPCC 2006 Guidelines no guidance is supplied for charcoal production.

Oil transport and storage and refining

Fugitive emissions from oil refining are estimated starting from the total crude oil losses as reported in the national energy balance. Emissions have been reported in the Refining/Storage category (1.B.2.a.iv); they occur prevalently from processes in refineries. Fugitive emissions from oil transport have been calculated according with the amount of transported oil (MIT, several years) and emission factors published on the IPCC guidelines (IPCC, 2006).

Most of the crude oil is imported in Italy by shipment and delivered at the refineries by pipelines as offshore national production of crude oil. Table 3.40 provides the length of pipelines for oil and the amount of oil products transported since 1990.

Table 3.40 Length of pipelines for oil transport (km) and amount of transported oil products (Gg)

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022*
Length of pipelines (km)	4,140	4,235	4,346	4,328	4,291	4,022	4,012	4,021	4,018	4,018	3,931	3,935	3,948
Amount transported (Gg)	94,600	102,274	116,803	133,024	128,854	110,369	112,031	114,124	115,685	114,451	99,295	106,610	109,303

Source: MIT
***provisional values**

Emissions in refineries have been estimated on the basis of activity data published in the national energy balance (MSE, several years [a]) or supplied by oil and gas industry association (UNEM, several years) and operators especially in the framework of the European Emissions Trading Scheme (EU-ETS), and emission factors published on the IPCC Guidelines (IPCC, 2006).

Fugitive CO_2 emissions in refineries are mainly due to catalytic cracking production processes, sulphur recovery plants, flaring and emissions by other production processes including transport of crude oil and oil products. Emissions are calculated on the basis of the total crude oil losses reported in the national energy balance. These emissions are then distributed among the different processes on the basis of average emission factors agreed and verified with the association of industrial operators (UP) and yearly updated, from 2000, on the basis of data supplied by the plants in the framework of the European Emissions Trading Scheme. In the EU-ETS context, refineries report CO_2 emissions for flaring and for processes separately.

In Table 3.41, the time series of crude oil losses published in the BEN and crude oil processed in Italian refineries are shown.

Table 3.41 Refineries activities and losses

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
Crude Oil losses (Mg)	1,004	937	757	576	584	664	574	627	603	767	550	474	475
Crude oil processing (Gg)	93,711	91,014	98,003	106,542	94,944	79,148	77,510	80,312	78,878	77,605	65,517	70,550	74,560

Source: MSE, UP

Oil and gas exploration

CO_2, CH_4, and N_2O fugitive emissions from oil and natural gas exploration have been calculated according with the number of exploration wells (MASE, several years [c]) and emission factors published on the IPCC Good practice Guidance (IPCC, 2000) as no emission factors for number of wells were available in 2006 IPCC guidelines. There are no EFs in the 2006 IPCC Guidelines when the only activity data available are the number of wells. In the IPCC good practice guidance, the tier 1 methodology and default EFs are based on the number of wells, whereas in the 2006 IPCC Guidelines, they are based on the volume of oil production. If overall oil production were used as a proxy in estimating emissions from oil and gas exploration, there would be an overestimation. Moreover, current oil production is mainly onshore, while exploration is now being done offshore, and the methodology in the 2006 IPCC Guidelines does not reflect this situation. The relationship between exploration/drilling activity and production volume applies when the two activities occur within the same bed. In the case of onshore production and offshore exploration, the onshore production is not necessarily related to the exploration, and only offshore exploration is recorded.

Emissions factors for drilling, testing and servicing have been used for productive wells, while only emissions factor for drilling has been used for non productive wells.

Oil and gas production and processing

CH_4 emissions from the production of oil and natural gas as well for natural gas processing have been calculated according with activity data published on national energy balance (MASE, several years [a]), data by oil and gas industry association (UNEM, several years), data supplied by operators, and emission factors published on the IPCC guidelines (IPCC, 2006).

CH4 emission factors for the whole time series have been calculated considering this information also for oil venting and flaring and for gas flaring. For CO_2, the IPCC default emission factor has not been modified for each category, as no specific information is available. N_2O emissions from flaring in oil and gas production have been estimated on the basis of activity production data and emission factors reported in the IPCC guidelines (IPCC, 2006).

As regards the decline of CH_4 IEF for natural gas production and processing, gas companies stated that along the time there has been an increasing awareness to reduce GHG emissions and new emergency management systems have been implemented periodically to reduce emissions from venting. Moreover, with the updating of management systems, more accurate methods to estimate vented gas have been adopted by the main gas company at regular intervals. Since 2016 the national oil&gas operator has implemented new standards to drastically reduce the fugitive emissions from its oil production sites. The leakage rate from oil operation sites has changed from 2016 onwards.

In Table 3.42, the time series of national production of oil and gas are reported. Natural gas production should further reduce in the next years.

Table 3.42 National production of oil and natural gas

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
Oil (Gg)	4,668	5,236	4,586	6,111	5,106	5,470	3,760	4,148	4,684	4,279	5,424	4,914	4,918
Natural gas (Mm^3)	17,296	20,383	16,766	11,962	8,265	6,877	6,021	5,657	5,553	4,983	4,417	3,499	3,405

Source: MASE

Natural gas transmission and distribution

CH_4 and CO_2 emissions from the transmission in pipelines and distribution of natural gas estimates are based on activity data published by industry, the national authority, and information collected annually by the Italian gas operators. In other word the most relevant information is the amount of natural gas transmitted/distributed and the methane emissions reported by operators in their environmental reports or communicated to ISPRA. The emissions communicated by main operators are estimated separately for transmission/distribution considering known lengths and materials of pipelines just to calibrate the model used to estimate fugitive emissions from minor operators.

Emission estimates take into account the information on: the amount of natural gas distributed (ENI, several years [a]; SNAM, several years); length of pipelines, distinct by low, medium and high pressure and by type, cast iron, grey cast iron, steel or polyethylene pipelines (AEEG, several years); natural gas losses reported in the national energy balance (MASE, several years [a]); methane emissions reported by operators in their environmental reports (ENI, several years [b]; EDISON, several years; SNAM, several years).

CO_2 emissions have been calculated considering CO_2 content in the leaked natural gas. The average natural gas chemical composition has been calculated from the composition of natural gas produced and imported. Main parameters of mixed natural gas, as calorific value, molecular weight, and density, have been calculated as well. Data on chemical composition and calorific value are supplied by the main national gas providers for domestic natural gas and for each country of origin.

Table 3.43 shows average data for national pipelines natural gas.

Table 3.43 Average composition for pipelines natural gas and main parameters

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
HCV (kcal/m3)	9,156	9,193	9,215	9,261	9,325	9,303	9,351	9,340	9,334	9,336	9,340	9,377	9,428
NCV (kcal/m3)	8,255	8,290	8,320	8,354	8,412	8,391	8,444	8,433	8,427	8,428	8,432	8,467	8,515
Molecular weight	17.03	17.19	17.37	17.45	17.46	17.34	17.53	17.44	17.34	17.29	17.33	17.48	17.56
Density (kg/Sm3)	0.72	0.73	0.74	0.74	0.74	0.73	0.74	0.74	0.73	0.73	0.73	0.74	0.74
CH_4 (molar %)	94.30	93.36	92.22	91.93	92.04	92.72	91.54	92.08	92.64	92.92	92.79	91.97	91.49
NMVOC (molar %)	3.45	4.09	4.84	5.35	5.74	5.26	6.17	5.93	5.62	5.49	5.63	6.21	6.74
CO_2 (molar %)	0.22	0.20	0.18	0.49	0.75	0.70	0.65	0.67	0.74	0.64	0.88	0.91	0.83
Other no carbon gas (molar %)	2.03	2.34	2.76	2.24	1.48	1.32	1.64	1.33	1.00	0.95	0.70	0.91	0.94
CH_4 (weight %)	88.83	87.14	85.16	84.53	84.54	85.81	83.79	84.72	85.68	86.23	85.88	84.39	84.59
NMVOC (weight %)	7.33	8.62	10.00	10.73	11.27	10.34	12.03	11.51	10.87	10.64	10.78	11.91	12.89
CO_2 (weight %)	0.57	0.51	0.47	1.23	1.89	1.78	1.62	1.70	1.88	1.63	2.25	2.29	2.09
Other no carbon gas (weight %)	3.27	3.74	4.37	3.51	2.30	2.08	2.55	2.07	1.56	1.50	1.09	1.41	1.43

More in details, emissions are estimated separately for the different phases: transmission in primary pipelines and distribution in low, medium, and high pressure network, losses in pumping stations and in reducing pressure stations (including venting and other accidental losses) with their relevant emission factors, considering also information regarding the length of the pipelines and their type. Emissions from low pressure distribution also include the distribution of gas at industrial plants and in residential and commercial sector; data on gas distribution are only available at an aggregate level thus not allowing a separate reporting. In addition, emissions from the use of natural gas in housing are estimated and included. Emissions calculated are compared and balanced with emissions reported by the main distribution operators. Finally, the emission estimates for the different phases are summed and reported in the most appropriate category (transmission/distribution).

Table 3.44 provides the trend of natural gas distribution network length for each pipeline material and the average CH_4 emission factor.

Table 3.44 Length of low and medium pressure distribution network (km) and network emission factors for CH_4

Material	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
Steel and cast iron (km)	102,061	131,271	141,848	154,886	198,706	203,116	204,062	204,890	205,273	206,855	208,044	208,935	209,740
Grey cast iron (km)	24,164	23,229	21,314	15,080	4,658	2,398	2,163	2,088	2,063	2,061	2,061	2,060	2,060
Polyethylene (km)	775	7,300	12,550	31,530	49,663	56,943	57,883	59,368	59,358	59,593	59,854	61,325	61,441
Total (km)	**127,000**	**161,800**	**175,712**	**201,496**	**253,027**	**262,457**	**264,108**	**266,346**	**266,693**	**268,509**	**269,959**	**272,320**	**273,241**
EF (kg/km)	**1,958**	**1,417**	**1,228**	**1000**	**703**	**540**	**522**	**516**	**469**	**371**	**350**	**333**	**378**

More details on the methodology used and on the basic information collected from operators are reported in a technical paper carried out by ISPRA in order to assess emissions from the whole natural gas distribution grid (Contaldi, 1999). The study addressed natural gas leakages, pipelines material, and operating pressure with data of 1995. All main gas operators were involved. An estimation model was set up in order to approximate the known gas emissions from the main operators and total emissions for year 1995. Emission factors distinct by pressure (low, medium and high) and material (cast iron, grey cast iron, steel or polyethylene) was applied to achieve the goal. Emission factors from Battelle study for former West Germany was applied, cross checked with operator's data and modified where it is needed. The emission factors of minor operators (Other in the next table) are "worsened" to take account for lower quality standard. The pipelines emission factors for transmission and distribution used for emission estimates are reported in the following box:

Leakage emission factors of natural gas for transmission and distribution in pipelines by material and pressure (2022)

Material	***Pressure***		
	High	***Medium***	***Low***
	m^3/km		
Steel	379.0	319.9	207.5
Cast iron	-	391.0	328.3
Grey cast iron	-	-	5,758.5
Polyethylene	-	-	189.9

High pressure natural gas leakage factor concerns transmission network. SNAM is the main operator for national gas transmission and import-export. Medium and low pressure leakage factors concern distribution network. ITALGAS and 2iRetegas are the main operators for gas distribution. They publish annually environmental reports with amount of natural gas conveyed and total leaks. Moreover, SNAM provides to ISPRA chemical composition and energy content of national gas imported and produced. In 2022, SNAM accounts for about 93% of national pipelines length and about 99% of transported gas. ITALGAS and 2iRetegas account for about 55% of distribution network length and about 47% of distributed gas. There are about 200 operators distributing natural gas. ARERA is the National Authority for Energy, Networks and Environment. Starting from 2000, ARERA issues a yearly report with information on pipelines and network length, operating pressure, and network type concerning pipelines material. The estimation model calibrated on the main operators was used to estimate fugitive emissions from minor operators. Natural gas leaks by main operators and average composition of natural gas are used to estimate fugitive emissions. For minor operators, lower quality standard and higher specific emission factors for network material, venting, and other accidental losses were considered. So EFs for distribution are generated by combining measured data obtained directly from the main gas operators with calibrated estimates from smaller operators.

In order to take account of different sources of emissions (LNG regasification plants, compression stations, pipeline import/transmission and distribution, venting, and other accidental losses) the total leaks communicated by main operators and those estimated for minor operators are distributed resulting in implied emission factors for the other sources of emissions than transmission and distribution.

In the following box, implied emission factors for transmission and distribution sources are reported:

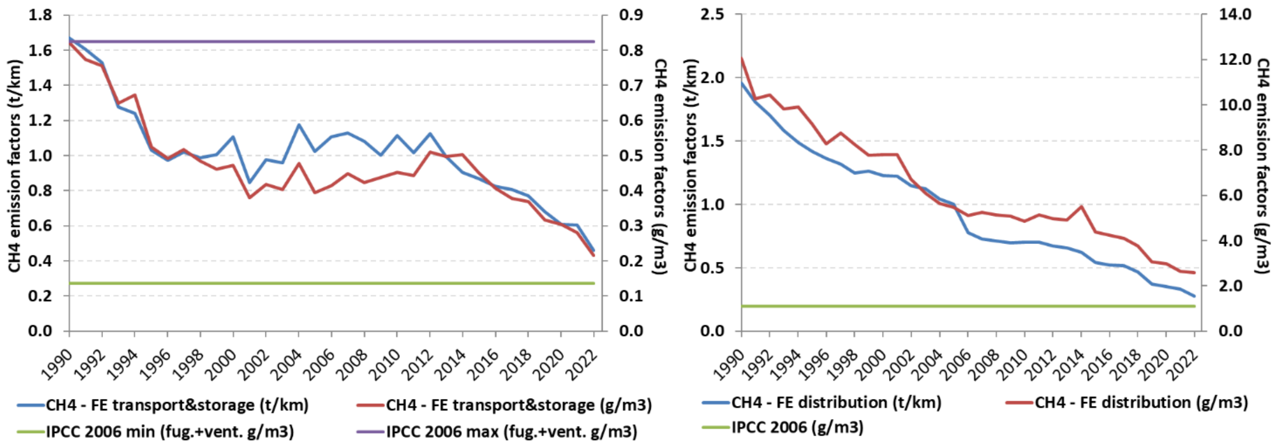
Implied emission factors (2022)

Transmission	***LNG regasification***	0.24 Mm^3 NG / Gm^3 NG imported
	Pipeline compression station	0.13 Mm^3 NG / Gm^3 NG transported
	Pipeline	379.0 m^3/km (See previous table for high pressure pipelines)
	Venting and other accidental losses	0.023 Mm^3 NG / Gm^3 NG transported
Distribution	***Pipeline***	See previous table for medium and low pressure pipelines
	Venting and other accidental losses	0.174 Mm^3 NG / Gm^3 NG distributed

Furthermore, fugitive emissions due to the use of natural gas at home are considered and estimated with an emission factor equal to *36 kg CH_4 / TJ* natural gas distributed. The estimation model used to estimate fugitive emissions is updated every year considering data published by ARERA on pipelines and it is calibrated with annual leakage data published by main operators in their environmental reports.

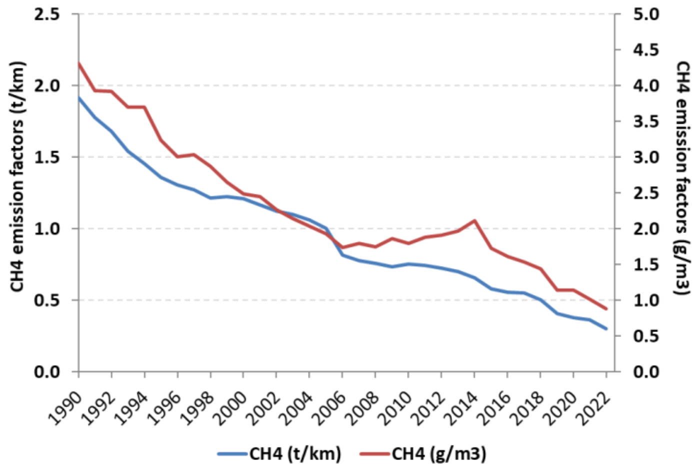
The next graph shows the CH_4 emission factors time series since 1990 for natural gas transmission and distribution compared with the respective default EFs provided by IPCC guidelines (2006). As for the transmission, the national EFs are between the range of default values. The national distribution emission factors are approaching the default value that includes fugitive and venting sources but are still more than three times higher.

Figure 3.1 Trend of CH_4 emission factors for natural gas transmission and distribution compared with the respective default EFs (IPCC, 2006).



However, it should be considered that a significant share of natural gas does not go through the distribution network but is instead directly transported to industrial sites, including power plants. According to ARERA gas distribution is also fulfilled by network operating at pressure between 5 and 24 bar which is part of the transmission network. This configuration explains why the amount of natural gas being distributed is less than 50% of the natural gas transmitted in the whole time series and shows how it is more useful to consider the matched EFs for transmission and distribution as illustrated in the next graph.

Figure 3.2 Trend of the matched CH_4 emission factors for transmission and distribution of natural gas



The different trends between the two unit of measures are explained by variable composition of natural gas along the time series as CH_4 content and average density.

Geothermal energy

Geothermal fluids can, depending on the site, contain greenhouse gases such as CO_2 and CH_4 and other minor gases such as H_2S, H_2, NH_3 and N_2. As geothermal energy is a renewable source it is considered carbon neutral so while the CO_2 emissions of are not accounted the emissions of CH_4 are evaluated.

In Italy the geothermal energy extraction for electricity production occurred up to now only in Tuscany. Starting with this submission CH_4 emissions have been estimated for the whole time series according to monitoring data of the environmental agency of Tuscany (ARPAT, several years). ARPAT issues a yearly report with CH_4 flux measures (kg/h) on a sample of power plants. There are no data on the operating hours for each plant, so the flux measures are summed up and multiplied by the average operating hours for all geothermal plants, the only available data, to obtain the total emitted amount for the sampled plants. To smooth the sampling distortion (i.e., in some year only plants with higher flux are sampled that would give an overestimation of emissions) for each year the average flux measures of the previous three years are considered for not sampled plants so obtaining an extended sample. The total emitted amount for all plants is calculated dividing the estimated amount for the extended sample plants by their power and multiplying such quantity by the total operating power.

3.10.3 Uncertainty and time-series consistency

The uncertainty in CO_2, CH_4, and N_2O emissions is quite differentiated for sources as shown in Table 3.45.

Table 3.45 Activity data (AD) and emission factor (EF) uncertainties for CO_2, CH_4, and N_2O emissions

	CO_2		CH_4		N_2O	
	AD	EF	AD	EF	AD	EF
Solid fuels	3%	10%	3%	50%	NA	NA
Oil and natural gas – Oil					3%	50%
Oil and natural gas – Natural gas					NA	NA
Oil and natural gas – Venting and flaring	50%	10%	50%	50%	50%	50%
Oil and natural gas – Flaring in refineries						

Fugitive emissions, in CO_2 equivalent, account for 1.5% out of the emissions in the energy sector in 2022. CH_4, CO_2, and N_2O emissions show a reduction from 1990 to 2022 by 68%, 55.5%, and 23.8% respectively. The overall decrease of CO_2 fugitive emissions is mainly driven by the reduction in crude oil losses in refineries, also gas venting and flaring contribute to the decreasing trend. The trend of CH_4 and CO_2 fugitive emissions from solid fuels is related to the extraction of coal and lignite that in Italy is quite low, zero from 2015, and abandoned mines. The decrease of CH_4 fugitive emissions from oil and natural gas is due to the reduction of losses for gas transportation and distribution, because of the gradual replacement of old grey cast iron pipelines with steel and polyethylene pipelines for low and medium pressure network. The CH_4 fugitive emissions from geothermal energy extraction show a relevant increase since 1990 (+121.5%) due to the entry into operation of bigger plants with higher flux values. As regards N_2O emissions, the main source, flaring in refineries, shows a reduction since 1990 by 24%.

Fugitive emissions since 1990 are reported in Table 3.46.

Table 3.46 Fugitive emissions from solid fuels and oil & gas (Gg CO_2 eq.)

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
CO_2													
Solid fuels	0.4	0.1	0.3	0.3	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oil and natural gas	4,047	4,002	3,262	2,557	2,377	2,574	2,189	2,351	2,295	2,756	2,112	1,816	1,799
CH_4													
Solid fuels	148	83	108	101	96	59	55	41	38	36	29	28	30

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
Oil and natural gas	9,784	9,052	8,398	7,573	6,776	5,500	5,034	4,897	4,474	3,612	3,470	3,323	2,742
Geothermal energy	213	228	312	374	416	536	595	585	634	552	575	481	473
N_2O													
Oil and natural gas	11	10	11	12	11	9	8	9	8	8	7	8	8
Total emissions	**14,203**	**13,376**	**12,090**	**10,616**	**9,676**	**8,677**	**7,881**	**7,883**	**7,449**	**6,964**	**6,193**	**5,656**	**5,051**

3.10.4 Source-specific QA/QC and verification

Different data sources are used for fugitive emissions estimates: official statistics by the Ministry of Environment (MASE, several years [a], [c]), Ministry of Transport (MIT, several years); national authorities (AEEG, several years; ISTAT, several years [a]), gas operators (ENI, several years [b]; EDISON, several years; SNAM, several years), and industrial association for oil and gas (UNEM, several years).

CH_4 flux data to estimate fugitive emissions from geothermal energy extraction are yearly registered by regional environmental agency of Tuscany for a sample of geothermal power plants (ARPAT, several years). Concerning CO_2 fugitive emissions from refineries activities, the estimates are balanced with the amount of crude oil losses reported in the national energy balance (MASE, several years [a]). CH_4 emissions from transmission and distribution of natural gas are verified considering emission factors reported in literature and detailed information supplied by the main operators (ENI, several years [b]; Riva, 1997).

3.10.5 Source-specific recalculations

The sources involved in the recalculations that affect the whole fugitive emission sector are:

- 1.B.2.a – 2021 Updated data of liquid fuel transported; updated country specific emission factors for oil production;
- 1.B.2.b – 2021 Updated data of natural gas imported; updated country specific emission factors for gas production and processing; updated leakage data by one of the main distribution operators;
- 1.B.2.c - Updated country specific emission factors for oil venting and flaring and for gas flaring in 2021;
- 1.B.2.d Geotherm - Minor change of emission factors used in the previous submission for 2018 and 2020. Updated data to recalculate the emission factor in 2021.

The recalculations affect 1.B.2.d source in 2018 and 2020 with 0.0002% more CH_4 emissions compared to the previous submission, and -13.5% in 2021. CO_2 emissions in 2021 from 1.B.2.a and 1.B.2.b sources are higher by 0.0001% and 1.1% respectively compared to the previous submission. CH_4 emissions from 1.B.2.a source are lower by 27.2%, while CH_4 emissions from 1.B.2.b source are higher by 1.2%. CH_4 emissions from 1.B.2.c venting and flaring are higher by 14.8% and 5.5% respectively.
The recalculations affect total CO_2eq emissions by -0.91% compared to the previous submission.

3.10.6 Source-specific planned improvements

No further improvements are planned for the next submission.

4 INDUSTRIAL PROCESSES AND PRODUCT USE

4.1 Sector overview

By-products or fugitive emissions, which originate from industrial processes, are included in this sector. Where emissions are released simultaneously from the production process and from combustion, as in the cement industry, these are estimated separately and included in category 1.A.2. All greenhouse gases as well as CO, NO_X, NMVOC and SO_2 emissions are estimated. N_2O emissions are also estimated, which arise from chemical industry (2B) and from "other product manufacture and use (2G). As for category 2G, the use of N_2O occurs in medical applications, such as anesthesia, and in the food industry, where N_2O is used as a propelling agent in aerosol cans, specifically those for whipped cream. Emissions from the use of N_2O in explosives are also included.

CO_2 emissions related to NMVOC from solvent use in paint application, degreasing and dry cleaning, chemical products manufacturing or processing and other use, are estimated and, from this year's submission, reported separately, as indirect emissions. These emissions are described under the section 'Solvent use and indirect CO_2 emissions'.

In 2022 industrial processes and product use account for 55.7% of CO_2 emissions, 0.2% of CH_4, 2.0% of N_2O, 42.2% of F gases. In terms of CO_2 equivalent, industrial processes and product use contribute 5.7% to the total national greenhouse gas emissions.

The trends of greenhouse gas emissions from the industrial processes sector are summarized in Table 4.1. Emissions are reported in kt for CO_2, CH_4 and N_2O and in kt of CO_2 equivalent for F-gases. An increase in HFCs emissions is observed from 1990 to 2022, while CO_2 emissions from chemical and metal and mineral industry reduced sharply in the period.

Table 4.1 Trend in GHG emissions from the industrial processes and product use sector, 1990-2022 (kt)

Gas/Subcategory	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
CO_2 (kt)	**27,992.0**	**26,049.3**	**24,742.7**	**27,662.7**	**20,804.3**	**14,354.6**	**14,230.2**	**12,932.0**	**14,620.9**	**13,145.2**
2A. Mineral Products	20,720.5	20,239.7	20,749.0	23,304.7	17,341.5	11,291.2	11,005.7	9,862.2	11,145.7	10,175.5
2B. Chemical Industry	2,524.2	1,584.0	1,356.4	1,635.0	1,361.9	1,219.7	1,314.5	1,358.5	1,427.6	1,093.9
2C. Metal Production	4,377.9	3,902.7	2,305.3	2,419.4	1,833.8	1,562.9	1,602.3	1,438.6	1,738.3	1,589.0
2D. Non-energy products from fuels and solvent use	369.5	322.9	332.0	303.6	267.1	280.9	307.8	272.8	309.4	286.8
CH_4 (kt)	**5.2**	**5.4**	**2.9**	**3.0**	**2.4**	**1.7**	**1.7**	**1.4**	**1.6**	**1.4**
2B. Chemical Industry	2.5	2.7	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1
2C. Metal Production	2.7	2.7	2.6	2.7	2.2	1.5	1.5	1.2	1.5	1.3
N_2O (kt)	**24.2**	**25.8**	**28.9**	**27.7**	**4.1**	**2.1**	**2.1**	**2.1**	**1.9**	**1.8**
2B. Chemical Industry	21.6	23.3	25.6	25.0	2.1	0.5	0.4	0.4	0.2	0.1
2G. Other product manufacture and use	2.6	2.5	3.3	2.7	2.0	1.6	1.7	1.7	1.7	1.7
HFCs (kt CO_2 eq.)	**372.0**	**1,099.5**	**3,747.3**	**9,666.1**	**12,804.9**	**12,081.5**	**11,089.5**	**9,971.4**	**9,411.1**	**9,085.4**
2B. Chemical Industry	372.0	471.5	24.6	22.8	0.9	1.1	1.0	0.7	0.9	0.9
2C. Metal Production	-	-	-	-	1.9	9.2	5.2	4.9	4.4	3.5

Gas/Subcategory	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
2E. Electronics Industry	-	6.1	8.7	7.2	10.7	9.5	6.6	7.8	7.8	8.3
2F. Product Uses as Substitutes of ODS	-	621.9	3,714.0	9,636.1	12,791.4	12,061.8	11,076.7	9,958.0	9,398.1	9,072.8
PFCs (kt CO_2 eq.)	**2,615.0**	**1,350.9**	**1,363.3**	**1,759.4**	**1,376.6**	**1,528.7**	**915.4**	**498.7**	**395.3**	**439.1**
2B. Chemical Industry	836.5	934.9	889.5	1,388.3	1,166.9	1,392.3	780.4	374.6	261.2	300.3
2C. Metal Production	1,778.5	315.0	207.6	190.7	89.2	-	-	-	-	-
2E. Electronics Industry	-	101.0	266.2	180.4	120.6	136.4	135.1	124.1	134.1	138.8
SF_6 (kt CO_2 eq.)	**420.9**	**700.1**	**621.0**	**565.1**	**404.9**	**483.5**	**437.6**	**251.7**	**282.3**	**390.3**
2B. Chemical Industry	117.5	117.5	-	-	-	-	-	-	-	-
2C. Metal Production	-	-	169.2	83.3	17.2	-	-	-	-	-
2E. Electronics Industry	-	14.9	61.9	57.2	30.6	47.3	52.5	36.9	40.8	40.3
2G. Other Products Manufacture and Use	303.4	567.7	389.9	424.7	357.2	436.2	385.1	214.8	241.5	350.1
NF_3 (kt CO_2 eq.)	**-**	**76.6**	**13.3**	**33.4**	**20.2**	**28.4**	**17.9**	**16.2**	**15.2**	**19.6**
2E. Electronics Industry	-	76.6	13.3	33.4	20.2	28.4	17.9	16.2	15.2	19.6
Unspecified mix of HFCs and PFCs (kt CO2 eq.)	**-**	**24.4**	**24.4**	**24.4**	**24.4**	**24.4**	**23.2**	**22.4**	**25.3**	**22.1**

Thirteen key categories have been identified for this sector, for level and trend assessment, with and without LULUCF, using both Approach 1 and Approach 2. The results for 2022 are reported in the following Table 4.2.

Table 4.2 Key-category identification in the industrial processes sector with the IPCC Approach 1 and Approach 2 for 2022

KEY CATEGORIES			without LULUCF	with LULUCF
2A	CO_2	Emissions from cement production	L, T	L, T
2A	CO_2	Emissions from lime production	L1	L1
2A	CO_2	Emissions from other process uses of carbonates	T	T
2B	CO_2	Emissions from ammonia production	T	T
2B	N_2O	Emissions from adipic acid production	T	T
2B	N_2O	Emissions from nitric acid production	T	T
2B	HFCs	Emissions from fluorochemical productions	T2	T2
2B	PFCs	Emissions from fluorochemical productions	T2	T2
2C	CO_2	Emissions from iron and steel production	T1	L1, T1
2C	PFC	Emissions from Aluminum production	T	T
2F	HFCs	Emissions from substitutes for ODS- Refrigeration and air conditioning	L, T	L, T
2F	HFCs	Emissions from substitutes for ODS- Foam blowing agents	T2	T2
2F	HFCs	Emissions from substitutes for ODS- Fire protection	L, T	L, T

CO_2 emissions from cement, lime and other carbonate uses are included in category 2A; N_2O emissions from adipic acid, nitric acid and CO_2 emissions from ammonia refer to 2B; CO_2 emissions from iron and steel production and PFC emissions from aluminum production are included in 2C; HFCs from substitutes

for ODS are included in 2F and HFC and PFC emissions from fluorochemical production are included in 2B. Methane emissions from the sector are not a key source. CO_2 from Ammonia production, Iron and steel, Cement production, Lime production and Other processes uses of carbonates; N_2O from Adipic acid production and Nitric acid production; HFCs from Product uses as substitutes for ODS are also key categories in the 1990 assessment.
For the industrial processes sector, emissions and background data collected in the framework of the European Emissions Trading Scheme, the National Pollutant Release and Transfer Register (Italian PRTR) have been used either directly in the estimation process or as verification of emission estimates, improving national emissions factors as well as activity data.

Emissions and activity data submitted under the ETS are mandatorily subject to verification procedures, as requested and specified by the European Directive 2003/87/EC (art. 15 and Annex V). In compliance with the above-mentioned legislation, independent certifications and verifications of activity data, emission data and emission factors are required. At national level, data verification must be carried out by verifiers accredited by the national ETS Committee. The verification of data submissions ensures reliability, credibility, and precision/accuracy of monitoring systems for data and any information relating emissions by plant. The guidelines for reporting under ETS are aligned to the 2006 IPCC Guidelines.

The Italian legislation implementing EPER Decision included a legislative decree and a Ministry decree providing guidelines for reporting by the Italian EPER facilities. The Italian legislation implementing Regulation (EC) 166/2006 is a Decree of the President of the Republic (DPR n.157/2011). Annexed to the DPR n.157/2011 is a guideline for the reporting by the Italian PRTR facilities.

Both guidelines for the reporting by the Italian EPER/PRTR facilities provide the list and description of the information to be reported, which includes: activity data (mandatory), total releases exceeding the reporting threshold values (mandatory); total off-site transfers of pollutant exceeding the reporting thresholds (mandatory); total off site transfers of waste exceeding the reporting thresholds (mandatory).

Releases/transfers information to be reported by facility operators can be based (in compliance with national and EU legislation) on measurement, calculation, and estimation. In the case that operators report information based on measurements/calculation they are requested to communicate also what methodology has been applied to measure/calculate total releases/transfers.

As for activity data reporting under the national PRTR, no detailed requirements have been included in the national PRTR legislation and guidelines, although some general guidance is provided and followed by operators. The operator is expected to report the best available information concerning activity data for each reporting year, basically the amount produced, manufactured or treated in the reporting year shall be reported. It is appropriate to consider also that most facilities in the scope of EPER/PRTR are also in the scope of EU and national legislation concerning the permitting procedures, monitoring and control obligation for industrial facilities larger in size. The quality of information reported by the facilities under the national EPER/PRTR is assessed by the competent authorities, the same authorities are usually involved also in the permitting procedure of these facilities, thus cross checks of information concerning AD and emissions are expected by the national legal framework.

Since emissions data reported under the national EPRTR can be measured, calculated or estimated, the European PRTR Guidance Document and the national guideline for reporting to the national PRTR include also references to the IPCC Guidelines methodologies.

The collection of facility reports under the national EPER/PRTR is a task that ISPRA has to carry out by law. The national inventory team is in the same unit of ISPRA where the national EPER/PRTR is managed, the inventory team has full access to the whole national dataset of the Italian EPER/PRTR without restrictions on the type of information (AD and emissions of each reporting facilities are available for the inventory team). Italian EPER/PRTR data (emissions and transfers of pollutants, transfers of wastes) are publicly available on the internet at the European Industrial Emissions Portal https://industry.eea.europa.eu/ (in compliance with the legislation, activity data of the reporting units are not disclosed to the public).

Data from the ETS and EPRTR databases are incorporated into the national inventory whenever the sectoral coverage is complete; in fact, not always data entirely cover the relevant categories whereas national statistics provide the complete basic data needed for the Italian emission inventory. Nevertheless, these data are entirely used to develop country-specific emission factors and check activity data levels.

4.2 Mineral Products (2A)

4.2.1 Source category description

In this sector CO_2 emissions from the following processes are estimated and reported: cement production, glass production, lime production and other processes uses of carbonates.

Cement

Cement production (2A1) is the main source of CO_2 emissions in this sector. As already mentioned, it is a key source both at level and trend assessment with and without LULUCF, also considering uncertainty, and accounts for 1.7% of the total national emissions.

During the last 15 years, in Italy, changes in cement production sector have occurred, leading to a more stable structure. The oldest plants were closed, wet processes were abandoned in favor of dry processes so as to improve the implementation of more modern and efficient technologies. The effects of the global recession period have led at national level to facilities closedowns and many conversions from full cycle to grinding plants. Since 2011 Italy has become the second cement producer country in the EU 27 because of the reduction of clinker production in the last years.

The picture of the cement sector in 2022 has 17 companies (50 plants of which: 29 full cycle and 21 grinding plants, i.e. in 2022 one full cycle plant more and two grinding plants less compared to 2021) operating in Italy: multinational companies and small and medium size enterprises (operating at national or only at local level) are present in the country. The operating plants are located as follows: 44.0% is in northern Italy, 18% is in the central regions of the country and 38% is in the southern regions and in the islands. The active sintering rotary kilns belong to the "dry" or of "semidry" types. In Italy different types of cement are produced; Federbeton/AITEC, the national cement association, has characterised the national production in 2022 as follows: 72% is CEM II (Portland composite cement); 12% is CEM I (ordinary Portland cement); 12% is CEM IV (pozzolanic cement) and 4% is CEM III (blastfurnace cement). Clinker production has been decreasing since 2007, although from 2016 to 2019 the production values have kept very close to the amount manufactured in 2016, in 2020 clinker production shows -6.0% compared to 2019 (Federbeton/AITEC [a], several years) due to pandemic, while in 2022 clinker production was +3.3% compared to 2021. Clinker demand in cement production was about 83% in 2022 (consumption of clinker out of production of cement).

Lime

In 2022, CO_2 emissions from lime production is key source at level assessment, with and without LULUCF, following the Approach 1.

CO_2 emissions occurring from processes where lime is produced account for 0.4% of the total national emissions. Lime production can also occur, beside lime industry, in different industrial sectors such as iron and steel making, pulp and paper production, soda ash production, sugar production; lime can also be used in a number of processes concerning wastewater treatment, agriculture and the neutralization of acidic emissions in the industrial flue gases. In particular, the other relevant lime productions accounted for in Italy are those occurring in the iron and steel making process and in the sugar production process (although lime production&use at sugar mills occurs without release of CO_2, since CO_2 released from decarbonization is used with lime in the purification of the sugar molasses).

Lime is basically produced by calcination of limestone (calcium carbonate) or dolomite (calcium/magnesium carbonate) at 900°C. The process leads to quicklime and CO_2 emissions according to the following reaction:

$$CaCO_3 + MgCO_3 + heat \rightarrow CaO + MgO + 2CO_2$$

CO_2 is released because of the process reaction itself and also because of combustion to provide energy to the process. CaO and MgO are called quicklime. Quicklime, together with water, give another product of the lime industry which is called calcium hydroxide $Ca(OH)_2$. CO_2 emissions estimation is related to lime production in mineral industry and it also includes the production of lime to feed other industrial processes (e.g. iron and steel making facilities).

The number of lime production facilities has been relevantly changing over the years as shown in the Table 4.3.

Table 4.3 Lime production facilities (number)

	1990	2003	2010	2014	2015	2016	2019	2020	2021	2022
Lime facilities (n.)	85	46	35	29	25	26	23	23	21	21

Figures from 2010 onwards are based on the number of facilities reporting under the EU-ETS. Moreover, 36% of the plants is in the southern regions and in the islands, 50% is in the northern regions and 14% in the central regions. The number of operating kilns has also decreased significantly through the years (about 171 in 1990, 75 in 2003 and 25 at present). During the nineties, lime industry invested in technology implementation to replace the old kilns with regenerative and high efficiency kilns, rotary kilns are no longer used.

Concerning lime industry fuel consumptions, based on TJ reported to the national ETS system, the main energy carriers in 2022 are solid biomass (52%) burnt in the kilns, natural gas (33%) mainly for thermal uses, oil and diesel oil account for less than 2%, coke and pet-coke account for 5.2% while anthracite consumption is 8.2%. In 2013 biomass burnt in the kilns was 5.3%, natural gas 47.1%, coke and petcoke accounted for 21.8% and anthracite was 7.4%, while in 2005 natural gas provided 78.4% of total energy input, pet-coke 13.8% and oil 4.9%.

Other processes uses of carbonates (limestone and dolomite use in brick and tiles; fine ceramics; paper industry and power plants)

This category is key source in 2022 at trend assessment, with and without LULUCF, following the Approach 1 and Approach 2.

CO_2 emissions are also related to the use of carbonates in different industrial processes, and they account for 0.16% of the total national emissions. Limestone or dolomite can be added in different steps of the production process to obtain the desired product features (i.e., colour, porosity). Sometimes carbonates in limestone and dolomite may have to be calcined ("dead burned") in order to be added to the manufacturing process. Limestone and dolomite are also used in paper production process and in the treatment of power plants flue gases. A steep decrease in the production processes and the relevant use of limestone can be observed between 2007 and 2009; use of limestone has been decreasing more gradually since 2009; the overall decrease being mainly driven by limestone and dolomite use in the brick and tiles sector. Mineral (stone) wool production which occurred in Italy along the years 1993-2009 is included in emission estimates for the energy sector. Stone wool has not been produced in Italy since 2009. This category also includes the whole time series for CO_2 emissions from other uses of soda ash.

Glass production

Glass industry in Italy can be characterized with regard to four glass product types: flat glass, container glass, borosilicate and lead/crystal glass. Flat glass is produced in facilities mainly located in the North; container glass is produced in facilities located all over the country; glass fibers and wool are produced in the North. About 70 companies carry out, currently, activities related to glass industry in Italy, about 27 companies carry out glass production processes in about 55 production units. With regard to glass chemical composition, the national glass production consists of 95% soda-lime glass, 4% borosilicate glass and 1% lead/crystal glass. The main steps of the production process in glass industry are the following:

- raw materials storage and batch formulation;
- melting of the formulated batch at temperature ranging from 1400°C to 1600°C, in different furnaces according to the type of glass product;
- forming into glass products at specific temperature ranges;
- annealing of glass products to prevent weak glass due to stress.

The formulated batch is generally melted in continuous furnaces, whose size and features are related to the types of glass production. In Italy glass industry production is basically fuelled using natural gas and low sulphur content oil (in 2022, 93% of energy input came from natural gas and 7% from oil; while in 2005 natural gas share and oil share were 84% and 16% respectively). Emissions are basically released by the high temperature melting step and depend on the type of glass product, raw materials and furnaces involved in the production process. Main pollutants are: dust, NO_x, SO_x, CO_2; occasionally and depending on the specific production process, heavy metals, fluorides and chlorides gases could be released. CO_2 emissions are mainly related to the decarbonisation of carbonates used in the process (soda ash, limestone, dolomite) during the melting phase, accounting for 0.15% of the total national emissions. The use of scrap glass (recycled cullets) in the production processes has been increasing in Italy since 1998 thus contributing to the reduction of emissions from decarbonation and from the melting phase.

In Table 4.4, values of the rate of glass recycling from 1998 are reported (CoReVe, several years).

Table 4.4 Rate of glass recycling

	1998	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
Rate of glass recycling (%)	38.8	46.9	57.2	58.4	70.9	71.4	73.9	73.4	77.4	78.6	76.6	80.8

4.2.2 Methodological issues

The IPCC Guidelines are used to estimate emissions from this sector (IPCC, 2006). Activity data are supplied by industries and/or provided in the national statistical yearbooks (ISTAT, several years [a]). Emission factors are those provided by the IPCC Guidelines (IPCC, 1997; IPCC, 2000; IPCC, 2006), by other international Guidebooks (EMEP/EEA, 2023; USEPA, 1997), or they are derived by data communicated at plant level.

Cement

CO_2 emissions from cement production are estimated using the IPCC Tier 2 approach.

Activity data derived from different official sources along the time series. More in details, from 1990 to 2008 official statistics provided by ISTAT were used (ISTAT, several years [a]). From 2009, data on clinker and cement production, based on a plant-by-plant monthly collection, were officially provided by the Ministry for the Economic Development, at national and regional level (MSE, several years).

These production data were cross checked with EPRTR and ETS data and with ISTAT statistics when available. From 2017, activity data referring to cement/clinker production have been taken from the data reported to the national ETS.

Emission factors are estimated on the basis of information provided by the Italian Cement Association (Federbeton/AITEC, several years[a]) and by cement facilities in the framework of the European pollutant release and transfer register (E-PRTR) and the European emissions trading scheme (EU-ETS). In this latter context, cement production facilities reported fuel consumption, raw materials and emissions, split between combustion process and decarbonising process and complying with a clinker kiln input method which is based on IPCC methodology.

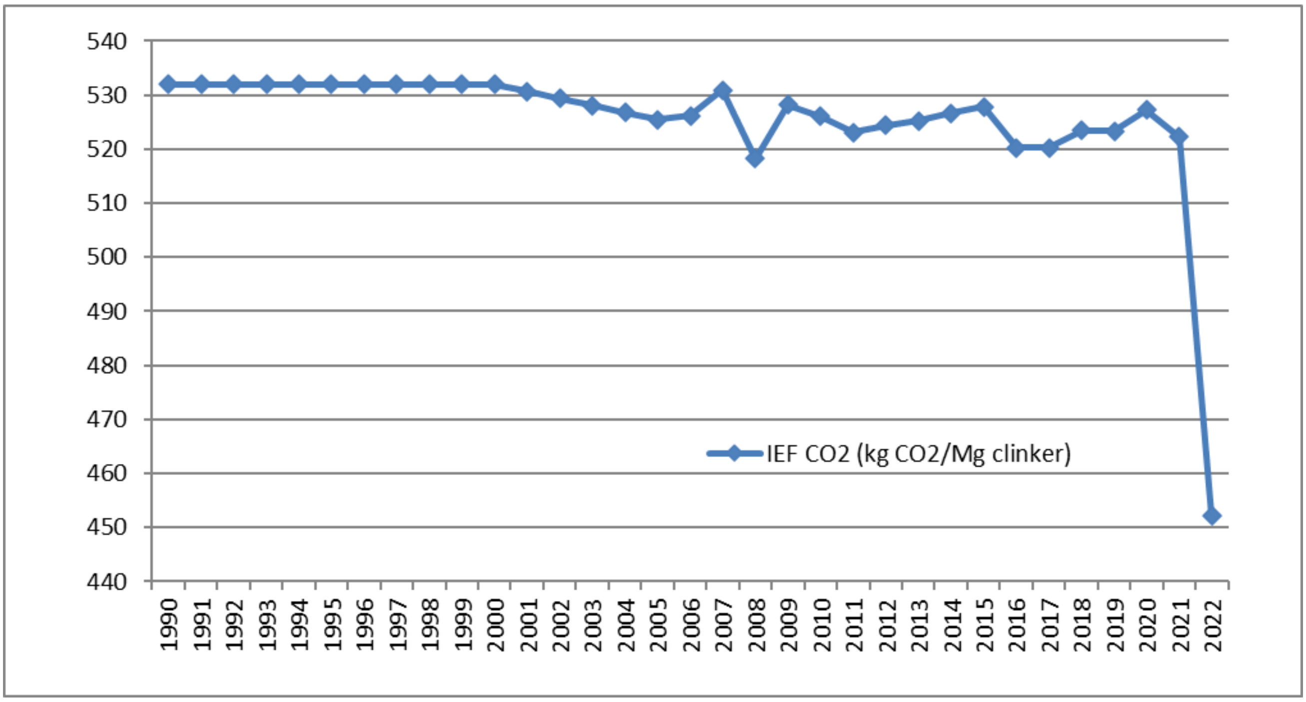
From 1990 to 2000 the resulting emission factor for cement production is equal to 532 kg CO_2/t clinker, based on the average CaO content in the clinker and considering the contribute of carbonates and additives. This value was assumed as representative of the Italian clinker manufacturing process by AITEC (AITEC, 2004) and officially reported to the Italian Ministry of Environment in order to set the national circumstances for the implementation of the European-Emissions Trading Scheme (EU-ETS) in our country. The value was calculated by the industrial association on the basis of a tool provided by the World Business Council for Sustainable Development, available on website at the address http://www.ghgprotocol.org/files/ghgp/tools/co2_CSI_Cement_Protocol-V2.0.pdf and data from some big Italian plants.

From 2001 to 2004, emission factors are the result of a linear interpolation of CO_2 IEF for 2000 and 2005.

From 2005, emission factors are based on the data reported within the frame of the EPER/EPRTR and EU-ETS. Based on emissions and activity data (which includes the average CaO content in the clinker produced and the use of carbonates and additives), reported and verified under the EU-ETS, the resulting emission factor has been fluctuating as shown in Figure 4.1: it resulted in a minimum equal to 518 kg CO_2/t clinker in 2008, and a maximum equal to 531 kg CO_2/t clinker in 2007. Since 2016 the CO_2 IEF has been ranging between 520÷525 kg CO_2/t clinker, in 2021 the values is 522 kg CO_2/t clinker while 452 kg CO_2/t clinker is observed in 2022. The average emission factor varies year per year also as a consequence of the different operating circumstances (e.g. quality of the raw materials and operating conditions) at the Italian clinker facilities. The strong decrease in 2022 results from an increase of decarbonized materials fed into the kilns of a group of clinker facilities owned by the same company, in such a way that in 2022 two omogeneous distinct groups of operating cement facilities can be identified against the values of CO_2 IEF.

The information related to activity data and emissions for the clinker facilities reporting to the national ETS system have been processed. The range of uncertainty based on data communicated by the plants is about 5% in the period 2005-2009, about 4% in the period 2010-2015, about 6% in 2016, 5% in 2017 and 3% in 2018 and in 2019, 5.5% in 2020 and 4.6% in 2021 and 42% in 2022. The same calculation performed separately on data referred to the two subgroups of cement facilities in 2022 results in uncertainty values comparable to those of previous years.

Figure 4.1 CO_2 IEF from decarbonation in clinker production, 1990-2022



In addition to this, Federbeton/AITEC has been reporting the overall consumption of natural raw materials by the national cement industry and also the replacement of natural raw material (either in the raw meal for the clinker manufacture or in the ground mix for the different cement types) with alternative materials in the Italian cement facilities, so:

- Specific consumption of natural raw materials has been varying for the last years;
- The rate of replacement of natural raw materials has been varying for the last years.

In 2022, approximately 7.8% of natural raw material was replaced by about 1.83 Mt non raw materials (0.65 Mt non hazardous wastes and 1.18 Mt secondary raw material) (Federbeton/AITEC[b], several years). Most of the alternative materials consist of already decarbonized materials. The use of decarbonized material in amounts varying year by year in clinker kilns contributes explaining the fluctuations in the trend of the CO_2 IEF from decarbonization.

In Table 4.5, the amounts of natural raw material consumption for the years 2009-2022 have been reported together with the amounts of secondary raw materials and the replacement rates.

Table 4.5 Replacement of natural raw materials by secondary raw materials at the Italian cement facilities

RAW MATERIALS DEMAND	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Natural raw materials (Mt)	43.6	43.4	40.4	34.2	29.8	25.1	23.5	25.4	27.5	25.4	23.7	21.6	24.4	23.5
Secondary raw materials (Mt)	1.9	1.8	1.9	2.3	1.9	1.7	1.5	1.6	1.8	1.5	1.6	1.5	1.7	1.8
Natural raw material/ clinker (t/t)	1.7	1.7	1.7	1.8	1.8	1.6	1.5	1.7	1.8	1.7	1.6	1.6	1.6	1.5
Replacement of natural raw material (%)	4.0	4.3	4.3	6.8	6.7	6.3	6.5	6.4	6.7	6.0	6.7	7.0	7.0	7.8

(source: Federbeton/AITEC, several years[b])

Regarding industry data verification, the available activity data for the cement/clinker production in Italy are consistent to the information supplied by the Italian cement industry association, to data reported under the national PRTR and also to data collected in the frame of the national ETS. Emission data reported under the different obligations are in accordance with all the facilities. The number of clinker facilities reporting under EPRTR and ETS are shown in Table 4.6 together with the corresponding number of operating facilities according to the cement association (AITEC).

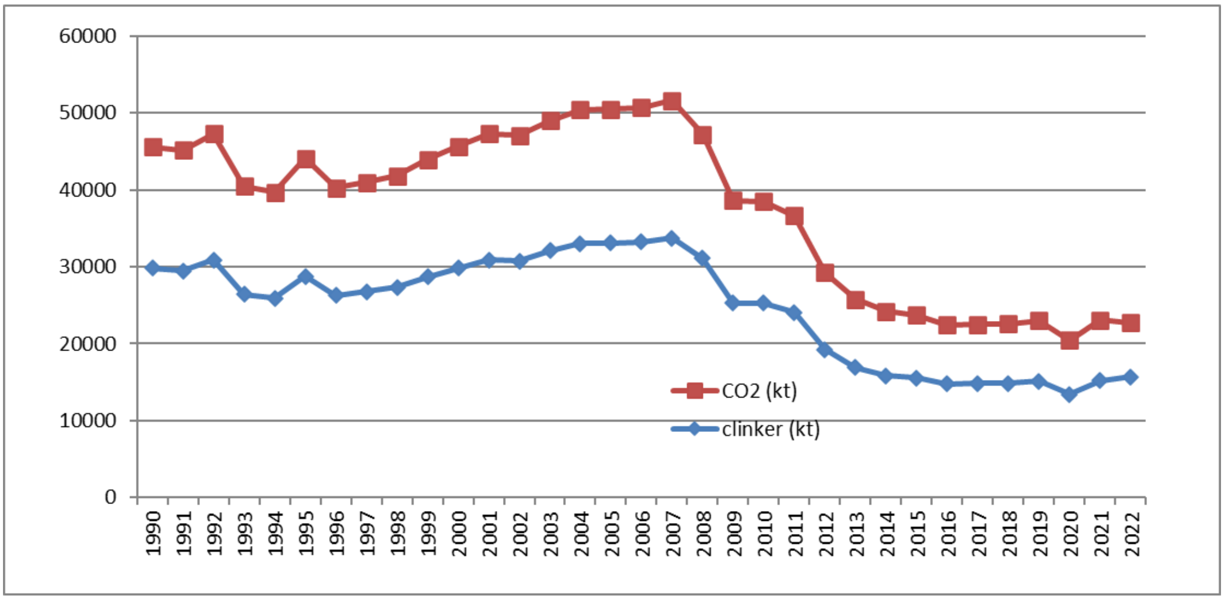
Table 4.6 Clinker facilities reporting under EPRTR and ETS

Clinker facilities	2005	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Reporting to the national PRTR (n)	52	53	50	50	51	47	37	34	32	30	30	29	27	28	29
Reporting under the national ETS (n)	52	52	52	51	51	48	39	36	32	32	31	31	29	28	29
Number of clinker manufacturers in Italy (AITEC)	59	58	58	57	56	50	40	37	33	33	32	32	30	28	29
PRTR/AITEC (%)	88	91	86	88	91	94	93	92	97	94	94	91	90	100	100
ETS/AITEC (%)	88	90	90	89	91	96	98	97	97	97	97	97	97	100	100

In the framework of the EU-ETS register, 29 cement facilities reported referred to 2022 whilst 29 reported releases to air under the EPRTR register. These figures out of 29 operating facilities according to Federbeton/AITEC represent the whole national clinker production. Generally, when the number of ETS clinker facilities is lower than Federbeton/AITEC figure, information concerning localization and production capacity is available for the facilities out of the scope of EU-ETS. Federbeton/AITEC reports every year the number of operating cement/clinker facilities in Italy and the cement production of the whole sector. Under the EU-ETS, cement plants communicate emissions and activity data split between energy and processes phases and specifying the amount of carbonates and additives which are constituents of the raw meal complying with a "clinker kiln input" approach; both activity data and emissions are independently verified and certified as requested by the EU-ETS directive. The implied CO_2 emission factor is applied to the total national clinker production.

Basically, CO_2 emissions time series is related to clinker production time series. Specifically, main decreases in the national production of cement industry, which well reflects the trend of the national economy, can be observed for the years 1992-1994; an increase in production can be observed from 1996 to 2001 and from 2002 to 2007, while a significant decrease in the production is observed for 2007- 2009 and 2011-2017 due to the effects of the economic crisis and the significant reduction in the number of authorizations to build between 2005 and 2015 (-84%). A weak increase in the number of new permits to build was recorded also in 2019, whilst a decrease is observed in 2020. Practically, the same variations can be observed in CO_2 emissions trend. Clinker production and CO_2 emissions time series are shown in Figure 4.2.

Figure 4.2 Trend of clinker production and CO_2 emissions 1990-2022 (kt)



Lime

CO_2 emissions from lime have been estimated on the basis of production activity data supplied by ISTAT up to 2008 (ISTAT, several years [a]) and by operators in the frame of the ETS reporting obligations from 2009.

ISTAT data included only marketed lime, so non-marketed lime productions were added to these data, where non-marketed lime is equal to the manufacture of lime at iron & steel sites and sugar mills. The information referring to the annual amount of non-marketed lime is supplied by the operators of such facilities under the national pollutant release and transfer register (PRTR).

ETS data has been used from 2009. All the national lime production plants are part of the EU-ETS.

CO_2 emissions from lime production and use in other industrial processes (e.g. iron and steel production, sugar mills) have been also considered. Emission factors have been based on detailed information supplied by lime facilities in the framework of the European emission trading scheme and by the national lime industrial association (CAGEMA, 2005). Specifically, the value of the emission factor from 1990-2000 has been officially supplied to the Italian Ministry of Environment by the industrial association (CAGEMA, 2005), in order to set the national circumstances for the implementation of the European-Emissions Trading Scheme (EU-ETS).

From 2001 to 2004, emission factors are the result of a linear interpolation of CO_2 IEF for 2000 and 2005. From 2005, in the frame of the ETS reporting obligation activity data (including fuels and raw materials such as carbonates and additives, in compliance with a "lime kiln input" approach) were available at facility level together with CO_2 emissions (combustion and process emissions). Both activity data and CO_2 emissions are certified and independently verified as requested by the EU-ETS legislation.

The CO_2 implied emission factor varies year by year because of the natural raw material fed to the kilns at facility level including different CaO and MgO contents. In Table 4.7, CaO and MgO contents for the years 2009-2022 are reported; these figures refer only to the production plants, excluding autoproduction.

Table 4.7 CaO and MgO oxides content for lime production (%)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CaO content (%)	96.9	96.7	96.2	93.6	94.4	89.8	90.7	97.1	97.7	95.5	88.8	84.1	82.3	83.2
MgO content (%)	3.1	3.3	3.8	6.4	5.6	10.2	9.3	2.9	2.3	4.5	11.2	15.9	17.7	16.8

Other processes uses of carbonates (Limestone and dolomite)

CO_2 emissions from other process uses of carbonates are related to the use of limestone and dolomite in bricks, tiles and ceramic production, paper production and also in the treatment of flue gases from power plants. In Italy only limestone is used for the activities included in this category, brick and tiles, fine ceramic, and pulp and paper production and power plant flue gases treatment, while no dolomite use is documented. CO_2 emissions from other uses of soda ash are included under this category, based on the activity data and emissions information reported by facilities in the scope of the national ETS. In 2022 about 83.4% of the total carbonates accounted for in this category has been used in the production processes of bricks and tiles, about 5.3% for the fine ceramic material, 9.8% in the treatment of flue gases in the power plants, about 0.2% in the paper industry and 1.2% is the share of the other uses of soda ash.

CO_2 emissions have been estimated on the basis of the IPCC default value for limestone equal to 0.44 t/t; the overall CO_2 emission time series is mainly driven by the CO_2 emissions from the use of limestone in the bricks and tiles sector.

In the CRTs the total amount of carbonates accounted for in this category used in these processes is reported.

Detailed production, consumption, activity data and emission factors have been supplied in the framework of the European emissions trading scheme and relevant data are annually provided by the Italian bricks and tiles industrial association and by the Italian ceramic industrial associations (ANDIL, 2000; ANDIL, several years; ASSOPIASTRELLE, several years; ASSOPIASTRELLE, 2004; Confindustria Ceramica, several years). Even though the EU ETS has not been in operation for the whole time-series relevant information concerning the use of carbonates was made available in the communications to the Italian Ministry of Environment to get the overview of the sector for the national ETS to be implemented.

Mineral (stone) wool production has been also taken into account and CO_2 emissions have been estimated but they are included under Energy sector because it is not possible to identify the share of emissions related to the process and to the energy aspects. Mineral wool production in Italy took place in Sardinia at one facility from 1993 to 2009 where the production was considered not profitable any longer and the facility was closed down.

Glass

CO_2 emissions from glass production have been estimated taking into account, from 1990 to 2004, production data published by ISTAT on the National Statistical Yearbooks (ISTAT, several years [a]); from 2005 ISTAT statistics have not been available anymore and consistent figures published by the national glass industry association have been used (Assovetro, several years). Glass wool production is included for the whole time series.

In Table 4.8, the complete time series of the national inventory for glass production is reported for the different types of glass.

Table 4.8 Glass production time series (Mg)

Type	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Flat glass	816,406	879,750	1,009,367	1,183,310	921,619	838,019	1,034,234	965,859	1,190,251	1,155,728
Container glass	2,609,826	3,094,893	3,417,851	3,716,509	3,656,425	3,936,885	4,485,190	4,429,110	4,702,984	4,773,762
Glass wool	105,029	119,120	139,421	129,958	115,332	86,929	99,552	88,319	105,574	104,898
Other glass	247,684	165,213	362,970	298,000	369,730	381,900	414,087	392,316	454,572	457,532

Since 2000, information provided by operators under the national ETS has been used to develop emissions estimation and relevant CO_2 emission factors. CO_2 emissions from the decarbonation, considering the national circumstances concerning the use of cullets (recycled scrap glass which does not cause CO_2 emissions) in the production processes, have been estimated. In 2022, CO_2 emission factor has been estimated equal to 96 t CO_2/t, based on the information supplied under the European emissions trading scheme by 47 out of 53 facilities.

4.2.3 Uncertainty and time-series consistency

The uncertainty in CO_2 emissions from cement, lime, other process uses of carbonates and glass production is estimated to be equal to 10.4% from each activity, resulting from 3% and 10% for activity data and emission factor, respectively. Official statistics of activity data for these categories are quite reliable when compared to the activity data reported by facilities under different data collections, thus leading to the considered uncertainty level for the activity data. The uncertainty level for emission factors is equal to the maximum level reported in the IPCC Good Practice Guidance (IPCC, 2000) for the cement production; this is a conservative estimation because the range of values of the emission factors of the Italian cement plants would lead to a lower uncertainty level. In Tables 4.9 and 4.10, the production of mineral products and CO_2 emission trend is reported.

Table 4.9 Production of mineral products, 1990 – 2022 (kt)

Activity data	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
					kt					
Cement production (decarbonizing)	29,786	28,778	29,816	33,122	25,239	15,527	15,119	13,389	15,162	15,684
Glass (decarbonising)	3,779	4,259	4,930	5,328	5,063	5,244	6,033	5,876	6,453	6,491
Lime (decarbonising)	2,583	2,873	2,760	3,447	2,789	2,348	2,420	2,178	2,623	2,665
Other processes use of carbonates (Limestone and dolomite use)	5,781	5,292	5,143	6,087	3,580	1,886	1,426	1,230	1,385	1,465

Table 4.10 CO_2 emissions from mineral products, 1990 – 2022 (kt)

CO_2 emissions	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
					kt					
Cement production (decarbonizing)	15,846	15,310	15,862	17,403	13,276	8,196	7,912	7,059	7,919	7,093
Glass (decarbonizing)	453	511	611	768	559	534	597	569	614	623
Lime (decarbonizing)	1,877	2,090	2,013	2,456	1,932	1,643	1,776	1,611	2,003	1,815
Other processes use of carbonates (Limestone and dolomite use)	2,544	2,328	2,263	2,678	1,575	830	627	541	609	644

Emission trends are generally related to the production level, which has been decreasing for the last years mainly because of the economic recession. In particular, the trend of carbonates used in power plants for flue gases treatment, is driven by the use of coal in the operating power plants.

4.2.4 Source-specific QA/QC and verification

CO_2 emissions have been checked with the relevant industrial associations. Both activity data and average emission factors are also compared every year with data reported in the national EPER/E-PRTR registry and in the European emissions trading scheme (EU-ETS). Under the EU-ETS, operators are requested to report activity data and CO_2 emissions as information verified and certified by auditors who check for consistency to the reporting criteria.

Activity data and emissions reported under EU-ETS and EPER/EPRTR are compared to the information provided by the industrial associations. In particular, comparisons have been carried out for cement, lime, limestone and dolomite, and glass sectors. The general outcome of this verification step shows consistency among the information collected under different legislative framework and the information provided by the relevant industrial associations. Information reported under the EU-ETS has allowed for estimating CO_2 emissions from other uses of soda ash, the whole time series is included in the present submission and allocated under the "Other processes use of carbonates" category.

4.2.5 Source-specific recalculations

No recalculations occurred for the categories included under "Mineral Products" for this inventory submission.

4.2.6 Source-specific planned improvements

Further investigations concerning the replacement of natural raw material in lime production are planned.

4.3 Chemical industry (2B)

4.3.1 Source category description

CO_2, CH_4, N_2O, HFCs and PFCs emissions from chemical productions are estimated and included in this sector.

Adipic acid

Adipic acid production is a multistep process which starts with the oxidation of cyclohexanol using nitric acid and Cu catalysts according to the following reaction:

$$C_6H_{11}OH+2HNO_3 \rightarrow HOOC(CH_2)_4COOH+N_2O+2H_2O+energy$$

Adipic acid is then used to produce nylon or is fed to other production processes. Together with adipic acid, N_2O is produced and CO_2 is one of the by-products (Radici Chimica, 1993).

Emissions data from adipic acid production are provided and referenced by one plant, which is the only producer in Italy (Radici Chimica, several years). Specifically, for N_2O, in 2022, adipic acid production is a key source at trend assessment, both with Approach 1 and Approach 2, with and without LULUCF. These emissions accounted for 21% of total N_2O emissions in 2005, 2.4% in 2010, 0.6% in 2015, 0.4% in 2020 and account for 0.09% in 2022; the notable decrease in share is due to the fact that the technology to reduce N_2O emissions has become fully operational at the existing producing facility since 2007.

N_2O emissions have relevantly decreased thanks to the implementation of a catalytic abatement system (pilot scale plant). The use of thermally stable catalysts in the pilot plant has allowed the treatment of highly N_2O concentrated flue gas from the adipic acid production plant, reducing the volume of treated gas and the size of the pilot plant itself. The abatement system is generally run together with the adipic acid production process. In 2004 this system was tested for one month resulting in complete decomposition of N_2O; in 2005 the catalytic process was started only at the end of the year because of technical changes in the system; in 2006 the abatement system had been operating continuously for 9 months (3 months were needed for maintenance and technical changes) leading to the decomposition of 92% (efficiency of the abatement system while in operation) of N_2O emissions. Since 2007 the operating time has been about 11 months (about one month was needed for maintenance operations) and the N_2O emissions abatement system while in operation has reached an efficiency exceeding 98% (Radici Chimica, several years). In 2011 further emissions reduction was achieved thanks to technical improvements implemented in the production process during 2010:

- the number of scheduled outages of the adipic acid production process is reduced (from about 1/month to 2/year);
- the abatement system is set to reach the operating level more quickly than in the previous years.

These two achievements allow reducing the significance of N_2O peak emissions related to the start&stop phases. Moreover, an emission monitoring and recording system was implemented in compliance with Decision 2007/589/EC (Radici Chimica, 2013).

Also, CO_2 emissions are estimated from this source.

Ammonia production

In 2022 CO_2 emissions from ammonia production are a key source, at trend assessment with the Approach 1 and Approach 2 with and without LULUCF.

In Italy only one facility has been producing ammonia since 2009 because of the resizing of the production at national level after the crisis of the largest fertilizer producer, Enichem Agricoltura, and as a consequence of the international financial crisis in the last years. Two facilities had been producing ammonia in Italy up to 2008, in 2009 one plant stopped the production and was decommissioned in the following years. Ammonia is obtained after processing in ammonia converters a "synthesis gas" which contains hydrogen and nitrogen. CO_2 is also contained in the synthesis gas, but it is removed in the decarbonising step within the ammonia production process. Part of CO_2 is recovered as a by-product and part is released to atmosphere. Recovered CO_2 can either be used as input for different production processes (e.g. urea or calcium nitrate lines; liquefaction of CO_2 plant) on site or can be sold to technical gas manufacturers. The amount of recovered CO_2 from ammonia production which is fed to urea production processes is also reported (YARA, several years). Since 2021 ammonia manufacturing has been experiencing planned stops at plant level due to the rising costs of energy and natural gas as a consequence of Russia-Ukraine war.

Nitric acid

In early nineties seven facilities manufactured nitric acid, but since 2003 the production has been carried on only in three plants. In 2008 another plant stopped the production of nitric acid, so since 2009 nitric acid production has been carried out in two plants only. Nitric acid is produced from ammonia by catalytic oxidation (with air) of NH_3 to NO_2 and subsequent reaction with water. Currently the reactions involved take place in low and medium pressure processes.

In 2022, N_2O emissions from nitric acid production are key source for trend assessment with both Approach 1 and 2 with LULUCF, and for trend with Approach 1 without LULUCF, as they show a relevant decrease in emissions from 1990 due to a reduction in production. Moreover, as far as YARA facility is concerned, the decrease in N_2O emissions is also related to the implementation of catalytic N_2O decomposition in the oxidation reactors a YARA De-N_2O patented technology, based on the use of CeO_2 catalyst (YARA, several years), while the improvements in the monitoring system of N_2O emissions at the other facility has been affecting N_2O emissions estimation time series for the very last years.

Carbon black

Three facilities have been carrying out this production which consists basically on cracking of feedstock oil (a mixture of PAH) at 1200 – 1900 °C. Together with black carbon, tail gas is a byproduct of the process. Tail gas is a mixture of CO, H_2, H_2O, NO_x, SO_x and H_2S; it is generally burnt to reduce the emissions to air and to recover energy to be used in the production process.

CO_2 emissions from carbon black production have been estimated on the basis of information supplied directly by the Italian production plants also in the framework of the EU ETS for the last years.

Ethylene, Ethylene oxide, Propylene, Styrene

Ethylene, ethylene oxide, propylene and styrene productions belong to the organic chemical processes. In particular, ethylene is produced in petrochemical industry by steam cracking to manufacture ethylene oxide, styrene monomer and polyethylenes. Ethylene oxide is obtained via oxidation of ethylene and it is largely used as precursor of ethylene glycol and in the manufacture of surfactants and detergents. Propylene is obtained by cracking of oil and it is used to manufacture polypropylene but also acetone and phenol. Styrene, also known as vinyl benzene, is produced on industrial scale by catalytic dehydrogenation of ethyl benzene. Styrene is used in the rubber and plastic industry to manufacture through polymerisation processes such products as polystyrene, ABS, SBR rubber, SBR latex.

Except for ethylene oxide production, which stopped in 2002, the other productions of the above-mentioned chemicals still occur in Italy.

As far as ethylene, ethylene oxide and propylene are concerned, Syndial Spa (former Enichem) and Polimeri Europa (Syndial, several years; Polimeri Europa, several years) were the main producers in Italy up to 2006. Since 2007 Polimeri Europa (the parent company name changed into Versalis in 2012) has become the main producer for those products in Italy, while it has been the main producer of styrene since 2002.

Titanium dioxide

Titanium dioxide (TiO_2) is the most used white pigment especially for paint and plastic industries. As described also in the IPCC Guidelines, two main production routes are available:

- the chloride route, which has both "combustion" and "process" emissions;
- the sulphate process, whose emissions are only related to the combustion of fuels.

In Italy there is only one facility where this production occurs and titanium dioxide is produced through the sulphate process. The "sulphate process" involves the use of sulphuric acid to concentrate the input raw mineral in terms of titanium dioxide content, then selective precipitation and calcination allow getting the final product. Main process chemical reactions can be summarized like in the following box:

$$FeTiO_3 + 2H_2SO_4 \rightarrow FeSO_4 + TiO.SO_4 + 2H_2O$$
$$TiO.SO_4 + 2H_2O \rightarrow TiO_2.H_2O + H_2SO_4$$
$$TiO_2.H_2O + heat \rightarrow TiO_2 + H_2O$$

Therefore, no process emissions are originated by the sulphate production process.

Caprolactame production

Caprolactame is a monomer used in the industrial production of nylon-6. It can be obtained by catalytic oxidation of toluene and cycloexane. The process releases N_2O. N_2O emissions from caprolactame production have been estimated and reported and are related to only one producing plant, which closed in 2003.

Calcium carbide production and use

Calcium carbide production process takes place in electric furnaces, CaO and coke are fed to the furnace and the product is obtained according to the following reaction:

$$CaO+3C \rightarrow CaC_2+CO$$

CARBITALIA S.p.A. is the only facility which can operate calcium carbide production in Italy. It produced calcium carbide up to 1995, when it stopped the production because of the increasing price of electricity. The plant still exists and it is maintained, but since 1995 it has just been supplying calcium carbide bought abroad. About 95% of the total CaC_2 sold in Italy is used to manufacture acetylene, the remaining share is bought by foundries for the desulphuration of steel or spheroidal pig iron (CARBITALIA S.p.A., several years). CO_2 emissions from manufacture and use of calcium carbide are estimated.

Soda Ash production and use

In Italy only one facility operates soda ash production via Solvay process. Solvay process allows producing soda ash through the conversion of sodium chloride into sodium carbonate using calcium carbonate and ammonia. CO_2 is released and calcium chloride is the waste. Up to the second half of the year 2000 in the unit for the production of peroxidates there was one sodium carbonate line and a sodium perborate line which was then converted to sodium carbonate production. Soda ash is also used in glass production processes.

Fluorochemical production

The sub-sector fluorochemical production consists of two sources, “By-product emissions” and “Fugitive emissions”. PFCs emissions from fluorochemical production is a key source at trend assessment using Approach 2 with and without LULUCF; also HFCs emissions from fluorochemical production is a key source at trend assessment, only using Approach 2 with and without LULUCF.

The production of halocarbons and SF_6 took place in two facilities in Italy up to 2008 (Spinetta Marengo and Porto Marghera). Since 2005, the plant in Spinetta Marengo has not produced SF_6 any longer. In the first quarter of 2008 the production plant at Porto Marghera stopped its activity. Then there is only one facility in Italy where HCFC22 is produced.

Within by-product emissions, HFC23 emissions are released from HCFC22 manufacture, CF_4 emissions are released from SF_6 and HCFC22/TFM productions, whereas C_2F_6 and HFC143a emissions are released from the production of C_3F_6 (and also CFC115) and HFC134a, respectively. Production of CFC115 was carried out only in one facility and stopped in 1998.

Production of HFC125, HFC134a, HFC227ea and SF_6 lead to fugitive emissions of the same gases. In particular, production of HFC227ea only occurred in 1999.

The share of F-gas emissions from the fluorochemical production in the national total of F-gases was 38.9% in 1990 and 3.0% in 2022.

4.3.2 Methodological issues

Adipic acid

Italian production figures and emission estimates for adipic acid have been provided by the process operator (Radici Chimica, several years) for the whole time series. Emissions estimates provided by the operator are based on the IPCC default EF, so the values provided and the estimates in the Italian emissions inventory are, basically, the result of the same methodology.

More specifically, N_2O emissions from adipic acid production (category 2B3) have been estimated using the default IPCC emission factor equal to 0.30 kg N_2O/kg adipic acid produced, from 1990 to 2003.

Since 2004 the operator has started to study how to introduce an abatement system; although emission estimates provided by the operator have still been based on the IPCC default emission factor (0.30 kg N_2O/kg adipic acid produced), the operating hours of the abatement system and the abatement rates have also been included in the estimation process. The abatement system is generally run together with the adipic acid production process. In 2004, the N_2O catalytic decomposition abatement technology has been tested so that the value of emission factor has been reduced taking into account the efficiency and the time, one month, that the technology operated.

From the end of 2005 the abatement technology is fully operational; the average emission factor in 2006 is equal to 0.05 kg N_2O/kg adipic acid produced and the abatement system had been operating continuously for 9 months; since 2007 the average emission factor has been 0.03 kg N_2O/kg adipic acid produced and the operating time of the abatement system has been 11 months.

Technical improvements in operating the production process and the abatement system have allowed achieving significant reduction in N_2O emissions since 2009 (Radici Chimica, 2013): in 2010 the average emission factor was 0.018 kg N_2O/kg adipic acid produced while in 2011-2013 the average EF is around 0.005 kg N_2O/kg adipic acid produced with the abatement rate exceeding 98%.

In 2015 the average EF is around 0.0045 kg N_2O/kg adipic acid while in 2022 is 0.0010 kg N_2O/kg adipic acid.

Thus, from 1990 to 2011, default EF has been used when no abatement system was operational; and abatement rates have been considered. The operator reports also under EPER/E-PRTR both adipic acid production and the N_2O emissions related to this production; adipic production and N_2O emissions have been also reported by the operator to the national competent authority for the ETS (the facility was included in the ETS system in 2013) together with additional information such as abatement rates and operating times. Since 2011 the implementation of a new monitoring system has also enabled the reporting of better-quality emissions data in terms of nitrogen and nitrous oxides emissions.

Based on information from the national PRTR and ETS, for verification purposes, EFs are calculated for the plant, considering the IPCC default EFs, the abatement technology rate and the operating time of the abatement technology at the facility according to the formula in Table 4.11.

The EFs submitted for the adipic acid production in the CRF and the EFs calculated for the plant in Table 4.11 are practically the same along those years.

Table 4.11 N_2O emission factors submitted vs calculations based on efficiency and utilization details.

Parameter/Year	2005	2006	2007	2008	2009	2010	2011
EFp (IPCC default)	0.3	0.3	0.3	0.3	0.3	0.3	0.3
A	0.925	0.9212	0.965	0.986	0.986	0.986	0.986
T	0.14	0.8825	0.93	0.91	0.91	0.952	0.999
EFs (average EF)	0.26	0.056	0.031	0.031	0.031	0.019	0.005

Values resulting according to the following formula

$$(1-A*T)*EFp = EFs$$

Where:

A= Abatement rate provided by the operator

EFp= N_2O Emission Factor for Adipic Acid production (kg N_2O /kg adipic acid prod)

T = operating time of the abatement system/ operating time of the adipic acid production line

EFs = N_2O actually released Emission Factor submitted (kg N_2O released/kg adipic acid prod)

CO_2 emissions from this source have been estimated according to the information communicated by the operator. Tier 2 is implemented up to 2012 estimates while Tier 3 is reported for the estimates related to the last part of the time series (from 2013 onwards), because AD and CO_2 emissions reported by the operator in the framework of the national ETS have been used. Measurements of plant specific information under the national ETS are not available for the period 1990-2012, so Tier 3 cannot be implemented for the whole time series, but the consistency of the time series is not affected because there is only one operator for the national production of adipic acid in Italy.

Ammonia

Ammonia production data are published in the international industrial statistical yearbooks (UN, several years), national statistical yearbooks (ISTAT, several years [a]) and from 2002 they have been checked with information reported in the national EPER/E-PRTR registry. More in detail for 1990-1999 the amount of ammonia produced was published on the UN "Industrial Commodity Statistics Yearbook" (UN, several years), while for the years 2000 and 2001 production indexes published by ISTAT were applied. Since 2002 national production of ammonia in Italy has been collected at facility level. The number of ammonia facilities in Italy is known along the whole time series so it is possible to make sure that the national emissions estimation from this source is consistent to the sum of emissions from the ammonia facilities.

Since 2009 only one facility has been producing ammonia in Italy and reporting data to the national PRTR.

Recovered CO_2 has been investigated with the cooperation of the operators and the resulting information has been used to revise the whole CO_2 emission time series and the emission factors. The analysis has allowed understanding that CO_2 emissions recovered from ammonia production are used to produce urea and technical gases. According to 2006 IPCC Guidelines the CO_2 recovered for technical gases should be accounted for emission and included in the estimate while that for producing urea should be reported in the relevant consumption categories. In particular, for the years 1990-2001, CO_2 emission factor has been calculated on the basis of information reported by the production plants for 2002 and 2003 in the framework of the national EPER/E-PRTR registry and considering also the amounts of CO_2 recovered since the beginning of the recovery operations. CO_2 reported to the national EPER/E-PRTR registry has been used for the previous years under the assumption, verified with the operator, that no change in technology at facilities have occurred along the period (YARA, 2007). Since 2002, the average emission factors result from data reported by the plants in the national EPER/E-PRTR and calculated taking in account the gas consumed for the reforming process; the plant supplies the recovered CO_2 detailed data allowing the proper application of the IPCC methodology.

Because of production of Urea and Ammonia are separate processes, when they are carried out in the same facility the CO_2 EF for Ammonia production, according to the IPCC 2006 GL, is based on the amount of CO_2 released from the production of ammonia, the amount of CO_2 recovered and sold as technical gas and the amount of ammonia produced. The recovery of CO_2 fed to Urea production, instead, has to be subtracted in the calculation of the EF. The resulting CO_2 EF could vary according to the decision of the operators in terms of increase/decrease of CO_2 recovered to be sold as technical gas or fed to Urea production. For example, in 2013-2015 the amounts of CO_2 fed to Urea production and the amount of CO_2 for technical gas decreased, consequently the overall amount of CO_2 released from ammonia production increased; moreover the fluctuation of ammonia manufactured in the same years has to be considered: production of ammonia increased in 2014, then it fell in 2015 while in 2019 the amount produced was the same as in 2013. Since last quarter of 2021 the rising price of natural gas resulted in extraordinary plant shutdowns which contributed also in the fluctuation of the CO_2 IEF. Table 4.12 shows the time series for the average CO_2 emission factor.

Table 4.12 Ammonia production, time series for the average CO_2 EF (t CO_2/t ammonia production)

	1990-2001	2005	2010	2011	2012	2013	2014	2015	2019	2020	2021	2022
EF (t CO_2/t ammonia production)	1.30	1.32	1.27	1.18	1.08	1.16	1.17	1.25	1.14	1.10	1.19	1.27

Italy investigated the differences between apparent consumption of urea and the final uses of urea at national level.

Apparent consumption can be calculated starting from the production, import and export of urea at national level, according to the equation P+I-E=apparent consumption (where: P is production; I means imports and E are the exports). The total amount of urea manufactured is supplied by the operator, while the amounts referring to import and exports can be obtained from the national institute of statistics dataset regarding the statistics about the foreign commercial exchange.

The operator of the facility producing ammonia and urea has provided us with the final markets of urea in Italy and an estimation of those market shares in 2017: SCR engines (7.6%); NOx abatement systems (2.8%); Industry ("industry-no-glue", such as cosmetics and instant cold packs, and "industry-glue", 15.1%) and fertilizers (74.5%). The review of the final urea market uses has been carried out also for the subsequent years, the exercise confirmed the completeness of the Italian inventory. As for 2021, the urea final market uses were: SCR engines (14.2%); NOx abatement systems (2.7%); Industry ("industry-no-glue", mainly instant cold packs, and "industry-glue", 8.1%) and fertilizers (74.5%).

About 95% of total natural gas consumption of ammonia production plants is used as feedstock in the production process while the remaining 5% is used as a fuel input. The amount of fuel used is included in the energy balance under the no energy final consumption sector (see Annex 5), therefore double counting does not occur.

Nitric acid

Regarding nitric acid production (2B2), production figures at national level are published in the national statistical yearbooks (ISTAT, several years [a]), while at plant level they have been collected from industry (Norsk Hydro, several years; YARA, several years; Radici Chimica, several years). The number of nitric acid facilities in Italy is known along the whole time series so it is possible to make sure that the national emissions estimation from this source is consistent to the sum of emissions from the nitric acid facilities. In 1990 there were seven production plants in Italy; three of them closed between 1992 and 1995, and another one closed in 2004, one more closedown in 2008 has left two plants still operating.

The N_2O average emission factors are calculated from 1990 on the basis of the emission factors provided by the existing production plants in the national EPER/E-PRTR registry, applied for the whole time series, and default IPCC emission factors for low and medium pressure plants attributed to the plants, now closed, where it was not possible to collect detailed information. Thus, N_2O emissions are estimated at plant level also considering the operating unit level, if necessary. Activity data have been collected at plant level for the whole time series. Unit specific default IPCC EFs have been used for plants closed in the nineties because it was not possible to collect more detailed information. For the other plants, data supplied in the framework of the EPER/EPRTR registry have been used: for the years 1990-2000 EFs at unit level have been calculated as an average of 2001-2004 data provided by operators in the EPER/EPRTR register. For the years 2001-2012 EPRTR data were used to calculate the national EF; the activity data and the emissions reported under ETS have been used from 2013 onwards thus moving from a Tier 2 approach to a Tier 3 approach. Tier 3 cannot be implemented along the whole time series because the nitric acid facilities entered the national ETS in 2013 and there isn't enough information available to support a Tier 3 for years before 2013. The implementation of different Tiers along the time series does not affect the consistency of the time series because there are only two operators for the national production of nitric acid in Italy both reporting the same AD under the national EPRTR and ETS registers.

Table 4.13 Nitric acid production, time series for the average N_2O EF (kg N_2O/t nitric acid production)

	1990	2007	2008	2010	2011	2012	2013	2014	2015	2017	2018	2019	2020	2021	2022
EF (kg N_2O/Mg nitric acid)	6.49	7.08	2.29	1.21	1.32	1.11	0.86	0.40	0.31	0.49	0.42	0.34	0.29	0.22	0.23

Relevant reductions in N_2O emissions have been observed since 2008. Specifically, in 2008 the implementation of catalyst N_2O abatement technology in one of the major production plants (i.e. in one unit of that plant) has led to a significant decrease in total N_2O emissions from nitric acid production, consequently a relevant reduction in the IEF can be observed too (YARA, several years) as shown in table 4.13: the implied emission factor for 2008 is in fact 2.29 kg N_2O/Mg nitric acid production (the abatement rate in one plant was 82% so far); in 2010 the implied emission factor is 1.21 kg N_2O/Mg nitric acid production and in 2022 it is 0.23 kg N_2O/Mg nitric acid; the relevant decrease is due to the installation of the abatement technology in the other unit of the same producing facility (YARA, several years) and to the technical improvements implemented in 2011 as far as monitoring of emissions is concerned at the second nitric acid facility (Radici Chimica, 2013). Sampling circumstances at the facility may affect the reported N_2O emission values: sampling in times very close to catalyst exhaustion generally leads to higher N_2O concentration in the process flue gases, this seems to have occurred for N_2O emissions in 2011 according to the operator (Radici Chimica, several years).

<u>*Caprolactame*</u>

N_2O emissions from caprolactame have been estimated on the basis of information supplied by the only plant present in Italy, production activity data published by ISTAT (ISTAT, several years [a]) and production and emission data reported in the national EPER/E-PRTR registry. For the years 2002 and 2003 activity data and emissions were reported by the operators to the national EPER register. For 1990-2001 no facility level specific information was available for the inventory team, only the amount of caprolactame manufactured in Italy was known. Based on the 2002 emission factor and after discussion with the technical expert at the facility an emission factor equal to 0.3 kg N_2O/Mg caprolactame production was assumed for 1990-2001. The plant closed in 2003.

Carbon Black

CO_2 and CH_4 emissions from carbon black production process have been estimated with a Tier 2 approach and plant specific data. Plant specific information (AD and emissions) has been supplied by the Italian production facilities in the framework of the national EPER/E-PRTR registry and the European emissions trading scheme, total AD and total emissions allow for calculating the EFs values to be used in the estimation process.

In 1996 a change in the production technology in the existing plants caused a reduction of CH_4, NMVOC, NO_x, SO_x and PM_{10} emissions. As for CH_4 emissions, the 2006 IPCC Guidelines default value for CH_4 emission factor (manufacturing process with thermal treatment) has been applied for this category and considered for the years since 1996. Table 4.14 include the values of the implied emission factor for CO_2 (t CO_2/t carbon black production) from 2005 to 2022.

Table 4.14 Carbon black production, time series for the average CO_2 EF (t CO2/t carbon black production)

	2005	2010	2013	2014	2015	2019	2020	2021	2022
EF (t CO_2/t Carbon black)	2.56	2.48	2.46	2.32	2.24	2.26	2.27	2.33	2.45

Ethylene, Ethylene oxide, Propylene, Styrene

Ethylene, ethylene oxide, propylene and styrene productions belong to the organic chemical processes, which are source of methane emissions.

For ethylene activity data have been provided by the Italian producers, specifically: for 1990-2001 by the sectoral industrial association (UNEM, several years) and since 2002 by the manufacturing companies (Syndial, several years; Polimeri Europa, several years; Versalis, several years). For ethilene oxide activity data have been provided by the manufacturing company for the whole time series (Enichem, several years); this production stopped in 2001. Propylene production activity data are reported in the UN "Industrial Commodity Statistics Yearbook" (UN, several years) for the years 1990-1994; since 1995 data have been provided by the manufacturing companies (Enichem, several years; Syndial, several years; Polimeri Europa, several years; Versalis, several years). Regarding Styrene, for the years 1990-1994, UN international statistics have been used (UN, several years). From 1995 the amount of styrene is supplied every year to the inventory team by the Italian producer at plant level (Enichem, several years; Polimeri Europa, several years; Versalis, several years).

For ethylene and propylene production, CH_4 emission factor is calculated, for the whole time series, on the basis of the EPRTR data submitted by the plants. In the framework of the E-PRTR registry, facilities manufacturing ethylene in Italy reported activity data and emissions following the E-PRTR classification. In particular, for these plants, CH_4 emissions, for these productions, were below the reporting threshold (which for methane is set to 100 t/year). Assuming that emissions of each plants were equal to the maximum value (threshold), 100 t/year, the emission factor resulted in 0.085 kg/t; this value has been used along the whole time series.

For Styrene CH_4 emissions, no specific information concerning the years 1990-1994 was available, so the EMEP/CORINAIR default emission factor (EMEP/EEA, 2007) has been applied (0.025 kg/t equal to 10% of total VOC emissions). Based on the information included in the Environmental Reports by the Italian producer (Enichem, several years), and confirmed by the operators, CH_4 emissions did not occur from 1995.

Methane emission factor for ethylene oxide production used for the whole time series (1990-2001) is equal to 6.841 kg/t as supplied by the air and waste management association (APEM, 1992).

Titanium dioxide

In Italy there is only one facility where titanium dioxide production occurs. As previously reported, because of the implementation of the sulphate process, no CO_2 process emissions occur. Emissions of CO_2 from fuel combustion in titanium dioxide production by sulphate process occur, but they have to be accounted for under the "Energy" sector.

Calcium carbide

CO_2 emissions from calcium carbide production process and use have been estimated on the basis of the activity data provided by the sole Italian producer/retailer (CARBITALIA SPA, 2023). Activity data relating to the manufacture of calcium carbide are referred to the years from 1990 to 1995 when the production stopped; activity data concerning the use of calcium carbide have been provided for the whole time series too. The default IPCC CO_2 emission factors (IPCC, 2006) have been used to estimate the emissions from manufacture and use along the whole time series.

Soda ash

CO_2 emissions from soda ash production have been estimated on account of information available about the Solvay process (Solvay, 2003), which is the technology applied for the production of soda ash in Italy, whereas those from soda ash use are included in glass production.

Soda ash production has been carried out at one facility in Italy; the facility is included in the scope of the national EPER/PRTR so the information concerning activity data and emissions of this facility has been made available for the years from 2002 up to now. For 1990-2001 the amount of soda ash produced was published on the UN "Industrial Commodity Statistics Yearbook" (UN, several years).

The CO_2 emission factor for those years is based on the estimation process of the GHG emissions inventory of Spain and on the information that Solvay has made available to the Spanish inventory team for a plant with the same technology as the Italian one. Since 2002 the emission factor is based on the data reported yearly by the Italian operator under the national EPER/PRTR and under ETS (preliminary data for years 2005-2009 and official data since 2013).

Fluorochemical production

For both source categories, "By-product emissions" and "Fugitive emissions", the IPCC Tier 2 method is applied, based on plant-level data. The communication is supplied annually by the only national producer, and includes productions, emissions, import and export data for each gas (Solvay, several years). CF_4 emissions represent additional by product emissions together with HFC23 emissions. The operator supplied all the relevant information for a better understanding of the activities taking place at the site of Spinetta Marengo and to help the inventory team to allocate CF_4 emissions from HCFC22 production properly. The industrial site of Spinetta Marengo hosts not only Solvay but also other Companies and is in the scope of EPRTR, IPPC permitting procedure and Seveso European Legislation. At the facility the monitoring system has 27 devices to perform gas chromatography analysis and about 540 monitoring points at the site. The resulting monitoring data flow, which regard other pollutants, is sent via web to the regional agency for the environmental protection (ARPA Piemonte).

In particular, the operator explained that HCFC22 production has been carried out in Spinetta Marengo since '50s and up to 1990 part of HCFC22 was probably also sold as a marketable product. Since 1990, all the HCFC22 produced has been the input for the TFM (tetrafluoroethylene monomer) production process (by pyrolysis of HCFC22 at 600 °C), the TFM has been then used to produce TFE (tetrafluoroethylene, C_2F_4) and PTFE (polytetrafluoroethylene), HFP (hexafluoropropylene) and the other different fluoropolymers and fluoroelastomers. All the fluorinated flue gases from the different production lines are collected and treated in a centralized abatement unit (thermal oxidation system), specifically designed for the Spinetta Marengo plant, working at a temperature of 1400 °C with a residence time of the gases minor of 2 seconds. The abatement unit is run continuously and allows reducing F-gas emissions not depending on the operating level of the main production process. In the treated flue gases CF_4 is still present (65% of CF_4 released to air pass through the abatement system untreated for thermodynamic reasons; 35% of CF_4 released to air is formed during the reactions occurring in the abatement unit). Estimations of CF_4 emissions released to air have been then reported to the national PRTR since 2007. The operator has provided the time series for the activity data from 2002 to 2010 (HCFC22 and TFM), since the activity data for the years before 2002 are not retrievable; in order to complete the activity data time series for the period 1990-2001 a linear increasing production level was assumed from 1990 to 2002. The ratio relating TFM production to HCFC22 production in 2002 has been taken also over the years 2001 back to 1990 to estimate the TFM productions. CF_4 emission factor for 2007 was set constant in order to estimate the CF_4 time series over the years from 1990 to 2006. CF_4 emissions time series have been then included in the estimates under the category 2.B.9.a.1 (By-product emissions from production of HCFC22).

In order to provide detailed information on the methodology applied for this category, CF_4 emissions estimation from HCFC22 can be summarised as follows:

- For the years 2007-2010 by-product CF_4 emissions from HCFC22 production has been supplied by the operator (through the national PRTR). Based on data reported to the national PRTR since 2007 and the activity data concerning HCFC production, the TFM/HCFC22 ratio along the time series, the EF for by-product CF_4 emission has been calculated.
- CF_4 EF (by-product emissions from HCFC22 production) for 2007 has been set as default value for the period 1990-2006 in order to estimate by-product CF_4 emissions consistently along the whole time series.
- Activity data for the facilities are available for the years 2002-2010, so the missing activity data were estimated based on the HCFC22 production capacity of the facility in 1990 and 2002 HCFC22 production figure assuming a linear increasing production level within the years. The TFM/HCFC22 ratio for 2002 was assumed as a default ratio to estimate TFM production consistently from 1990 and 2002.
- By product CF_4 emissions were estimated by applying the EF derived in point 2) to the TFM production levels along the years 1990-2002.

HFC23 is a by-product of the HCFC22 production process, the HFC23/HCFC22 rate is about 3%. The abatement system, as previously mentioned, allows for treating all the fluorinated flue gases, vented gases originated in the processes at the facility before being released to air. Since 1989 the abatement system has allowed to reduce HFC23 released to air, up to 1996 HFC23 emissions had been about 30 t/y. In 1996 the abatement system was improved with a second operating unit, since 1996 the abatement rate has been 99.99% thus reducing drastically HFC23 emissions close to zero. The operator communicated that for a HCFC22 production of 30,000 tons, HFC23 theoretical residual emissions are less than 100 kg; a monitoring analysis has measured about 10 kg of HFC-23 in one year (Spinetta Marengo, 2011).

C_2F_6 and HFC143a emissions are released from the production of C_3F_6 (and also CFC115) and HFC134a, respectively. Fluorochemical were produced in one plant (Porto Marghera) and progressively stopped in the last years. More in details C_3F_6 (and also CFC115) production stopped in 1998 while HFC134a production stopped in 2007. Data production and emission figures have been provided by the company (Solvay Fluor, several years).

Production of HFC-125, HFC-134a, HFC-227ea and SF_6 lead to fugitive emissions of the same gases. In particular, the production of HFC-227ea only occurred in 1999. Emissions figures have been communicated by the operator (Solvay Fluor, several years).

4.3.3 Uncertainty and time-series consistency

The uncertainty in N_2O emissions from adipic and nitric acid and caprolactame production and in CO_2 emissions from ammonia and for other chemical production is estimated by 10.4%, for each activity, as combination of uncertainties related to activity data (3%) and emission factors (10%). Uncertainty level for activity data is an expert judgement, taking into account the basic source of information, while the uncertainty level for emission factors is equal to the level reported in the IPCC Good Practice Guidance (IPCC, 2000) for the adipic and nitric acid N_2O emissions and for CO_2 emissions from other industrial processes. The uncertainty in F-gas emissions from fluorocarbons production is estimated to be 50.2% in annual emissions, 5% and 50% concerning respectively activity data and emission factors.

In Tables 4.15 and 4.16, the production of chemical industry, including non-key sources, and emission trends are reported. An overview of the emissions per compound from fluorochemical production is given for the 1990-2022 period.

In general, total emission trends for all the chemical productions have been affected by fluctuations in productions along the time series (and by reductions in productions over the years 2007-2009, except for adipic acid and titanium dioxide activity data), whenever abatement technologies (e.g. nitric acid since 2008) or closures of plants cannot be regarded to as the specific causes for the decreasing emissions.

Table 4.15 Production of chemical industry, 1990 –2022 (kt)

Activity data	1990	1995	2000	2005	2010	2015	2016	2019	2020	2021	2022
						kt					
2B.1 - Ammonia	1,455	592	414	607	505	396	564	465	598	532	194
2B.2 - Nitric acid	1,037	588	556	572	417	390	426	421	447	402	342
2B.3 - Adipic acid	49	64	71	75	85	82	83	76	73	73	56
2B.4 - Caprolactame	120	120	111	-	-	-	-	-	-	-	-
2B.5 - Calcium carbide production	12	7	7	7	6	4	4	4	3	4	3
2B.6 - Titanium dioxide	58	69	72	60	70	60	61	63	51	62	43
2B.7 - Soda ash production and use	610	1,070	1,000	915	620	880	916	898	851	907	874
2B.8b - Ethylene	1,466	1,807	1,771	1,721	1,551	1,187	1,252	1,040	1,046	1039	833
2B.8d - Ethylene oxide	61	54	13	-	-	-	-	-	-	-	-
2B.8f - Carbon black	184	208	221	214	205	205	212	210	188	220	237
2B.8g - Styrene	365	484	613	520	524	547	512	511	501	472	413
2B.8g.i - Propylene	774	693	690	1,037	880	630	643	538	531	542	464
2B.9 – HCFC 22 production	20	23	26	27	21	26	24	23	18	22	21

Table 4.16 CO_2, CH_4 and N_2O emissions from chemical industry, 1990 – 2022 (kt) and HFCs, PFCs per compound 1990 - 2022 (kt CO_2 eq.)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
CO_2 (kt)										
Ammonia	1,891.50	769.60	537.91	802.29	639.77	495.54	531.26	658.36	631.09	246.79

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Calcium carbide	26.28	14.24	7.7	8.01	6.63	4.59	3.96	3.80	4.75	3.47
Carbon black	422.05	477.48	508.83	548.22	510.38	462.39	476.56	426.33	511.33	581.14
Titanium dioxide	-	-	-	-	-	-	-	-	-	-
Adipic acid	1.33	1.72	1.93	1.50	1.76	1.82	1.70	1.62	2.06	1.92
Soda ash production and use	183	321	300	275	203.33	255.35	300.99	268.37	278.38	260.54
CH_4 (kt)										
Carbon black	1.84	2.08	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Ethylene	0.12	0.15	0.15	0.15	0.13	0.10	0.09	0.09	0.09	0.07
Propylene	0.07	0.06	0.06	0.09	0.07	0.05	0.05	0.05	0.05	0.04
Styrene	0.01	-	-	-	-	-	-	-	-	-
Ethylene oxide	0.42	0.37	0.09	-	-	-	-	-	-	-
N_2O (kt)										
Nitric acid	6.73	4.22	4.09	5.44	0.51	0.12	0.14	0.13	0.09	0.08
Adipic acid	14.77	19.09	21.42	19.59	1.58	0.37	0.26	0.27	0.13	0.06
Caprolactame	0.04	0.04	0.03	-	-	-	-	-	-	-
kt CO_2 eq.										
HFC 23	372.00	372.00	1.05	1.09	0.85	1.05	0.96	0.76	0.91	0.85
HFC 143a	-	28.80	4.80	5.28	-	-	-	-	-	-
CF4	792.12	890.54	889.50	1,388.28	1,166.88	1,392.30	780.35	374.60	261.22	300.34
PFC C2÷C3 (C2F6)	44.40	44.40	-	-	-	-	-	-	-	-
Total F-gas by product emissions	*1,208.52*	*1,335.74*	*895.35*	*1,394.65*	*1,167.73*	*1,393.35*	*781.31*	*375.35*	*262.13*	*301.19*
HFC 125	-	31.70	3.17	3.80	-	-	-	-	-	-
HFC 134a	-	39.00	15.60	12.61	-	-	-	-	-	-
HFC 227ea	-	-	-	-	-	-	-	-	-	-
SF6	117.50	117.50	-	-	-	-	-	-	-	-
Total F-gas fugitive emissions	*117.50*	*188.20*	*18.77*	*16.41*	-	-	-	-	-	-
Total F-gas emissions from fluorochemical production	***1326.02***	***1523.94***	***914.12***	***1411.06***	***1167.73***	***1393.35***	***781.31***	***375.35***	***262.13***	***301.19***

HFC23 emissions from HCFC22 had been drastically reduced since 1996 due to the installation of a second thermal oxidation system in the facility located in Spinetta Marengo (the only facility currently producing HCFC22 in Italy). Productions and emissions from 1990 to 1995 are constant as supplied by industry; from 1996, untreated leaks have been collected and sent to the thermal oxidation system, thus allowing reduction of emissions under 100 kg (E.F. 3.3 g of HFC23/t of HCFC22). CF_4 by-product emissions in

HCFC22 production process have been fully investigated, information supplied by the operator has allowed estimating emissions for the whole time series. This information about production and emissions is updated yearly by the producer, and it is also reported in the framework of the national PRTR register, confirming that the technology is fully operating. Since 2020, a drastic reduction of CF_4 emission has occurred: as part of Solvay's commitment to reducing greenhouse gas emissions, a new project for the abatement of CF_4 by thermo-oxidation has been developed.

PFC (C_2F_6) by-product emissions and SF_6 fugitive emissions were constant from 1990 to 1995 (4 t/y for C_2F_6 emissions; 5 t/y for SF_6 emissions) and from 1996 to 1998 (1 t/y for C_2F_6 emissions; 2 t/y for SF_6 emissions) and have eventually reduced to zero since 1999 due to the stop of the CFC115 production in one facility and the upgrade of the thermal oxidation system mentioned above in the other facility. Besides, SF_6 production has stopped since the 1st of January 2005.

Regarding fugitive emissions, emissions of HFC125 and HFC134a have been cut in 1999 thanks to a rationalisation in the new production facility located in Porto Marghera, whereas HFC143 released as by-products from the production of HFC134a has been recovered and commercialized. The relevant productions in Italy which originate these fugitive emissions stopped in the first quarter of 2008.

4.3.4 Source-specific QA/QC and verification

Emissions from adipic acid, nitric acid, ammonia and other chemical industry production have been checked with the relevant process operators and with data reported to the national EPER/E-PRTR registry. Emissions and activity data for adipic acid, nitric acid and ammonia productions have also been checked against the relevant information reported by operator to the national competent authority for the ETS, the resulting consistency of both emissions and activity data for those sectors is the outcome of this control.

Emissions from fluorochemical production have been checked with data reported to the national EPER/E-PRTR registry.

4.3.5 Source-specific recalculations

Recalculation occurred for CO_2 emissions from Calcium carbide and Carbon black production in 2021 (Table 4.17). As for CO_2 emissions from Calcium carbide production and use (2.B.5.b) the recalculation is due to the update of the activity data in 2021. As for CO_2 emissions from Carbon black production (2.B.8.f) recalculation in 2021 is due to the official correction of CO_2 emissions reported by one operator to the national ETS registry.

Table 4.17 Recalculation of CO_2 emissions from Calcium carbide (2.B.5.b) and from Carbon black (2.B.8.f) (%)

Gas/subcategory	2021
2.B.5.b. Calcium carbide	0.37
2.B.8.f. Carbon black	5.06

4.3.6 Source-specific planned improvements

A detailed balance of the natural gas reported in the energy balance, as no energy fuel consumption, and the fuel used for the production processes in the petrochemical sector is planned.

4.4 Metal production (2C)

4.4.1 Source category description

The sub-sector metal production comprises five sources: iron and steel production, ferroalloys production, aluminum production, magnesium foundries and zinc/lead production; CO_2 emissions from iron and steel production are key sources at trend assessment with the Tier1 with and without LULUCF; PFC emissions from aluminum production are key sources at trend assessment both with the Tier1 and Tier2 approach. In the base year, PFC emissions were key sources at level assessment with LULUCF only and CO_2 emissions from iron and steel production were key sources at level assessment only with Tier1.

In 2022, the share of CO_2 emissions from metal production accounts for 0.47% of the national total CO_2 emissions, and 12.09% of the total CO_2 from industrial processes. The share of CH_4 emissions is, in 2022, equal to 0.08% of the national total CH_4 emissions while N_2O emissions do not occur. The share of F-gas emissions from metal production out of the national total F-gas levels was 52.5% in the base-year and has decreased to 0.03% in the year 2022.

Iron and steel

The main processes involved in iron and steel production are those related to sinter and blast furnace plants, to basic oxygen and electric furnaces.

The sintering process is a pre-treatment step in the production of iron where fine particles of metal ores are agglomerated. Agglomeration of the fine particles is necessary to increase the passageway for the gases during the blast furnace process and to improve physical features of the blast furnace burden. Coke and a mixture of sinter, lump ore and fluxes are introduced into the blast furnace. In the furnace the iron ore is increasingly reduced and liquid iron and slag are collected at the bottom of the furnace, from where they are tapped. The combustion of coke provides both the carbon monoxide (CO) needed for the reduction of iron oxide into iron and the additional heat needed to melt the iron and impurities. The resulting material, pig iron (and also scrap), is transformed into steel in subsequent furnaces which may be a basic oxygen furnace (BOF) or electric arc furnace (EAF). Oxygen steelmaking allows the oxidation of undesirable impurities contained in the metallic feedstock by blowing pure oxygen. The main elements thus converted into oxides are carbon, silicon, manganese, phosphorus and sulphur.

In an electric arc furnace steel is produced from polluted scrap. The scrap is mainly produced by cars shredding and does not have a constant quality, but the recent stringent legislation and the adoption of BAT (Best Available Techniques) in scrap management allow an input with better product characteristics.

The iron and steel cycle is closed by rolling mills with production of long products, flat products and pipes.

In 1990, there were six integrated iron and steel plants in Italy. In 2014, there were only three of the above-mentioned plants, one of which lacking sintering facilities and another one not equipped with a BOF. Since 2015 there have been only two plants because the plant without sinter production has been closed and in 2021 only the largest integrated plant is still producing. In 2022, oxygen steel production represents about 15.8% of the total production and the arc furnace steel the remaining 84.2% (FEDERACCIAI, several years).

Currently, long products represent about 49.0% of steel production in Italy, flat products about 38.9% and pipes the remaining 12.0%. In 2022 long production has been equal to 12.0 Tg with an increase of -12.0% over the previous year and still below 27.8% compared to 2008; flat production has been equal to 9.6 Tg with a decrease of -13.8% on the previous year but a decrease of 31.7% compared to 2008 level. Most of the flat production derives from the only integrated iron and steel plant, while in steel plants equipped with electric ovens, almost all located in the northern regions, long products are produced predominantly (e.g. carbon steel, stainless steels) and seamless pipes (only one plant) (FEDERACCIAI, several years).

CO_2 emissions from steel production refer to carbonates used in basic oxygen furnaces and crude iron, carbonates, *coals* and electrodes in electric arc furnaces. CO_2 emissions from pig iron production refer to carbonates used in sinter and pig iron production. CO_2 emissions from iron and steel production due to the fuel consumption in combustion processes are estimated and reported in the energy sector (1A2a) to avoid double counting.

CH_4 emissions from steel production refer to blast furnace charging, basic oxygen furnace, electric furnaces and rolling mills. CH_4 emissions from coke production are fugitive emissions during solid fuel transformation and have been reported under 1B1b category while CH_4 emissions from the combustion of fuels are allocated in the energy sector.

Ferroalloys

Ferroalloy is the term used to describe concentrated alloys of iron and one or more metals such as silicon, manganese, chromium, molybdenum, vanadium and tungsten. Usually, alloy formation occurs in electric arc furnaces (EAF) and CO_2 emissions occur during oxidation of carbon still present in coke and because of consumption of the graphite electrodes.

In early nineties there were 13 plants producing various kinds of ferroalloys: FeCr, FeMn, FeSi, SiMn, Si-metal and other particular alloys, but since 2001 the production has been carried on only in one plant (ISPESL, 2005). The last remaining plant in Italy produces mainly ferro-manganese and silicon-manganese alloys but since 2015 the facility has not been working.

Aluminum

From primary aluminum production CO_2 and PFCs (CF_4 and C_2F_6) are emitted. PFCs are formed during a phenomenon known as the 'anode effect', when alumina levels are low.

In 1990 primary aluminum production in Italy was carried out in 5 sites where different technologies were implemented:

- Fusina: Point Fed Prebake and Side Work Prebake (up to 1995);
- Portovesme: Point Fed Prebake and Side Work Prebake (up to 1990);
- Bolzano: Vertical Stud Soderberg;
- Fusina 2 and Porto Marghera: Side Work Prebake.

Since then, the implemented technology has been upgraded from Side Work Prebake to Point Fed Prebake; while three old plants stopped the operations in 1991 (Bolzano) and in 1992 (Fusina 2 and Porto Marghera). Since 2000 Alcoa has replaced ENIRISORSE in operating the plants.

Up to 2010, two primary aluminum production plants, which use a prebake technology with point feeding, characterised by low emissions, have operated. Only one plant, located in Portovesme, was operating until 2012 (99.5 kt of primary aluminum). In 1990, primary aluminum production was 232 kt. In 2021the plant did not produce primary aluminum. The plant is stopped but not dismantled: in 2018 the new Company Sider Alloys has taken over Portovesme plant from Alcoa, that is currently under renovation. The restart of the renovated plant was scheduled for 2024.

Magnesium foundries

In the magnesium foundries, SF_6 is used as a cover gas to prevent oxidation of molten magnesium. In Italy there is only one plant, located in the north, which started its activity in September 1995.

Since the end of 2007, SF_6 has been replaced by HFC125, due to the enforcement of fluorinated gases regulations (EC, 2006; EU, 2014) which, however, allow for the use of SF_6 in annual amounts less than 1 Mg. HFC125 emissions also occurred and, in 2010, they were equal to 605 kg. Since 2011 HFC125 has been replaced by HFC134a (2,667 kg of emissions in 2022).

Zinc production

Since 1998, in Italy there is just an integrated plant for the zinc and lead production which cover the entire production of zinc and of primary lead. In 2013, this plant began to submit data in the framework of ETS reporting data subdivided in combustion and process emissions; consequently, a survey has been started to investigate time series for process emissions resulting in CO_2 emissions from 1990 to 2022. CO_2 emissions are referred both to zinc and lead production.

4.4.2 Methodological issues

CO_2 and CH_4 emissions from the sector have been estimated on the basis of activity data published in the national statistical yearbooks (ISTAT, several years [a]), data reported in the framework of the national EPER/E-PRTR registry and the European Emissions Trading Scheme, and supplied by industry (FEDERACCIAI, several years; ALCOA, several years). Emission factors reported in the EMEP/EEA Guidebook (EMEP/EEA, 2009), in sectoral studies (APAT, 2003; CTN/ACE, 2000) or supplied directly by industry (FEDERACCIAI, 2004; ALCOA, 2004; Italghisa, 2011) have been used.

Iron and steel

CO_2 emissions from iron and steel production refer to the carbonates used in sinter plants, in blast furnaces and in steel making plants to remove impurities; they are also related to the steel and pig iron scraps, carbonates, *coals* and graphite electrodes consumed in electric arc furnaces.

Basic information for this sector derives from different sources in the period 1990-2022. Activity data are supplied by official statistics published in the national statistics yearbook (ISTAT, several years [a]) and by the sectoral industrial association (FEDERACCIAI, several years).

For the integrated plants, emission and production data have been communicated by the two largest plants for the years 1990-1995, distinguished by sinter, blast furnace and BOF, and by combustion and processes emissions. From 2000, CO_2 emissions and production data have been supplied by all the plants in the framework of the ETS scheme, for the years 2000-2004 disaggregated for sinter, blast furnace and BOF plants, from 2005 specifying carbonates and fuels consumption and related CO_2 emissions. For 2002-2022 data have also been supplied by all the integrated iron and steel plants in the framework of the European EPER/E-PRTR registry not distinguished for combustion and processes. Qualitative information and documentation available on the plants allowed reconstructing their history including closures or modifications of part of the plants; additional qualitative information regarding the plants collected and checked for other environmental issues or directly asked to the plant permitted to individuate the main driving of the emission trends for pig iron and steel productions. Finally, since 2017, national experts have also been involved in the process of elaboration of the "monitoring and control plan" for the largest integrated plant in Italy in the framework of IPPC permit, allowing other terms of comparison and verification.

Time series of carbonates used in basic oxygen furnaces have been reconstructed on the basis of the above-mentioned information resulting in no emissions in the last years. In fact, carbonates have been substituted by autoproduced lime avoiding CO_2 emissions. Indeed, as regards the largest Italian producer of pig iron and steel, lime production has increased significantly from 2000 to 2008 by about 250,000 over 410,000 tonnes and the amount introduced in basic oxygen furnaces was, in 2004, about 490,000 tonnes (ILVA, 2006). In 2009 lime production, for the same plant, is equal to 216,000 tonnes but also steel production has sharply decreased because of the economic recession; in the following years lime production increased again up to 390,000 but in the last years it decreased because the plant went into receivership. Emissions from lime production in steel making industries are reported in 1.A.2 Manufacturing Industries and Construction category and in 2.A Mineral production respectively for the combustion and processes emissions.

Concerning the electric arc furnaces, additional information on the consumption of scraps, pig iron, graphite and electrodes and their average carbon content has been supplied together with the steel production by industry for a typical plant in 2004 (FEDERACCIAI, 2004) and checked with other sectoral study (APAT, 2003). On the basis of these figures an average emission factor has been calculated and applied for the period 1990 - 2003. Since 2004, the same scheme as the previous period has been followed but using data becoming from ETS and related to the amounts of pig iron, metallurgical coke, graphite, anthracite, dolomite, limestone and electrodes for 33 plants in 2022. The availability of data for each plant has allowed also the application, for a first attempt, of the Tier 3 methodology (IPCC, 2006) that demonstrated the soundness of estimates.

On account of the amount of carbonates estimated in sinter plants, average emission factor was equal in 1990 to 0.15 t CO_2/t pig iron production, while in 2022 it reduced to 0.09 t CO_2/t pig iron production. The reduction is driven by the increase in the use of lime instead of carbonates in sinter and blast furnaces in the Italian plants. Emissions are reported under pig iron because they are emitted as CO_2 in the blast furnaces producing pig iron.

CO_2 average emission factor in basic oxygen furnaces results in 1990 equal to 0.079 t CO_2/t steel production, while from 2003 is null.

CO_2 average emission factor in electric arc furnaces, equal to 0.035 t CO_2/t steel production, has been calculated on the basis of the Tier 2 of the 2006 IPCC Guidelines (IPCC, 2006) taking into account the pig iron and graphite electrodes used in the furnace and the amount of carbon stored in the final product. The same emission factor has been used for the period 1990 - 2003. Since 2004 ETS data have been used, in this way it has been possible to evaluate the contribute of anthracite and metallurgical coke producing an emission factor equal 0.060 t CO_2/t of steel in 2022. The amount of carbon stored in steel produced with EAF has been considered and subtracted from the carbon balance (see Annex 3). Implied emission factors for steel production reduced from 0.053 to 0.051 t CO_2/t steel production, from 1990 to 2022, due to the reduction in the basic oxygen furnaces.

CO_2 emissions due to the consumption of coke, coal or other reducing agents used in the iron and steel industry have been accounted for as fuel consumption and reported in the energy sector, including fuel consumption of derived gases; in Annex 3, the energy and carbon balance in the iron and steel sector, with detailed explanation, is reported.

During the last in country review, Italy reported on the results of a survey which found that there is no accurate information by which to disaggregate the emissions between energy and process. Coke is the only irreplaceable material in the blast furnace as it has several roles:

- the combustion of coke produces carbon monoxide which is responsible for the reduction of iron ores;
- the combustion of coke generates the heat needed to melt the iron ore;
- coke mechanically supports the charge allowing the crossing of the reducing gas;
- coke allows the process of carburation of liquid iron by lowering its melting point.

These are intrinsic properties of the coke and cannot be separated one from the other, all the coke when burning simultaneously produces energy in the form of heat and CO as a reducing agent.

As any arbitrary disaggregation would not reflect the real situation, the ERT agreed that leaving the total emissions from the use of coke in the iron and steel industry in the energy sector is appropriate.

Ultimately, carbon plays the dual role of fuel and reductant and it is very important not to double-count the carbon from the consumption of coke or other reducing agents if this is already accounted for as fuel consumption in the energy sector. For this reason, a balance is made between the coal used for coke production and the quantities of derived fuels used in various sectors. The iron and steel sector gets the resulting quantities of energy and carbon after subtraction of what is used for electricity generation, non energy purposes and other industrial sectors (see Annex 3).

The amount of carbon stored in steel produced in integrated plants has been considered and subtracted from the carbon balance (see Annex 3). The amount of carbon contained in steel has been estimated on the basis of EN standard and, from 2005, with emission trading data. Carbon stored is equal to 48,511 tonnes of CO_2 in 1990 and equal to 10,514 Mg in 2022.

CH_4 emissions from steel production have been estimated on the basis of emission factors derived from the specific IPPC BREF Report (IPPC, 2001 available at http://eippcb.jrc.es), sectoral study (APAT, 2003) and the EMEP/CORINAIR Guidebook (EMEP/CORINAIR, 2007) and refer to blast furnace, basic oxygen furnace, electric furnaces and rolling mills.

Ferroalloys

CO_2 emissions from ferroalloys have been estimated on the basis of activity data published in the national statistical yearbooks (ISTAT, several years [a]) until 2001. Time series of ferroalloys activity data have been reconstructed from 2002 on the basis of statistical information (ISTAT, several years [b), personal communication (Italghisa, 2011) and on the basis of production data communicated to E-PRTR register and to ETS from the only plant of ferroalloys in Italy. The comparison between E-PRTR and ETS data revealed some differences: further investigation led to a direct contact with the plant and to rectify the incorrect activity data.

The average emission factor has been calculated according to the IPCC Guidelines (IPCC, 2006) taking into consideration the different types of ferroalloys produced. The splitting up of national production in different types of ferroalloys was obtained from U.S. Geological Survey until 2001 (USGS, several years). Since 2002 only one plant of ferroalloys is located in Italy and different types of production are reconstructed on the basis of information listed above. This information is reported in the Table 4.18.

Table 4.18 Splitting up of ferroalloys national production and IPCC 2006 emission factors

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015-2020	IPCC 2006 EF
Ferroalloy (%)											kg/t
FeCr	0.30	0.26	-	-	-	-	-	-	-	-	1,300
FeMn	0.24	0.10	0.28	0.50	0.40	0.60	0.36	0.29	0.61	-	1,500
FeSi	0.02	-	-	-	-	-	-	-	-	-	4,800
SiMn	0.32	0.53	0.62	0.50	0.60	0.40	0.64	0.71	0.39	-	1,400
Si-Metal	0.06	0.05	0.03	-	-	-	-	-	-	-	5,000
Other	0.07	0.06	0.07	-	-	-	-	-	-	-	5,000

Implied emission factor for ferroalloys has been reduced from 1.90 to 1.46 t CO_2/t ferroalloys production, from 1990 to 2014 as a consequence of the sharp reduction in ferroalloys production, which is characterized by high emission factors (ferro-silicon and silicon-metal alloys). The simultaneous reduction of total production (from about 200 kt to 16 kt) has resulted in CO_2 emissions decreasing from 395 Kt in 1990 to 24 Kt in 2014. Since 2015 the plant has not been working.

Primary aluminum production

PFC emissions from aluminum production have been estimated using both Tier 1 and Tier 2 - IPCC methodologies. The Tier 1 has been used to calculate PFC emissions from 1990 to 1999, while Tier 2 has been used since 2000; the use of different methods along the period is due to the lack of detailed data for the years before 2000.

Although a number of attempts have been tried over the last years by the inventory team to retrieve the 1990-1999 historical operating data, it is not possible to retrieve the information: Alcoa cannot provide operating data for the period from 1990 to 1999 as the plants were managed by a different company not operating anymore. Thus the decision to use both tiers, which was supported by previous review processes, confirming the transparency, accuracy and conservativeness of this approach.

PFC emissions, specifically CF_4 and C_2F_6, have been calculated on the basis of information provided by national statistics (ENIRISORSE, several years; ASSOMET, several years) and the national primary aluminum producer (ALCOA, several years), with reference to the documents drawn up by the International Aluminium Institute (IAI, 2003; IAI 2006) and the IPCC Guidelines (IPCC, 2006).

Tier 1 method has been used to calculate PFC emissions related to the entire period 1990-1999. The emission factors for CF_4 and C_2F_6 were provided by the main national producer (ALCOA, 2004) based on the IAI document (IAI, 2003).

The Tier 1 method used by ALCOA is based on the IAI methodology, which collected anode effect data from 1990 up to 2000, accounting also for reductions in specific emission for all technology categories (specific factors for Point Fed Prebake cells have been considered to estimate emissions).

In 1990 at the five production sites the following technologies were implemented:

- Fusina: Point Fed Prebake (16% of the cells) and Side Work Prebake (84% of the cells);
- Portovesme: Point Fed Prebake (84% of the cells) and Side Work Prebake (16% of the cells);
- Bolzano: Vertical Stud Soderberg (100% of the cells)
- Fusina 2 and Porto Marghera: Side Work Prebake (100% of the cells).

The EFs for PFCs were then calculated by ALCOA as weighted arithmetic mean values of EFs for the different technologies (IAI, 2003), the weights representing the implemented technologies.

In the following tables (Tables 4.19, 4.20) the emission factors and the default parameters used are reported; site specific values are confidential but they have been supplied to the inventory team and taken into account in the estimation process.

Table 4.19 Historical default Tetrafluoromethane (CF_4) emission values by reduction technology type (IAI, 2003)

	Technology specific emissions (kg CF_4 / t Al)		
	1990 - 1993	1994 - 1997	1998 – 1999
Point Fed Prebake	0.3	0.1	0.08
Side Work Prebake	1.4	1.4	1.4
Vertical Stud Søderberg	0.6	0.5	0.4

Table 4.20 Multiplier factor for calculation of Hexafluoroethane (C_2F_6) by technology type (IAI, 2003)

	Technology multiplier factor
Center Work Prebake	0.17
Point Fed Prebake	0.17
Side Work Prebake	0.24
Vertical Stud Søderberg	0.06

PFC emissions from the year 2000 are estimated by the IPCC Tier 2 method, based on default technology specific slope factors and facility specific anode effect minutes. Site-specific values (CF_4 and C_2F_6 emissions) and default coefficients (slope coefficients for CF_4 and C_2F_6) were provided by the main national producer (ALCOA, several years). Moreover, from 2005 certificated emission values and parameters, including anode effects, have been communicated under EU-ETS (ALCOA, 2010). In Table 4.21 slope coefficients used for CF_4 and C_2F_6 are reported. ALCOA uses these values suggested by International Aluminium Institute (IAI, 2006), in accordance to the coefficients reported in the IPCC 2006 Guidelines (IPCC, 2006).

Table 4.21 CF_4 and C_2F_6 Slope Coefficients (IAI, 2006)

Type of Cell	CF_4	C_2F_6
	Slope Factor (kg PFC/tAl/AE-minutes/cell day)	
Center Work Prebake	0.143	0.0173

Anode Effects (minutes/cell day)

	2000	2005	2006	2007	2008	2009	2010	2011	2012
Primary Aluminum Plant	0.96	0.87	0.74	1.00	0.55	0.81	0.60	0.53	0.31

CO_2 emissions from aluminum production have been also estimated on the basis of activity data provided by industrial association (ENIRISORSE, several years; ASSOMET, several years) and default emission factor reported by industry (ALCOA, 2004) and by the IPCC Guidelines (IPCC, 1997) which refer to the prebaked anode process.

Emission factor has been assumed equal to 1.55 t CO_2/t primary aluminum production for the years 1990-2001, on the basis of data provided by the producer for 2002; this value is also consistent with the emission factors contained in the IPCC Guidelines and in the Aluminium Sector Greenhouse Gas Protocol. Since 2002 the emission factor has been calculated on account of information from the relevant plant supplied to the national EPER/EPRTR registry (emissions and productions). Therefore, thanks to the availability of this additional information, CO_2 emission estimations have been carried out by the operator since 2002 according to the criteria defined by the International Aluminium Institute (IAI) and are given by the following three components:

- Electrolysis Emissions from Prebake Anode
- Pitch Volatile Matter Oxidation from Pitch Coking
- Bake Furnace Packing Material

This detailed information is not available for previous years (1990-2001) although a number of attempts had been tried by the inventory team. So the Tier 2 approach can not be extended to those years and Tier 1 has to be used. Therefore, the Tier1+Tier2 approach allows ensuring the quality of the estimates and also the consistency of the CO_2 emissions time series on account of the quality of the available information.

In the following tables (Tables 4.22, 4.23), the emission factors and the default parameters used are reported; site specific values are confidential, but they have been supplied to the inventory team.

Table 4.22 Coefficients used for estimation of CO_2 from aluminium production process with the Tier 2 methodology by plant

	Baked Anode Properties		
	Sulphur *Weight %*	Ash *Weight %*	Impurities *Weight %*
Portovesme	ssv*	Ssv	DV** = 0.4
Fusina	DV = 1.6	Ssv	DV = 0.4

* *site specific value*
** *default value*

Table 4.23 Coefficients used for estimation of CO_2 from aluminium production process with the Tier 2 methodology by plant

	Pitch content in green anodes	Hydrogen content in pitch	Recovered tar	Packing coke consumption	Sulphur content of packing coke	Ash content of packing coke
	Weight %	*Weight %*	*kg/t BAP*	*t Pcc/ t BAP*	*Weight %*	*Weight %*
Portovesme	ssv*	ssv	DV** = 0	DV = 0.05	DV = 3	DV = 5
Fusina	ssv	DV = 4.45	DV = 0	DV = 0.05	DV = 3	DV = 5

* *site specific value*

** *default value*

<u>*Magnesium Production*</u>

For SF_6 used in magnesium foundries, according to the IPCC Guidelines (IPCC, 2006), emissions are estimated from consumption data made available by the company (Shiloh Industries Italia, several years), assuming that all SF_6 used is emitted. In 2007, SF_6 has been used partially, replaced in November by HFC125, due to the enforcement of fluorinated gases regulation (EC, 2006). This regulation allows for the use of SF_6 in annual amounts less than 850 kg starting from 1 January 2008; for this reason, SF_6 was still reported together with HFC 125 emissions for the years 2008, 2009 while for 2010 only HFC125 was reported. Since 2011 HFC134a has replaced HFC125.

<u>*Zinc production*</u>

Until the 2016 submission, emissions from lead and zinc production have been reported only in 1.A.2 because of the lack of information about process emissions. Since 2013, ETS data contain info about the sole integrated plant in Italy but, as it is an integrated plant, it is not possible to distinguish zinc from lead emissions, so in CRT tables IE is reported for category 2.C.5 Lead production and CO_2 emissions are reported in 2.C.6 Zinc production.

Starting from ETS activity and CO_2 emissions data for the period 2013 – 2017, it has been possible to reconstruct the time series on the basis of different sources as this plant already submitted its data to INES/E-PRTR register since 2002 (but without the distinction between combustion and process) and on the basis of activity data and info on the technological evolution provided by industrial association (ENIRISORSE, several years; ASSOMET, several years). In the period 1990 – 2022 activity data and CO_2 emissions show a decreasing trend, in particular emissions decrease from 500 Mg in 1990 to 197 Mg in 2022 and the IEF change from 1.56 to 2.05 $kgCO_2/Mg$ of Pb and Zn.

4.4.3 Uncertainty and time-series consistency

The combined uncertainty in PFC emissions from primary aluminum production is estimated to be about 20% in annual emissions, 3% and 20% concerning respectively activity data and emission factors; the uncertainty for HFC emissions from magnesium foundries is estimated to be about 20%, 3% for activity data and 20% for emission factors. The uncertainty in emissions from iron and steel, ferroalloys and zinc production is estimated to be 10.4%.

In Table 4.24 emission trends of CO_2, CH_4 and F-gases from metal production are reported. The decreasing of CO_2 emissions from iron and steel sector is driven by the use of lime instead of limestone and dolomite to remove impurities in pig iron and steel and by the production level while CO_2 emissions from aluminum, zinc and ferroalloys are driven mainly by the production levels.

In Table 4.25 the emission trend of F-gases per compound from metal production is given. PFC emissions from aluminum production decreased because of the closure of three old plants in 1991 and 1992 and the update of technology for the two plants still operating. The decreasing of SF_6 consumption in the magnesium foundry from 2003 is due to the abandonment of recycling plant and the optimisation of mixing parameters.

Table 4.24 CO_2, CH_4 and F-gas emissions from metal production, 1990 – 2022 (kt)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
CO_2 (kt)										
Iron and steel	3,124	2,897	1,280	1,656	1,343	1,327	1,357	1,215	1,506	1,392
Aluminium production	359	276	295	299	250	-	-	-	-	-
Ferroalloys	395	230	229	89	77	-	-	-	-	-
Zinc production	500	500	501	375	164	236	245	224	232	197
CH_4 (kt)										
Pig iron	2.13	2.10	2.02	2.06	1.54	0.91	0.83	0.61	0.74	0.61
Steel	0.58	0.60	0.60	0.67	0.63	0.62	0.68	0.61	0.73	0.65
PFC (kt CO_2 eq.)										
Aluminium production	1,778	315	208	191	89	-	-	-	-	-
SF_6 (kt)										
Magnesium foundries	-	-	0.0072	0.0035	0.0007	-	-	-	-	-
HFC125 - (kt)										
Magnesium foundries	-	-	-	-	0.0006	-	-	-	-	-
HFC134a - (kt)										
Magnesium foundries	-	-	-	-	-	0.0071	0.0040	0.0038	0.0034	0.0027

Table 4.25 F-gas emissions per compound from metal production in kt CO_2 equivalent, 1990 – 2022

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
					kt CO_2 eq.					
CF_4 (PFC-14)	1,315.0	240.5	172.6	158.6	74.2	-	-	-	-	-
C_2F_6 (PFC-16)	463.4	74.4	35	32.1	15.0	-	-	-	-	-
Total PFC emissions from aluminium production	*1,778*	*315*	*208*	*191*	*89*	-	-	-	-	-
SF_6 emissions from magnesium foundries	-	-	*169.2*	*83.3*	*17.2*	-	-	-	-	-
HFC-125 emissions from magnesium foundries	-	-	-	-	*1.92*	-	-	-	-	-
HFC-134a emissions from magnesium foundries	-	-	-	-	-	*9.2*	*5.2*	*4.9*	*4.4*	*3.5*
Total F-gas emissions from metal production	**1,778.5**	**315**	**376.8**	**274.0**	**108.3**	**9.2**	**5.2**	**4.9**	**4.4**	**3.5**

A more robust Tier 1 comparison has been evaluated to strengthen the conservativeness of combined Tier 1 and Tier 2 approaches (detailed information are reported in previous submissions).

4.4.4 Source-specific QA/QC and verification

Emissions from the sector are checked with the relevant process operators. In this framework, primary aluminum production supplied by national statistics (ENIRISORSE, several years; ASSOMET, several years) and the only national producer ALCOA (ALCOA, several years), in addition with data reported in a site-specific study (Sotacarbo, 2004), have been checked. Moreover, emissions from magnesium foundries are annually compared with those reported in the national EPER/E-PRTR registry while for the iron and steel sector emissions reported in the national EPER/E-PRTR registry and for the Emissions Trading Scheme are compared and checked. Emissions from primary aluminum production have been also checked with data reported under EU-ETS.

4.4.5 Source-specific recalculations

Recalculations occurred on account of the update of EFs for zinc and steel, for the year 2021.

4.4.6 Source-specific planned improvements

The analysis of data reported in the IPPC permits of the integrated plant for zinc and lead production should allow a better allocation between zinc and lead emissions.

4.5 Non-energy products from fuels and solvent use (2D)

4.5.1 Source category description

The sub-sector comprises the following sources: lubricant use, paraffin wax, and other categories which include the use of urea, asphalt roofing and paving with asphalt and solvent use. CO_2 emissions from this category is a key source at level assessment with Approach 2 without and with LULUCF and at trend assessment with Approach 2 only with LULUCF considering the uncertainty; in 1990 it was a key category at level assessment.

Following different UNFCCC review recommendations, for this year's submission, Italy has reported CO_2 emissions from the oxidation of NMVOCs from solvent use not in the relevant categories but, separately and all together, as indirect CO_2 emissions. The description on the methodology to estimate indirect CO_2 emissions are described in this chapter under the section 'Solvent use and indirect CO_2 emissions'.

Lubricant use

Lubricants are mostly used in industrial and transportation applications. Lubricants are produced either at refineries through separation from crude oil or at petrochemical facilities. Under this category, emissions originated by lubricant use in industry and white lubricants and lubricants used for insulating purposes have been considered, CO_2 and NMVOC emissions have been estimated for the whole time series. Emissions from lubricant use in vehicles have been accounted for in the Energy Sector.

Paraffin wax

Paraffin waxes are separated from crude oil during the production of light (distillate) lubricating oils. Paraffin waxes are categorised by oil content and the amount of refinement. About 60-70% of the total amount of paraffin waxes produced in the EU area is used to manufacture candles. Nowadays about 95% of candles are paraffin wax candles; 3% are stearic candles and the remaining 2% is made of beeswax. Slack oils could enter the manufacturing process thus potentially resulting into the emissions of SOx and PAH.

Use of urea

Urea can be used in Selective Catalyst Reduction (SCR) systems to reduce NOx emissions from combustion. SCR systems are generally applied to engines (vehicles) and to industrial combustion (e.g. Power Plants). CO_2 emissions originated using urea in SCR systems have been estimated and reported in this sub-sector.

Asphalt roofing and road paving with asphalt

In 2022 in Italy 17 facilities manufactured bitumen, binders and bituminous emulsions, 11 facilities have been producing bitumen roofing membranes and about 80 facilities operate in the production and laying of asphalt mix products for road paving. SITEB, the Italian asphalt and road association is the relevant source of information for these two source categories. NMVOC emissions have been estimated for these two source categories along the whole time series.

Solvent use and indirect CO_2 emissions

The use of solvents manufactured using fossil fuels as feedstocks can lead to evaporative emissions of various NMVOC and CO_2 emissions, after oxidation of NMVOC in the atmosphere.

Methodologies for estimating NMVOC emissions can be found in the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2009). Also some indications on the subcategories to include in the ‘solvent use’ category are reported in the 2006 IPCC guidelines (IPCC, 2006), which are the following: solvent use in paint application, degreasing and dry cleaning, manufacture and processing of chemical products, other solvent use, such as printing industry, glues application, use of domestic products.

Following different UNFCCC review recommendations, from this year’s submission, Italy has reported CO_2 emissions from the oxidation of NMVOCs from solvent use separately from CO_2 from other source categories and as indirect CO_2 emissions.

4.5.2 Methodological issues

Lubricant use

The use of lubricants in industrial engines is primarily for their lubricating properties and associated emissions are therefore considered as non-combustion emissions to be reported in the IPPU Sector. NMVOC and CO_2 emissions are reported for this category. CO_2 emissions for the whole time series are calculated based on a Tier 1 approach considering the average Lower Heating Value (LHV) of lubricants, the average ODU factor and the average carbon content of lubricants (Equation 5.2 IPCC Guidelines 2006):

$$CO_2\ Emissions = LC \cdot CC_{Lubricant} \cdot ODU_{Lubricant} \cdot 44/12$$

where

LC= lubricant consumption

$CC_{lubricant}$= carbon content

$ODU_{lubricant}$= oxidation factor

44/12= mass ratio CO_2/C

Statistics related to the total amount of lubricants consumed in Italy are officially provided by MASE every year in the Oil Bulletin (MASE, several years) but no details concerning different kind of lubricants are available thus allowing us only for a Tier 1 approach; LHV, Carbon Content and ODU factors used are the default values included in the IPCC 2006 Guidelines are taken. The activity data for this subcategory is the total consumption of lubricants minus the amount of lubricants used in 2-stroke engines (which is derived from reversing COPERT equation to estimate CO_2 emissions in 2-stroke engines). Emissions from the use of lubricants in 2-stroke engines have been accounted for in the Energy Sector.

NMVOC emissions for the whole times have been estimated too, based on the total lubricants consumption and a NMVOC EF= 28 kg NMVOC/tons of lubricant (EMEP/EEA, 2013). The whole time series for NMVOC emissions has been revised in the present submission as a consequence of the review of the activity data time series.

Paraffin wax

In Italy paraffin waxes are mostly used in the manufacture of candles, although a number of different applications (e.g. food production and many others) could have paraffin waxes as an input. Emissions from the use of waxes derive primarily when the waxes or derivatives of paraffins are combusted during use (e.g., candles). No other use of paraffin wax in products implying wax combustion during the product use is known in Italy. In order to estimate CO_2 emissions for the whole time series it has been assumed that 65% of total amount of paraffin wax is destined to the manufacture of candles on account of information provided by the industrial association (Assocandele, 2015). Total paraffin wax consumption is included in the Oil Bulletin provided by the MASE and publicly available on https://sisen.mase.gov.it/dgsaie/bollettino-petrolifero.

Default values for carbon content of paraffin wax as well as ODU factor and LHV have been assumed (2006 IPCC Guidelines) and applied to the activity data according to a Tier 1 approach as in Equation 5.4 of the 2006 IPCC Guidelines:

$$CO_2\ Emissions = PW \cdot CC_{Wax} \cdot ODU_{Wax} \cdot 44/12$$

where:

CO_2 Emissions = CO_2 emissions from waxes, tonne CO_2

PW = total wax consumption, TJ

CCWax = carbon content of paraffin wax (default), tonne C/TJ (= kg C/GJ)

ODUWax = ODU factor for paraffin wax, fraction

44/12 = mass ratio of CO_2/C

Use of urea

Emissions of CO_2 originated by the use of urea in SCR systems in engines and Power plants have been estimated and reported in this sub-sector.

Concerning vehicles, SCR systems were introduced in Italy in 2006 so CO_2 emissions related to SCR systems can be traced back in the time series up to 2006. The amount of urea and CO_2 emitted using urea can be estimated by COPERT, which is the model used by Italy to estimate emissions for road transport. For further details, see paragraph 3.5.2 in the energy chapter.

Concerning power plants, the amount of urea used in SCR systems has been reported by operators under the Italian ETS together with CO_2 emissions since 1997.

Asphalt roofing and road paving

NMVOC emissions from the manufacturing of asphalt roofing materials have been estimated based on the total surface of bitumen roofing membranes (Federchimica, several years; Siteb, several years) and default emission factors (EMEP/CORINAIR, 2007; EMEP/EEA, 2009).

NMVOC emissions from road paving operations have been estimated based on the amount of asphalt mix produced for each year (ISTAT, several years [a]; Siteb, several years) and the emission factors are set constant along the whole timeseries and taken from the EMEP/EEA Guidebook.

Solvent use and indirect CO_2 emissions

Emissions of NMVOC from solvent use have been estimated according to the methodology reported in the EMEP/EEA guidebook, applying both national and international emission factors (Vetrella, 1994; EMEP/CORINAIR, 2007, EMEP/EEA, 2013). Country specific emission factors provided by several accredited sources have been used extensively, together with data from the national EPER/EPRTR Registry; in particular, for paint application (Offredi P., several years; FIAT, several years [b]), solvent use in dry cleaning (ENEA/USLRMA, 1995), solvent use in textile finishing and in the tanning industries (TECHNE, 1998; Regione Toscana, 2001; Regione Campania, 2005; GIADA 2006). Basic information from industry on percentage reduction of solvent content in paints and other products has been applied to EMEP/EEA emission factors in order to evaluate the reduction in emissions during the considered period.

Emissions from domestic solvent use have been calculated using a detailed methodology, based on VOC content per type of consumer product.

As regards household and car care products, information on VOC content and activity data has been supplied by the Sectoral Association of the Italian Federation of the Chemical Industry (Assocasa, several years) and by the Italian Association of Aerosol Producers (AIA, several years [a] and [b]). As regards cosmetics and toiletries, basic data have been supplied by the Italian Association of Aerosol Producers too (AIA, several years [a] and [b]) and by the national Institute of Statistics and industrial associations (ISTAT, several years [a], [b], [c] and [d]; UNIPRO, several years); emission factors time series have been reconstructed on the basis of the information provided by the European Commission (EC, 2002).

The conversion of NMVOC emissions into CO_2 emissions has been carried out considering a fossil carbon content equal to 65% as indicated in the 2006 IPCC Guidelines (chapter 5.5.4).

4.5.3 Uncertainty and time-series consistency

The combined uncertainty in CO_2 emissions from non-energy products from fuels and solvent use is estimated equal to 58.3% due to an uncertainty of 30% and 50% in activity data and emission factors, respectively. In 2022, CO_2 derive mainly from the subcategory 'Lubricants use' for 63% of the sectoral emissions. Table 4.26 shows CO_2 emission trend from 1990 to 2022.

Table 4.26 Trend in CO_2 emissions from the non energy products from fuels and solvent use category (kt)

Gas/subcategory	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
2D. Non-energy products from fuels. Other	**370**	**323**	**332**	**303.5**	**267.1**	**280.9**	**307.8**	**272.8**	**309.4**	**286.8**
2D1. Lubricant use	351	303	308.5	287.4	217.5	211.6	219.7	187.2	207.1	180.4
2D2. Paraffin wax use	19	20	21.1	13.8	13.0	14.5	6.7	7.2	9.7	7.2
2D.3. Other	-	-	2.4	2.3	36.6	54.8	81.4	78.4	92.6	99.2

Gas/subcategory	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
2D3a. Urea (emissions abatement in engines)	-	-	-	-	24.9	47.5	71.0	67.8	84.3	89.3
D3b. Urea (emissions abatement in power plants)	-	-	2.4	2.3	11.7	7.3	10.3	10.6	8.3	9.8
D3c. Road paving	-	-	-	-	-	-	-	-	-	-
2D3d. Asphalt roofing	-	-	-	-	-	-	-	-	-	-

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Indirect CO_2 emissions-Solvent	**1,311**	**1,210**	**1,073**	**1,041**	**860**	**692**	**786**	**705**	**740**	**728**
Paint application	595	555	497	471	345	286	340	277	280	272
Degreasing and dry cleaning	101	61	47	41	36	32	29	28	28	27
Chemical products	170	189	182	131	128	115	112	107	113	115
Other	444	405	347	398	351	260	306	292	318	315

Indirect CO_2 emissions decreased by 44.5% from 1990 to 2022. This category is a key category when applying Approach 2 both at level and trend assessment (with and without LULUCF). The uncertainty of the category is equal to 58.3%.

The decrease observed in emission levels of indirect CO_2 emissions from solvent use from 1990 to 2022, is to be attributed to the reduction in emissions from solvent use, mainly for the reduction in paint application, application of glue and adhesives and domestic solvent use; specifically, the reduction of emissions from paint application for domestic use, which drop by about 54.4% from 1990, is due to the implementation of Italian Legislative Decree 161/2006. Other European directives applies to the solvent use category, which represents the main source of NMVOC emissions at national level (40.2% of the total NMVOC in 2022); for instance, the European Directives (EC, 1999; EC, 2004) regarding NMVOC emission reduction in paint application entered into force, in Italy, in January 2004 and in March 2006, establishing a reduction of the solvent content in products.

4.5.4 Source-specific QA/QC and verification

Emissions from the category are checked with the relevant data providers and industrial associations.

For the solvent use category, and indirect CO_2 emissions, different QA/QC and verification activities are carried out. Data production and consumption time series for some activities (paint application in constructions and buildings, polyester processing, polyurethane processing, pharmaceutical products, paints manufacturing, glues manufacturing, textile finishing, leather tanning, fat edible and non-edible oil extraction, application of glues and adhesives) are checked with data acquired by the National Statistics Institute (ISTAT, several years [a], [b] and [c]), the Sectoral Association of the Italian Federation of the Chemical Industry (AVISA, several years) and the Food and Agriculture Organization of the United Nations (FAO, several years). For specific categories, emission factors and emissions are also shared with the relevant industrial associations; this is particularly the case of paint application for wood, some chemical processes and anesthesia and aerosol cans.

For paint application, data communicated from the industries in the framework of the EU Directive 2004/42, implemented by the Italian Legislative Decree 161/2006, on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain paints and varnishes and vehicle refinishing products have been used as a verification of emission estimates. These data refer to the composition of the total amount of paints and varnishes (water and solvent contents) in different subcategories for interior and exterior use and the total amount of products used for vehicle refinishing and they are available from the year 2007.

4.5.5 Source-specific recalculations

Following different UNFCCC review recommendations, from this year's submission, Italy has reported CO_2 emissions from the oxidation of NMVOCs from solvent use as indirect CO_2 emissions.

Recalculation occurred for CO_2 emissions from Lubricant use (2.D.1) due to the use of updated activity data timeseries and also in 2.D.3. As for CO_2 emissions from lubricants use (2.D.1) and from the use of urea in the engines (2.D.3.a), recalculations occurred from 2005 and 2006, respectively, due to the update of the data resulting from COPERT model as shown in Table 4.27.

Table 4.27 Recalculation of CO_2 emissions from 2.D.1 lubricants use; from the use of urea in SCR systems (2.D.3.a) (%)

Year	2D.1 Lubricants- CO_2	2D.3.a UREA in SCR systems (vehicles) - CO_2
2005	0.04	
2006	0.54	0.73
2007	0.67	1.86
2008	0.86	2.44
2009	1.13	-1.94
2010	1.17	3.15
2011	1.29	3.39
2012	1.64	3.46
2013	1.51	4.17
2014	0.66	9.55
2015	-0.40	6.07
2016	0.92	4.35
2017	0.85	3.65
2018	0.82	3.06
2019	0.72	5.26
2020	0.97	6.56
2021	0.84	7.64

4.5.6 Source-specific planned improvements

No further improvements are planned.

4.6 Electronics Industry Emissions (2E)

4.6.1 Source category description

Fluorocarbons emissions from this sub-sector are from semiconductor manufacturing industry (2.E.1). Actually, in Italy, there are three national plants of semiconductor manufacturing, owned by two company, ST Microelectronics (in the past purchased for a couple of years by Numonyx) and LFoundry (ex Micron Technology): in particular, ST Microelectronic is active from 1995, while LFoundry from 1998. The semiconductor manufacturing companies supply yearly consumption and emission data for each plant

(ST Microelectronics, several years; Micron, several years; Numonyx, several years; LFoundry, several years).

F-gas emissions from semiconductor manufacturing are estimated using the Tier 2a methodology of the new 2006 IPCC Guidelines (IPCC, 2006).

Fluorinated compounds emissions from heat transfer fluids are also estimated. Since 2017 the industry has started to communicate the consumption of the substances used in service equipment and consequently emissions have been estimated equal to consumptions (ST Microelectronic, several years; LFoundry, several years). For the previous years, industry communicated that no data is available and explained that consumptions of these substances are of course linked to the production but not dependent on it (i.e. if production of semiconductor occur, the use of these service equipment occur, but the refrigerant consumption is random). Because of previous considerations, emissions have been estimated constant for the whole time series.

As concerns photovoltaic (PV) manufacturing, currently in Italy there is no production of PV cells, but only assembly. Before 2011, PV cells production occurred but no fluorinated compounds have been used for the process (Lux, 2015; Solsonica, 2015). Finally, no thin-film-transistor flat panel display (TFT-FPD) production occurs in Italy (Linde Gas, 2015). The share of F-gas emissions from the electronics industry in the national total of F-gases accounts for 2.3% in 2022.

4.6.2 Methodological issues

F-gas emissions from semiconductor manufacturing are estimated using the Tier 2a methodology of the 2006 IPCC Guidelines (IPCC, 2006). As reported in the Guidelines, total emissions are equal to the sum of emissions from the gas FCi used in the production process plus the emissions of by-product calculated with equation 6.3/6.4/6.5/6.6.

Companies involved in the semiconductor manufacturing provide yearly data on consumption and emissions (ST Microelectronics, several years; Micron, several years; Numonyx, several years; LFoundry, several years), calculated on the basis of the following equation, accepted by the World Semiconductor Council (WSC). The formula gathers the IPCC Guidelines equations (combining equations 6.2/6.3/6.4/6.5/6.6 of the Guidelines) and includes both direct and by-product emissions):

$$\text{Emissions for } PFC_i = PFC_i*(1-h)[(1-C_i)(1-A_i)*GWP_i + B_i*GWP_{(byproduct)}*(1-A_{(byproduct)})]$$

where:

h = fraction of gas_i remaining in container (heel)

PFC_i = purchases of gas_i = kgs_i

kgs_i = mass of gas_i purchased

GWP_i = 100 yr global warming potential of gas_i

C_i = average utilization factor of gas_i (average for all etch and CVD processes) =1-EF_i

EF_i = average emission factor of gas_i (average for all etch and CVD processes)

B_i = mass of CF_4 created per unit mass of PFC_i transformed

A_i = fraction of PFC_i destroyed by abatement = $a_{i,j}*V_a$

By product formation

A_{CF4} = fraction of PFC_i converted to CF_4 and destroyed by abatement = $a_{CF4}*V_a$

$a_{i,j}$ = average destruction efficiency of abatement $tool_j$ for gas_i

a_{CF4} = average destruction efficiency of abatement $tool_j$ for CF_4

V_a = fraction of gas_i that is fed into the abatement tools

A_{CF4} = fraction of PFC_i converted to CF_4 and destroyed by abatement = $a_{CF4}*V_a$

$a_{i,j}$ = average destruction efficiency of abatement $tool_j$ for gas_i

a_{CF4} = average destruction efficiency of abatement $tool_j$ for CF_4

A_{C2F6} = fraction of PFC_i that is converted to C_2F_6 and destroyed by abatement = $a_{C2F6}*Va$

a_{C2F6} = average destruction efficiency of abatement $tool_j$ for C_2F_6

A_{C3F8} = fraction of PFC_i that is converted to C_3F_8 and destroyed by abatement = $a_{C3F8}*Va$

a_{C3F8} = average destruction efficiency of abatement $tool_j$ for C_3F_8

V_a = fraction of gas_i that is fed into the abatement tools

Emissions are calculated for the following fluorinated gases: HFC 23, HFC 32, HFC 134a, C_2F_6, CF_4, C_3F_8, C_4F_8, SF_6 and NF_3. From 2012, according to the World Semiconductor Council (WSC), data on CH_2F_2, C_4F_6, C_5F_8 are gathered. Since 2000, emissions are calculated considering the contribution of abatement systems.

ST Microelectronics provided emissions for each gas (CF_4, C_2F_6, HFC 23, C_2F_6, C_3F_8, C_4F_8, SF_6 and NF_3) for the year 1995 and from 2001 onwards. For the years 1996-2000 the company was not able to provide detailed data but only aggregated total emissions confirming that they occurred for all the gases and emissions of each gas have been estimated proportionally taking in account their distribution in 1995 and 2001. Moreover, on the basis of the 2001 emission factors (emission gas_i/consumption gas_i), consumption data have been extrapolated for the missing years.

For what concern Heat Transfer Fluids, during the manufacture of semiconductor devices, HTFs serve as coolants in chillers, removing excess heat during many manufacturing processes. During semiconductor device testing, containers of HTFs are cooled or heated to a desired temperature into which the devices are immersed to test their integrity. In addition, when testing the function of devices, HTFs are used to remove the heat the devices generate while being tested. HTFs are also used to attach semiconductor devices to circuit boards via solder, which may be melted by the vapour of an HTF heated to its boiling point. HTFs may also serve to cool semiconductor devices and other devices or systems that generate high heat during operation (EPA, 2006). The semiconductor industry started to collect data and communicated from the year 2017 the annual recharge of these coolants. Emissions have been estimated in terms of tonnes of CO_2 equivalent of unspecified mix of HFCs and PFCs (ST Microelectronic, several years; LFoundry, several years).

4.6.3 Uncertainty and time-series consistency

The combined uncertainty in F-gas emissions for PFC, HFC, SF_6 and NF_3 emissions from semiconductor manufacturing, included Heat Transfer Fluids, is estimated to be about 20.6% in annual emissions, 5% and 20% concerning respectively activity data and emission factors. In Table 4.28 emissions from semiconductor manufacturing are reported.

Table 4.28 Fluorocarbon emissions from semiconductor industry, 1990 –2022 (kt CO_2 eq.)

GAS	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
HFC 23	NO	6.07	8.65	7.19	10.73	9.36	9.62	7.71	7.69	8.24
HFC 32	NO	0.00	0.00	0.00	0.00	0.11	0.01	0.06	0.07	0.03
HFC 134a	NO	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CF_4	NO	65.27	131.86	84.89	66.52	94.97	92.39	91.99	93.13	95.89
C_2F_6	NO	17.08	121.08	81.22	27.48	21.44	26.09	22.23	23.87	18.83
C_3F_8	NO	8.62	11.75	4.29	0.03	0.21	0.07	0.03	0.07	0.21
C_4F_8	NO	10.01	1.51	10.02	26.54	19.81	16.51	9.82	17.04	23.82
C_5F_8	NO	NO	NO	NO	NO	NO	NO	NO	NO	0.01
SF_6	NO	14.90	61.90	57.16	30.58	47.31	52.52	36.91	40.77	40.26
NF_3	NO	76.57	13.26	33.38	20.17	28.42	17.94	16.24	15.23	19.56

GAS	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Unspecified mix of HFCs and PFCs from Heat Transfer Fluids	NO	24.43	24.43	24.43	24.43	24.43	23.15	22.37	25.83	22.13
F-gas emissions (kt CO_2 eq.)	NO	222.95	375.04	302.58	206.47	246.06	235.29	207.35	223.19	228.98

4.6.4 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures. Where information is available, emissions from production and consumption of fluorinated gases have been checked with data reported to the national EPER/E-PRTR registry.

4.6.5 Source-specific recalculations

No recalculations occurred.

4.6.6 Source-specific planned improvements

No further improvements are planned.

4.7 Emissions of fluorinated substitutes for ozone depleting substances (2F)

4.7.1 Source category description

The sub-sector Emissions of fluorinated substitutes for ozone depleting substances consists of the following sub-applications:

2.F.1 – Emissions from Refrigeration and Air Conditioning

2.F.2 – Emissions from Foam Blowing agents

2.F.3 – Emissions from Fire Protection

2.F.4 – Emissions from Aerosols

For category 2.F.5 Solvents, there is no evidence that these emissions occur in Italy. Data collected, in the context of Article 19 of Regulation (EU) 517/2014, has been analyzed. Only one company has declared a small quantity of HFC preparation placed on Community market for the years 2008, 2009, 2010, 2011 and 2013 for solvents applications: since the substances declared, HFC-134a, R-507A and R-410A, are not usually used as solvents, the Company was contacted and replied that these data referred to RAC systems in Chemistry industry. Moreover, Assogastecnici, the Association of companies involved in the production and distribution of technical, special and medicinal gases also confirmed that they have no evidence of F-gases used as Solvents..

HFC emissions from Refrigeration and Air Conditioning and from Fire extinguishers are key categories at level and trend assessment, both using Tier 1 and Tier 2, with and without LULUCF, in 2022. HFC emissions from Foam blowing agents are a key category at trend assessment using Tier 2 with and without LULUCF.

The share of F-gas emissions of fluorinated substitutes for ozone depleting substances in the national total of F-gases (including the contribution of the unspecified mix of HFC and PFC) is 91.1% in 2022.

4.7.2 Methodological issues

The methods used to calculate F-gas emissions of fluorinated substitutes for ozone depleting substances are presented in Table 4.29.

Table 4.29 Sub-sources of F-gas emissions and calculation methods

Source category	Sub-application	Calculation method
Fluorinated Substitutes for ODS (2F)	Refrigeration and air conditioning equipment (2F1)	IPCC Tier 2a
	Foam blowing (2F2)	IPCC Tier 2a
	Fire extinguishers (2F3)	IPCC Tier 2a
	Aerosols/metered dose inhalers (2F4)	IPCC Tier 2a

Total emissions have been calculated as the sum of Manufacturing emissions, Use (Operation) emissions and Disposal emissions, as indicated by the following equation of the 2006 IPCC Guidelines.

EQUATION 7.4

SUMMARY EMISSIONS EQUATION BASED ON PHASES OF THE LIFECYCLE

Total Emissions of Each PFC or HFC =

Assembly/Manufacturing Emissions + Operation Emissions + Disposal Emissions

Moreover, for Refrigeration and Air Conditioning, the following equation has been applied, also considering emissions from containers, which comprise all emissions related to the refrigerant transfers from bulk containers down to small capacities, ready to be sell to the manufacturers or users.

EQUATION 7.10

SUMMARY OF SOURCES OF EMISSIONS

$$E_{total,t} = E_{containers,t} + E_{charge,t} + E_{lifetime,t} + E_{end\ of\ life,t}$$

"Recovery" has been calculated as the "Amount remaining in products at decommissioning" minus "Disposal emissions".

The Legislative Decree n. 151/05 has implemented in Italy the EU Directive on Waste from Electric and Electronic Equipment (WEEE). According to this Decree when equipment is disposed of it is by law required to recover the remaining F-gas and either reuse or destroy it. At the moment, although the number of authorized centers for the treatment of WEEE is known, bulk data, not only F-gases, are not available and there are many small, authorized centers which do not have to report about their activities and also the major centers are not able to communicate data on single gas recovered. From last year we are in contact with Erion, the largest Italian system of extended producer responsible for the management of waste associated with electronic products, because they are finalizing a study on stationary conditioning appliances end-of-life.

IPCC Tier 2a implies the availability of either number of applications/equipment using the individual gas, or the amounts of the gas used in the different sectors.

Based on the amount of individual gas produced in Italy until 2012 and the sectoral uses of the gas, emissions are estimated according to IPCC Tier 2a. The estimates are based on single gas consumptions data supplied, until 2013, by the only national refrigerants producer (Solvay, 1998; Solvay, 2006) and from 2014 by Assogastecnici who supply data on F-gases consumption for different applications (Assogastecnici, several years. In the context of a survey, at a national level, about HFCs alternative substances with low GWP, natural refrigerants and alternative technologies led by ISPRA (ISPRA, 2018), collaboration with air conditioning and refrigeration national associations, major import/export F-gas companies, and the major experts of the sector, as well as companies, has been put in place. This collaboration with Assogastecnici led to an important achievement for F-gases consumption data on RACHP. Data are also supplied for Mobile Air Conditioning and medical Aerosols. For Domestic refrigeration and Stationary Air Conditioning sub-sector, emissions have been calculated based on appliances produced and placed on the market supplied by APPLiA (Association of Manufacturers of the Domestic and Professional Appliances) and Assoclima (Association of Manufacturers of Air Conditioning Systems). The applied methodology, although it is not a balance of chemical sales, uses specific emission factors for each consumption type.

Since the methodology is based on the consumption of the F-gases in the different categories, the estimated consumption, where relevant, also includes the amount of fluid contained in the imported products, which contribute only to the estimates of operating emissions and not to manufacturing emissions (i.e. MAC, Stationary Air Conditioning).

In Table 4.30 a summary of refrigerants and chemicals used in Italy in each sub-application is reported. The ozone layer-depleting substances used in the early nineties were also reported, as well as the alternative substances to HFCs that entered the market following the European Directive 517/2014, now replaced by the new Regulation (EU) 2024/573.

Table 4.30 Refrigerants and other chemicals and propellants used in Italy over the period 1990 – 2022

Sub-application	1990-1995	1995-1998	1998-2010	2010-2014	2014-2022
Commercial Refrigeration (2.F.1.a)	R-11, R-12, R-22	R-11, R-12, R-22, R-404A, R-507A	R-22, R-404A, R-507A, R-134a	R-404A, R-507A, R-134a	R-404A, R-507A, R-134a, R-407F, R-407H, R-448A, R-449A, R-600a, R-290, R-744
Domestic Refrigeration (2.F.1.b)	R-12	R-12, R-134a	R-134a	R-134a	R-600a
Industrial Refrigeration (2.F.1.c)	R-12, R-22, R-717	R-717, R-23, R-404A, R-507A	R-717, R-23, R-404A, R-507A, R-134a	R-717, R-23, R-404A, R-507A, R-134a	R-717, R-23, R-404A, R-507A, R-134a, R-407F, R-407H, R-448A, R-449A
Transport Refrigeration (2.F.1.d)	R-11, R-12, R-22, R-502	R-11, R-12, R-22, R-502, R-404A, R-507A	R-22, R-404A, R-507A, R-134a	R-404A, R-507A, R-134a	R-404A, R-507A, R-134a, R-452A, R-744
Mobile Air Conditioning (2.F.1.e)	R-12, R-134a	R-134a	R-134a	R-134a	R-134a, R-1234yf
Stationary Air Conditioning (2.F.1.f)	R-12, R-22	R-12, R-22, R-410A, R-407C, R-134a	R-22, R-410A, R-407C, R-134a	R-410A, R-407C, R-134a	R-410A, R-407C, R-134a, R-32, R-513A, R-290, R-1234ze-

Sub-application	1990-1995	1995-1998	1998-2010	2010-2014	2014-2022
Foams (2.F.2)	R-22, R-141b, R-142b	R-22, R-141b, R-142b	R-22, R-141b, R-142b, R-134a, R-245fa	R-134a, R-245fa	R-134a, R-245fa, HC, HFO
Fire Extinguishers (2.F.3)	Halon, HCFC mixture, NAF S-III, R-23, R-125, R-227ea	R-23, R-125, R-227ea	R-23, R-125, R-227ea	R-23, R-125, R-227ea	R-23, R-125, R-227ea, FK-5-1-12, NOVEC 1230
Aerosols (MDI) (2.F.4)	R-11, R-12, R-114	R-11, R-12, R-114	R-134a	R-134a	R-134a

Assogastecnici provided the percentage distribution of refrigerants consumptions by sector of use, from 2014 to 2022 (Assogastecnici, 2022; Assogastecnici 2023), as reported in Tables 4.31 and 4.32.

Table 4.31 Market distribution of HFCs and HFO (%), 2014 - 2021

Refrigerant HFC/HFO	Commercial and Industrial refrigeration	Stationary Air Conditioning	Mobile Air Conditioning	Transport refrigeration
R134a	20%	15%	60%	5%
R407C/F/H	20%	80%		
R410A		100%		
R32		100%		
R448A/R449A/R452A	85%			15%
YF/ZE		20%	80%	
R404A/R507	90%			10%

Table 4.32 Market distribution of HFCs and HFO (%), 2022

Refrigerant HFC/HFO	Commercial and Industrial refrigeration	Stationary Air Conditioning	Mobile Air Conditioning	Transport refrigeration
R134a	20%	15%	60%	5%
R407C/F/H	60%	40%		
R410A		100%		
R32		100%		
R448A/R449A/R452A	90%			10%
ZE		100%		
YF			100%	
R404A/R507	85%			15%

Moreover, for the year 2022, Assogastecnici has also provided the data split between *First Charge* consumption and *Service* consumption.

These data were subjected to a review process with the involvement of the Refrigeration and Air Conditioning national association, import/export F-gas companies, and experts of the RACHP sector that validated them, as well as continuous comparison with data from F-gases database.

At present, these data represent the best available information of this source category, together with data provided directly from automotive industry for the Mobile Air Conditioning sub-category, from Assoclima for Stationary Air Conditioning sub-category and the from pharmaceutical industry for Aerosols sub-category.

Finally, in Table 4.33, the sources of activity data and emissions factors for each sub-sector are summarized.

Table 4.33 Summary of activity data and emission factors sources

CRF Category	Category	Substance	Activity Data References	Emission Factors References
2.F.1.a	Commercial Refrigeration	HFC-134a R-404A R-507A R-407F R-407H R-448A R-449A	Solvay, Assogastecnici	Expert Judgement/IPCC
2.F.1.b	Domestic Refrigeration	HFC 134a	APPLiA	Expert Judgement/IPCC
2.F.1c	Industrial Refrigeration	HFC-23 HFC-134a R-404A R-507A R-407F R-407H R-448A R-449A	Solvay, Assogastecnici	Expert Judgement/IPCC
2.F.1.d	Transport Refrigeration	HFC-134a R-404A R-507A R-452A	Solvay, Assogastecnici	Expert Judgement/IPCC
2.F.1.e	Mobile Air Conditioning	HFC-134a	Solvay, Assogastecnici FIAT, IVECO, UNRAE, CNH, ACI	Expert Judgement/IPCC
2.F.1.f	Stationary Air Conditioning	HFC-134a R-410A R-407C R-32 R-513A	Assoclima Solvay, Assogastecnici	Expert judgement
2.F.2.a	Foam Blowing	HFC-245fa HFC-134a	Solvay, Assogastecnici	IPCC
2.F.3	Fire Extinguishers	HFC-227ea	Clean Gas, Gastec Vesta, Expert judgment Solvay, Assogastecnici	ASSURE
2.F.4	Metered Dose Inhalers	HFC-134a	Menarini, Chiesi, Sanofi Aventis, GSK, Lusofarmaco, Istituto De Angeli, BoehringerSolvay, Assogastecnici	Chiesi

4.7.3 Emissions from Commercial refrigeration subsector (2.F.1.a)

Commercial refrigeration includes emissions from those refrigeration systems and small appliances used in the food retail industry.

IPCC Tier 2a methodology has been applied, using activity data and resulting bank calculations derived and emission factors that reflect the unique emission characteristics related to various processes, products and equipment.

The collaboration with the experts of the sector have led to important improvements in this submission: Industrial refrigeration and Transport refrigeration have been estimated separately, while professional refrigeration such as blast chiller estimations is still included in Commercial refrigeration because no detailed information is available to split consumptions and emissions.

Refrigerants market: activity data and HFC used in Commercial refrigeration

The Tier 2a methodology 2006 IPCC Guidelines of the takes into account the phase out or the phase down of CFCs and HCFCs depending on the Montreal Protocol schedule and possible national or regional regulations, in order to establish the refrigerant choice for all applications. This has been done by Solvay (Solvay, 1998; Solvay, 2006) who produced fluorinated gases in Porto Marghera plant until 2012. The Company communicated production, import and export data of the substances, as well as the emissions of HFC, PFC and SF_6 from 2B9 category; moreover, in order to calibrate its productions based on market demand, Solvay, who was the only producer in Italy, supplied an annual estimates of total national refrigerants consumption, including also all other substances not included in their production but placed in the market.

The year in which HFCs entered the market to replace ozone layer-depleting substances is 1995. Consumption data of those specific refrigerants used in the refrigeration sector from 1995 to 2013 are derived from Solvay communications, whereas data from 2014 to 2022 have been supplied by Assogatecnici (Assogastecnici, 2022; Assogastecnici 2023).

In Table 4.34, annual consumption of refrigerants used overall in large systems and small appliances is reported.

Table 4.34 Gas consumption for Commercial refrigeration, 1990 - 2022

2.F.1.a Total consumptions (t)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
HFC-134a	NO	NO	693.3	892.0	561.8	256.0	192.0	144.0	152.3	158.8
R-404A	NO	4.5	317.9	756.0	987.0	1,134.0	245.7	189.0	194.0	106.7
R-507A	NO	3.6	106.0	144.0	188.0	216.0	46.8	36.0	37.0	20.3
R-407F	NO	NO	NO	NO	NO	67.5	30.0	27.5	31.4	92.9
R-407H	NO	NO	NO	NO	NO	67.5	30.0	27.5	31.4	92.9
R-448A	NO	NO	NO	NO	NO	24.0	622.6	593.3	632.9	569.2
R-449A	NO	NO	NO	NO	NO	18.0	286.2	239.0	254.9	229.3
Total Consumption	***NO***	***8.1***	***1,117.1***	***1,792.0***	***1,736.8***	***1,783.0***	***1,453.3***	***1,256.4***	***1,333.9***	***1,270.1***

R-407F and R-407H have been included in Commercial refrigeration sub-category, from this year submission, as well as a different distribution of refrigerants between small commercial appliances and large refrigeration systems. Apart from R-507A which is used only in large refrigeration systems, other refrigerants have also been used Stand Alone appliances, currently replacing with hydrocarbons. In fact, as consequence of HFC bans and phase down, and of the market dynamic of the last years, with the increasing of the cost of HFC with higher GWP and a reduction of their availability, such as for R-404A and R-507A, new HFC and alternative substances with lower or null GWP have been entering the market. The refrigerants market is moving towards a model characterized by a presence of many different gases, each one with a specific different application

Assogastecnici communicated the share of consumption of refrigerant used for the first charge and the share of refrigerant used for service. This allowed the *First Charge* consumption to be used to calculate Manufacturing emissions, as well as *Service* consumption to calculate Operation emissions. The shares were communicated for the year 2022, but the experts supported the inventory team to reconstruct back the time series. The share of consumption used for the first charge of the appliance or used for service is reported in the Technical Document *Emission of fluorinated substances from ODS* (ISPRA, 2024).

Emission factors for Commercial refrigeration

Appropriate losses rates have been applied taking into account the equipment where refrigerants are generally used, as suggested by a pool of experts during a specific meeting held at the Ministry of the Environment (ISPRA-MATTM, 2013), in order to assess F-gas emissions from refrigeration and air conditioning. For the years 1990-1999 leakage rates were supplied by the industrial associations of manufacturers as the best available country specific information. For the years from 2000 they have been revised to take into consideration the changes in technology which have been occurring in the manufacturing of the equipment: the year 2000 has been taken as a turning point in terms of changes of technologies and good practice in the refrigerants handling, because of the transition from the use of CFCs and HCFCs towards the use of HFCs.

The Regulation (EC) 2037/2000 of the European Parliament and of the Council of 29 June 2000 on substances that deplete the ozone layer (EC, 2000) entered into force in 2000, introducing the phase out of CFC and the phase down of HCFC and restriction in handling these substances. Because of the legislation, together with the increase of refrigerant prices, the relevant operational procedures in manufacturing, during installation and in exercise changed resulting in a turning point of leakage rates, as well as 2015.

For operational emission factors for the large commercial refrigeration, a 10% emission factor has been adopted since 2015, to account for the entry into force of the F-Gas Regulation (EU) 517/2014, which has resulted in an increased focus on refrigerant gas management.

The average lifetimes for each type of refrigeration systems are from expert judgement and from IPCC Guidelines (IPCC, 2006; ISPRA-MATTM, 2013; WG1, 2013) In the following Table 4.35 the emission factors, average lifetime, recovery efficiency and the initial charge remaining are reported.

Table 4.35 Manufacturing and operating emission factors and parameters for the end-of-life emissions estimation for Commercial refrigeration equipment

	1995 - 1999	2000 - 2014	2015 - 2022
Stand-alone Commercial Applications			
Manufacturing emission factor	0.5%	0.5%	0.5%
Operational emission factor	5%	5%	5%
Average lifetime	12	12	12
Initial Charge Remaining	40%	40%	40%
Recovery Efficiency	50%	50%	50%
Medium & Large Commercial refrigeration			
Initial emission factor	3.0%	0.5%	0.5%
Operational emission factor	15%	12%	10%
Average lifetime	12	12	12
Initial Charge Remaining	75%	75%	75%
Recovery Efficiency	50%	50%	50%

Finally, the emissions related to the complete refrigerant management of containers are estimated between 5 and 0.5 percent of the refrigerant market. The appropriate losses rates were provided by experts of the sector. The emission factor from containers is equal for all sub-category, because refrigerants are stored in the same containers, regardless of the market sector where they will be sold. This emission factor decreased over the time due to the implementation of the F-gas Regulation and the good practices adopted by the operators, as reported in Table 4.36.

Table 4.36 Management of containers emission factors

Refrigerants containers management leakage rates			
1994-1999	**2000-2004**	**2005-2014**	**from 2015**
5.0%	2.0%	1.0%	0.5%

HFC emissions estimation from Commercial refrigeration

As reported above, in a Tier 2a calculation, refrigerant emissions at a year t result from the sum of containers emissions, manufacturing emissions, operational emissions and disposal emissions. All these quantities have to be calculated for each type of HFC used in the applications.

HFC market supplied by Solvay and Assogastecnici is already net of losses from containers, thus, to calculate the amount of HFC contained in the containers, F-gas consumptions was increased by the amount that it would then have lost.

It should be noted that for sectors for which containers emissions have been estimated, they have been reported in the "*CRT reporting table*" included in the voice *"Emissions from stocks",* together with the operating emissions.

The availability of data split between *First Charge* and *Service* has led to changes in the application of the methodology, compared to the previous Submission. The first charge consumption was used to calculate manufacturing emissions directly by multiplying the annual tons used for new equipment placed on the market by the relevant emission factor, as reported in equation 7.12 of the 2006 IPCC Guidelines.

The amount charged as *First Charge* includes all systems which are charged in Italy, including those which are produced for export. Unlike Stationary Air Conditioning, in the Commercial refrigeration imported pre-charged equipment seems to be very rare.

Annual leakage from the refrigerant banks represents operational emissions.Besides component failures, such as compressor burn-out, equipment is serviced mainly when the refrigerating capacity is too low due to loss of refrigerant from fugitive emissions. Depending on different conditions, servicing could be done every year, every certain time interval, or sometimes not at all during the entire lifetime. The formula 7.13 of the 2006 IPCC Guidelines is applied to calculate operational emissions.

On the basis of the HFC consumption data, the average annual stock for Commercial refrigeration is calculated. The stock is given by the sum of the amount of refrigerant in the machines placed on the market in the considered year, plus the amount of the refrigerant still in the machines from the previous year and less the quantity of refrigerant in the machines that left the market in that year because at the end of their life, plus the amount of refrigerant used for service. For each refrigerant the average annual stocks are calculated according to the 2006 IPCC Guidelines.

In the following Table 4.37 the HFC average annual stocks for each refrigerant used in commercial refrigeration are reported. Data are reported by single F-gas, considering the composition of each blend.

Table 4.37 Amount of HFC banked in existing systems (tons) for Commercial refrigeration, 1990 - 2022

2.F.1.a Commercial refrigeration (t)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
HFC 134a	NO	0.2	1,611.0	4,323.8	5,163.6	3,732.4	2,681.0	2,430.2	2,281.0	2,178.4
HFC 143a	NO	4.1	391.6	1,684.8	2,618.5	2,793.5	1,811.6	1,605.3	1,441.0	1,227.8
HFC 125	NO	3.8	345.1	1,479.5	2,288.5	2,474.2	1,887.8	1,728.6	1,636.6	1,491.9
HFC 32	NO	NO	NO	NO	NO	52.8	313.7	333.7	385.2	436.7
Total HFC bank (t)	*NO*	*8.1*	*2,347.7*	*7,488.0*	*10,070.6*	*9,052.9*	*6,694.2*	*6,097.8*	*5,743.8*	*5,334.8*

Until the last submission, because consumption data were not split in two components (*First Charge* and *Service*), the estimates were based on single gas consumption data that also included the quantity of refrigerant used for the maintenance: manufacturing emissions were overestimated because the amount charged in new equipment was the total quantity of consumptions. Moreover, the combination of the emission factors and the lifetime of the equipment and since no gas was added to the bank as refill (because already included in the total consumption) implied that some appliances were able to lose its charge completely during its lifetime and consequently, the charge remaining at decommissioning was zero. In these particular cases, it was assumed that emissions were included in "operating systems" emissions and no emissions from disposal and emissions from recovery were present.

From this submission 2024, the fact of having a quantity of gas used for service every year means that it is not known exactly when equipment is topped up. Therefore, the quantity at the end of its life is not calculated based on the loss rate and years of its life but an average percentage of the initial charge remaining inside the equipment is assumed, based on the values reported in the 2006 IPCC Guidelines.

Thus, End-of-life emissions are calculated as the difference between the quantity of refrigerant present in the equipment when it is dismantled and the quantity of gas that is recovered, in line with equation 7.14 of the 2006 IPCC Guidelines.

In the following Table 4.38, total emissions are reported, distinguished in Containers, Manufacturing, Operational and Disposal, both for stand-alone and large commercial refrigeration systems by single F-gas, considering the composition of each blend.

Table 4.38 HFC Total emissions (tons) from Commercial refrigeration, 1990 – 2022

2.F.1.a Commercial refrigeration (t)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Containers Emissions (t)										
HFC 134a	NO	0.01	14.41	9.32	6.07	1.88	2.18	1.82	1.95	2.15
HFC 143a	NO	0.22	4.46	4.70	6.13	3.51	0.76	0.58	0.60	0.33
HFC 125	NO	0.20	3.94	4.09	5.34	3.26	1.90	1.64	1.74	1.53
HFC 32	NO	NO	NO	NO	NO	0.27	1.26	1.15	1.24	1.32
Manufacturing Emissions (t)										
HFC 134a	NO	0.004	2.99	3.32	1.76	0.67	0.57	0.44	0.45	0.42
HFC 143a	NO	0.10	0.80	1.32	1.21	0.81	0.08	0.04	0.02	NO
HFC 125	NO	0.09	0.71	1.15	1.06	0.72	0.30	0.25	0.24	0.20
HFC 32	NO	NO	NO	NO	NO	0.01	0.23	0.21	0.23	0.20
Lifetime Emissions (t)										
HFC 134a	NO	0.03	188.01	504.57	603.53	367.92	265.47	240.52	225.37	214.79
HFC 143a	NO	0.58	44.25	190.38	295.89	265.38	172.11	152.51	136.89	116.64

2.F.1.a Commercial refrigeration (t)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
HFC 125	NO	0.53	39.00	167.19	258.61	235.05	179.34	164.22	155.48	141.73
HFC 32	NO	NO	NO	NO	NO	5.02	29.81	31.70	36.59	41.49
Disposal Emissions (t)										
HFC 134a	NO	NO	NO	NO	106.37	143.51	106.81	94.20	82.24	70.57
HFC 143a	NO	NO	NO	NO	9.65	62.53	52.20	51.37	50.16	48.58
HFC 125	NO	NO	NO	NO	8.50	55.24	45.41	44.69	43.64	42.26
HFC 32	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total Emissions (t)										
HFC 134a	NO	0.04	205.41	517.21	717.73	513.97	375.03	336.98	310.00	287.93
HFC 143a	NO	0.90	49.51	196.39	312.88	332.23	225.14	204.50	187.68	165.55
HFC 125	NO	0.82	43.64	172.42	273.49	294.26	226.95	210.80	201.10	185.72
HFC 32	NO	NO	NO	NO	NO	5.29	31.29	33.07	38.06	43.00

As reported above, professional refrigeration such as blast chiller estimations is still included in Commercial refrigeration because no detailed information is available to split consumptions and emissions. A brief focus on professional refrigeration is reported in the technical document (ISPRA, 2024). Because the new Regulation (EU) 2024/573 establishes further limitations for this sector, further investigation is planned for next submissions.

4.7.4 Emissions from Domestic refrigeration subsector (2.F.1.b)

Domestic refrigeration includes appliances used for the storage of chilled and frozen food and drink products in households' spaces. The sector includes refrigerators, freezers and fridge-freezers.

Prior to 1990 most refrigeration appliances used CFC-12. In developed countries there was a shift to HFC-134a from around 1993 (in Italy in 1994). Many countries have subsequently moved to systems using hydrocarbon HC-600a which is now the predominant refrigerant for new domestic refrigeration appliances.

In Italy, from 2015, new appliances placed on the market are equipped with isobutane.

Refrigerants market: activity data and HFC used in Domestic refrigeration

Domestic refrigeration estimations are based on data of manufactured and sold fridges and freezers provided by APPLiA Italia who represents the manufacturers of the Domestic and Professional Appliance sector.

Domestic refrigeration appliances started to use HFC-134a from 1994 (RAEE, 2017), as a consequence of the ban of CFC forced by Law n. 549/1993, reporting the measures to protect the stratospheric ozone and the environment (Law 28th of December 1993). APPLiA Italia supplied production data of fridges and freezers from 1987 (APPLiA Italia, several years). Data for the other years (1992, 1994, 1995, 1996, 1998, 2000) have been interpolated. Production data have been used to estimate emissions from manufacturing.

Emissions from stocks have been estimated starting from the number of appliances placed on the market each year. Data have been supplied by APPLiA Italia for the year 1993 and from 2001 (APPLiA Italia, several years), even if for the year 1993 the appliances placed on the market still used CFCs. Data for the other years have been interpolated (1994-2000). Data are reported in Table 4.39. APPLiA Italia also supplied data on HFCs coverage on the total of sales, the average charge of appliances and the lifetime (APPLiA Italia, several years). The percentage of appliances containing HFC-134a decreased over the time passing from 35% in 1994 to 0% in 2015, due to the bans of the F-gas Regulation 517/2015. For the emissions estimation an average lifetime of 14 years was assumed for equipment together with an average charge equals to 137.5 g from 1994 to 2000, 117.5 g in 2001 and 2002 and 110 g from 2003 (a specific table is reported in ISPRA (ISPRA, 2024).

Table 4.39 Number of manufactured and sold equipment for Domestic refrigeration, 1994-2022

Domestic refrigeration	1994	1995	2000	2005	2010	2015	2019	2020	2021	2022
Manufactured equipment (units*1000)										
Fridges	5,461	5,746	7,169	5,496	2,400	1,804	1,515	1,438	1,714	NA
Freezers	1,693	1,782	2,229	1,890	1,200	521.91	385	583	670	NA
Sold equipment (units*1000)										
Fridges	1,701	1,783	2,190	2,232	2,294	1,832	1,575	1,846	2,056	NA
Freezers	420	455	630	593	647	425	378	671	733	NA

The quantities of HFC contained in the manufactured and sold equipment are reported in the following Table 4.41. As all the domestic equipment are factory charged and are hermetically sealed units (and no gas refilling is necessary during their lifetime), the quantities of refrigerants used to fill new manufactured products coincides with the annual HFC Domestic refrigeration consumption.

Table 4.41 Quantities of HFC contained in the manufactured and sold Domestic refrigeration equipment, 1994-2022 (t)

2.F.1.b Domestic refrigeration	1994	1995	2000	2005	2010	2015	2019	2020	2021	2022
HFC in manufactured equipment (t)										
HFC-134a	344.26	724.53	775.33	162.51	27.72	0.00	0.00	0.00	0.00	0.00
HFC in sold equipment (t)										
HFC-134a	102.09	215.39	232.67	62.15	22.64	0.00	0.00	0.00	0.00	0.00

Emission factors and HFC emissions estimation from Domestic refrigeration

As for Commercial refrigeration, IPCC Tier 2a methodology has been applied, using activity data and resulting bank calculations derived and emission factors. Total emissions are the sum of containers, manufacturing, operational and disposal emissions. For each term equations 7.11, 7.12, 7.13 and 7.14 of the 2006 IPCC Guidelines have been applied.

Unlike the previous Submission, this year the emission from containers were also estimated. This resulted in a recalculation of emissions.

The appropriate losses rates were provided by experts of the sector. The emission factor from containers are reported in Table 4.36.

In the following table 4.42 the emissions factors, the initial charge remaining and recovery at decommissioning for Domestic refrigeration are reported.

Table 4.42 Manufacturing and operating emission factors, initial charge remaining and recovery at decommissioning for domestic refrigeration equipment.

2.F.1.b Domestic refrigeration	%
Manufacturing leakage rate	3%
Product life leakage rate	0.7%

2.F.1.b Domestic refrigeration	%
Initial Charge Remaining	90.2%
Recovery at decommissioning	85%

On the basis of the HFC consumption data, the average annual stock for domestic sub-sectors was calculated (Table 4.43)

Table 4.43 HFC average annual stocks from the Domestic refrigeration, 1994-2022 (t)

2.F.1.b Domestic refrigeration (t)	1994	1995	2000	2005	2010	2015	2019	2020	2021	2022
Average annual stock (t)										
HFC-134a	101.38	314.55	1,580.21	2,152.09	1,762.92	620.80	201.04	152.49	105.74	71.48

Table 4.44 shows the emissions separated into container emissions, manufacturing emissions, lifetimes emissions and disposal emissions: the emissions, after a peak in 1995, decrease over the years and in 2022 are equal to 5.53 t.

Table 4.44: HFC total emissions from Domestic refrigeration (t), 1994-2022

2.F.1.b Domestic refrigeration	1994	1995	2000	2005	2010	2015	2019	2020	2021	2022
Containers emissions (t)										
HFC-134a	18.12	38.13	15.82	1.64	0.28	0.00	0.00	0.00	0.00	0.00
Manufacturing emissions (t)										
HFC-134a	10.33	21.74	23.26	4.88	0.83	0.00	0.00	0.00	0.00	0.00
Lifetime emission (t)										
HFC-134a	0.71	2.20	11.06	15.06	12.34	4.35	1.41	1.07	0.74	0.50
Disposal emission (t)										
HFC-134a	NO	NO	NO	NO	32.85	25.68	8.41	7.07	6.85	5.03
Total HFC-134a emissions (t)	***29.16***	***62.07***	***50.14***	***21.58***	***46.30***	***30.02***	***9.82***	***8.14***	***7.59***	***5.53***

4.7.5 Emissions from Industrial refrigeration subsector (2.F.1.c)

Industrial Refrigeration includes refrigeration systems used in manufacturing and process industries.

Most of the industrial refrigeration is used in the processing and storage of food and beverages and the manufacturing of petrochemicals, chemicals and pharmaceuticals. Several other industrial operations use refrigeration, such as the manufacture of plastic products and semi-conductors.

The industrial sector was the only refrigeration market using a significant amount of non-fluorocarbon refrigerants prior to 1990. In particular, R-717 (ammonia) was in widespread use and actually is increasing following the phase-out of the F-gases with high GWP.

Most small and medium sized systems used fluorocarbons such as R-12, R-22 prior to 1990. From 1995 various HFCs were introduced in Italy, such R-23, R-404A, R507A and from 1998 HFC-134a. In recent years, new blends R-407F, R 407H, R-448A and R-449A are used in the industrial refrigeration alternatives to high GWP gases.

Refrigerants market: activity data and HFC used in Industrial refrigeration

As for Commercial, also for Industrial Refrigeration estimates are based on single gas consumptions data supplied by Solvay and Assogastecnici (Solvay, 1998; Solvay, 2006; Assogastecnici 2022; Assogastecnici 2023). Until last submission, only HFC-23 emissions were estimated because consumption data for other gases in this sector were not available separately. From 2022 Assogastecnici provided the consumption data for the industrial refrigeration of following gases: HFC-134a, R-404A, R-507A, R-407F, R-407H, R-448A and R-449A.

Assogastecnici also provided HFC consumption data by use (*First Charge* and *Service*) for the year 2022. This information is reported in ISPRA (ISPRA, 2024). In 2022, 100% of R-404A and R-507A are used for service, the amount of R-134a and R-452A used for maintenance are 80% and 90% respectively. For the years before 2022 the percentage allocation of gas between first charge and service is based on expert judgment. R-407F, R-407H, R-448A and R-449A entered the market in 2015 to replace R-404A, R-507A and HFC-134a following the implementation of the F-Gas Regulation. Their use has therefore increased steadily in the following years, while that of R-404A, R-507A and HFC-134a has decreased. In particular, in 2022 the use of HFC-23, R-404A and R-507A as the first charge is zero due to the bans of the F-Gas Regulation. These gases were used only for the servicing operations. The following table (Table 4.45) shows the HFC total consumptions of the industrial refrigeration subsector.

Table 4.45: HFC consumption from Industrial refrigeration (t), 1990-2022

2.F.1.c Industrial refrigeration	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
HFC-23	NO	15.00	16.56	21.11	11.11	11.15	10.23	10.00	9.50	10.50
HFC-134a	NO	NO	1039.88	1337.99	842.69	384.00	288.00	216.00	228.40	238.20
R-404A	NO	4.50	317.91	756.00	987.00	1134.00	245.70	189.00	194.04	106.74
R-507A	NO	3.60	105.97	144.00	188.00	216.00	46.80	36.00	36.96	20.33
R-407F	NO	NO	NO	NO	NO	67.50	30.00	27.50	31.42	92.85
R-407H	NO	NO	NO	NO	NO	67.50	30.00	27.50	31.42	92.85
R-448A	NO	NO	NO	NO	NO	16.00	415.07	395.56	421.93	379.48
R-449A	NO	NO	NO	NO	NO	12.00	190.81	159.34	169.96	152.86
Total Consumption (t)	***NO***	***23.10***	***1,480.32***	***2,259.11***	***2,028.81***	***1,908.15***	***1,256.61***	***1,060.90***	***1,123.63***	***1,093.82***

Emission factors from Industrial refrigeration

As for the other refrigeration subsectors, appropriate losses rates have been applied taking into account the equipment where refrigerants are generally used, as suggested by a pool of experts during a specific meeting held at the Ministry of the Environment (ISPRA-MATTM, 2013).

Emission factors have been checked recently with Assogastecnici and with those reported in the 2006 IPCC Guidelines.

The average lifetimes for each type of refrigeration systems are from expert judgement and from IPCC Guidelines (IPCC, 2006; ISPRA-MATTM, 2013; WG1, 2013). In the following Table 4.46 the emission factors, average lifetime, recovery efficiency and the initial charge remaining are reported.

Table 4.46 Emission factors, average lifetime, initial charge remaining and recovery at decommissioning for Industrial refrigeration

2.F.1.c Industrial refrigeration	1995 - 1999	2000 - 2014	2015 - 2022
Initial emission factor	1.8%	1.8%	1.8%
Operational emission factor	15%	15%	11%
Average lifetime	20	20	20
Initial charge remaining	75%	75%	75%
Recovery efficiency	50%	50%	50%

HFC emissions estimation from Industrial refrigeration

As reported above, in a Tier 2a calculation, refrigerant emissions result from the sum of emissions from containers, manufacturing emissions, operational emissions and disposal emissions, using equations 7.11, 7.12, 7.13 and 7.14 of the 2006 IPCC Guidelines.

All these quantities have to be calculated for each type of HFC used in the applications.

Emissions from containers have been estimated using appropriate losses rates provided by experts of the sector (see Table 4.36).

To estimate the amount of HFC stored in containers, before being used for different operations (installation, topping up, etc.), it is necessary to increase the stock by the quantity that will be lost when switching between containers larger to smaller ones.

In Table 4.47 the HFC average annual stocks for each refrigerant used in Industrial refrigeration are reported. Data are reported by single F-gas, considering the composition of each blend.

Table 4.47 Average annual stock for Industrial refrigeration (t) 1990-2022

2.F.1.c Industrial refrigeration	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Average annual stock (t)										
HFC 23	NO	14.76	56.29	73.78	61.50	43.56	31.46	29.62	27.60	28.59
HFC 134a	NO	0.18	2,292.94	5,047.40	4,882.31	3,344.34	1,413.76	660.09	426.43	480.34
HFC 143a	NO	4.07	355.87	1,330.67	1,787.78	1,891.40	968.61	728.73	501.46	223.17
HFC 125	NO	3.72	313.82	1,167.35	1,559.62	1,686.27	1,051.81	850.02	679.38	467.85
HFC 32	NO	NO	NO	NO	NO	51.36	215.16	223.28	253.00	294.35
Total HFC average annual stock (t)	***NO***	***22.73***	***3,018.92***	***7,619.19***	***8,291.21***	***7,016.93***	***3,680.79***	***2,491.74***	***1,887.86***	***1,494.30***

In Table 4.48, total emissions are reported, distinguished in containers, manufacturing, operational and disposal, by single F-gas considering the composition of each blend.

Table 4.48: HFC total emissions from Industrial refrigeration (t), 1990-2022

2.F.1.c Industrial refrigeration	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Containers emissions (t)										
HFC 23	NO	0.79	0.34	0.21	0.11	0.06	0.05	0.05	0.05	0.05
HFC 134a	NO	0.01	21.48	13.82	8.91	2.50	2.32	1.87	2.00	2.25
HFC 143a	NO	0.22	4.46	4.70	6.13	3.51	0.76	0.58	0.60	0.33
HFC 125	NO	0.20	3.94	4.09	5.34	3.24	1.51	1.29	1.36	1.18
HFC 32	NO	NO	NO	NO	NO	0.25	0.87	0.80	0.86	0.97
Manufacturing emissions (t)										
HFC 23	NO	0.24	0.22	0.22	0.08	0.05	0.02	0.01	0.01	0.00
HFC 134a	NO	0.00	16.08	17.77	9.39	3.55	2.48	1.84	1.84	1.79
HFC 143a	NO	0.07	2.88	4.74	4.37	2.93	0.27	0.14	0.07	0.00
HFC 125	NO	0.06	2.55	4.13	3.80	2.60	0.81	0.64	0.62	0.53
HFC 32	NO	NO	NO	NO	NO	0.06	0.57	0.53	0.56	0.54
Lifetime emission (t)										
HFC 23	0.00	2.21	8.44	11.07	9.22	6.32	3.93	3.55	3.17	3.14
HFC 134a	0.00	0.03	343.94	757.11	732.35	484.93	176.72	79.21	49.04	52.84
HFC 143a	0.00	0.61	53.38	199.60	268.17	274.25	121.08	87.45	57.67	24.55
HFC 125	0.00	0.56	47.07	175.10	233.94	244.51	131.48	102.00	78.13	51.46
HFC 32	NO	NO	NO	NO	NO	7.45	26.89	26.79	29.09	32.38
Disposal emission (t)										
HFC 23	NO	NO	NO	NO	NO	5.06	4.67	4.55	4.43	4.31
HFC 134a	NO	NO	NO	NO	NO	0.06	309.75	334.96	359.56	371.16
HFC 143a	NO	NO	NO	NO	NO	0.63	8.68	15.15	21.04	25.78
HFC 125	NO	NO	NO	NO	NO	1.28	30.39	53.04	73.65	90.22
HFC 32	NO	NO	NO	NO	NO	0.00	0.00	0.00	0.00	0.00
Total emission (t)										
HFC 23	0.00	3.25	9.00	11.50	9.42	11.48	8.67	8.17	7.66	7.50
HFC 134a	0.00	0.04	381.50	788.70	750.64	491.05	491.27	417.88	412.44	428.04
HFC 143a	0.00	0.90	60.72	209.04	278.67	281.32	130.79	103.32	79.38	50.66
HFC 125	0.00	0.82	53.55	183.32	243.08	251.63	164.18	156.97	153.76	143.39
HFC 32	NO	NO	NO	NO	NO	7.76	28.34	28.12	30.51	33.89

4.7.6 Emissions from Transport refrigeration subsector (2.F.1.d)

This market sector includes refrigeration systems used in various modes of transport. Most transport refrigeration systems are used for the carriage of frozen or chilled food and beverage products.

Prior to 1990 most of road transport systems and containers used R-502, R-12 and R-22. From 1995, R-404A and R-507A have been introduced, followed by HFC-134a in 1998 and the new R-452A in 2015, the new blend targeted at the transport sector as an alternative with low discharge temperature at high ambient.

Refrigerants market: activity data and HFC used in Transport refrigeration

Until the last submission, emissions from the refrigerated transportation subsector were included in commercial refrigeration. This year, the emissions from this subsector were estimated separately.

Assogastecnici conducted a new survey of members at the end of 2023, by allowing for the collection of data on this specific sector. In particular, Assogastecnici provided the percentage distribution of R-404A, R-507A, R-452A, and R-134a consumptions by sector of use, including refrigerated transport, as reported in Tables 4.31 and 4.32.

For the years from 1990 to 2013 HFC consumption data were communicated by Solvay (Solvay, 1998; Solvay, 2006).

Also, for Transport refrigeration, HFC consumption data have been communicated split by use (*First Charge* and *Service*). In 2022, 100% of R-404A and R-507A are used for service, the amount of R-134a and R-452A used for maintenance are 80% and 90% respectively.

In Table 4.49, the total consumptions of R-404A, R-507A, HFC-134a and R-452A are shown. The consumption by use (*First Charge* and *Service*) is reported in ISPRA (ISPRA, 2024). The consumption of R-404A and R-507A in Transport refrigeration began in 1995 and increased steadily until 2014, when it peaked with 260.4 t of R-404A and 49.6 t of R-507A used. The consumption of R-404A has always been predominant over R-507A. In 2022 the consumption of R-404A was equal to 37.7 t and the ones for R-507A was 7.2 t. HFC-134a entered the market in 1998 (367.3 t used); the amount used increased until 2004 then began to decline and in 2022 a consumption of 99.3 t was registered. In 2015, the use of R-452A began, as the main replacement for R-404A gradually banned from the market by the F-gas Regulation. In particular, in 2015 a consumption of 10 t of this gas was registered and in 2022 it increased to 156.1 t.

Table 4.49: HFC Consumption from Transport refrigeration (t), 1990-2022

2.F.1.d- Transport refrigeration	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Total Consumption (t)										
HFC 134a	NO	NO	433.28	557.50	351.12	160.00	120.00	90.00	95.17	99.25
R 404A	NO	1.00	70.65	168.00	219.33	252.00	54.60	42.00	43.12	37.67
R 507A	NO	0.80	23.55	32.00	41.78	48.00	10.40	8.00	8.21	7.18
R-452A	NO	NO	NO	NO	NO	10.00	185.30	162.75	173.60	156.14
Total Consumption (t)	**NO**	**1.80**	**527.48**	**757.50**	**612.23**	**470.00**	**370.30**	**302.75**	**320.10**	**300.24**

Emission factors for Transport refrigeration

Country specific emission factors for this sector are under investigation, and at the moment Italy uses those reported in the 2006 IPCC Guidelines.

In Table 4.50 the emission factors, average lifetime, recovery efficiency are reported.

Table 4.50 Manufacturing and operating emission factors, average lifetime and recovery at decommissioning for Transport refrigeration

2.F.1.b Transport refrigeration	
Manufacturing leakage rate	0.5%
Product life leakage rate	20%
Initial charge remaining	35%
Recovery at decommissioning	50%
Average lifetime	9 years

HFC emissions estimation from Transport refrigeration

IPCC Tier 2a methodology has been applied for the estimations of the sub-sector. Emissions from containers have been estimated using appropriate losses rates provided by experts of the sector (see Table 4.36).

In Table 4.51, the average annual stock for the single compound is reported. The presence of R-32 since 2015 is due to the market entry of R-452A, of which R-32 is a component. The HFC-134a increased over the years reaching the maximum value in 2006 (1,690.81 t) then progressively decreased.

Table 4.51 Average annual stock for Transport refrigeration (t), 1990-2022

2.F.1.d Transport refrigeration	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Average annual stock (t)										
HFC 134a	NO	0.04	864.40	1,689.44	1,102.84	293.83	91.56	70.08	75.42	80.91
HFC 143a	NO	0.92	76.82	268.04	307.20	266.36	69.18	38.86	25.64	23.18
HFC 125	NO	0.84	67.75	235.03	267.41	237.30	181.68	148.26	147.19	138.40
HFC 32	NO	NO	NO	NO	NO	1.10	22.68	21.36	23.28	22.04
Total HFC average annual stock (t)	***NO***	***1.79***	***1,008.97***	***2,192.51***	***1,677.45***	***798.60***	***365.10***	***278.56***	***271.54***	***264.53***

In Table 4.52 the emissions from Transport refrigeration subsector are reported, distinguished by containers, manufacturing, operational and disposal emissions. The largest contribution to total emissions is operating emissions along the entire timeseries. In 2022 the lifetime emissions with 52.91 t represent 61.5% of the total emissions (including containers emissions).

Table 4.52 HFC total emissions from Transport refrigeration (t), 1990-2022

2.F.1.d Transport refrigeration	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Containers emissions (t)										
HFC 134a	NO	0.00	8.90	5.70	3.64	0.85	0.61	0.46	0.49	0.51
HFC 143a	NO	0.05	0.99	1.04	1.36	0.78	0.17	0.13	0.13	0.12
HFC 125	NO	0.04	0.87	0.91	1.19	0.71	0.70	0.60	0.63	0.56
HFC 32	NO	NO	NO	NO	NO	0.01	0.10	0.09	0.10	0.09
Manufacturing emissions (t)										
HFC 134a	NO	0.00	1.64	1.76	0.90	0.31	0.17	0.11	0.11	0.10
HFC 143a	NO	0.00	0.18	0.29	0.27	0.18	0.02	0.01	0.00	0.00
HFC 125	NO	0.00	0.16	0.25	0.23	0.16	0.07	0.06	0.06	0.05
HFC 32	NO	NO	NO	NO	NO	0.00	0.01	0.01	0.01	0.01
Lifetime emissions (t)										
HFC 134a	NO	0.01	172.88	337.89	220.57	58.77	18.31	14.02	15.08	16.18
HFC 143a	NO	0.18	15.36	53.61	61.44	53.27	13.84	7.77	5.13	4.64
HFC 125	NO	0.17	13.55	47.01	53.48	47.46	36.34	29.65	29.44	27.68
HFC 32	NO	NO	NO	NO	NO	0.22	4.54	4.27	4.66	4.41
Disposal emissions (t)										
HFC 134a	NO	NO	NO	0.05	61.11	55.40	31.34	26.06	21.15	16.56
HFC 143a	NO	NO	NO	0.71	8.65	10.24	9.45	9.06	8.61	8.08
HFC 125	NO	NO	NO	0.61	7.64	8.91	8.22	7.89	7.49	7.03
HFC 32	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

2.F.1.d Transport refrigeration	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Total emissions (t)										
HFC 134a	NO	0.01	183.42	345.40	286.21	115.33	50.43	40.65	36.83	33.35
HFC 143a	NO	0.24	16.53	55.65	71.72	64.47	23.47	16.97	13.88	12.83
HFC 125	NO	0.22	14.58	48.78	62.54	57.23	45.32	38.19	37.61	35.32
HFC 32	NO	NO	NO	NO	NO	0.23	4.65	4.37	4.76	4.50

4.7.7 Emissions from Mobile air conditioning subsector (2.F.1.e)

This sector includes Mobile Air-Conditioning (MAC) systems used to cool the driver and passengers in land transport including cars, vans, lorries, buses, etc.

Prior to 1990, all MACs for cars and small vans used CFC-12. Italy started to use HFC-134a in new cars and for retrofit in 1992. HFC-134a is the global standard refrigerant for small MAC systems, replaced by R-1234yf from 2013, due to entering into force the European Directive 40/2006, relating to emissions from air conditioning systems in motor vehicles (EU, 2006).

Refrigerants market: activity data and HFC used in MAC

As reported above, HFC market, including HFC-134a has been supplied by Solvay and Assogastecnici (Solvay, 1998; Solvay, 2006; Assogastecnici, 2022; Assogastecnici, 2023).

The information collected, such as the distribution of consumption of HFC-134a between the different sub-sectors of use and the distribution of total consumption between *First Charge* and *Service*, made it possible to obtain the consumption of HFC-134a used in mobile air conditioning.

Moreover, since 1992 the national motor company and the agent's union of foreign motor-cars vehicles have provided HFC-134a yearly consumptions of HFC-134a used in new vehicles (FIAT, several years [a]; IVECO, several years; UNRAE, several years).

Combining these sources, at present, consumption data reported in Table 4.53 represent the best available information of this sub-category: it was decided to use data from car manufacturers regarding the quantities of HFC-134a contained in the MAC systems of new vehicles produced and placed on the market, while as regards *Service*, data from Solvay and Assogastecnici were used.

Regarding HFC 134a used in new trucks, data supplied by the industry is missing for some years and an interpolation has been made. Data from national statistics on vehicles from the Automobile Club of Italy (ACI, several years) have been used together with the assumption of a nominal refrigerant charge of 1.2 kg and a lifetime of 12 years, according to IPCC Guidelines (IPCC, 2006).

Data from off-road vehicles have been supplied too by Case New Holland (CNH, several years).

Worthy of remark is that vehicles that are imported pre-charged are not considered in *First Charge* consumption but contribute to the calculation for operational emissions (UNRAE, several years). Similarly, vehicles produced in Italy but exported are accounted for the calculation of manufacturing emissions but not for that of operational emissions.

Table 4.53: HFC consumption from Mobile Air Conditioning (t), 1990-2022

2.F.1.e MAC (t)	1992	1995	2000	2005	2010	2015	2019	2020	2021	2022
First Charge (t)										
HFC-134	83.3	278.6	631.1	548.5	492.9	346.3	260.2	221.8	75.4	45.2

Service (t)										
HFC-134a	300.0	800.0	1,000.0	1,800.0	1,704.2	1,575.5	1,181.1	859.3	1,067.0	1,146.0
Total Consumptions (t)	***383.3***	***1,078.6***	***1,631.1***	***2,348.5***	***2,197.1***	***1,921.7***	***1,441.3***	***1,081.1***	***1,142.4***	***1,191.2***

Emission factors for MAC

Country specific emission factors for this sector are under investigation, and at the moment Italy uses those reported in the 2006 IPCC Guidelines (Table 7.9), revised with experts of Assogastecnici for what concerns the trend over the years.

For the emission factor from containers management, in line with the other RAC sectors and according to national experts, its value varies from 5% in 1992 to 0.5% in 2022.

In the following Table 4.54 the emission factors, average lifetime, recovery efficiency and the initial charge remaining are reported.

Table 4.54 Emission factors, average lifetime, initial charge remaining and recovery at decommissioning for Mobile Air Conditioning

2.F.1.e MAC	1992 - 1999	2000 - 2014	2015 - 2022
Manufacturing emission factor	4%-3%	2%-0.5%	0.5%
Operational emission factor	20%	20%	20%-16%
Average lifetime	12	12	20
Initial charge remaining	40%	40%	75%
Recovery Efficiency	0%-6%	6%-10%	10%

HFC emissions estimation from MAC

IPCC Tier 2a methodology has been applied for the estimations of the sub-sector, using, as for the other subsectors, equations 7.11, 7.12, 7.13 and 7.14 of the 2006 IPCC Guidelines.

For the Mobile Air Conditioning, following the fruitful collaboration with Assogastecnici, a revision of the estimates has been made. A crucial aspect is that until last year activity data did not include consumption used for *Service*.

In Submission 2023 emissions estimation from MAC systems was based on the methodology reported in Box 7.4 of the 2006 IPCC Guidelines, assuming all MACs were serviced each year in order to make up for the lack of data of refrigerant used for Service. For this submission, based on new available information, we assume that a MAC leaks over several years before being serviced. Depending on different conditions, servicing could be done every two years, every certain time interval, or sometimes not at all during the entire lifetime.

Thus, the HFC-134a stock in MAC systems is given by the sum of the amount of refrigerant in the new vehicles placed on the market in the considered year, plus the amount of the refrigerant still in the vehicles from the previous year and less the quantity of refrigerant in the vehicles that left the market in that year because at the end of their life, plus the amount of refrigerant used for service.

The disposal emissions have been calculated as the difference between the remaining HFC-134a in MAC at decommissioning and the quantity of HFC-134a recovered, equal to zero until 1996 because vehicles are still dismantled in junkyard car. From 1997, due to enforcement of Legislative Decree no. 22 of 5 February 1997 regarding hazardous waste which establishes authorized centers for demolition, recovery efficiency has started to increase slightly (10% in 2022) although the sector of car demolition is still poorly controlled.

In the following Table 4.55, the HFC-134a average annual stock in MAC systems is reported.

Table 4.55 Average annual stock for Mobile Air Conditioning (t), 1990-2022

2.F.1.e Mobile Air Conditioning	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Average annual stock (t)										
HFC-134a	NO	1,550.34	4,530.50	6,676.88	6,133.60	4,720.50	3,472.87	2,689.16	2,188.13	1,687.41

The total emissions, distinguished in containers, manufacturing, operational and disposal emissions. from MAC subsector are reported in the following Table 4.56.

Table 4.56: HFC total emissions from Mobile Air Conditioning (t)), 1990-2022

2.F.1.e Mobile Air Conditioning	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Containers emissions (t)										
HFC-134a	NO	40.00	20.00	18.00	17.04	7.88	5.91	4.30	5.33	5.73
Manufacturing emissions (t)										
HFC-134a	NO	11.15	12.62	2.74	2.46	1.73	1.30	1.11	0.38	0.23
Lifetime emissions (t)										
HFC-134a	NO	310.07	906.10	1.335.38	1,226.72	920.50	607.75	457.16	361.04	269.99
Disposal emissions (t)										
HFC-134a	NO	NO	NO	52.81	347.93	400.77	436.81	400.90	384.09	377.28
Total HFC-134a emissions	***NO***	***361.21***	***938.72***	***1,408.93***	***1,594.15***	***1,330.87***	***1,051.77***	***863.46***	***750.84***	***653.22***

4.7.8 Emissions from Stationary Air Conditioning subsector (2.F.1.f)

The estimates of emissions from the Stationary air conditioning sector are based on data on air conditioning equipment production and sales, provided by Assoclima, the Italian Association of Air Conditioning Systems Manufacturers, who collects an annual statistical survey of the Italian companies in the sector, taking into account the production and sales data by type of equipment and capacity. The Association supplied data on production and sales from 1995 to 2022 (Assoclima, several years [a]) together with data on the average refrigerant charge of each type of appliance (Assoclima, several years [b]). Data interpolation has been done in those cases where data was not available for confidential reasons (this affected some cases for which the companies that declare their production and/or sales were less than 3). Data on production include the appliances manufactured and sold in Italy plus the appliances manufactured in Italy and sold in the foreign market (EU and external EU); data on sales include appliances manufactured and sold in Italy plus appliances imported from abroad and sold in Italy. As Assoclima represents most of the industry but, for some kinds of appliances, not 100%, multiplicative factors have been provided by the Association to cover the total of the air conditioning companies, including those that are not associated. Multiplicative factors have been used for each type of equipment and are constant for all the years of the time series (Assoclima, several years[b]).

Production data have been used to estimate emissions from manufacturing while sales data have been used for estimating operating emissions.

Hybrid machines are included in the estimates. These machines are similar to chillers with capacities up to 50 kW, so the parameters used for chillers were assigned to hybrid machines with the same capacity. This approach was shared with the experts of the sector. Domestic hot water production machines were also be introduced in 2022. For these machines, Assoclima provided the information and parameters needed to estimate emissions (average charge, gases used and emission factors).

The equipment type, capacity, average charge and the multiplication factor used for estimation are given in the technical document (ISPRA, 2024). The average charge depends on the equipment and on its capacity: i.e. for air-cooled chillers it ranges from 2.2 to 154.3 kg, while for water-cooled chillers the charge is between 0.9 kg and 200 kg. For split the average charge goes from 1.1 to 3.9 kg. The charge of equipment using R-32 is reduced by 20% compared to the same equipment using R-410A; in fact, as this refrigerant has higher capacity in terms of cooling and heating compare with R-410A, R-32's equipment uses up to 20% less refrigerant than R-410A for the same performance.

Regarding the general trend of products and components for air conditioning systems, 2015 has been the year in which the sector restarts to grow after a period of economic crisis. The timeseries of the equipment production data shows a steady and significant decrease from 2000 to 2014 due to an increment to the import sector, with a very weak recovery in subsequent years (but in 2022 the production shows a 79% decline compared to 1996). A different trend is registered for sales data. Overall, total sales of air conditioning equipment increased from 477,068 units in 1996 to 2,425,972 in 2022, with a fluctuating trend over the period.

Referring to Assoclima's latest survey (Assoclima, 2023), 2022 showed positive results for sales and production compared to the previous year. The direct expansion sector recorded growth trends for all types of products. The largest sales were in the hydronic sector: the heat pumps and the air-cooled condensing chiller units. In particular, the best performance concerned the heat pump up to 17KW with 155,046 units sold in 2022 against 83,356 in 2021, with an increase of more than 80%. Instead, sales of water-cooled condensing chiller units (cooling and heating) recorded a decrease compared to the previous year. In recent years, several measures for promoting energy efficiency have been taken by the national government with positive effects on the heat pump market.

Regarding the portable air conditioners with remote condenser, production stopped in 2013, because they don't respect the minimum efficiency limits required by the Energy-Related Products Directive ErPD, 2009/125/EC (Assoclima, several years [b]). For further details, see ISPRA (ISPRA, 2024).

In Table 4.57, data on manufactured and sold equipment in the Stationary air conditioning sector are reported. Small corrections were made to the number of estimated units, resulting in a slight recalculation.

Table 4.57 Number of manufactured and sold equipment in the Stationary air conditioning, 1996-2022

2.F.1.f Stationary Air Conditioning	1996	2000	2005	2010	2015	2019	2020	2021	2022
Production (units)									
Room air conditioner	309,318	244,769	165,152	34,938	10,566	18,998	17,614	44,702	46,524
Monosplit	229,900	575,242	65,286	25,141	35	0	0	0	0
Multisplit	22,718	46,680	18,576	4,464	0	0	0	0	0
VRF	0	0	0	51	0	0	0	0	0
Packaged, roof top	7,090	2,384	3,376	1,990	1,891	1,910	1,507	1,386	1,585
Precision air conditioning	9,927	24,635	13,619	2,237	5,387	4,784	4,087	4,224	4,825
Air cooled chiller	28,852	46,294	55,871	67,085	36,253	35,260	34,562	42,537	70,627
Water cooled chiller	2,744	4,907	5,736	5,762	5,689	4,327	4,266	4,352	3,653
Hybrid machines	NO	NO	NO	NO	0	0	0	0	0
Hot water-only machines	NO	NO	NO	NO	0	0	0	0	0
Sales (units)									
Room air conditioner	112,212	101,860	111,540	143,632	72,552	113,560	157,093	143,966	140,987

Monosplit	358,756	875,558	1,082,572	910,491	741,229	1,205,609	1,271,003	1,622,428	1,683,972
Multisplit	22,879	129,860	326,525	281,118	222,176	376,556	375,282	458,520	488,584
VRF	0	0	8,292	18,116	15,131	25,343	22,436	29,058	32,546
Packaged, roof top	2,429	3,907	4,141	1,744	1,199	1,582	1,258	1,297	1,315
Precision air conditioning	4,233	11,458	3,515	791	1,247	525	309	515	357
Air cooled chiller	21,707	31,530	34,258	27,707	33,105	51,580	52,482	109,934	192,773
Water cooled chiller	1,631	2,993	2,730	2,155	1,921	1,511	1,486	1,577	975
Hybrid machines	NO	NO	NO	NO	3,767	8,699	15,706	70,915	148,662
Hot water-only machines	NO	NO	NO	NO	2,300	8,145	8,256	17,305	34,125

Refrigerants market: activity data and HFC used in the Stationary air conditioning sector

Air conditioning appliances started to use HFC, as substitutes of HCFC, in the second half of the 1990s (Assoclima, several years [b]), and the replacement process was completed by 2005, with the elimination of HCFCs in new equipment.

R-410A, R-134a and R-407C have long been the main refrigerants used in the air conditioning sector. R-410A was the dominant HFC for many years, followed by R-134a. R-410A has always been used mainly for small air conditioning systems even if in the last years it was replaced by R-32, R-134a is a good replacement for larger equipment; for intermediate power machines both R-410A and R-134a can be used. R-407C was used for different years in the past as a substitute for R-22, instead of R-410A because this refrigerant allows the use of the same components of a R-22 system but, due to thermodynamic problems, it has been progressively substituted by R-410A. For this reason, the use of R-407C started to decrease from 2010.

In the last years, with the introduction of new refrigerants (natural refrigerants, HFOs) in substitution of the HFC, due to the F-gas Regulation and market dynamics, the percentage of sales and production of HFC equipment has changed. For portable air conditioners, the replacement of HFCs with HCs started earlier than the other machines thanks to the low charge involved that allow the use of flammable refrigerants. According to expert judgment, propane has started to be used after 2005, and in 2010 the 50% of the portable room air conditioner are with R-290; this percentage grew to 90% in 2017 (Assoclima, several years [b]) and became equal to 100% in 2020 because, according to the F-gas Regulation, as of January 2020, portable room air conditioners that contain a refrigerant with a GWP of 150 or more are banned from the market. In 2021 propane chiller entered the Italian market: these are lower power (<= 50 kW) air-cooled chillers. According to expert judgment, the percentage of these propane machines in 2021 is 1%. Air and water-cooled chillers with R-1234ze also entered the market in 2022. For the water-cooled chiller only the machine with higher capacity (>= 351 kW) have been started to use this new refrigerant, while it is used in all the air-cooled chiller, both with small than large capacity. As a result, the percentage of this equipment running on HFCs has been reduced to 98%. The percentage share of HFC equipment on the total of sales and production per year (1996-2022) is reported in ISPRA (ISPRA, 2024).

The percentage of HFC conditioning equipment, by type of refrigerant has been supplied by Assoclima (Assoclima, several years [b]) and show a deep changing in the mix of refrigerants used over the years. Initially the portable air conditioners used mainly R-134a due to the lower operating pressures but then they mainly passed to R-410A. Regarding the R-407C, chillers with rotary compressors also initially used this gas, while those with screw compressors (and centrifugal) switched directly to R-134a. Over the years, R-407C has lost market share, and in 2022 it is only present in limited percentages in packaged and roof tops. High-capacity air and water chillers mainly use R-134a; they are losing market share.

Among the new refrigerants with lower GWP, the R-32 has received the most interest. Because of its flammable nature (A2L class), at present it is mainly used for split equipment in the residential sector. As the sectoral experts communicated (Assoclima, several years [b]), mono e multisplit have started using this refrigerant, as a replacement for the R-410A, in 2016, in that year the percentage of R-32 split equipment manufactured and sold was estimated to be 20% and it increased in the following years. According to Assoclima, the percentage of R-32 equipment sold and produced reached 99% in 2022. It was 95% in 2020, 80% in 2019, 60% in 2018, 40% in 2017.

VRFs, roof top and packaged with R-32 also entered the market in 2022. As for VRFs, these are still very low percentages of 1% for machines with capacity >=16 KW and 2% for mini-VRF (< 16kW); the remainder of these appliances uses R-410A. Regarding packaged and roof top the percentage of R-32 machines is equal to 10% and 15% respectively. The remainder runs on R-410A and R-407C (to a lesser extent).

In 2020 R-32 air cooled chiller with a capacity up to 50 kW appeared in the Italian market. In 2021, the percentage of these R-32 chillers increased to 40 % and consequently the percentage of chiller using R-410A decreased to 60%. In 2022, R-32 air-cooled chillers with capacities above 50 kW also entered the market; specifically, these are chillers with capacities up to 350 kW. The percentage of these R-32 appliances decreases as the capacity increases: from 70% for chillers under 17 kW to 10% for chillers between 201 and 350 kW. In addition, air and water-cooled chillers operating with R-513A also entered the market in 2022; these are chillers with a capacity greater than or equal to 201 kW. The percentage of these machines is between 5% and 10%.

The percentage of HFC conditioning equipment sold and produced in 2022 by type of refrigerant is reported in ISPRA (SPRA, 2024).

Based on the number of equipment manufactured and sold in the Italian market, of the average refrigerant charge and of the percentage of equipment by type of HFC, the quantities of HFC contained in the equipment manufactured and sold have been calculated (Table 4.58).

As already mentioned, compared to the previous Submission, some corrections were made to the estimate of the number of equipment produced and sold and to the percentages of equipment by refrigerant type. These changes affected some years of the time series. Additionally, domestic hot water machines (using both R-32 and R-134a) have been introduced. These machines are considered from 2014. All these changes led to a slight recalculation of the quantities of gas contained in the machines produced and sold.

Table 4.58 Quantities of HFCs contained in the air conditioning equipment manufactured and sold in the Italian market, 1996-2022 (t)

2.F.1.f Stationary Air Conditioning	1996	2000	2005	2010	2015	2019	2020	2021	2022
HFC in manufactured equipment (t)									
HFC-134a	18.76	71.77	171.28	353.29	272.13	241.85	240.21	239.33	207.86
R-410A	3.39	8.60	238.39	626.90	544.11	524.04	459.26	481.16	384.53
R-407C	3.32	65.60	551.20	16.02	4.58	4.47	3.55	3.34	1.64
R-32	NO	NO	NO	NO	NO	NO	11.23	29.20	147.46
R-513A	NO	NO	NO	NO	NO	NO	NO	NO	25.68
HFC in sold equipment (t)									
HFC-134a	7.23	33.72	184.32	102.99	89.34	102.53	72.92	80.38	74.25
R-410A	4.26	8.54	1,189.29	1,955.93	1,646.17	968.71	588.97	794.31	708.35
R-407C	2.34	71.63	981.82	10.44	2.60	3.37	2.68	2.77	1.36
R-32	NO	NO	NO	NO	NO	1,303.40	1,611.85	2,239.52	2,790.34
R-513A	NO	NO	NO	NO	NO	NO	NO	NO	7.18

Emission factors for the Stationary air conditioning subsector

Appropriate losses rates have been applied for each gas used in the stationary air conditioning sector, taking into account the equipment where refrigerants are generally used, as suggested by a pool of experts during a specific meeting held at the Ministry of the Environment (ISPRA-MATTM, 2013). These experts represent the National Association of Manufacturers of aerodynamic equipment and systems (ASSOCLIMA-ANIMA) and the Italian Association of Air Conditioning, Heating and Refrigeration (AICARR).

For more information about this, please see the paragraph relative to Commercial refrigeration. The manufacturing and operating emission factors of the Stationary air conditioning sector have not changed compared to last year's estimates.

Regarding the operating emission factors, for all the types of equipment, except split and VRF, two different periods have been considered: from 1996 to 2006 and from 2007 onward. For split and VRF, as communicated by the expert, three periods have been identified: from 1996 to 2006, from 2007 to 2014, from 2015. The emission factors for the period 1996-2006 have been assumed to be higher than those of the following period, because with the entry into force of Regulation 842/2006 on certain fluorinated greenhouse gases, improvements on the prevention of leaks from equipment containing F-gases were introduced.

Consequently, starting from that year, more attention has been paid by the technicians to install, service and maintain, repair or decommission of AC systems and the year 2007 has been taken as another turning point in terms of changes of good practice in the refrigerants handling. According to the sectoral experts, the emission factors of the period 1996-2006 are 50% higher than those from 2007 onwards (Associlima, several years [b]).

Similarly, also the emission factors for the period from 2007 to 2014 have been estimated by expert judgment and the values of losses presented are an average of the risk relating to the entire fleet, by including machines that work correctly and those that may have problems.
For split system, the leakages are directly proportional to the number of connections according to the following equation:

$$Leakage\ rate_{Split/multisplit} = 3\% \bullet \frac{N°\ of\ connection}{4}$$

For monosplit, the number of connections is equal to 4; for multisplit, it has been considered a weighted average of the connections equals to 10, that means a loss rate of 7.5%. Chillers and rooftops (being packaged systems) are factory sealed products, therefore leak rate is estimated equals to 1%, while VRF system, being similar to multisplit, have leak rate depending on the number of connections. The emission factor value for this equipment is 12%. More information on the assumptions is reported also in the document *"Comments on Appendix A&B of the "Preparatory study for the Review of Regulation 842/2006 /Working group 1"* (WG1, 2013).

For the period from 2015 onward the operating emission factors have been reduced to consider the good practices adopted in refrigerants management as the result of the F-gas Regulation implementation. Based on the expert judgment, the emission factor for monosplit has been assumed equal to 2%, the emission factor for multisplit has been assumed equals to 4% and that for VRF equal to 6%.

The appropriate manufacturing and operating emission factors for stationary air conditioning sector are reported in the following Tables 4.59 and 4.60.

As some procedures used in manufacturing or during the installation of the RAC systems changed in 2000, also F-gases market price has influenced losses control. In fact, since the F-gases are also expensive material in the manufacturing process it was a matter of concern of the manufacturers to succeed in limiting losses in that stage and that was achieved by setting higher levels in the acceptance testing procedures.

Table 4.59 Manufacturing and operating emission factors 1/2

Manufacturing ad operating leakage rate in the Stationary Air Conditioning sector				
Type of equipment	**Manufacturing (%)**		**Operating (%)**	
	1996-1999	**from 2000**	**1996-2006**	**from 2007**
ROOM AIR CONDITIONER (Monoblock without outdoor unit (ductable duct) Portable air conditioner up to 3 kW (single duct) Portable air conditioner with remote condenser up to 4 kW (split type)	3.0%	0.5%	1.5%	1.0%
PACKAGED, ROOF TOP (ductable or not)	3.0%	0.5%	1.5%	1.0%
PRECISION AIR CONDITIONING	3.0%	0.5%	1.5%	1.0%
CHILLER (Air/water cooled chiller, only cooling or heat pump)	3.0%	0.5%	1.5%	1.0%
HYBRID MACHINES (Heath pump + boiler)	3.0%	0.5%	1.5%	1.0%
DOMESTIC HOT WATER MACHINES (Heath pump)	NO	0.5%	NO	1.0%

Table 4.60 Manufacturing and operating emission factors 2/2

Manufacturing ad operating leakage rate in the Stationary Air Conditioning sector					
Type of equipment	**Manufacturing (%)**		**Operating (%)**		
	1996-1999	**from 2000**	**1996-2006**	**2007-2014**	**from 2015**
MONOSPLIT Outdoor condensing units connected to an indoor unit (wall floor installation, cassette, ducted false ceiling)	3.00%	0.50%	4.50%	3.00%	2.00%
MULTISPLIT Outdoor condensing units connected to indoor units (wall floor installation, cassette, ducted false ceiling)	3.00%	0.50%	11.30%	7.50%	4.00%
VRF (Only external condensing units)	3.00%	0.50%	18%	12.00%	6.00%

Emissions related to refrigerant container management are also estimated. The emission factors from containers are reported in Table 4.36.

The average lifetime for each type of air conditioning systems is from expert judgement and from IPCC Guidelines (IPCC, 2006; Associma, several years [b]; ISPRA-MATTM, 2013; WG1, 2013). Regarding the average lifetime, a distinction must be made between air-conditioning units used for human comfort and those used with other purposes (in example to ensure an appropriate temperature level for flower foodstuffs shops or process plants). The formers are more susceptible to fashions and are often replaced before the end of their natural life cycle, also because these units are usually not subjected to constant maintenance that is often required by industrial machines. The machines aimed at human comfort are mainly with heat pump configuration while for the other uses only cooling machines are used. For this reason, only cooling chillers have a lifetime higher than heat pump chillers.

Regarding the HFC recovery at the end of life of equipment, the national experts communicated that almost all the gases of larger size machines are currently recovered, while in the smaller equipment the recovery quotas can be lower. For this smaller equipment, the gas recovery percentage has been assumed equal to 50% for the period from 1996 to 2015, while from 2015 it was set to 70% to take into account the effect of F-gas Regulation (Assogastecnici, 2022). For chiller a 90% of recovery has been adopted. Future improvements could come from the National Register of fluorinated greenhouse gases and equipment containing fluorinated gases (DPR 146/2018).

Some issues emerged from the analysis of the database carried out by ISPRA and although some gaps were overcome thanks to the cooperation with the Responsible of the Registry, there are still criticalities on data. For this reason, we have decided not to use the information contained in the registry yet. In the recent months, a new collaboration with Assofrigoristi (the national association of installers and refrigeration technicians) has been started to improve the Data Bank collection system and obtain more precise information on emission factors, gas recovery percentage, frequency of topping up but no new data or information is currently available (for more details, please see paragraph 4.7.13). Data on average lifetimes and recovery at decommissioning are reported in ISPRA (ISPRA, 2024).

Service of appliances during lifetime is also considered. Unlike the refrigeration sector, where consumption data are supplied split by use (*First Charge* and *Service*), for this sector a different approach is used.

For each type of equipment and thus according to the specific emission factor of this equipment, a periodic gas refilling frequency is adopted. In detail, for equipment with a higher emission factor a higher frequency is assumed. Therefore, the total amount of refrigerant placed on the market every year is equal to the amount contained in the new equipment sold in that year plus the amount used for the maintenance in the same year.

In the following Table 4.61, the amounts of HFC placed on the market equal to the amount sold equipment plus amount used for topping up, by type of refrigerant are reported. As a result of some corrections in sales data and in the estimation process the time series of the amount of HFCs put on the market has changed compared the previous submission.

Table 4.61 Amounts of HFC placed on the market of Stationary air conditioning (t), 1996-2022

2.F.1.f Stationary Air Conditioning	1996	2000	2005	2010	2015	2019	2020	2021	2022
Amounts of HFC placed on the market (t)									
HFC-134a	7.23	33.72	184.32	107.54	109.61	113.53	83.87	92.11	87.40
R-410A	4.26	8.79	1,205.51	2,349.04	2,230.16	1,583.70	1,115.31	1,274.26	1,268.59
R-407C	2.34	71.77	1012.53	293.88	211.31	80.00	40.54	19.40	8.80
R-32	NO	NO	NO	NO	NO	1,314.23	1,630.75	2,270.91	2,874.04
R-513A	NO	NO	NO	NO	NO	NO	NO	NO	7.18

HFC emissions estimation from Stationary air conditioning subsector

HFC emissions from the Stationary air conditioning have been estimated according to 2006 IPCC Guidelines (Tier 2a methodology). Based on the amounts of refrigerant placed on the market, the HFC average annual stock for each year and refrigerant is calculated.

In Table 4.62 the HFC average annual stocks are reported. As mentioned earlier, some corrections in sales data and other parameters have resulted in an update of the HFC average annual stock.

Table 4.62 HFC average annual stock for the Stationary air conditioning (t), 1996-2022

2.F.1.f Stationary Air Conditioning	1996	2000	2005	2010	2015	2019	2020	2021	2022
Average annual stock (t)									
HFC-134a	7.23	98.23	758.10	1,357.65	1,592.30	1,800.16	1,855.94	1,920.08	1,975.60
R-410A	4.26	35.45	3,018.58	11,201.24	18,800.02	23,078.29	22,544.75	22,030.13	21,079.70
R-407C	2.34	127.60	3,821.49	5,779.46	5,729.26	3,605.63	2,894.69	2,280.42	1,704.95
R-32	NO	NO	NO	NO	NO	3,062.84	4,614.91	6,767.62	9,471.21
R-513A	NO	NO	NO	NO	NO	NO	NO	NO	7.18

Amount of refrigerants stocked in the containers is also estimated. Compared to the previous submission 2023, a revision of the process of estimating these quantities was carried out thanks to the collaboration with Assogastecnici, increasing the HFCs stored in containers by the quantity that will be lost when switching between large containers to smaller ones. As mentioned above, containers emissions have been reported under *"Emissions from stocks"*, together with the operating emissions.

The amount of HFC stocked in the containers is reported in Table 4.63.

Table 4.63 HFC stocked in containers for the Stationary air conditioning sector (t), 1996-2022

2.F.1.f Stationary Air Conditioning	1996	2000	2005	2010	2015	2019	2020	2021	2022
HFC stocked in containers (t)									
HFC-134a	19.75	73.23	173.01	361.45	296.42	254.11	252.42	252.33	220.92
R-410A	3.57	9.03	257.34	1,031.29	1,131.57	1,144.69	990.55	966.02	949.62
R-407C	3.50	67.09	588.16	303.47	214.81	81.47	41.59	19.64	8.24
R-32	NO	NO	NO	NO	NO	10.89	30.28	60.89	221.43
R-513A	NO	NO	NO	NO	NO	NO	NO	NO	25.81

The disposal emissions have been calculated as the difference between the remaining HFC in products at decommissioning and the quantity of HFC recovered. Based on the product life leakage rate and the average lifetimes, the charge remaining at decommissioning is calculated as:

(1- product life leakage rate) * average lifetimes.

In the following Table 4.64 the containers, manufacturing, lifetime and disposal emissions are reported.

Table 4.64 HFC emissions from Stationary air conditioning (t), 1996-2022

2.F.1.f Stationary Air Conditioning	1996	2000	2005	2010	2015	2019	2020	2021	2022
Containers emissions (t)									
HFC 134a	1.08	2.16	4.79	5.19	2.04	1.48	1.37	1.31	1.18
HFC-125	0.13	0.43	2.76	5.92	3.10	2.96	2.53	2.44	2.38
HFC-32	0.13	0.40	2.64	5.85	3.08	3.01	2.68	2.74	3.49
Manufacturing emissions (t)									
HFC 134a	0.61	0.53	2.29	1.81	1.39	1.22	1.21	1.21	1.10

2.F.1.f Stationary Air Conditioning	1996	2000	2005	2010	2015	2019	2020	2021	2022
HFC-125	0.08	0.10	1.28	1.59	1.36	1.32	1.15	1.21	0.96
HFC-32	0.07	0.10	1.23	1.59	1.36	1.32	1.21	1.35	1.70
Lifetime emissions (t)									
HFC 134a	0.14	4.41	108.48	113.17	78.63	54.86	46.20	39.34	32.78
HFC-125	0.12	2.27	138.40	285.15	270.46	317.10	305.28	294.13	278.04
HFC-32	0.11	2.15	134.66	281.32	268.05	394.35	422.41	463.78	508.06
Disposal emissions (t)									
HFC-134a	NO	NO	NO	8.05	36.88	265.70	176.02	141.30	130.14
HFC-125	NO	NO	NO	0.16	11.07	280.20	240.65	247.06	307.59
HFC-32	NO	NO	NO	0.15	10.40	270.25	233.99	241.70	302.68
Total emissions (t)									
HFC-134a	1.84	7.10	115.56	128.22	118.94	323.26	224.80	183.15	165.21
HFC-125	0.33	2.80	142.44	292.81	285.98	601.58	549.62	544.84	588.98
HFC-32	0.32	2.65	138.53	288.91	282.88	668.92	660.29	709.57	815.93

Total HFC emissions from the stationary air conditioning equipment increased from 1996 driven by the increase of their consumptions. In years when the operating emission factor was decreased (2006 and 2015) to account for the effects of F-gas regulations, emissions decreased but the trend has been always increasing throughout the period from 1996 to 2019. The year 2020 has shown a contraction in gas consumptions dure to effect of the Sars-Covid 19 pandemic, followed by an increase in 2021 and 2022.

4.7.9 Emissions from Foam blowing subsector (2.F.2)

Refrigerants market: activity data and HFC used in Foam blowing

The estimates of emissions from Foam blowing subsector are based on single gas consumption data supplied by Solvay, the only national refrigerants producer, and by Assogastecnici, the Association of companies involved in the production and distribution of technical, special and medicinal gases (Solvay, 1998; Solvay, 2006; Assogastecnici, 2022, Assogastecnici, 2023).

HFC-245fa and HFC-134a only are used in the subsector and no information is available on the type of foam, if open or closed cells, on which a different emission factor depends. To gather these information and data, the inventory team contacted the main national associations of foam blowing and the experts of the sector who reported that closed cell are more widespread than open cell foams and that other information at present is not available. For this reason, the HFC consumptions have been entirely attributed to closed cells.

In the following Table 4.65, the gas consumptions are reported.

Table 4.65 Consumption of HFC contained in the Foam blowing (t), 1994-2022

2.F.2.a Foam blowing	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Consumptions (t)										
HFC 134a	NO	NO	338.00	980.00	718.39	408.34	261.10	224.29	187.48	160.00
HFC 245fa	NO	NO	NO	800.00	973.32	1010.66	498.70	370.71	242.72	200.00
Total HFC Consumptions (t)	***NO***	***NO***	***338.00***	***1780.00***	***1691.72***	***1419.00***	***759.80***	***595.00***	***430.20***	***360.00***

HFC emissions estimation from Foam blowing sub-sector

The methods used to calculate F-gas emissions from the Foam blowing subsector is the 2006 IPPC Guidelines Tier2a. Total emissions have been calculated as the sum of manufacturing emissions, lifetime emissions and disposal emissions. The "Recovery" was calculated as the "Amount remaining in products at decommissioning" minus "Disposal emissions".

Emission factors for the closed cells reported in the 2006 IPCC Guidelines were used (Table 4.66), constant for the whole time series.

The average lifetimes and the percentage of recovered gas at decommissioning have been applied are also based on default values from 2006 IPCC Guidelines and expert judgment. However, since an average life of 50 years has been assumed, the foam decommissioning will start only in 2048.

Table 4.66 Manufacturing and product life leakage rate, average lifetime and recovery at decommissioning for Foam blowing

Subsector	Leakage rate (%)		Average Lifetimes (years)	Recovery at decommissioning (%)
	Manufacturing	Operating		
Foam blowing (closed cells)	10%	4.5%	50	0

Based on the gas consumptions, the emission factors and the average lifetimes, the average annual stock for each gas and year was calculated (Table 4.67).

Table 4.67 HFC average annual stock for the Foam blowing (t), 1996-2022

2.F.2.a Foam blowing	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Average annual stock (t)										
HFC 134a	NO	NO	345.92	1,823.77	3,155.01	3,566.28	3,494.92	3,438.58	3,368.21	3,288.64
HFC 245fa	NO	NO	NO	1,528.61	3,074.34	4,627.11	4,998.20	4,940.10	4,827.02	4,699.81
Total HFC average annual stock (t)	***NO***	***NO***	***345.92***	***3,352.38***	***6,229.35***	***8,193.40***	***8,493.12***	***8,378.68***	***8,195.23***	***7,988.44***

In Table 4.68, an overview of the total emissions (manufacturing, lifetime and disposal) from the Foam blowing sub-sectors is given for the 1990-2022 period, per compound. No recalculation occurred for this sector.

Table 4.68 HFC emissions from Foam blowing (t), 1990-2022

2.F.2.a Foam blowing	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Manufacturing emissions (t)										
HFC 134a	NO	NO	33.80	98.00	71.84	40.83	26.11	22.43	18.75	16.00
HFC 245fa	NO	NO	NO	80.00	97.33	101.07	49.87	37.07	24.27	20.00
Lifetime emissions (t)										
HFC 134a	NO	NO	15.57	82.07	141.98	160.48	157.27	154.74	151.57	147.99
HFC 245fa	NO	NO	NO	68.79	138.35	208.22	224.92	222.30	217.22	211.49
Disposal emissions (t)										
HFC 134a	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
HFC 245fa	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

2.F.2.a Foam blowing	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Total HFC emissions (t)										
HFC 134a	NO	NO	49.37	180.07	213.81	201.32	183.38	177.17	170.32	163.99
HFC 245fa	NO	NO	NO	148.79	235.68	309.29	274.79	259.38	241.49	231.49

4.7.10 Emissions from Fire protection subsector (2.F.3)

Refrigerants market: activity data and HFC used in Fire protection

The estimates of emissions from Fire extinguishers are based on single gas consumption data. The European Association for Responsible Use of HFCs in Fire Fighting was contacted (ASSURE, 2005), as well as the Consortium of fire protection systems (Clean Gas, 2001). More in details HFC-227ea partial consumptions for fire extinguishers along the whole time series has been provided by Clean Gas Consortium. Because other Consortia of fire protection systems are present in the country, consumption data provided by Clean Gas have been multiplied for a factor equal to five according to expert judgment and a comparison with the stock of gas estimated in 2005 (Gastec Vesta, 2017). HFC-227ea consumption levels have been supplied for the years 1990-2000 together with projections of consumptions for the years 2005 and 2010, for which Clean Gas estimated the same value (130 t). Data from 2000 to 2004 have been extrapolated, data from 2005 to 2010 has been assumed constant (130 t) and data from 2011 onwards have been estimated on the basis of the following assumptions. From 2010, according to information supplied by industry (Gastec Vesta, 2017) the amount of HFC-227ea started to decrease, replaced by the new chemical Novec concurrently with the entering in force of the Regulation n. 517/2014 (EU, 2014): in 2016 the consumption of HFC-227ea can be assumed the 80% of the 2010 consumption. According to the expert judgment and ASSURE, because of HFC-227ea covers the 90% of the fire extinguishers market, consumption data of HFC-125 and HFC-23 have been estimated, considering that HFC-125 is 2/3 of the remaining quota. In addition to the Novec, among the best alternative solutions to HFCs on the market are inert gases but at the moment no information about the quotas placed in the market is available.

From 2021 the value has been estimated on the basis of HFC 227ea, HFC 23 and HFC 125 consumptions provided by Assogastecnici (Assogastecnici 2022, Assogastecnici 2023).

ANIMA, the Federation of National Associations of Mechanical and Engineering similar which includes fire protection industry, has been contacted in order to verify the presence of Consortia of fire protection systems. At present also the Federation does not provide updated information. The main national fire protection industries (Gielle and Gastec Vesta), which were involved also for the Survey about HFCs alternative substances with low GWP, natural refrigerants and alternative technologies made in Italy (ISPRA, 2018 [a]) in the framework of the agreements with the Ministry of Environment, have been contacted and approved the estimation approach.

Investigation to collect information on the HFC recovery, recycling, regeneration or disposal activities used in fire extinguishers sector was carried out from ISPRA, contacting one of the major fire protection Company, Gielle, that collects, throughout the national territory, exhausted refrigerant gases, CFCs, HCFCs and HFCs, to be sent for recovery, recycling, regeneration or disposal. According to Gielle, at the end of life no emissions occur when the equipment is delivered to an authorized and expert company.

In the following Table 4.69, the HFC consumptions are summarized.

Table 4.69 Consumptions of HFC contained in the Fire protection (t), 1994-2022

2.F.3 Fire protection	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Consumptions (t)										
HFC 227ea	NO	38.75	210.00	780.00	780.00	650.00	456.30	433.49	410.67	350.00
HFC 23	NO	1.44	7.78	28.89	28.89	15.00	11.67	10.83	10.00	9.17
HFC 125	NO	2.87	15.56	57.78	57.78	48.15	33.80	32.11	30.42	25.93
Total HFC Consumptions (t)	***NO***	***43.06***	***233.33***	***866.67***	***866.67***	***713.15***	***501.77***	***476.43***	***451.09***	***385.09***

HFC emissions estimation from Fire protection

Emissions from Fire Protection are calculated based on 2006 IPCC Guidelines Tier2a methodology.

ASSURE provided us with the information concerning losses rates in manufacturing of firefighting systems (0%) and during the average lifetime of the fire extinguishers (less than 5%) (ASSURE, 2005). About the lifetime emission, national fire protection industries explained that an alarm safety system installed in the fire protection equipment starts when losses are over 5%. The whole gas is considered emitted and not recovered as required by the latest European and National legislation. In Table 4.70 the leakage rate, the average lifetime and recovery at decommissioning used for the emissions estimation are reported.

Table 4.70 Manufacturing and product life leakage rate, average lifetime and recovery at decommissioning for Fire extinguishers

Subsector	Leakage rate (%)		Average lifetime (years)	Recovery at decommissioning (%)
	Manufacturing	Operating		
Fire protection	0%	5%	15	0%

The average annual stock for each gas used in the Fire protection sector is shown in the following table 4.71. Data are from 1990 to 2022.

Table 4.71 HFC average annual stock for the Fire protection (t), 1996-2022

2.F.3 Fire protection	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Average annual stock (t)										
HFC 227ea	NO	77.58	804.21	3,172.59	5,983.91	7,794.30	8,292.75	8,311.59	8,306.68	8,241.35
HFC 23	NO	2.87	29.79	117.50	221.63	279.60	275.46	272.52	268.89	264.62
HFC 125	NO	5.75	59.57	235.01	443.25	577.36	614.28	615.67	615.31	610.47
Total HFC average annual stock (t)	***NO***	***86.20***	***893.57***	***3,525.10***	***6,648.79***	***8,651.26***	***9,182.48***	***9,199.79***	***9,190.89***	***9,116.44***

In Table 4.72, an overview of the total emissions (manufacturing, lifetime and disposal) from the Fire protection sector is given for the 1990-2022 period, per compound. Emissions from manufacturing are not occurring because the emission factor is equal to zero. No recalculation occurred compared to the previous submission 2023.

Table 4.72 HFC emissions from Fire protection (t) 1990-2022

2.F.3 Fire protection	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Manufacturing emissions (t)										
HFC 227ea	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
HFC 23	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
HFC 125	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Lifetime emissions (t)										
HFC 227ea	NO	3.88	40.21	158.63	299.20	389.71	414.64	415.58	415.33	412.07
HFC 23	NO	0.14	1.49	5.88	11.08	13.98	13.77	13.63	13.44	13.23
HFC 125	NO	0.29	2.98	11.75	22.16	28.87	30.71	30.78	30.77	30.52
Disposal emissions (t)										
HFC 227ea	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
HFC 23	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
HFC 125	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total emissions (t)										
HFC 227ea	NO	3.88	40.21	158.63	299.20	389.71	414.64	415.58	415.33	412.07
HFC 23	NO	0.14	1.49	5.88	11.08	13.98	13.77	13.63	13.44	13.23
HFC 125	NO	0.29	2.98	11.75	22.16	28.87	30.71	30.78	30.77	30.52

4.7.11 Emissions from Aerosol subsector (2.F.4)

Refrigerants market: activity data and HFC used for Aersosol

The estimates of emissions are based on single gas consumption data. Pharmaceutical industry has provided aerosols/metered dose inhaler data (Sanofi Aventis, several years; Boehringer Ingelheim, several years; Chiesi Farmaceutici, several years; GSK, several years; Lusofarmaco, several years; Menarini, several years; Istituto De Angeli, several years).

Due to the methodology used to estimate emissions, based on the consumption of the F-gases the estimated consumption also includes the amount of fluid contained in the imported products. As for aerosols (i.e. MDI), every year the relevant operators at the national level provide us with the consumption of F-gases used in the national production process. Some of the reporting operators manufacture the MDI at Italian facilities as well as export the products, while some others just market in Italy imported MDI.

In the following Table 4.73 the HFC-134a consumptions are reported.

Table 4.73 Consumption of HFC contained in the MDI (t), 1994 -2022

2.F.2.a Aerosol	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Consumptions (t)										
HFC 134a	NO	NO	8.80	97.25	208.39	221.78	305.12	332.78	336.76	411.65

HFC emissions estimation from Aerosol

Emissions from MDI are estimated on the basis of HFC consumptions and losses rates provided by the relevant operators in Italy, using the Equation 7.6 of the 2006 IPCC Guidelines. Specifically, the loss rate during manufacturing is set at 1.95% while it is assumed that 50% of the chemical charge escapes within the first year and the remaining charge escapes during the second year, according to 2006 IPCC Guidelines. The average lifetimes and the percentage of recovered gas at decommissioning applied are based on default values from 2006 IPCC Guidelines and expert judgment. In the following table 4.74 the main parameters used for the emissions estimations are reported.

Table 4.74 Manufacturing and product life leakage rate, average lifetime and recovery at decommissioning for MDI.

Subsector	Leakage rate (%)		Average lifetimes (years)	Recovery at decommissioning (%)
	Manufacturing	Operating		
Metered Dose Inhalers	1.95	50%	2	0

The total emissions from Aerosol subsector for each year are reported in Table 4.75.

Table 4.75 HFC emissions from MDI(t), 1990-2022

2.F.2.a Aerosol	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Manufacturing emissions (t)										
HFC 134a	NO	NO	0.17	1.90	4.06	4.32	5.95	6.49	6.57	8.03
Lifetime emissions (t)										
HFC 134a	NO	NO	81.37	223.42	196.63	125.05	176.92	152.00	114.96	109.09
Disposal emissions (t)										
HFC 134a	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total HFC emissions from MDI (t)	***NO***	***NO***	***81.54***	***225.32***	***200.69***	***129.37***	***182.87***	***158.49***	***121.52***	***117.12***

4.7.12 Uncertainty and time-series consistency

The combined uncertainty in F-gas emissions for HFC emissions from HFC used as substitutes for ODS is estimated to be about 58% in annual emissions, 30% and 50%, concerning activity data and emission factors, respectively.

HFC emissions from refrigeration equipment increased from 1994 to 2012 driven by the increase of their consumptions. The maximum value of emissions was registered in 2012 with 7,633.69 ktCO2eq then emission started to decrease and in 2022 they were equal to 3,384.11 ktCO2eq (Table 4.76).

The largest contribution to emissions comes from the commercial refrigeration subsector for all years except for the period from 1995 to 2010, when the industrial refrigeration subsector registered the highest emissions. The lowest emissions are from domestic refrigeration (Figure 4.3).

HFC total consumptions, expressed in tons started to decrease from 2003 due to the reduction of the quantity of hydrofluorocarbons placed on the market. Over the entire series, the maximum value of gases consumptions was registered in 2003 with 5,316 t. From 2003 to 2020 consumptions constantly decreased until 2,620 in 2020. In 2021 a slight increase was registered as a response to the 2020 pandemic crisis. In 2022 consumptions were equal to 2,664 t.

If, on the other hand, we analyse the consumption of these gases in ktCO_2eq, there is a rapid increase from the mid-1990s to 2003 (with 12,757.22 ktCO_2eq) followed by a decrease until 2005. From 2005, consumption growth resumed until 2014. This increase was much less pronounced than in the previous period and is because, although total tons of gases used decreased, the contribution of high-GWP R-404A increased. Since 2015, however, there has been a sharp decrease in consumption in ktCO_2eq due to the effects of fluorinated gas legislation with the replacement of high-GWP gases with new alternatives with a lower GWP (Figure 4. 4).

Table 4.76 Total HFC emissions from Refrigeration sector (ktCO_2eq), 1990-2022

Emissions (ktCO2eq)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Refrigeration sector (commercial refrigeration + domestic refrigeration+ industrial refrigeration+ transport refrigeration)										
HFC 23	NO	40.25	111.60	142.54	116.77	142.37	107.51	101.33	95.01	93.06
HFC 134a	NO	80.81	1,066.61	2,174.75	2,341.16	1,495.48	1,204.50	1044.75	996.92	981.30
HFC 143a	NO	9.74	608.43	2,213.23	3,183.72	3,254.51	1,821.10	1,559.03	1,348.49	1,099.39
HFC 125	NO	5.87	354.35	1,282.31	1,835.81	1,911.90	1,383.54	1,286.88	1,244.13	1,155.26
HFC 32	NO	NO	NO	NO	NO	8.99	43.52	44.38	49.65	55.11
Total emissions (ktCO2eq)	***NO***	***136.67***	***2,140.98***	***5,812.83***	***7,477.46***	***6,813.26***	***4,560.18***	***4,036.36***	***3,734.19***	***3,384.11***

Figure 4.3 Total HFC emissions by sub-sector of refrigeration sector (ktCO₂eq), 1990-2022

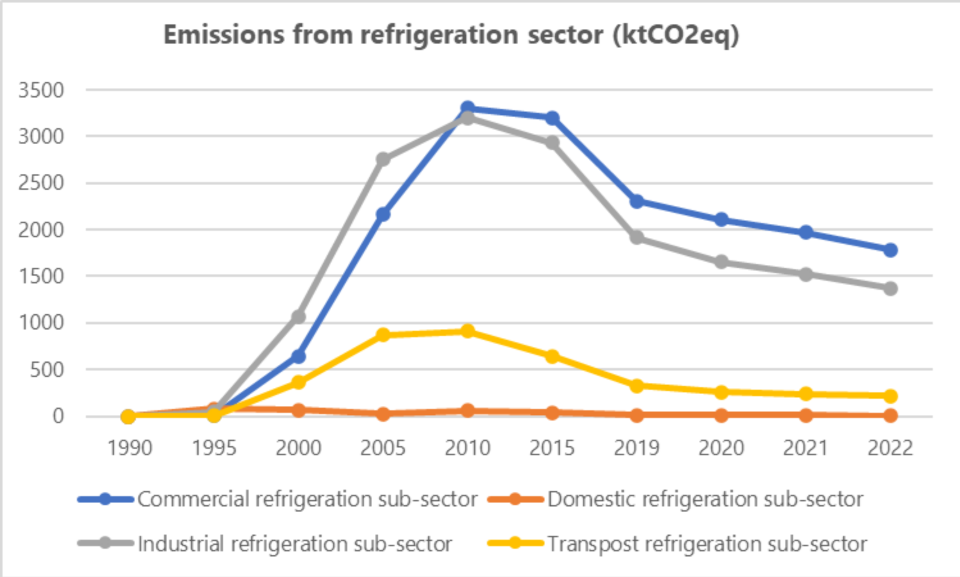
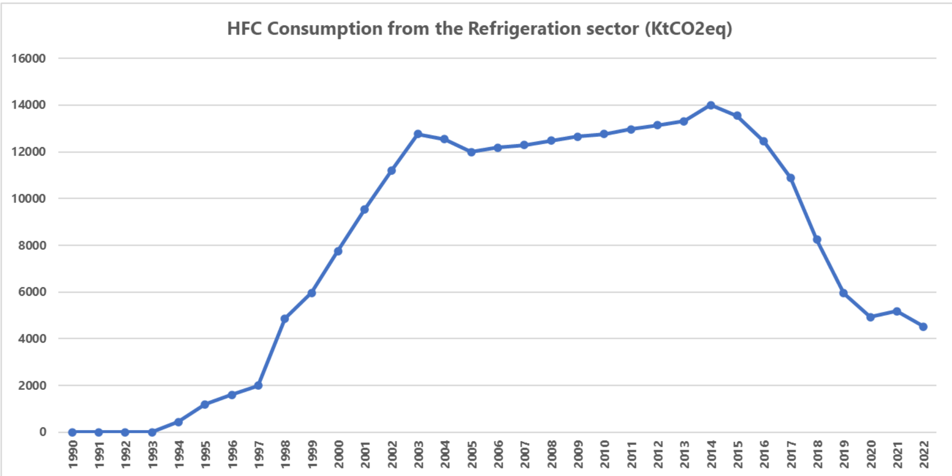


Figure 4.4 Total HFC consumptions from Commercial refrigeration (ktCO₂eq), 1990-2022



HFC consumptions from MAC sub-sector increased until 2006 when they reached the value of 2,452.5 t (equal to 3,192.65 ktCO₂eq). In 2020 a strong decline in consumptions compared to the previous year was registered, probably due to the SARS_COVID19 pandemic, with a new increase in the following two years. Specifically, in 2022 a consumption of 1,191 t (1,548.59 ktCO₂eq) was recorded. HFC total emissions from MAC continued to increase until 2009 when they reached the maximum value of 2,074.68 ktCO₂eq. A major decrease started from 2018. In 2022 the emissions were equal to 849.18 ktCO₂eq t. The emissions reduction trend is postponed compared the consumption trend because of the methodology adopted. In Table 4.77 the total consumption of HFC from MAC subsector is reported.

Table 4.77 Total HFC emissions from MAC sector (ktCO₂eq), 1990-2022

Emissions (kt CO2eq)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
2.F.1.e Mobile Air Conditioning										
HFC-134a (ktCO2eq)	NO	469.58	1,220.34	1,831.61	2,072.40	1,730.14	1,367.30	1,122.50	976.09	849.18

HFC emissions from the Stationary air conditioning equipment increased from1996 driven by the increase of their consumptions. The overall consumptions trend was increasing until 2016 and then it started to decline. In 2022 there was a slight recovery compared to 2020, when the market was affected by the Sars Covid-19 pandemic. For emissions, the maximum value was registered in 2019 with 2,780.09 ktCO2eq t while in 2022 emissions were 2,634.22 ktCO2eq (Table 4.78). Because of the methodological approach adopted, emission reduction is postponed compared to consumption reduction. The HFC substitution process with the alternatives with a lower or null GWP, some of which flammable, started in delay in respect the other sectors because of highly restrictive Italian regulation about the use of flammable refrigerants in public buildings. In this context, the use of HC, highly inflammable, as alternative of the traditional gases initially concerned the portable conditioning systems due to their small charge. R-32 gas entered in the Italian market in 2016 in the residential split with an increasing use over the years and in 2022 VRFs, roof tops and air-cooled chillers using R32 have also entered the market. Also in 2022, the first R-513A chillers appeared, albeit in small percentages. Among the new refrigerants, not belonging to the F-gas family, hydrocarbons and hydrofluoroolefins should be mentioned. Small percentages of chillers use these gases today and are expected to increase in the coming years.

Table 4.78 Total HFC emissions from Stationary Air Conditioning sector (ktCO2eq), 1996 - 2022

Emissions (KtCO2eq)	1996	2000	2005	2010	2015	2019	2020	2021	2022
2.F.1.f Stationary Air Conditioning									
HFC-134a	2.39	9.24	150.22	166.69	154.62	420.24	292.24	238.10	214.77
HFC-125	1.03	8.86	451.53	928.21	906.57	1,906.99	1,742.28	1,727.13	1,867.07
HFC-32	0.22	1.79	93.79	195.59	191.51	452.86	447.01	480.38	552.38
***Total HFC emissions* (ktCO2eq)**	***3.63***	***19.89***	***695.54***	***1,290.48***	***1,252.70***	***2,780.09***	***2,481.54***	***2,445.61***	***2,634.22***

HFC emissions from Foam blowing, Fire extinguishers and Aerosols sub-sectors increased from 1994 driven by the increase of their consumptions. HFC consumptions from Foam blowing increased until 2004 when the maximum value of 1,865.36 t (equal to 2,027.17 ktCO2eq) was registered. A much more pronounced reduction in consumption has begun since 2014, due to the reduction of the quantity of hydrofluorocarbons placed on the market as well as the restrictions for some products and equipment derived from the entering in force of the European F-gases Regulation (EU, 2014). The foam emissions started to decrease since 2014 when they reached the maximum value of 531.45 ktCO2eq. In 2022, emissions were equal to 411.80 ktCO2eq.

For Fire extinguishers sub-sector, F-gas consumptions increased until 2005 and after a few years of stability, in 2011 they started to decrease. In fact, as with the foam sector, the availability of low- or zero-GWP alternatives has enabled a more rapid phase out of HFCs. The HFC total emissions for Fire extinguishers increased until 2020 when they reached the value of 1,658.74 ktCO2eq. In 2022, with 1,641.25 t, a slightly decrease compared the two previous year was registered. Due to the methodological approach followed, the reduction in emissions is postponed in time compared to the reduction in consumptions.

For Aerosol sub-sector, emissions increased from 1990 to 2006 when they registered the maximum value of 303.61 ktCO2eq t. Then they decreased until 2016 with the minimum value of 149.24 ktCO2eq. A new increase was registered from 2016 to 2019 and then they came back to decline. In 2022 HFC emissions were equal to 152.25 ktCO2eq. Emissions from MAC, foam blowing, fire extinguishers and Aerosols sector are reported in Table 4.79.

Table 4.79 HFC emissions from MAC, Foam blowing, Fire extinguishers and Aerosols sectors ($ktCO_2eq$), 1990-2022

COMPOUND (ktCO2eq)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
2.F.2.a - Foam blowing (closed cell)										
HFC 134a	NO	NO	64.18	234.09	277.96	261.71	238.40	230.31	221.41	213.19
HFC 245fa	NO	NO	0.00	127.66	202.21	265.37	235.77	222.54	207.20	198.62
Total emissions ($ktCO_2eq$)	***NO***	***NO***	***64.18***	***361.75***	***480.17***	***527.08***	***474.16***	***452.86***	***428.61***	***411.80***
2.F.3 - Fire Extinguishers										
HFC 227ea	NO	12.99	134.71	531.41	1,002.30	1,305.54	1,389.03	1,392.19	1,391.37	1,380.43
HFC 23	NO	1.78	18.47	72.85	137.41	173.35	170.79	168.96	166.71	164.06
HFC 125	NO	0.91	9.44	37.25	70.26	91.51	97.36	97.58	97.53	96.76
Total emissions ($KtCO_2eq$)	***NO***	***15.69***	***162.61***	***641.51***	***1,209.97***	***1,570.41***	***1,657.18***	***1,658.74***	***1,655.61***	***1,641.25***
2.F.4 - Aerosol										
HFC-134a (ktCO2eq)	NO	NO	106.00	292.91	260.90	168.19	237.74	206.03	157.98	152.25
Total HFC emissions ($ktCO_2eq$)	***NO***	***NO***	***106.00***	***292.91***	***260.90***	***168.19***	***237.74***	***206.03***	***157.98***	***152.25***

4.7.13 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures.

Air conditioning category, as well as refrigeration, foam blowing, fire extinguishers and aerosols has been analyzed with experts of the national associations, in the framework of the study planned by the agreements with the Ministry of Environment for a survey, about HFCs alternative substances with low GWP, natural refrigerants and alternative technologies. Besides, a continuous sharing of information between the experts of the national association and the Inventory team is ongoing by enabling both the collection of new data and the verification and updating of those used to date.

In January 2019, the new National Telematic Registry of fluorinated greenhouse gases and equipment containing fluorinated gases instituted by the DPR 146/2018, entered into force. Compared to the previous National F-gas Data Bank (established by Presidential Decree 43/2012), which includes refrigeration, air conditioning and fire protection systems, the new Registry also contains data on electrical switches and cold rooms in refrigerated trucks or trailers. ISPRA is not involved in the data collection but has access to the database.

We have already started to check data of the Registry and, from a first analysis, it emerged that the information contained is not always in the form and at the level of detail useful for estimating the Inventory. We worked with the Responsible of the Registry to try to overcome some of the issues that have emerged after an initial check of the database. Although some gaps were overcome, there are still critical on data. For this reason, we have decided not to use the information contained in the registry yet. As already reported in the previous paragraphs, in recent months a new collaboration with Assofrigoristi has been initiated to improve the Data Bank collection system and obtain more precise information on emission factors, gas recovery percentage, frequency of equipment topping up. In detail, Assofrigoristi launched an initial survey among of the Association by requesting data and information. The data collected at the moment does not yet have statistical value and therefore cannot be used. For this reason, this survey will be carried out in the coming months, with the aim of involving a greater number of members and also including other sectors such as refrigeration. Through this collaboration, we expect to be able to continue to verify and update the data we use.

4.7.14 Source-specific recalculations

Recalculation affected the emission estimates of Commercial, Domestic and Industrial Refrigeration, Stationary Air conditioning and Mobile air conditioning.
Commercial, industrial and transport refrigeration have undergone major changes summarized below:

1) new estimation of the container emissions, not considered in previous submissions;
2) availability of refrigerants consumptions by subsectors and consequently possibility to estimate separately commercial, industrial, and transport refrigeration;
3) availability of refrigerants consumption split between *First Charge* and *Service*;
4) update of lifetimes emission factors (industrial refrigeration);
5) update of end-of-life charge and end-of-life gas recovery rates.

Regarding the Domestic refrigeration the recalculation is due to the new estimations management containers emissions, as well as for refrigeration sector. These emissions, as already reported in the previous paragraphs, were included in the lifetime emissions of these equipments.
In Table 4.80 the difference between 2024 and 2023 submissions for total refrigeration sector is reported, by single gas and by total in terms of CO_2 equivalent.

Table 4.80 Differences between 2024 and 2023 Submission for Refrigeration sector (%)

Refrigeration	1990	1995	2000	2005	2010	2015	2020	2021	2022
Recalculation (%)									
HFC 23	-	181.3%	114.7%	87.2%	53.5%	114.4%	72.5%	66.4%	99.2%
HFC 134a	-	158.9%	275.4%	255.0%	135.9%	79.2%	54.3%	51.8%	70.3%
HFC 143a	-	25.7%	16.5%	-11.6%	-23.0%	-32.2%	-62.5%	-65.1%	-68.4%
HFC 125	-	25.7%	16.5%	-11.7%	-23.0%	-30.9%	-55.1%	-55.6%	-54.0%
HFC 32	-					576.1%	-46.1%	-50.9%	-38.6%
Total HFC CO2 eq.	-	135.9%	84.2%	25.1%	-1.4%	-19.6%	-48.5%	-50.1%	-49.5%

A review process also affected the MAC, sub-sector and, as a consequence, the HFC emissions have been changed. As reported in paragraph 4.7.7, following the fruitful collaboration with Assogastecnici, a revision of the estimates has been made. A crucial aspect is, as for the refrigeration sectors, that until last year activity data did not include consumption used for *Service*.

In Submission 2023 emission estimation from MAC systems was based on the methodology reported in Box 7.4 of the 2006 IPCC Guidelines, assuming all MACs were serviced each year in order to make up for the lack of data of refrigerant used for *Service*. For this submission, based on new available information, we assumed that a MAC leaks over several years before being serviced. Depending on different conditions, servicing could be done every two years, every certain time interval, or sometimes not at all during the entire lifetime. Thus, the HFC 134a stock in MAC systems is profoundly changed by causing a revision of operational and disposal emissions.

As already reported in the previous paragraphs, for the Stationary air conditioning sub-sector, the recalculation is due to the revision of the estimation process of emission from containers and to the introduction of the domestic heat water machines from 2014 A review of the activity data, which resulted in the corrections of some values, together with the updating of the percentages of equipment by refrigerant type was also carried out.

Table 4.81 shows the differences between the current submission and last year's submission for Air Conditioning sector, by single gas and by total in terms of CO_2 equivalent.

Table 4.81 Differences between 2024 and 2023 submission for Air Conditioning sector (%)

Air Conditioning	1990	1995	2000	2005	2010	2015	2020	2021	2022
Recalculation (%)									
MAC									
HFC 134a	-	51.7%	-2.7%	-10.5%	-40.5%	-52.2%	-66.6%	-69.1%	-71.5%
Stationary Air Conditioning									
HFC 134a	-	-	-1.7%	-2.2%	-0.1%	0.0%	-0.7%	-1.1%	-18.6%
HFC 125	-	-	0.5%	-0.3%	-0.1%	0.0%	-0.7%	-0.7%	3.4%
HFC 32	-	-	0.5%	-0.3%	-0.1%	0.0%	-0.5%	-0.7%	11.8%
Total HFC CO2 eq.	-	51.7%	-2.7%	-8.0%	-29.5%	-38.8%	-38.5%	-39.1%	-37.1%

For the Aerosol subsector, minor recalculation occurred due to the update of HFC-134a consumption data for 2021.

No recalculation has occurred for Fire protection and Foam blowing sub-sectors.

4.7.15 Source-specific planned improvements

To improve our estimation in all the sectors described above we are constantly in contact with the national experts and Associations in order to collect any new information that gradually become available by taking into account changes in the market both in terms of the entry of new refrigerants and technological advances in equipment, and also considering good practices in gas management that affect emission factors.

Concerning the recovery of gas at the end of life of equipment, Erion, the largest Italian system of extended producer responsibility for the management of waste associated with electronic products, is finalizing a study on stationary conditioning appliances end-of-life. Improvements should be also obtained by consulting the new National Telematic Registry of fluorinated greenhouse gases and equipment containing fluorinated gases that has been instituted by the DPR 146/2018, entered in force in January 2019. Compared to the previous National F-gas Data Bank (established by Presidential Decree 43/2012), which includes refrigeration, air conditioning and fire protection systems, the new Registry also contains data on electrical switches and cold rooms in refrigerated trucks or trailers. Therefore, it will be possible to investigate these types of systems as well. We have already started to check data of the Registry and, from a first analysis, it emerged that the information contained is not always in the form and at the level of detail useful for estimating of the Inventory. Although some gaps were overcome, there are still critical issues on data. For this reason, we have decided not to use the information contained in the registry yet. Also, a new collaboration with Assofrigoristi has been initiated at the end of 2023 to improve the Data Bank collection system (paragraph 4.7.13 Source-specific QA/QC and verification for more information on this topic).

Finally, a further improvement could come from a study conducted by a research group including several Italian universities, which continuously measures the atmospheric concentration of HFC-134a using inverse modeling and a top-down approach. The results of this study could be compared with the Inventory estimates.

4.8 Other product manufacture and use (2G)

4.8.1 Source category description

The sub-sector "Other product manufacture and use" consists of the following sub-applications:

2.G.1 – SF_6 Emissions from electrical equipment

2.G.2 – SF_6 used in equipment in university and research particle accelerators

2.G.3 – N_2O from product uses

The share of SF_6 emissions from the sector in the national total of SF_6 was 72% in the base-year 1990, and 89.7% in 2022, whereas in the national total of F-gases, the share of SF_6 emissions from the sector was 8.9% in 1990 and 3.52% in 2022. N_2O accounts for only 2.8% of the national total N_2O emissions in 2022.

4.8.2 Methodological issues

<u>*Electrical Equipment (SF6)*</u>

As regard SF_6 emissions from electrical equipment, these have been estimated according to the IPCC Tier 2 approach. Concerning manufacturing and installation emissions, since 1995 the methodology used is largely in accordance with the IPCC Tier 3 methodology. In 1997, the ANIE Federation began a statistical survey within their associated companies, in accordance with ISPRA, in order to monitor yearly SF_6 used in electrical equipment > 1kV, and thus SF_6 manufacturing emissions (ANIE, 2001). ANIE Federation is the Confindustria member representing the electrotechnical and electronic companies operating in Italy. ANIE has developed data sheets for their associated companies in accordance with the methodology drawn up by CAPIEL, the Coordinating Committee for the Associations of Manufacturers of Switchgear and Controlgear equipment in the European Union: the CAPIEL inventory methodology covers all sorts of use of SF_6 in the electrical sector, from the SF_6 purchase till the end of life of the equipment and covers all aspects of the required data (CAPIEL, 2002). It is based on a Mass Balance Methodology, as given by IPCC Tier 3b, comparing the input and output on a yearly basis.

In the following box the summary sheet used for manufacturing inventory is reported (ANIE, several years).

SF_6 inventory at manufacturing level

INVENTORY'S CATEGORIES					**Year 2022 (kg)**
1. Purchased amount	1.1 In Italy		Weight of SF_6 contained in the tanks		5,065
	1.2 Abroad		Weight of SF_6 contained in the tanks		67,125
				TOTAL 1.	**72.190**
2. Amount contained in the equipment at the terms of sale	2.1 In Italy	2.1.1 ENEL	Weight of SF_6 contained in the equipment and in the tanks		19,552
		2.1.2 Energy industry and railways	Weight of SF_6 contained in the equipment and in the tanks		20,162
		2.1.3 Others (Industry, Tertiary, Private, etc.)	Weight of SF_6 contained in the equipment and in the tanks		4,940
	2.2 Abroad		Weight of SF_6 contained in the equipment and in the tanks		13,805
				TOTAL 2.	**58,459**

INVENTORY'S CATEGORIES			Year 2022 (kg)
3. Amount contained in the equipment returned to the manufacturer	Weight of SF_6 contained in the equipment and in the tanks	**TOTAL 3.**	**0**
4. a) Destroyed amount	Weight of SF_6 in the equipment sent to authorized disposal treatment		0
4. b) Amount returned to the manufacturer	Weight of SF_6 returned to manufacturer for authorized recycling		7,503
		TOTAL 4.	**7,503**
5. Annual stock changes		**TOTAL 5.**	**3,705**
SF_6 emissions from manufacturing	**Balance input-output (1+3-5)-(2+4)**		**2,523**

From 1990 to 1994 emissions have been estimated on the basis of leakage rate during manufacturing and installation and the amount of SF_6 contained in the equipment sold to the end users, because, for this period, only data referred to point 1 and point 2 of the box, are available from ANIE. The loss rates during manufacturing and installation of the equipment, used to estimate the SF_6 emissions, are reported in Table 4.82. Leakage rates have been derived from ANIE Federation expert judgement.

Table 4.82 Leakage rates used to estimate SF6 emissions from manufacturing and installation from 1990 to 1994

	1990	1991	1992	1993	1994
Manufacturing	0.060	0.060	0.060	0.060	0.060
Installation	0.060	0.055	0.050	0.045	0.040

In Table 4.83, SF_6 emissions from manufacturing (which include installation), use and disposal are reported. Emissions from manufacturing were about 14 tons in 1995, whereas in 2022 are only 2.523 tons, due to the great increase of the SF_6 recycled. Emissions trend from manufacturing is strongly decreasing thanks to the diligence of the companies involved, which have taken voluntary actions to reduce emissions as much as technically possible. Probable fluctuations within the time series in manufacturing emissions are basically due to yearly variation of the stocked quantity of SF_6.

Table 4.83 SF_6 emissions from manufacturing, use and disposal from 1990 to 2022

SF6 EMISSIONS (Mg)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Manufacturing	8.470	14.657	5.637	3.562	3.185	1.259	0.795	0.488	0.246	2.523
Use	0.460	4.886	6.469	9.592	10.302	11.572	12.281	8.208	9.181	9.820
Disposal	NO	0.622	0.464	0.199	0.059	0.037	0.088	0.000	0.002	0.000
Total	**8.930**	**20.165**	**12.571**	**13.354**	**13.546**	**12.868**	**13.164**	**8.696**	**9.429**	**12.343**

SF_6 use emissions are those from Closed Pressure Systems, including high voltage equipment that requires refilling with gas during its lifetime. Equipment use emissions are estimated by multiplying the quantity of SF_6 yearly accumulated by a use emission factor. The quantity of SF_6 accumulated is estimated using SF_6 annual sales activity data (ANIE, several years), multiplied for the factor 0.8, which considers the percentage of the total sales referred to Closed Pressure Systems. Moreover, equipment use emissions are the sum of three components:

- emissions from ENEL (the former electricity monopoly);
- emissions from electricity utilities and the national railways company;

– emissions from industries and other private operators.

Since 1994, refilling data of SF_6 used in high voltage gas-insulated transmission lines have been supplied by the main energy distribution companies (in the past included in ENEL) checked with data reported under the national PRTR register (EDIPOWER, several years; EDISON, several years; ENDESA, 2004; ENDESA, several years [a] and [b]; ENEL, several years; TERNA, several years). The leakage rate used to estimate the SF_6 use emissions is assumed equal to 0.01 from 1990 to 2009 and 0.005 from 2010, based on national expert judgment (AIET, 2007). Finally, SF_6 disposal emissions from electrical equipment are estimating by multiplying the quantity of SF_6 contained in retired equipment by the fraction of SF_6 left in the equipment at the end of its life, assumed to be constant and equal to 0.15 from 1990 to 1995, and linearly decreasing until to 2010 value 0.03, as reported in Table 4.84. Since 1995, activity data (point 3 of the SF_6 inventory at manufacturing level reported above**)** are directly supplied by ANIE (ANIE, several years), whereas from 1990 to 1994 the total amount of SF_6 accumulated in the equipment is multiplied by a disposal rate which is equal to zero in that period. Leakage disposal rate and disposal rate derived from personal communication.

Table 4.84 Disposal rates and leakage rates at disposal used to estimate SF6 emissions from disposal, 1990-2022

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Disposal rate	0.000	0.000	0.010	0.020	0.030	0.030	0.030	0.030	0.030	0.30
Leakage rate at disposal	0.150	0.150	0.110	0.070	0.030	0.030	0.030	0.030	0.030	0.030

As for fluctuation in emissions within the years, Figure 4.5 is reported for a better understanding. As regard the years from 1995 to 2000, please consider that the total SF_6 emission values result by the sum of emissions from “manufacturing”, “operating” and “retiring” and that concerning the trends of these contributions the following facts should be pointed out:

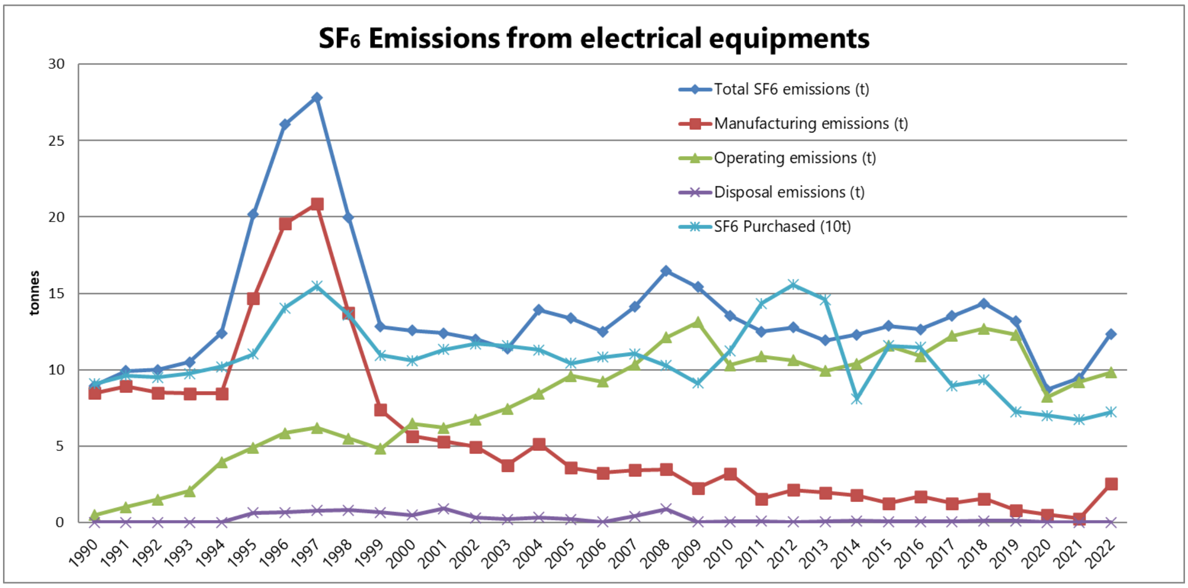
1) emissions from manufacturing reach a peak in 1997;

2) emissions from operating reach a peak in 1997;

3) emissions from retiring reach a peak in 1997 although the relevant contributions to total SF_6 emissions are those from manufacturing and operating.

Data between 1995 and 2000 are consistent and come from the SF_6 mass balance. In Figure 4.5 the time series for SF_6 purchased amounts and of the three contributions to SF_6 emissions from electrical equipment are illustrated. It could be noted that the trend of the amounts of SF_6 estimated for “manufacturing” is driven by the trend of purchased SF_6.

Figure 4.5 Time series for SF6 purchased amounts and emissions from electrical equipment.



SF_6 used in equipment in university and research particle accelerators

SF_6 emissions from research particle accelerators have been estimated since 1990. A survey on the particle accelerators used for research purpose has been carried on, asking directly information to the national research institutes: INFN, the National Institute for Nuclear Physics and INAF the National Institute of Astrophysics.

INFS has supplied refilling data of SF_6 for four particle accelerators located in three laboratories, Catania, Legnaro and Firenze (INFN, several years), for the entire time series 1990–2022. These particle accelerators use SF_6 from 1984, 1981, 1976 and 2004 respectively. INAF does not use SF_6 in their research activities.

SF_6 emissions from industrial and medical particle accelerators have been estimated from 1990 too. As for research particle accelerators, a survey on the accelerators used for medical purposes has been carried out. In Italy particle accelerators for medical purposes are supplied by only three companies, Siemens Healthcare, Varian Medical System and Elekta. Data on the number of accelerators and the charge of SF_6 have been communicated from 1990 (Siemens, several years; Varian, several years).

N_2O from product use

N_2O emissions from the use of N_2O for anesthesia, aerosol cans and explosives are estimated.

Emissions of N_2O have been estimated according to information available by industrial associations. Specifically, the manufacturers and distributors association of N_2O products has supplied data on the use of N_2O for anesthesia from 1994 (Assogastecnici, several years). For previous years, data have been estimated by the number of surgical beds published by national statistics (ISTAT, several years [a]). It is assumed that all N_2O used will eventually be released into the atmosphere, therefore the emission factor for anesthesia is equal to 1 Mg N_2O/Mg product use.

Moreover, the Italian Association of Aerosol Producers (AIA, several years [a] and [b]) has provided data on the annual production of aerosol cans used for whipped cream which contain N_2O as propellant. The emission factor used is 0.025 Mg N_2O/Mg product use, because the N_2O content is assumed to be 2.5% on average (Co.Da.P., 2005). The association also provides the number of aerosol cans for other uses (cosmetics, household and cleaning products, pharmaceutical products) and the propellants (LPG and

HFC-134a for pharmaceutical products); relevant emissions are estimated in domestic solvent use category as NMVOC and in HFC-134a emissions from aerosols/metered dose inhalers category.

For the estimation of N_2O emissions from explosives, data on the annual consumption of explosives have been obtained by a specific study on the sector (Folchi and Zordan, 2004); as stated in the document, this figure is believed to be constant for all the time series with a variation within a range of 30%. As for the emission factor, the estimated N_2O emissions represent the theoretically maximum emittable amount; in fact, no figures are available on the amount of N_2O emissions actually emitted upon detonations and the value of 3,400 Mg N_2O/Mg explosive use is provided by a German reference (Benndford, 1999) which corresponds to the assumption of 68 g N_2O per kg ammonium nitrate.

N_2O emissions have been calculated multiplying activity data, total quantity of N_2O used for anesthesia, total aerosol cans and explosives, by the related emission factors.

4.8.3 Uncertainty and time series consistency

The uncertainty in SF_6 emissions from electrical equipment and particle accelerators is estimated to be 20.6% in annual emissions, 5% and 20% concerning respectively activity data and emission factors.

In Table 4.85 an overview of SF_6 emissions from electrical equipment and particle accelerators is given for the 1990-2022 period. SF_6 emissions from electrical equipment increased from 1990 to 1997 and decreased in the following years; from 2004 emissions are stable enough, from 2020 a significant decrease was registered especially due to a drop in operating emissions.

Table 4.85 SF_6 emissions from other product manufacture and use (t), 1990-2022

COMPOUND (t)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
2.G.1										
SF_6 emissions from electrical equipment	8.93	20.17	12.57	13.35	13.55	12.87	13.16	8.70	9.43	12.34
2.G.2.b										
SF_6 emissions from research particle accelerators	3.95	3.99	4.02	4.72	1.65	5.69	3.22	0.44	0.85	2.55
Total SF_6 emissions from 2G sector	**12.88**	**24.16**	**16.59**	**18.07**	**15.20**	**18.56**	**16.39**	**9.14**	**10.28**	**14.90**

The combined uncertainty in N_2O emissions is estimated equal to 11.2% due to an uncertainty in activity data of 5% and 10% in the emission factor. N_2O emissions remain almost at the same levels from 1990 onwards although, from 2000, a reduction is detected, due to a decrease in the anesthetic use of N_2O that has been replaced by halogen gas. Table 4.86 shows the N_2O emission trend from 1990 to 2022.

Table 4.86 Trend in N_2O emissions from product uses, 1990 – 2022 (kt)

GAS/SUBSOURCE	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
2.G.3 Other product manufacture and use: N_2O (kt)										
N_2O from product uses (use of N_2O for anesthesia, aerosol cans and explosives)	2.62	2.49	3.31	2.66	2.02	1.57	1.74	1.71	1.68	1.67

4.8.4 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures. Where information is available SF_6 data for refilling have been checked with data reported to the national EPER/E-PRTR registry. For N_2O emissions from anesthesia and aerosol cans, emission factors and emissions are also shared with the relevant industrial associations.

Other relevant uses of SF_6, as listed in the IPCC Guidelines, have been investigated to study the occurrence at national level. Some of these applications could be excluded, such as car tyres, soundproof windows and shoes soles also due to manufacturing additional costs.

Regarding the other potential sources of emissions, such as SF_6 emissions from AWACs, in 2014 the Italian Air Force has been contacted in order to investigate the presence of such aircraft. The Italian Air Force answered that such kind of aircraft is a NATO aircraft and according to the Decision 3/CP.3 of the Kyoto Protocol, emissions resulting from multilateral operations pursuant to the Charter of the United Nations shall not be included in national total.

4.8.5 Source-specific recalculation

A minor recalculation of emissions occurred for the electrical equipment sub-sector due to the updating of activity data.

4.8.6 Source-specific planned improvements

For SF_6 emissions from electrical equipment, improvements should be also obtained by consulting the new National Telematic Registry of fluorinated greenhouse gases and equipment containing fluorinated gases that has been instituted by the DPR 146/2018, entered in force in January 2019. In fact, compared to the previous National F-gas Data Bank (established by Presidential Decree 43/2012), which includes refrigeration, air conditioning and fire protection systems, the new Registry also contains data on electrical switches. Therefore, it will be possible to investigate these types of systems as well.

4.9 Other production (2H)

4.9.1 Source category description

Only indirect gases and SO_2 emissions occur from these sources. In this sector, non-energy emissions from pulp and paper as well as food and drink production, especially wine and bread, are reported. CO_2 from food and drink production (e.g., CO_2 added to water or beverages) can be of biogenic or non-biogenic origin but only information on CO_2 emissions of non-biogenic origin should be reported in the CRT.

According to the information provided by industrial associations, CO_2 emissions do not occur, but only NMVOC emissions originate from these activities. CO_2 emissions from food and beverages do not occur since they originated from sources of carbon that are part of a closed cycle. As regards the pulp and paper production, NO_X and NMVOC emissions as well as SO_2 are estimated. NO_X and SO_2 emissions have been referred to the paper and pulp production from acid sulphite and neutral sulphite semichemical processes up to 2009, activity data and emissions were provided by the two Italian production plants: in 2008 the bleached sulphite pulp production has stopped while in 2009 the neutral sulphite semi-chemical pulp process has closed (reconversion of the plant is currently under negotiation). NMVOC emissions are related to chipboard production and have been estimated and reported.

5 AGRICULTURE

5.1 Sector overview

In this chapter information on the estimation of greenhouse gas (GHG) emissions from the Agriculture sector is given. Emissions from enteric fermentation (3A), manure management (3B), rice cultivation (3C), agriculture soils (3D), field burning of agriculture residues (3F), liming (3G), urea application (3H) and other carbon-containing fertilizers (3I) are included in this sector. Methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions are estimated and reported. Savanna areas (3E) are not present in Italy. Emissions from other sources (3J) do not occur.

To provide information on the characteristics of the agriculture sector in Italy, figures from the latest available Agricultural Census (2020), released by ISTAT, are reported. According to these data, in Italy there are 1.1 million of farms with a total Utilized Agricultural Area (UAA) of 12.5 million hectares. Comparing the data from the censuses (see box below), it can be noted as the number of farms and the agricultural area have decreased; in particular, between 2010 and 2020 more than about 480 thousand farms have been closed and between 2000 and 2010, the reduction of farms is equal to 33% (about 780 farms). At national level, the average size of farms varied from 5.5 hectares in 2000 to 11.1 hectares in 2020. This trend is in line with the average size of farms increment from 7.4 hectares (in 2005) to 7.6 hectares (in 2007) observed by the Farm structure survey (FSS). According to 2010 data, more than 50% of farms have an area of less than 2 hectares of UAA. The distribution of farms by type confirms a typical family conduction system, which characterized the Italian agriculture system. About one million farms (93.5 percent of total farms) are sole proprietorships or family farms. These farms hold about 9 million hectares of UAA (73.0% of total)[7] (EUROSTAT, 2007[a], [b], 2012; ISTAT, 2008[a]). CREA[8] annually updates figures of the agriculture sector such as added value, employment, productivity (CREA, 2020).

Farms characteristics from Agricultural Censuses

Farms characteristics	1982	1990	2000	2010	2020
Number of farms	3,133,118	2,848,136	2,393,161	1,615,590	1,133,023
Utilized agricultural area - hectares	15,833,000	15,026,000	13,181,859	12,856,048	12,535,000
Total area of farms - hectares	22,398,000	21,628,000	18,767,000	17,081,000	16,474,000
Average size of farms - hectares	5.1	5.3	5.5	8.0	11.1

7 Agricultural Census data are available at the link https://esploradati.istat.it/databrowser/#/it/censimentoagricoltura

8 Council for agricultural research and analysis of the agrarian economy https://www.crea.gov.it/en/about-crea

5.1.1 Emission trends

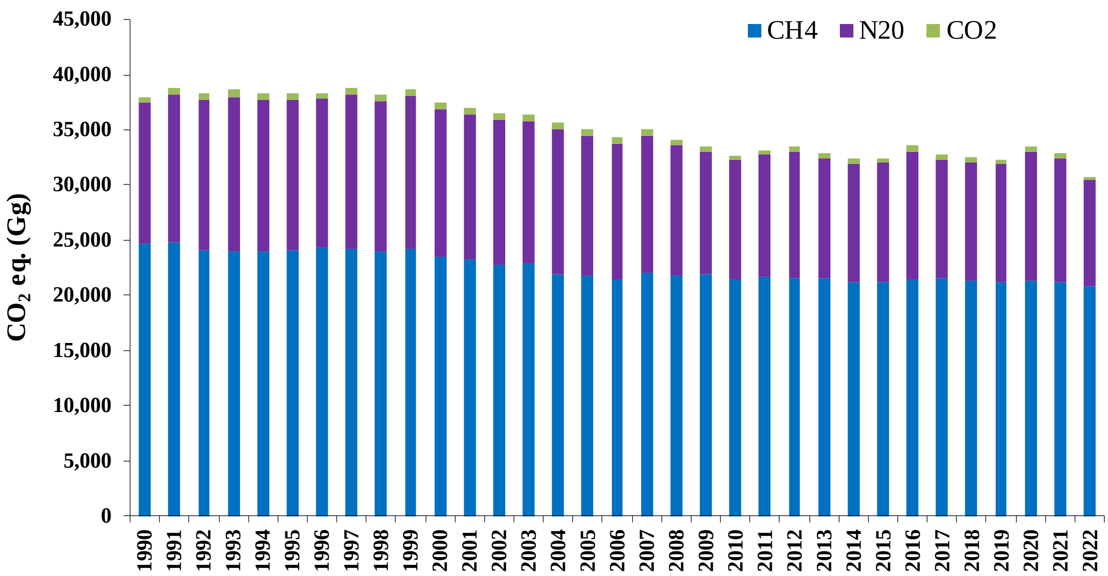
Emission trends per gas

In 2022, 7.4% of the Italian GHG emissions, excluding emissions and removals from LULUCF, (7.3% in 1990) are originated from the agriculture sector. Therefore, it is the second source of emissions, after the energy and followed by IPPU sector which account for 81.8% and 5.7%, respectively. For the agriculture sector, the trend of GHGs from 1990 to 2022 shows a decrease of 18.9% due to the reduction of the activity data, such as the number of animals, the cultivated surface/crop production, the amount of synthetic nitrogen fertilisers applied, and the changes in manure management systems (see Figure 5.1). In 2022, CH_4, N_2O and CO_2 emissions account for 67.7%, 31.5% and 0.8%, respectively. In the period 1990-2022, CH_4, N_2O and CO_2 emissions have decreased by 15.4%, 24.3% and 53.9%, respectively (see Table 5.1). The large reduction in 2022 of N_2O and CO_2 emissions is due in particular to the reduction in the synthetic fertilizer figure compiled by ISTAT. The data refer to the quantities sold in the country, which are assumed to be distributed on agricultural soils. According to *Assofertilizzanti– Federchimica*[9], the 2022 data are lower than annual average (for nitrogen, phosphorus pentoxide, and potassium oxide) because they follow a two-year period in which quantities purchased increased and refer to a year in which high market prices prompted operators to delay purchases in anticipation of falling prices, an event, which actually occurred during 2023. In 2022, the agriculture sector has been the first source for CH_4 sharing 45.6% of national CH_4 levels and for N_2O accounting for 61.6% of national N_2O emissions. As for CO_2, the agriculture sector represents 0.1% of national CO_2 emissions.

Table 5.1 GHG emissions and trend from 1990 to 2022 for the agriculture sector (Gg CO_2 eq.)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
CH_4	24,634	24,100	23,502	21,824	21,452	21,241	21,185	21,356	21,169	20,833
N_2O	12,809	13,644	13,358	12,641	10,801	10,756	10,699	11,675	11,232	9,696
CO_2	510	567	571	564	381	458	430	503	461	235
Total	**37,953**	**38,312**	**37,430**	**35,028**	**32,634**	**32,455**	**32,314**	**33,534**	**32,862**	**30,764**

Figure 5.1 Trend of GHG emissions for the agriculture sector from 1990 to 2022 (Gg CO_2 eq.)



[9] Federchimica is the National Association of the Chemical Industry and Assofertilizzanti represents the production companies of the fertilizer industry.

Emission trends per sector

Total GHG emissions and trends by subcategory from 1990 to 2022 are shown in Table 5.2 (expressed in Gg. CO_2 eq.). CH_4 emissions from enteric fermentation (3A) and N_2O emissions from agricultural soils (3D) are the most relevant categories. In 2022, their individual share in national GHG emissions excluding LULUCF was 3.5% and 1.9%, respectively.

Table 5.2 Total GHG emissions from 1990 to 2022 for the agriculture sector (Gg CO2 eq.)

	GHG emissions (Gg CO_2 eq.) by subcategory						
Year	**3A**	**3B**	**3C**	**3D**	**3F**	**3G-H-I**	**TOTAL**
1990	17,093	7,942	2,102	10,288	19	510	**37,952.8**
1995	16,697	7,569	2,228	11,233	18	567	**38,311.9**
2000	16,509	7,452	1,855	11,024	18	571	**37,430.2**
2005	14,484	7,396	2,078	10,490	17	564	**35,028.4**
2010	14,100	7,167	2,255	8,720	12	381	**32,633.7**
2015	14,272	6,885	1,943	8,886	11	458	**32,455.3**
2019	14,584	6,682	1,721	8,888	10	430	**32,313.7**
2020	14,771	6,685	1,696	9,868	10	503	**33,533.9**
2021	14,695	6,554	1,677	9,463	11	461	**32,862.2**
2022	14,487	6,513	1,547	7,972	10	235	**30,763.8**

5.1.2 Key categories

In 2022, CH_4 emissions from enteric fermentation and manure management, direct N_2O emissions from manure management, direct and indirect N_2O emissions from managed soils were ranked among the level key sources with the Approach 2, including the uncertainty (L2). CH_4 emissions from enteric fermentation was ranked among the trend key sources with Approach 2, including the uncertainty (T2). Including LULUCF sector in the analysis, CH_4 emissions from enteric fermentation and manure management and direct N_2O emissions from managed soils are key sources at trend assessment with Approach 2 (T2). In Table 5.3, key and non-key categories from the agriculture sector are shown, with a level and/or trend assessment (*IPCC Approach 1 and Approach 2*), excluding and including the LULUCF sector in the analysis.

Table 5.3 Key-sources identification in the agriculture sector with the IPCC Approach 1 and Approach 2 for 2022

GHG source categories			***excluding LULUCF***	***including LULUCF***
3A	CH_4	Emissions from enteric fermentation	Key (L, T)	Key (L, T)
3B	CH_4	Emissions from manure management	Key (L)	Key (L, T)
3Ba	N_2O	Direct emissions from manure management	Key (L)	Key (L)
3Bb	N_2O	Indirect emissions from manure management	Non-key	Non-key
3C	CH_4	Rice cultivation	Non-key	Key (L1)
3Da	N_2O	Direct emissions from managed soils	Key (L)	Key (L, T2)
3Db	N_2O	Indirect emissions from managed soils	Key (L)	Key (L)
3F	CH_4	Emissions from field burning of agriculture residues	Non-key	Non-key
3F	N_2O	Emissions from field burning of agriculture residues	Non-key	Non-key
3G	CO_2	Liming	Non-key	Non-key
3H	CO_2	Urea application	Non-key	Non-key
3I	CO_2	Other carbon-containing fertilizers	Non-key	Non-key

5.1.3 Activities

Emission factors used for the preparation of the national inventory reflect the characteristics of the Italian agriculture sector. Information from national research studies is considered. Activity data are mainly collected from the National Institute of Statistics (ISTAT, *Istituto Nazionale di Statistica*). Every year, national and international references, and personal communications used for the preparation of the agriculture inventory are archived in the *National References Database*.

Improvements for the Agriculture sector are described in the Italian Quality Assurance/Quality Control plan (ISPRA, several years [a]). Moreover, an internal report describes the procedure for preparing the agriculture UNFCCC/CLRTAP national emission inventory and projections (Di Cristofaro, several years).

The national agriculture UNFCCC/CLRTAP emission inventory is used, every 4 years (from 2021; previously it was every 5 years), to prepare a more disaggregated inventory by region and province as requested by CLRTAP. A database with the time series for all sectors and pollutants is available (ISPRA, 2021; ISPRA, several years [b]). The methods and emission factors applied for GHG inventory are also used for emission scenarios and projections (MASE, 2022).

5.1.4 Agricultural statistics

Every year, the Italian National Statistical System (SISTAN[10]) revises the National Statistical Plan that covers three years and includes, among others, the system of agricultural statistics. In this framework, the Agriculture, Forestry and Fishing Quality Panel has been established under the coordination of the agriculture service of ISTAT where the producers and key users of agricultural statistics (mainly public institutions) meet each other every year to monitor and improve national statistics. ISTAT plays the major role in the agricultural sector collecting comprehensive data through different surveys (Greco and Martino, 2001):

- Structural surveys (FSS, survey on economic results of the farm, survey on the production inputs);
- Conjunctural surveys[11] (survey on the cultivation area and relative production, livestock number, milk production, slaughter, fertilizers, etc.);
- General Agricultural Census[12], carried out every 10 years (1990, 2000, 2010, 2020).

Detailed information on the agriculture sector is found every two/three years in the FSS[13] (ISTAT, 2018; ISTAT, 2015; ISTAT, 2008[a]; ISTAT, 2007[a]; ISTAT, 2006[a]). ISTAT has provided quality reports of the FSS 2005 and FSS 2007 (ISTAT, 2008[b]; ISTAT, 2007[d]) and a report on the assessment of the quality of the agricultural census data (ISTAT, 2013). The main agricultural statistics used for the agriculture emission inventory are available on-line. Detailed information is provided in Table 5.4.

[10] SISTAN, *Sistema Statistico Nazionale* (http://www.sistan.it/)
[11] http://agri.istat.it/
[12] http://dati-censimentoagricoltura.istat.it/; https://esploradati.istat.it/databrowser/#/it/censimentoagricoltura
[13] *Indagine sulla struttura e produzione delle aziende agricole (SPA)*, survey carried out every two/three years in agricultural farms.

Table 5.4 Main activity data sources used for the Agriculture emission inventory

Agricultural statistics	Time series	Web site
Livestock number	Table 5.7; 5.8; 5.12; 5.15	http://dati.istat.it/
Milk production	Table 5.7	http://dati.istat.it/
Fertilizers	Table 5.38; 5.45	http://dati.istat.it/
Crops production/surface	Table 5.48; Tables A.7.17-18	http://dati.istat.it/

Differences on some animal populations data are found comparing national statistics and FAOSTAT[14] data. FAO publishes figures of the *x-1* year on 1st January of the *x* year. Each year ISPRA verifies the official statistics directly contacting the experts responsible for each agricultural survey (number of animals, agricultural surface/production, fertilizers, etc). Agricultural statistics reported by ISTAT are also published in the European statistics database[15] (EUROSTAT).

Whenever outliers are identified, these are shown to ISTAT and category associations. Differences in the livestock number are found comparing conjunctural surveys (used for emissions estimation) and the Agricultural census for the year 2020: +5% non-dairy cattle, +3% poultry, -2% buffalo and swine, +12% goats; while equines are almost three times as large. The verification of statistics is part of the implemented QA/QC procedures. The livestock data represents the number of animals present on the farm at any given time of the year (conventionally June the 1st or December the 1st). Therefore, livestock figures do not represent the number of animals produced annually; for animal populations that are alive for only part of a complete year, the annual average population is estimated on the basis of "places" instead of the days of life and the number of cycles.

5.2 Enteric fermentation (3A)

5.2.1 Source category description

Methane is produced as a by-product of enteric fermentation, which is a digestive process where carbohydrates are degraded by microorganisms into simple molecules.

Methane emissions from enteric fermentation are a key category, in terms of level and trend assessment, for Approach 1 and Approach 2. All livestock categories have been estimated except camels and llamas. Methane emissions from poultry and fur animals are not applicable. Emissions from rabbits, mules and asses, goats, buffalo and horses are estimated and included in "Other livestock" as shown in the CRT tables. In 2022, CH_4 emissions from this category were 517.38 Gg which represents 69.5% of CH_4 emissions for the agriculture sector (69.4% in 1990) and 31.7% for national CH_4 emissions excluding LULUCF (31.1% in 1990). Methane emissions from this source consist mainly of cattle emissions: dairy cattle (227.87 Gg) and non-dairy cattle (180.44 Gg). These two sub-categories represented 44.0% (48.1% in 1990) and 34.9% (36.2% in 1990) of total enteric fermentation emissions, respectively.

[14] FAOSTAT http://www.fao.org/faostat/en/#home
[15] http://ec.europa.eu/eurostat/data/database

5.2.2 Methodological issues

Methane emissions from enteric fermentation are estimated by defining an emission factor for each livestock category, which is multiplied by the population of the same category. Data for each livestock category are collected from ISTAT (several years [a], [b], [c], [f], [g]; ISTAT, 1991; 2007[a], [b]). Livestock categories, provided by ISTAT, are classified according to the type of production, slaughter or breeding, and the age of animals. In Table 5.5, livestock categories and source of information are provided. Parameters for the livestock categories are shown in Table 5.31. In order to have a consistent time series, it was necessary to estimate the number of animals for some categories. The estimation is based on information available from other official sources such as FAO and UNAITALIA (FAO, several years; UNAITALIA, several years).

Table 5.5 Activity data for the different livestock categories

Livestock category	Source
Cattle	ISTAT
Buffalo	ISTAT
Sheep	ISTAT
Goats	ISTAT
Horses	ISTAT/FAO(a)
Mules and asses	ISTAT/FAO(a)
Swine	ISTAT
Poultry	ISTAT/UNAITALIA(b)
Rabbits	ISTAT(c)

(a) Reconstruction of a consistent time series; (b) For 1990 data from the census and reconstruction for broilers, hens and other poultry based on meat production (UNAITALIA, several years); (c) For 1990 data from the census and reconstruction based on a production index (ISTAT, 2007[b]; ISTAT, several years [k]).

Dairy cattle

Methane emissions from enteric fermentation for dairy cattle are estimated using a Tier 2 approach, following the 2006 IPCC Guidelines (IPCC, 2006). Feeding characteristics are described in a national publication (CRPA, 2004[a]) and have been discussed in a specific working group in the framework of the MeditAIRaneo project (CRPA, 2006[a]; CRPA, 2005). Parameters used for the calculation of the emission factor are shown in Table 5.6.

Table 5.6 Parameters for the calculation of dairy cattle emission factors from enteric fermentation

Parameter	Value	Reference	IPCC 2006(*)
Average weight (kg)	602.7	CRPA, 2006[a]	600
Coefficient NE_m (lactating cows)	0.386	NRC, 2001; IPCC, 2006	0.386
Pasture (%)	5	CRPA, 2006[a]; ISTAT, 2003	0(**)
Weight gain (kg day^{-1})	0.051	CRPA, 2006[a]; CRPA, 2004[b]	0
Milk fat content (%)	3.59-3.95	ISTAT, several years[a], [b], [d], [e], [h]	
Hours of work per day	0	CRPA, 2006[a]	0
Portion of cows giving birth	0.97-0.92	AIA, several years[a]	0.9
Milk production (kg $head^{-1}$ day^{-1})	11.5-24.6	CRPA, 2006[a]; OSSLATTE/ISMEA, 2003; ISTAT, several years[a], [b], [c], [d], [e], [f], [h]; OSSLATTE, 2001	16.4
Digestibility of feed (%)	68.67	CRPA, 2006[a]; CRPA, 2005; IPCC, 2006	65
Methane conversion factor (%)	5.99	CRPA, 2006[a]; IPCC, 2006	6.5
Energy content of methane (MJ/kg methane)	55.65	IPCC, 2006	55.65

(*) Data for estimating tier 1 enteric fermentation CH_4 emission factors for dairy cows (Western Europe); (**) Stall fed (feeding situation).

The coefficient for calculating net energy for maintenance (NE_m) for dairy cattle is the default value of the 2006 IPCC Guidelines.

The national statistics on milk production were analysed. Milk used for dairy production and milk used for calf feeding contributes to total milk production. The latter was estimated on national and ISTAT publications (ISTAT, several years[h]). For the calculation of milk production (kg head^{-1} d^{-1}), total production is divided by the number of animals and by 365 days, as suggested by the IPCC (IPCC, 2006). Therefore, lactating and non-lactating periods are included in the estimation of the CH_4 dairy cattle EF (CRPA, 2006[a]).

The dairy cattle, reared in the mountain areas (above the 600 meters of altitude) were assigned to pasture for three months a year (MeditAIRaneo project - CRPA, 2006[a]); the percentage of abovementioned animals is equal to 5% of the national total, in line with 2010 General Agricultural Census data.

In Table 5.7, the time series of the dairy cattle population, fat content in milk, portion of cows giving birth and milk production are shown. Further information on parameters used for dairy cattle estimations is reported in Annex 7.1.

According to the 2019 IPCC Refinement (IPCC, 2019), DE e Ym parameters for dairy cows have been estimated considering average annual milk production per cow and per production level (low "<5000 kg/head/year", medium "5000-8500 kg/head/year" and high ">8500 kg/head/year") and information on animal diets. On the basis of data from the Italian Livestock Breeders' Association (AIA) on average annual milk production and the number of dairy cows in production, by region and breed, the distribution of animals was calculated according to the three productivity levels identified by the 2019 IPCC Refinement, for the years 2004-2019. The AIA carries out milk productivity checks on behalf of the Ministry of Agriculture and each year the sample of animals checked is about 50% of the number of animals reared. The difference in cow numbers between the AIA total and the ISTAT total (used for emission estimates) was attributed to the low production level. The DE values assigned to the three production levels (low, medium, high) are 62, 65 and 70.11% of gross energy intake respectively and were identified in collaboration with the CRPA (Research Centre on Animal Production) dairy cow feeding experts. The value 62 is the minimum value of the range indicated in Table 10.12 for low producing cows of the 2019 IPCC Refinement (Chapter 10 of the Volume 4). The value 65 is lower than the average value of the range indicated in Table 10.12 for medium producing cows. The value 70.11 for high-producing cows is a weighted average of two values: the first is 65 (corresponding to diets with DE≥70 and NDF≥35) and was attributed to 27% of the high-producing cows fed without silage fodder; the second is 72 (corresponding to diets with DE≥70 and NDF≤35) and was attributed to 73% (=100-27%) of the high-producing cows fed with silage fodder. With reference to the 27% of cows, this value includes cows whose milk is intended for the production of Parmigiano Reggiano (17% of total cows), and cows fed with good quality dry and green fodder (e.g. for the production of Trentingrana PDO (Protected Designation of Origin), Latte Fieno STG (Traditional Speciality Guaranteed) and other mountain cheeses) which correspond to the other 10% of total cows. In support of the choices made for high productivity values, mention is made of a study published in 2020 (Gislon et al, 2020) carried out on eight Italian Friesian cows in multiparous lactation, with high productivity, using a 4 × 4 replicated Latin square pattern. The experimental design of the square involves all cows receiving all diets (with adaptation periods between each), so 2 groups of 4 cows that rotated 4 times on 4 diets have been considered. The number of observations for each diet is 32. According to CRPA experts, the cow effect is nullified because all of them received all diets and, therefore, the results obtained are irrefutable and highly representative. Four diets, based on the following forages (expressed in % of dry matter of forages, DM, and in the neutral detergent fiber content, NDF, expressed as % of dry matter intake), were tested: corn silage (CS, 49.3; 32.8 NDF), alfalfa silage (AS, 26.8; 27.1 NDF), wheat silage (WS, 20.0; 33.7 NDF), and a typical hay-based Parmigiano Reggiano cheese production diet (PR, 25.3 of both alfalfa and Italian ryegrass hay; 36.7 NDF). The lowest DM digestibility was observed for the PR diet (64.5%) and the highest for the CS diet (73.3%); AS and WS diets showed intermediate values (71.4 and 70.3% respectively). PR diet is associated with diets with DE≥70 and NDF≥35 in Table 10.12 of the 2019 IPCC Refinement (Chapter 10 of the Volume 4) and the other three diets are associated with diets with DE≥70 and NDF≤35 in the same table. For the year 2022, the percentages of dairy cows according to the three productivity levels (low, medium e high milk production) are 10.7%, 11.2% and 78.2%, respectively. The digestibility values associated with these productivity levels are, as previously mentioned, 62% and 70.11%, respectively. With these data, the average digestibility value of the diets consumed by dairy cows was estimated in 68.67%. The weighted average value of Ym for the year 2022 is 5.99% of gross energy intake. This value was estimated from the percentage distribution of dairy cows according to the three productivity levels and using the default factors given in Table 10.12 of the 2019 IPCC Refinement (Chapter 10 of the Volume 4). These values are: for lactating phase, 6.5 for low producing cows, 6.3 for medium producing cows, 6.0 and 5.7 for high producing cows; for dry phase, 7 for low producing cows, 6.3 for medium and high producing cows. From the two values for high producing cows in lactating phase, a weighted average value of 5.78 was estimated, with the distribution of cows according to diet type, shown above: 27% of high-productivity cows are associated with diets with DE≥70 and NDF≥35 (Ym 6.0); 73% of high-productivity cows are associated with diets with DE≥70 and NDF≤35 (Ym 5.7).

In Table 5.14, the dairy cattle emission factors (EF) are reported. In 2022, the CH_4 dairy cattle EF was 139.7 kg CH_4 head^{-1} year^{-1} with an average milk production of 8,973 kg head^{-1} year^{-1} (24.6 kg head^{-1} day^{-1}). The IPCC default EF is 117 kg CH_4 head^{-1} year^{-1} with a milk production of 6,000 kg head^{-1} year^{-1} (IPCC, 2006).

Table 5.7 Parameters used for the estimation of the CH_4 emission factor for dairy cattle

Year	Dairy cattle (head)	Fat content in milk (%)	Portion of cows giving birth	Milk production yield (kg head^{-1} d^{-1})
1990	2,641,755	3.59	0.97	11.5
1995	2,079,783	3.64	0.95	14.8
2000	2,065,000	3.65	0.93	15.1
2005	1,842,004	3.71	0.91	17.2
2010	1,746,140	3.72	0.90	18.8
2015	1,826,484	3.76	0.89	19.1
2019	1,643,117	3.72	0.91	22.9
2020	1,638,382	3.88	0.91	23.7
2021	1,609,948	3.82	0.92	25.0
2022	1,631,128	3.95	0.92	24.6

Non-dairy cattle

For non-dairy cattle, CH_4 emissions from enteric fermentation are estimated with a Tier 2 approach of the 2006 IPCC Guidelines. The estimation of the EF uses country-specific data, disaggregated livestock categories (see Table 5.8), and it is based on dry matter intake (kg head^{-1} day^{-1}) calculated as percentage of live weight as estimated by CRPA in 2022 and described in the Annex 7. Dry matter intake is converted into gross energy (MJ head^{-1} day^{-1}) using 18.45 MJ/kg dry matter conversion factor (IPCC, 2006). Emission factors for each category are calculated with equation 10.21 from 2006 IPCC guidelines (Chapter 10 of the Volume 4).

In Table 5.9, parameters used for the estimation of non-dairy cattle EF are shown. Average weights have been assessed with information from the Nitrogen Balance Inter-regional Project (CRPA, 2006[a]; Regione Emilia Romagna, 2004). For reporting purposes, some animal categories are aggregated, such as the non-dairy cattle and the swine categories. The non-dairy cattle category includes different sub-categories as shown in Table 5.8; consequently, the gross energy intake, CH_4 conversion factor and EFs for this category are calculated as a weighted average.

Table 5.8 Non-dairy cattle population (heads) classified by type of production and age

Year	<1 year		1-2 years males		1-2 years females		>2 years males	>2 years females			
	for slaughter	others	breeding	for slaughter	breeding	for slaughter	all	breeding	for slaughter	others	Total
1990	300,000	2,127,959	72,461	708,329	749,111	186,060	128,958	467,216	57,654	312,649	**5,110,397**
1995	458,936	1,796,034	27,871	783,300	684,881	154,548	155,116	430,564	40,198	657,856	**5,189,304**
2000	408,000	1,783,000	27,521	641,479	736,000	160,000	93,000	500,000	51,000	588,000	**4,988,000**
2005	500,049	1,418,545	26,424	615,921	588,660	181,971	102,081	466,566	37,971	471,733	**4,409,921**
2010	507,452	1,228,696	23,913	557,386	597,733	212,983	70,284	445,370	70,411	372,089	**4,086,317**
2015	492,126	1,141,545	19,966	465,391	638,566	205,966	82,304	524,745	64,570	319,685	**3,954,864**
2019	461,877	1,241,787	22,615	527,137	723,737	256,341	99,095	546,867	99,932	352,442	**4,331,830**
2020	463,597	1,253,974	22,574	526,175	726,873	260,935	101,006	536,547	101,810	361,142	**4,354,633**
2021	450,312	1,214,907	22,025	513,390	706,874	260,270	99,930	552,414	101,821	338,983	**4,260,926**
2022	419,500	1,084,594	22,616	527,155	656,355	253,922	88,891	399,022	77,476	472,077	**4,001,608**

Table 5.9 Main parameters used for non-dairy cattle CH_4 emission factor estimations

	<1 year	1-2 years males		1-2 years females		>2 years males	>2 years females		
Parameters	others (*)	breeding	for slaughter	breeding	for slaughter	all	breeding	for slaughter	others
Average weight (kg)	236	557	557	405	444	700	540	540	557
Percentage weight ingested	2.1	2.0	1.7	3.0	2.0	2.0	2.5	1.7	2.0
Dry matter intake (kg head $^{-1}$ day^{-1})	4.8	11.1	9.5	12.2	8.9	14.0	13.5	9.2	11.1
Gross Energy (MJ head^{-1}day^{-1})	89.4	205.5	174.7	224.2	163.8	258.3	249.1	169.4	205.5
CH_4 conversion (%)	4.16	4.72	4.62	4.63	4.68	4.32	4.54	4.65	4.48

(*) It has been considered that calves for slaughter of <1 year do not emit CH_4 emissions, as they are milk fed. Therefore, the average weight for the category "others" of <1 year considers fattening male cattle, fattening heifer and heifer for replacement.

EFs reflect the national characteristics of Italian breeding as well as the age classification of animals and dry matter intake.

Detailed information on the CH_4 conversion factors for non-dairy cattle category is reported in Annex 7.

In Table 5.14, Implied Emission Factors (IEF) for non-dairy cattle are shown. In 2022, the non-dairy cattle EF was 45.1 kg CH_4 head^{-1} year^{-1}, while the 2006 IPCC Guidelines default EF is 57 kg CH_4 head^{-1} year^{-1} (Chapter 10 of Volume 4). The subcategory of calves (included in 'less than 1 year for the slaughter' category) has not been considered when estimating methane emissions as calves are milk fed. The relevant parameters, for estimating N_2O emissions from manure management, for this category, are the following:

- Average body weight: 157 kg;
- Nitrogen excretion: 14.6 kg N/head/year;
- Average milk period: 4-6 months;
- Average weight at slaughter: less than 300 kg.

As regards the share of grazing animals, the same value used for dairy cattle was assumed for the other females in the category non-dairy cattle and no grazing is assumed for the males (see paragraph *Dairy cattle*).

Buffalo

The 2006 IPCC Tier 2 approach was applied for the buffalo category. Two different country specific CH_4 EFs, for cow buffalo and other buffaloes, were estimated. In 2022, the CH_4 EFs were 87.8 and 61.8 kg CH_4 head^{-1} year^{-1} for cow buffaloes and other buffaloes respectively. The CRT IEF is an average value for the two categories (76.4 kg CH_4 head^{-1} year^{-1}). Parameters used for the Tier 2 approach are shown in Table 5.10 and 5.11.

Table 5.10 Parameters to estimate emission factors from enteric fermentation of cow buffalo

Parameters	Value	Reference
Average body weight (kg)	630	Infascelli, 2003; Consorzio per la tutela del formaggio mozzarella di bufala campana, 2002
Coefficient NEm (lactating cows)	0.386	IPCC, 2006
Pasture (%)	2.90	ISTAT, 2003; Zicarelli, 2001; De Rosa and Di Francia, 2006
Weight gain (kg day^{-1})	0.055	Infascelli, 2003; Consorzio per la tutela del formaggio mozzarella di bufala campana, 2002
Milk fat content (%)	7.73-6.97	ISTAT, several years [a], [b], [d], [e], [h]
Hours of work per day	0	De Rosa and Di Francia, 2006
Proportion of calving cows	0.89-0.84	Barile, 2005; De Rosa and Trabalzi, 2004
Milk production (kg head^{-1} day^{-1})	1.91-3.33	OSSLATTE/ISMEA, 2003; OSSLATTE, 2001; ISTAT, several years [a], [b], [c] [d], [e], [f], [h]
Digestibility of feed (%)	65	Infascelli, 2003; Masucci et al., 1997, 1999
Methane conversion factor (%)	6.5	CRPA, 2006[a]; IPCC, 2006
Energy content of methane (MJ/kg methane)	55.65	IPCC, 2006

The buffalo grazing is very infrequent, equal to 5%, in the provinces of Caserta and Frosinone, where according to the University of Naples experts (MeditAIRaneo project (CRPA, 2006[a]), 58% of national livestock are rised.

Table 5.11 Parameters to estimate emission factors from enteric fermentation of other buffaloes

Parameter	Calves (3 months-1 year)	Sub-adult buffaloes (1-3 years)
Average body weight (kg)	150	405
Dry matter intake (% of body weight head^{-1} day^{-1})	3.0	2.5
Dry matter intake (kg head^{-1} day^{-1})	4.5	10.1
Gross Energy (MJ head^{-1} day^{-1})	82.75	186.58
CH_4 conversion (%)	6.5	6.5
CH_4 emission factor (kg head^{-1} year^{-1})	26.46 (*)	79.54

(*) original CH_4 emission factor was 35.28 kg CH_4 head^{-1} year^{-1}; a correction factor of 9/12 has been applied in order to consider the time between 3 months and 1 year, therefore the final emission factor was 26.46 kg CH_4 head^{-1} year^{-1}.

The coefficient for calculating net energy for maintenance (NE_m) and the methane conversion factor (Ym) for buffalo are the default values of the 2006 IPCC Guidelines.

Sheep

Methane emissions from enteric fermentation for sheep are estimated using a Tier 2 approach, following the 2006 IPCC Guidelines (IPCC, 2006). Gross energy intake was estimated separately for three sub-categories: mature ewes, growing lambs, other mature sheep. Data of mature ewes and other sheep (which includes growing lambs and other mature sheep) are provided by ISTAT (as reported in the 5.1.4 *Agricultural statistics*). Growing lambs and other mature sheep were estimated by applying the percentages of 85% and 15% respectively to the total number of other sheep (CRPA, 2006[a]). In Table 5.12, time series of sheep population are shown.

Table 5.12 Sheep population (heads) classified by sub-categories

Year	Mature ewes (head)	Growing lambs (head)	Other mature sheep (head)
1990	7,492,089	1,060,089	187,075
1995	8,518,496	1,827,054	322,421
2000	8,334,000	2,341,750	413,250
2005	7,007,217	804,908	142,043
2010	7,089,123	689,259	121,634
2015	6,196,466	809,258	142,810
2019	6,086,538	777,191	137,151
2020	6,110,114	785,443	138,608
2021	5,867,151	732,020	129,180
2022	5,939,610	533,746	94,190

The sharp decline between 2000 and 2005 is mainly due to the spreading of Bluetongue infectious disease in 2001. In addition, the sheep number reduction along the whole time-series has been cause by the gradual erosion of profit margins in the production system of Sardinia, the Italian administrative region which holds the largest number of farms rearing sheep. Parameters used for the calculation of the emission factor are shown in Table 5.13.

Table 5.13 Parameters for the calculation of sheep emission factors from enteric fermentation

Parameter	Mature ewes	Growing lambs	Other mature sheep	Reference
Average weight (kg)	51	14	59	CRPA, 2006[a]
Coefficient NE_m	0.217	0.236	0.217-0.250 (1)	IPCC, 2006
Pasture (%) (2)	29	31	33	Estimated data
Weight gain (kg day^{-1}) (3)		0.019		ARA, 2017; Agraria, 2009; AIA, several years[b]
Milk production (kg head^{-1} day^{-1})	0.30-0.38			ISTAT, several years[h], [l], [b]; ISTAT, 2006[a]
Wool production (kg head^{-1} y^{-1})	1.88-1.31			ISTAT, several years[l]
Portion of ewes giving birth	0.93			AIA, several years[c]
Single birth fraction (%)	70.8-74.8			AIA, several years[b]
Double birth fraction (%)	29.2-25.2			AIA, several years[b]
Digestibility of feed (%)	65	75 (4)	65	IPCC, 2006 (5)
Methane conversion factor (%)	6.5	4.5 (4)	6.5	IPCC, 2006 (5)

(1) The value increased by 15% for intact males; (2) Values estimated assuming an average of 11 month on pasture for 8 hours per day; (3) Assumptions made: sex ratio 40% males and 60% females; weight at weaning (30 days) 10 kg; weight at slaughter (90 days) 18 kg for males and 17 kg for females; (4) diets based on forage and concentrates (LAORE, 2014); (5) see Table 10.2 and 10.13 of the 2006 IPCC Guidelines.

In the CRT tables, the weighted average values of parameters reported in Table 5.13 were considered for sheep category.

Considering DE parameter, Italy uses the average default value of Table 10.2 of the 2006 IPCC Guidelines, relating to the ruminant categories and class 'pasture fed animals'. DE parameter is accompanied by a general description of the type of diets corresponding to the default values indicated. A literature review on dairy sheep feeding (Molle et al., 2008) and an available database on fresh forages and supplement composition commonly used for feeding sheep (Molle and Cannas, 2015) show that sheep diet digestibility (on dry matter basis) averages 70% in adult ewes during lactation (6-4 months) when they are usually fed at pasture and receive concentrate and hay as supplements. In contrast, diet digestibility as low as 60% (FU[16] 0.5-0.7/ kg dry matter) is common in mature ewes fed standing-hay or hay with a low amount of concentrate during dry period (8-6 months). These data support the use of the median level of diet digestibility (65%) shown in Table 10.2 and 10.13 of the 2006 IPCC Guidelines.

Rabbits

Methane emissions from rabbits have been estimated using a country-specific EF suggested by the CRPA. Daily dry matter intake for brood-rabbits and other rabbits are 0.13 kg day^{-1} and 0.11 kg day^{-1}, respectively. Besides, a value of 0.6% has been assumed as CH_4 conversion rate (CRPA, 2004[c]).

Other livestock categories

A Tier 1 approach, with IPCC default EFs, is used to estimate CH_4 emissions from swine, goats, horses, mules and asses (IPCC, 2006). In Table 5.14, EFs for all livestock categories (dairy cattle, non-dairy cattle, buffalo, swine, sheep, goats, horses, mules and asses and rabbits) are presented. In Table 5.15, time series of the number of animals are shown.

Table 5.14 Average CH_4 emission factors for enteric fermentation (kg CH_4 head^{-1} year^{-1})

Year	Dairy cattle	Non-dairy cattle	Buffalo	Sheep	Goats	Horses	Mules and asses	Sows	Other swine	Rabbits
	average CH_4 EF (kg CH_4 head^{-1} year^{-1})									
1990	111.1	43.2	74.4	7.2	5.0	18.0	10.0	1.5	1.5	0.08
1995	123.6	43.7	75.8	7.0	5.0	18.0	10.0	1.5	1.5	0.08
2000	124.6	43.9	78.2	6.5	5.0	18.0	10.0	1.5	1.5	0.08
2005	122.5	43.1	84.6	7.4	5.0	18.0	10.0	1.5	1.5	0.08
2010	122.6	43.0	76.7	7.4	5.0	18.0	10.0	1.5	1.5	0.08
2015	124.8	44.0	77.2	7.3	5.0	18.0	10.0	1.5	1.5	0.08
2019	131.9	44.9	76.2	7.5	5.0	18.0	10.0	1.5	1.5	0.08
2020	135.7	44.8	76.6	7.5	5.0	18.0	10.0	1.5	1.5	0.08
2021	139.5	45.0	76.6	7.6	5.0	18.0	10.0	1.5	1.5	0.08
2022	139.7	45.1	76.4	7.7	5.0	18.0	10.0	1.5	1.5	0.08

Table 5.15 Time series of number of animals from 1990 to 2022 (heads)

Year	Buffalo	Sheep	Goats	Horses	Mules and asses	Sows	Other swine	Rabbits	Poultry
					heads				
1990	94,500	8,739,253	1,258,962	287,847	83,853	650,919	7,755,602	14,893,771	173,341,562
1995	148,404	10,667,971	1,372,937	314,778	37,844	689,846	7,370,830	17,110,587	184,202,416
2000	192,000	11,089,000	1,375,000	280,000	33,000	708,000	7,599,000	17,873,993	176,722,211
2005	205,093	7,954,167	945,895	278,471	30,254	721,843	8,478,427	20,504,282	174,667,361
2010	365,086	7,900,016	982,918	373,324	46,475	717,366	8,603,753	17,957,421	175,912,339
2015	374,458	7,148,534	961,676	384,767	70,872	582,447	8,092,346	15,760,502	177,391,671
2019	402,286	7,000,880	1,058,720	367,561	72,455	556,009	7,954,259	11,755,922	175,520,313

[16] Feed unit is the net energy contained in one kg of barley = 1760 kcal

Year	Buffalo	Sheep	Goats	Horses	Mules and asses	Sows	Other swine	Rabbits	Poultry
2020	407,027	7,034,164	1,065,712	367,561	72,455	568,550	7,974,479	11,010,203	178,906,532
2021	409,408	6,728,351	1,060,748	367,561	72,455	550,991	7,856,977	10,945,940	178,243,638
2022	416,053	6,567,546	1,010,143	365,414	75,978	692,714	8,046,670	12,674,189	165,277,922

5.2.3 Uncertainty and time-series consistency

Uncertainty related to CH_4 emissions from enteric fermentation was 20.2% for annual emissions, resulting from the combination of 3% of uncertainty for activity data and 20% for emission factors.

In 2022, CH_4 emissions from enteric fermentation were 517.38 Gg, i.e., 15.2% lower than in 1990 (610.46 Gg). Between 1990 and 2022 cattle livestock has decreased by 27.3% (from 7,752,152 to 5,632,736 heads). Dairy cattle and non-dairy cattle have decreased by 38.3% (from 2,641,755 to 1,631,128) and 21.7% (from 5,110,397 to 4,001,608), respectively. The reduction in number of cattle is the main driver for the reduction in CH_4 emissions, particularly as emissions per head from cattle are more than 10 times greater than those of sheep or goat. In 2022, cattle contribute with 78.9% to total CH_4 emissions from enteric fermentation. In Table 5.16, emission trends from the enteric fermentation category are shown. Emissions from swine (13.11 Gg) are disaggregated in 'other swine' and 'sow'.

Table 5.16 Trend of CH_4 emissions from enteric fermentation (Gg)

Year	Dairy cattle	Non-dairy cattle	Buffalo	Sheep	Goats	Horses	Mules and asses	Sows	Other swine	Rabbits	Total
1990	293.57	220.88	7.03	62.89	6.29	5.18	0.84	0.98	11.63	1.16	**610.46**
1995	256.99	226.59	11.25	75.17	6.86	5.67	0.38	1.03	11.06	1.33	**596.32**
2000	257.36	218.97	15.02	72.18	6.88	5.04	0.33	1.06	11.40	1.39	**589.62**
2005	225.58	190.23	17.36	58.69	4.73	5.01	0.30	1.08	12.72	1.59	**517.29**
2010	214.02	175.66	28.02	58.39	4.91	6.72	0.46	1.08	12.91	1.39	**503.56**
2015	227.92	173.88	28.90	52.34	4.81	6.93	0.71	0.87	12.14	1.22	**509.71**
2019	216.67	194.44	30.67	52.75	5.29	6.62	0.72	0.83	11.93	0.91	**520.84**
2020	222.29	195.06	31.16	52.68	5.33	6.62	0.72	0.85	11.96	0.86	**527.53**
2021	224.66	191.82	31.38	50.87	5.30	6.62	0.72	0.83	11.79	0.85	**524.84**
2022	227.87	180.44	31.79	50.79	5.05	6.58	0.76	1.04	12.07	0.98	**517.38**

5.2.4 Source-specific QA/QC and verification

Information related to the Agricultural census has been analysed and verified, as mentioned in paragraph 5.1.4.

Information and administrative data related to number of heads, average weight by livestock category, milk production data are collected by the Ministry of Agriculture as part of the 2016 December the 9th Decree of Ministry for the Environment, Land and Sea enteteled "*Attuazione della legge 3 maggio n. 79 in materia di ratifica ed esecuzione dell'Emendamento di Doha al Protocollo di Kyoto*" (GU, 2016[b]) and comparisons and verifications were made with the data used to estimate emissions.

5.2.5 Source-specific recalculations

The recalculation for 2021 is due to the corrected average weight for cattle less than one-year for 2021.

5.2.6 Source-specific planned improvements

Additional data and information will be collected to improve the estimation of methane emissions from sheep, in particular for the DE parameter for mature ewes and other mature sheep, as recommended during the 2019 UNFCCC review. Actually, Italy uses the average default value of Table 10.2 of the 2006 IPCC Guidelines, relating to the ruminant categories and class 'pasture fed animals' and which is accompanied by a general description of the type of diets corresponding to the default values indicated. In the 2006 IPCC Guidelines (Chapter 10 of Volume 4), the data reported in Table 10A-9 (where there is no description of the data reported) do not fit with those of Table 10.2 probably because the Table 10A-9 was affected by a typo error (0.6% instead of 60%). This table has been removed from the 2019 IPCC Refinement. The data used have been confirmed by experts in the sheep sector of AGRIS Sardegna, the agency of the Region of Sardinia for scientific research, experimentation and technological innovation in the agricultural, agro-industrial and forestry sectors.

5.3 Manure management (3B)

5.3.1 Source category description

In 2022, CH_4 emissions from manure management were 171.12 Gg, which represents 23.0% of CH_4 emissions for the agriculture sector (22.0% in 1990) and 10.5% of national CH_4 emissions (9.9% in 1990). CH_4 emissions from cattle were 84.86 Gg and from swine were 71.13 Gg. These two sub-categories represented 49.6% and 41.6% of total CH_4 manure management emissions, respectively. CH_4 emissions from manure management also include emissions from ostriches and emissions from pasture of cattle and buffalo categories, as recommended during 2019 UNFCCC review.

N_2O direct and indirect emissions, produced during the storage and treatment of manure before it is applied to soils, are reported separately. In 2022, N_2O emissions from manure management were 6.50 Gg (of which 4.08 Gg are direct emissions and 2.41 Gg are indirect emissions), which represents 17.8% of total N_2O emissions for the agriculture sector (19.7% in 1990) and 10.9% of national N_2O emissions (10.3% in 1990). In 2022, direct N_2O emissions from manure management consist of the solid storage system (1.97 Gg), which also includes the chicken-dung drying process system, and of liquid system (2.11 Gg). N_2O emissions of the anaerobic digesters, another management system used in the country, are reported equal to zero in line with the 2006 IPCC Guidelines (IPCC, 2006).

In the framework of the Nitrogen Balance Inter-regional Project, parameters related to the estimation of CH_4 and N_2O emissions, such as average weight, production of slurry and solid manure and the nitrogen excretion rates, have been set.

CH_4 emissions and direct N_2O emissions from manure management are key sources at level, following Approach 1 and Approach 2, excluding. Including the LULUCF sector in the analysis, CH_4 emissions from manure management are also key sources at trend following Approach 1 and 2.

5.3.2 Methodological issues

The IPCC Tier 2 approach is used for estimating methane EFs for manure management of cattle, buffalo and swine. For estimating slurry and solid manure EFs and the specific conversion factors, a detailed methodology (*Method 1*) was applied at a regional level for cattle and buffalo categories. Then, a simplified methodology, for estimating EF time series, was followed (*Method 2*). Livestock population activity data is collected from ISTAT (see Table 5.7; Table 5.8; Table 5.15).

Methane emissions (cattle and buffalo)

Method 1: Regional basis

Methane emission estimations for manure management are drawn up on a regional basis and depend on specific manure management practices and environmental conditions (Safley *et al.*, 1992; Steed and Hashimoto, 1995; Husted, 1993; Husted, 1994). The following factors are used: average monthly temperatures (ISPRA, 2020), amount of slurry and solid manure produced per livestock category (CRPA, 2018; CRPA, 2006[a]; Regione Emilia Romagna, 2004), storage temperatures and timescale for emptying manure storages for the application of slurry and solid manure to soils for agricultural purposes in Italy (CRPA, 1993).

For cattle and buffalo, the estimation of the EF starts with the calculation of the *methane emission rate* (g CH_4 m^{-3} day^{-1}), which is obtained from equations 5.1 and 5.2 reported below for slurry and solid manure respectively.

For the quantification of emissions from storage of cattle manure, the methodology adopted is based on the studies conducted by Husted. The Husted methodology allows estimating methane based on the parameters defining the manure storage in Italy. These parameters, which are mentioned in the introduction of this section, are average monthly temperatures, amount of slurry and solid manure produced per livestock category, storage temperatures and timescale for emptying manure storages. This method was adopted as it is based on experimental surveys carried out in the field, in environmental and breeding conditions that are transferable to the Italian reality with appropriate adaptations. This methodology allows to modulate the mass of methane emitted in relation to changes in temperature on a monthly basis. The average annual temperature represents an approximate datum for the elaboration of the methane emission estimates, since the same average annual value can correspond to more or less wide temperature excursions between the months (Steed and Hashimoto, 1995). This is followed by different methane emissions from manure storage depending on the number of months for which the 10°C threshold is exceeded, below which emissions are considered negligible. According to the methodology adopted, the mass of methane is calculated based on two parameters, one of which is measured experimentally in field conditions (emission per unit volume of manure in relation to temperature) and the other estimated (the amount of slurry and solid manure produced and stored).

Average monthly temperature data were updated based on SCIA[17] data. SCIA made available the climatic normal temperature values for the 30-year climatological periods 1971-2000, 1981-2010 and 1991-2020 in raster format. Using GIS software, the raster data were converted into points and intersected with the shape of the municipal boundaries to which altitude and LU data (i.e., data on the number of animals reared at municipal level, expressed in livestock unit, where 1 LU=one adult dairy cow) were also associated. Average data of 1971-2000 climatological period were considered to estimate the emissions in the first decade of the time series (1990-2000), while average data of 1981-2010 climatological period were considered to estimate the emissions for the period 2001-2010 and average data of 1991-2020 climatological period were considered to estimate the emissions from 2011 onward. Temperature data above 1000 m were not considered. National average monthly temperature data (obtained by weighing provincial average monthly temperature data with LUs) were used to update methane emissions from storage, according to the country-specific methodology. This update resulted in a revision of the CH_4 estimate from manure management for cattle and buffalo categories. Temperature data, aggregated per province by weighting with LUs, were used to recalculate MCF.

Equations are presented below (CRPA, 2006[a]; Husted, 1994).

17 SCIA is the national system for the collection, elaboration and dissemination of climatological data, by ISPRA, in the framework of the national environmental information system, in collaboration with the relevant institutions: http://www.scia.isprambiente.it/wwwrootscia/Home_new_eng.html

For slurry:

CH_4 (g m^{-3} day^{-1}) = $e^{(0.68+0.12) * t (°C) \text{ (average monthly temperature)}}$ *Eq. 5.1*

For solid manure:

CH_4 (g m^{-3} day^{-1}) = $e^{(-2.3+0.1) * t (°C) \text{ (average monthly storage temperature)}}$ *Eq. 5.2*

The monthly storage temperature from the solid manure is estimated with the following equation (Husted, 1994):

T solid manure storage = $6{,}7086e^{0.1014t (°C) \text{ (average monthly temperature)}}$

For temperatures below 10°C emissions are considered negligible.

The volume of slurry and solid manure produced per livestock category (m^3 $head^{-1}$) was obtained by multiplying the average production of slurry and solid manure per livestock category per day (m^3 $head^{-1}$ day^{-1}) by the days of storage of slurry and solid manure. The volume of slurry and solid stored manure is based on regional regulations concerning the spreading of manure on agricultural land. Information about days of storage considers the retention time in storage facilities and temporal dynamics of storage and application on soils of slurry and manure (CRPA, 1997[a]). The production of solid manure and slurry were estimated assuming a distribution of housing systems in Italy. The distribution of housing for dairy cattle has been assessed on the basis of a 1998 CRPA survey carried out in Lombardy, Emilia Romagna and center of Italy, and on the basis of ISTAT statistics of 2003 (CRPA, 2006[a]; Bonazzi *et al*., 2005; APAT, 2004[a]; APAT, 2004[b]) for the period 1990-2005; from 2010 onward, the housing systems distribution has been deduced by the results of the 2010 Agricultural Census. Between 2005 and 2010 a gradual transition to the updated distribution of housing systems has been assumed for the intermediate years, taking in account the gradual penetration of systems to ensure animal welfare. For non-dairy cattle and buffalo categories data on distribution of housing systems derive from national studies and expert judgment (CRPA, 2006[a]).

By multiplying the *methane emission rates* (obtained from equations 5.1 and 5.2) with the volume of slurry and solid stored manure, the methane emissions were calculated.

The next step is to estimate the volatile solid (VS) production, calculated by multiplying the average production of slurry and solid manure (previously converted from volume to weight: slurry and solid manure values expressed in volume were multiplied by 1 t/m^3 and 0.75 t/m^3, respectively, to obtain the values in mass unit) by the factors proposed by Husted: 47.5 g VS/kg (slurry) and 142.7 g VS/kg (solid manure) (Husted, 1994; CRPA, 2006[a]). These values are very close to those obtained from a survey carried out by the CRPA on the characteristics of zootechnical manure in different types of breeding, equal to 48.21 g VS/kg (slurry) and 128.31 g VS/kg (solid manure). This survey allowed a collection of national data relating to solid and liquid manure of dairy cows for different types of housing. This collection of samples made it possible to quantify the production of manure, the total solids and the volatile solids (APAT, 2004[a]).

Finally, the *specific conversion factors* for slurry and solid manure are calculated as the ratio between methane emissions and VS production. These *specific conversion factors* are used for the simplified methodology (*Method 2*). The *specific conversion factor* values for slurry are 17.25, 18.12 and 19.24 g CH_4/kg VS for the period 1990-2000, 2001-2010 and from 2011 onward, respectively; and for solid manure are 8.11, 9.28 and 10.68 g CH_4/kg VS for the period 1990-2000, 2001-2010 and from 2011 onward, respectively.

Method 2: National basis

A simplified methodology (*Method 2*) for estimating methane EFs from manure management was used for the whole time series. Slurry and solid manure EFs (kg CH_4 $head^{-1}$ $year^{-1}$) were calculated with

Equations 5.3 and 5.4, respectively. These equations include the *specific conversion factors* and the production of VS (kg head^{-1}day^{-1}), estimated with the slurry and solid manure production and the Husted factors (Husted, 1994; CRPA, 2006[a]): 47.5 g VS/kg (slurry) and 142.7 g VS/kg (solid manure).

The daily VS excreted, estimated for slurry and solid manure, are summed and used for calculating the methane producing potential (Bo).

In Table 5.17, EF estimations are shown.

EF slurry (for the period 1990-2000) = 17.25 g CH_4/kg VS • VS production slurry (kg VS head-1 day-1) • 365 days Eq. 5.3(a)

EF slurry (for the period 2001-2010) = 18.12 g CH_4/kg VS • VS production slurry (kg VS head-1 day-1) • 365 days Eq. 5.3(b)

EF slurry (for the period since 2011) = 19.24 g CH_4/kg VS • VS production slurry (kg VS head-1 day-1) • 365 days Eq. 5.3(c)

EF solid manure (for the period 1990-2000) = 8.11 g CH_4/kg VS • VS production solid manure (kg VS head-1 day-1) • 365 days Eq. 5.4(a)

EF solid manure (for the period 2001-2010) = 9.28 g CH_4/kg VS • VS production solid manure (kg VS head-1 day-1) • 365 days Eq. 5.4(b)

EF solid manure (for the period since 2011) = 10.68 g CH_4/kg VS • VS production solid manure (kg VS head-1 day-1) • 365 days Eq. 5.4(c)

Table 5.17 Methane manure management EFs for cattle and buffalo in 2022 (kg CH_4 head^{-1} yr^{-1})

Livestock category	Slurry (kg CH_4 head^{-1} yr^{-1})	Solid manure (kg CH_4 head^{-1} yr^{-1})	CH_4 manure management EF (kg CH_4 head^{-1} yr^{-1})
Calf	7.89	0.00	**7.89**
Male cattle	6.71	6.47	**13.18**
Female cattle	3.23	7.04	**10.27**
Other non-dairy cattle (*)	3.88	11.67	**15.55**
Dairy cattle	10.17	14.70	**24.87**
Cow buffalo	6.28	13.99	**20.27**
Other buffaloes	3.41	6.36	**9.77**

(*) Suckling cows and cows in late career (average weight 557 kg).

The sub-category 'Other non-dairy cattle' includes suckling cows (cows farmed for feeding of calves, whose milk is not normally intended for human consumption) and cows in late career defined as cows after the last lactation, no longer productive that will be slaughtered. Dairy cows in late career but still productive are included in dairy cattle category.

The average production of slurry and solid manure per livestock category per day (m^3 head^{-1} day^{-1}) has been set with results from the Nitrogen Balance Inter-regional Project (Regione Emilia Romagna, 2004). The updating on manure production for cattle and buffalo, based on Ministerial Decree of 25 February 2016 on criteria and general technical standards for the regional regulation of the agronomic use of farmed effluents and wastewater, as well as for the production and agronomic use of digestate (GU, 2016[a]), has been done. Based on the type and housing systems distribution for the different animal categories, and on the average weight of animals, a time series of slurry and solid manure production was obtained. The manure production data (liquid/slurry and solid) from the 2016 Ministerial Decree were used for the cattle and buffalo categories from 2016 onward and a gradual change from 2006 to 2016 production factors was calculated over the period from 2007 to 2015.

In Table 5.18 the disaggregated manure management EFs for cattle and buffalo are shown. In Table 5.24 the average EFs of main categories (dairy, non-dairy, buffalo and swine) are reported.

Table 5.18 Methane manure management EFs for cattle and buffalo (kg CH_4 head^{-1} yr^{-1})

Year	Calf	Male cattle	Female cattle	Other non dairy cattle (*)	Dairy cattle	Cow buffalo	Other buffaloes
	(kg CH_4 head^{-1} yr^{-1})						
1990	7.07	11.08	9.81	15.85	22.38	23.61	9.32
1995	7.07	11.70	9.82	15.85	22.38	23.45	9.26
2000	7.07	11.29	9.95	15.85	22.38	23.29	9.19
2005	7.43	12.92	11.31	17.71	25.01	25.94	10.11
2010	7.43	12.48	10.51	16.15	25.09	22.80	9.56
2015	7.89	12.93	10.71	15.99	25.39	21.18	9.92
2019	7.89	12.97	10.43	15.55	24.87	20.27	9.77
2020	7.89	12.98	10.40	15.55	24.87	20.27	9.77
2021	7.89	13.00	10.47	15.55	24.87	20.27	9.77
2022	7.89	13.18	10.27	15.55	24.87	20.27	9.77

(*) Suckling cows and cows in late career (average weight 557 kg).

In Table A.7.12-14 in Annex 7, all data, parameters and equations used to estimate CH_4 emission from manure management for cattle and buffalo are reported. These data are: the average monthly temperature; storage temperatures and timescale for emptying manure storages; the amount of manure generated by each subcategory of cattle and buffalo (m^3/head day^{-1}); the *methane emission rates* (g CH_4/m^3 day^{-1}) calculated on the basis of the equations 5.1 and 5.2; the specific conversion factors (g CH_4/kg VS); the content of VS in manure (g VS/head day^{-1}) produced by different subcategories of cattle (dairy and non-dairy cattle) and buffalo (cow buffaloes and other buffaloes); the slurry and solid manure EFs (kg CH_4/head year^{-1}) calculated with Equations 5.3 and 5.4 respectively; the total (slurry and solid manure) amount of VS handled in slurry/liquid and solid manure management systems for the entire reporting period; the total (slurry and solid manure) CH_4 emission factors.

CH_4 emissions from manure management category (3B) also include emissions from the biogas production.

A national census on biogas production/technology/installed power/organic matrix used is available in CRPA and CRPA/AIEL (CRPA, 2013; CRPA, 2011; ENAMA, 2011; CRPA, 2008[a]; CRPA/AIEL 2008). Biogas production data are collected annually by the National Electric Network (TERNA, several years). Emissions of methane, from biogas produced by anaerobic digesters fed with animal manure, to be deducted to the total amount of methane from manure management, were calculated using the information and data provided by TERNA and CRPA. For further information on the country-specific methodology used see Annex 7.2.

On the basis of the study for the evaluation of the effects on emissions of livestock management practices carried out by CRPA (CRPA, 2018), the percentages of the different substrates feeding the anaerobic digesters and data on the average content of volatile solids by type of substrates have been changed resulting in a decrease of the estimated amount of manure feeding anaerobic digesters. For the year 2022 this amount is equal to about 16 million of tons and that is 46% of the total amount of feed treated in anaerobic digesters. Emissions from plant biogas losses, fueled by manure, energy crops and agro-industrial by-products, are greater than avoided emissions due to biogas recovery (for cattle until 2011). This is due to the estimated amount of manure that feeds the digesters, which is low compared to other substrates. Therefore, increases in CH_4 emissions related to biogas recovery are assumed for cattle until 2011 according to the methodology described in Annex 7.2 (see paragraph *CH_4 emissions to be subtracted*).

In 2022, the CRT IEFs, for dairy cattle and non-dairy cattle, were 24.57 kg CH_4 head^{-1} year^{-1} and 11.19 kg CH_4 head^{-1} year^{-1}, respectively. IPCC default EFs of cool temperature are 29 kg CH_4 head^{-1}year^{-1} and 8 kg CH_4 head^{-1}year^{-1} for dairy cattle and non-dairy cattle, respectively (IPCC, 2006). The IPCC default EFs of cool temperate are considered as the estimate of the national average temperature is 14.8 °C calculated from SCIA data of 1991-2020 climatological period.

The IEF for non-dairy cattle and buffalo represents a weighted average. The non-dairy cattle IEF includes: calves, male cattle, female cattle and other non-dairy cattle. The buffalo category includes: cow buffalo and other buffaloes categories. In Table 5.19, EFs and IEFs are shown. Differences, as mentioned before, are related to the amount of CH_4 reductions from biogas recovery and IEFs include also CH_4 emissions from pasture. In Table 5.19, the default EFs of the IPCC 2006 Guidelines are also reported.

Table 5.19 CH_4 EFs, IEF and default EF for cattle and buffalo (kg CH_4 head^{-1} yr^{-1})

Livestock category	EF (*) (kg CH_4 head^{-1} yr^{-1})	IEF (**) (kg CH_4 head^{-1} y^{r-1})	IPCC 2006 default EF (kg CH_4 head^{-1} yr^{-1})
Dairy cattle	24.87	24.57	29
Non-dairy cattle	11.36	11.19	8
Buffalo	15.67	15.73	5

(*) Data do not include EFs for pasture; (**) IEF as reported in the CRF submission 2024.

Emissions from the biogas combustion for energy production are estimated and reported in the energy sector in the 1.A.4.c category, agriculture, forestry and fisheries, biomass fuel.

Detailed information on the estimate of weighted average values of CH_4 producing potential (Bo) and methane conversion factor (MCF) is provided below.

The methodology used, based on Husted studies, do not require the estimate of Bo. Therefore, the factor is estimated with 2006 IPCC Guidelines Equation 10.23 (Chapter 10 of Volume 4) and using country specific EFs and VS by livestock category described above and the average value of MCF by livestock category.

The 2006 IPCC MCF values by temperature for manure management systems (solid storage, pasture, liquid/slurry system) are used. In particular for liquid/slurry system, at first, the values of MCF at the provincial level were calculated based on the 2006 IPCC MCFs, by temperature, on the basis of the average provincial temperatures (i.e., the average temperature at provincial level was calculated by weighing the temperature at municipal level data with the percentage of animals at provincial level). Subsequently, the MCF national average values by livestock category for climate zone (considering cool (<15°C) and temperate (≥ 15°C) climate zone) were calculated as the average of the provincial MCF values weighed with the animals distributed by province for climatic zone. In relation to the climatic zones of the country and the average temperatures, see also the paragraph *Other livestock categories* below. The number of animals at provincial level come from the Agriculture Census from 1990, 2000 and 2010, and from the FSS for 2005 (ISTAT, 2007[a]), 2007 (ISTAT, 2008[a]), 2013 and 2016[18].

Information on the estimation process of the weighted average values of MCF for animal manure digested in anaerobic digesters are reported in Annex 7.2. Average MCFs were not used for estimating manure management EF, but they are useful to verify the EF accuracy.

In Table 5.20, estimated country-specific VS and Bo parameters, and IPCC default values are shown (IPCC, 2006). Differences are mainly attributed to country-specific characteristics.

[18] http://dati.istat.it/?lang=en&SubSessionId=cead0f83-139d-4121-9178-e7de3f81675f

Table 5.20 VS and Bo parameters for cattle, buffalo and swine

Livestock category	VS country-specific (*) (kg dm head^{-1} day^{-1})	VS IPCC default (kg dm head^{-1} day^{-1})	B_o country-specific (*) (CH_4 m^3/kg VS)	Bo IPCC default (CH_4 m^3/kg VS)
Dairy cattle	5.22	5.10	0.24	0.24
Non-dairy cattle	2.38	2.60	0.26	0.18
Buffalo	3.45	3.90	0.18	0.10
Swine	0.33	0.31(**)	0.40	0.45

(*) as reported in the CRF submission 2024; (**) weighted average with the number of heads of sows and other swine categories.

As recommended during 2019 UNFCCC review, the VS for cattle and buffalo are calculated also using equation 10.24 of the 2006 IPCC Guidelines (Chapter 10 of Volume 4). The results are: for dairy cattle 5.07 kg dm/head/day in 1990 and 6.26 kg dm/head/day in 2022; for non-dairy cattle 2.86 kg dm/head/day in 1990 and 2.96 kg dm/head/day in 2022; for buffalo 3.44 kg dm/head/day in 1990 and 3.54 kg dm/head/day in 2022.

For dairy cows, VS from manure are affected by the variation over the years of the housing systems, which affect the production of manure; the equation 10.24 of the 2006 IPCC Guidelines does not allow for this important parameter to be considered when estimating methane emissions from storage. For non-dairy cattle category, the enteric VS was calculating assuming DE equal to 65%, but this value should be higher given the Ym values estimated using Ellis' formula, as described in Section 5.2.2 Methodological issues (Non-dairy cattle).

As regard the contribution of straw, the methodology used, based on Husted studies, does not require a control on the straw used. As reported in the MeditAIRaneo project, the VS produced in slurry/liquid and solid animal manure were elaborated using Husted data, i.e., 47.5 gVS/kg of slurry and 142.7 gVS/kg of solid manure (Husted, 1994; CRPA, 2006[a]). As reported in Husted (Husted, 1994), cattle slurry does not contain bedding material and cattle solid manure consisted mainly of faeces and a minor fraction of bedding material. Finally, as reported in the 2006 IPCC Guidelines, since the bedding materials typically are associated with solid storage systems, their contribution would not add significantly to overall methane production. However, the amount of straw used as bedding was estimated and the cross-check of amounts of bedding material contained in the manure used to estimate CH_4 emissions and N_2O emissions from animal manure applied to agricultural soils has been done, as recommended by the 2019 UNFCCC review. The amount of straw used as bedding that ends up on agricultural land during the spreading of manure was estimated considering the amount of straw per day (per tonnes of live weight, per type of housing, for cattle and buffalo), contained in the Ministerial Decree of 25 February 2016 on the use of zootechnical effluents, combined with the manure production coefficients used in the estimation of CH_4 emissions from storage. The nitrogen content was considered and was added to the nitrogen input from manure applied to soils for N_2O emissions estimate. Data for cattle were updated, while data for buffaloes, previously missing, were included. Data have been updated since 1990. Further information and data can be found in paragraph 5.5.2 (Direct N_2O emissions from F_{AM}) and in the Annex 7.3.

In the calculation of CH_4 EFs, for cattle and buffalo categories, the MCF value for both cool and temperate climate conditions was considered in the estimate in line with equation 10.23 of the 2006 IPCC Guidelines (Chapter 10 of Volume 4). In Table 5.21 the disaggregated manure management EFs from pasture of cattle and buffalo are shown.

Table 5.21 CH_4 EFs from pasture for cattle and buffalo (kg CH_4 head^{-1} yr^{-1})

Year	Calf	Male cattle	Female cattle	Other non-dairy cattle (*)	Dairy cattle	Cow buffalo	Other buffaloes
	(kg CH_4 head^{-1} yr^{-1})						
1990	0.019	0.029	0.026	0.042	0.164	0.128	0.050

Year	Calf	Male cattle	Female cattle	Other non-dairy cattle (*)	Dairy cattle	Cow buffalo	Other buffaloes
	(kg CH_4 head^{-1} yr^{-1})						
1995	0.020	0.033	0.028	0.045	0.164	0.123	0.048
2000	0.023	0.036	0.032	0.050	0.164	0.118	0.047
2005	0.022	0.038	0.034	0.053	0.182	0.128	0.050
2010	0.023	0.039	0.033	0.050	0.145	0.106	0.045
2015	0.030	0.049	0.040	0.060	0.155	0.086	0.040
2019	0.030	0.050	0.040	0.060	0.158	0.081	0.039
2020	0.032	0.052	0.042	0.063	0.168	0.081	0.039
2021	0.033	0.054	0.043	0.064	0.170	0.081	0.039
2022	0.031	0.053	0.041	0.062	0.171	0.081	0.039

(*) Suckling cows and cows in late career (average weight 557 kg).

Methane emissions (swine)

For the estimation of CH_4 emissions for swine, a country-specific *methane emission rate* was experimentally determined by the Research Centre on Animal Production (CRPA, 1996). The estimation of the EF considers: the storage systems for slurry (tank and lagoons), type of breeding and production of biogas.

Different parameters were considered, such as the livestock population, average weight for fattening swine and sows, and *methane emission rate*. Methane emission rates used are 41 normal litres CH_4/100 kg live weight/day for fattening swine, and 47 normal litres CH_4/100 kg live weight/day for sows including piglets (CRPA, 2006[a]). These data were based on experimental measurements on covered storage systems.

The shares of covered/uncovered storage systems are equal to 4% and 96% (CRPA, 2006[b]), respectively; the CH_4 emission rates used for uncovered storage systems were: 37.6 normal litre CH_4/100 kg live weight/day for fattening swine and 43.1 normal litre CH_4/100 kg live weight/day for sows, including piglets. These figures have been estimated on the basis of data provided by CRPA on methane emission rates from covered and total storages (CRPA, 1997 [a]; CRPA, 2006[a]; CRPA, 2006[b]).

The uncovered systems are emitting less than the covered ones since the temperatures are lower. According to the information on the storage systems collected by the 2010 Agriculture Census, the shares of covered/uncovered storage systems are equal to 11% and 89%, respectively; the shares of covered/uncovered storage systems are equal to 25% and 75%, respectively, taking into account the outcomes of the 2013 FSS ISTAT survey.

Characteristics of swine breeding and EFs are shown in Table 5.22; the emission factors reflect the share of covered/uncovered storage systems. The slurry production considered the different swine categories (classified by weight and housing characteristics); the average weight of sows, the production of slurry (t year^{-1} per t live weight) and the volatile solid content in the slurry (g SV/kg slurry w.b.) have been set based on 598 measurements carried out by CRPA (CRPA, 1996; CRPA, 2006[a]).

In 2022, the EF from sow was 22.80 kg CH_4 head^{-1}year^{-1}, and for the other swine category was 8.92 kg CH_4 head^{-1} year^{-1} (average swine EF is 8.30 kg CH_4 head^{-1}year^{-1}). In Table 5.24 the time series of EFs for the swine category (sow and other swine) are shown. The CRF IEF reported is 8.14 kg CH_4 head^{-1} year^{-1}. IPCC 2006 Guidelines default EF is 8 kg CH_4 head^{-1}year^{-1} for market swine and 12 kg CH_4 head^{-1}year^{-1} for breeding swine respectively, for cool temperature and 14°C as average annual temperature (IPCC, 2006). The difference between the EF and the IEF is due to the reduction in CH_4 because of biogas recovery (see Annex 7.2).

For reporting purposes, the VS daily excretion and Bo is estimated and is useful to verify the EF accuracy. The VS daily excretion was estimated for each sub-category with the following parameters: animal number, production of slurry (t/y/t live weight) and the volatile solids content in the slurry (g VS/kg slurry). Methane producing potential (Bo) used 2006 IPCC Guidelines Equation 10.23 (Chapter 10 of Volume 4). See paragraph *Methane emissions (cattle and buffalo)* for more details on the estimation process.

Table 5.22 Methane manure management parameters and emission factors for swine in 2022

Livestock category	Average weight (kg)	Breed live weight (t)	Methane emission rate reduction (Nl CH_4/100 kg live weight)	Emission factor (kg CH_4 head^{-1} yr^{-1})
Other swine	**87**	**560,082**	**14,036**	**8.92**
20-50 kg	35	54,463	14,036	3.54
50-80 kg	65	82,662	14,036	6.58
80-110 kg	95	131,409	14,036	9.62
110 kg and more	135	286,690	14,036	13.67
Boar	200	4,858	14,036	20.25
Sows	**172**	**136,093**	**16,090**	**22.80**
Piglets	10	16,877	16,090	1.16
Sows	172.1		16,090	19.98
			Total	**8.30**

The fundamental characteristic of Italian swine production is the high live weight of the animals slaughtered as related to age; the optimum weight for slaughtering to obtain meat suitable for producing the typical cured meats is between 155 and 170 kg of live weight. Such a high live weight must be reached in no less than nine months of age. Other characteristics are the feeding situation, to obtain high quality meat, and the concentration of Italian pig production, limited to a small area (*Lombardia, Emilia-Romagna, Piemonte* and *Veneto*), representing 75% of national swine resources (Mordenti *et al.*, 1997). These peculiarities of swine production influence the methane EF for manure management as well as nitrogen excretion factors used for the estimation of N_2O emissions.

Other livestock categories

Methane EFs used for calculating the other livestock categories are those included in the 2006 IPCC Guidelines. CH_4 emissions from pasture of other livestock categories (i.e., sheep, goats, horses, mules and asses) were not calculated as the manure management emissions for these animal categories were calculated using Tier1 emission factors, which include all management systems, including grazing.

Data on the number of broilers and laying hens in the period 2001-2009 and since 2011 have been updated. The estimation methodology involved successive steps. Firstly, ISTAT data from the Census and FSS surveys (available for the years 2000, 2005, 2007, 2010, 2013 and 2016) were considered; on the basis of these data the number of heads has been estimated for the missing years from 2001, assuming a linear trend. Secondly, the number of animals since 2001 based on production data provided by UNAITALIA. The annual variation in production was multiplied by the number of animals in the 2000 Census. Thirdly, the average of the two time series, which were recreated in the previous steps, was calculated.

Based on the number of heads at provincial level (NUTS2) and the average temperature of each province, CH_4 emissions were calculated using the 2006 IPCC default emission factors by average annual temperature (considering cool (<15°C) and temperate (≥ 15°C) climate zone) at the provincial level. For the national estimate an IEF was calculated based on the sum of the provincial emissions.

In Table 5.23 the distribution of animals of 2019 are distributed between temperate and cool zones based on provincial FSS 2016 (ISTAT) survey data and provincial average temperatures for the 30-year period 1991-2020.

Table 5.23 Number of animals of 2019 in temperate and cool zones

Livestock categories in 2019 based on data from the FSS 2016	Heads	Animals in temperate zone (≥ 15°C)		Animals in cool zone (< 15°C)	
		N animals	% animals	N animals	% animals
Non-dairy cattle	4,331,830	1,099,630	25.38	3,232,200	74.62
Dairy cattle	1,643,117	368,382	22.42	1,274,735	77.58
Buffalo	402,286	368,323	91.56	33,963	8.44
Other swine	7,954,259	358,731	4.51	7,595,528	95.49
Sows	556,009	56,357	10.14	499,652	89.86
Sheep	7,000,880	5,621,944	80.30	1,378,936	19.70
Goats	1,058,720	774,441	73.15	284,279	26.85
Horses	367,561	158,228	43.05	209,333	56.95
Mules and asses	72,455	26,135	36.07	46,320	63.93
Broilers	102,143,056	6,627,016	6.49	95,516,041	93.51
Layer hens	39,045,286	6,946,533	17.79	32,098,753	82.21
Other poultry	34,331,971	1,422,174	4.14	32,909,797	95.86
Rabbits	11,755,922	212,962	1.81	11,542,960	98.19

In Table 5.24, the average methane EFs for cattle, buffalo and swine categories are shown for the whole time series.

For the other categories, the EFs are as follows:

- rabbits, 0.080 kg CH_4 head^{-1} year^{-1}
- sheep, 0.262 kg CH_4 head^{-1} year^{-1}
- goats, 0.181 kg CH_4 head^{-1} year^{-1}
- horses, 1.896 kg CH_4 head^{-1} year^{-1}
- mules and asses, 0.883 kg CH_4 head^{-1} year^{-1}
- laying hens, 0.030 kg CH_4 head^{-1} year^{-1}
- broilers, 0.020 kg CH_4 head^{-1} year^{-1}
- other poultry, 0.090 kg CH_4 head^{-1} year^{-1}
- fur animals, 0.680 kg CH_4 head^{-1} year^{-1}
- ostriches, 5.67 kg CH_4 head^{-1} year^{-1}

The difference between the EF and the IEF for poultry is due to the reduction in CH_4 because of biogas recovery (see Annex 7.2).

Table 5.24 Average methane EFs for manure management (*) (kg CH_4 head^{-1} year^{-1})

Year	Dairy cattle	Non-dairy cattle	Buffalo	Sows	Other swine
	(kg CH_4 head^{-1} year^{-1})				
1990	22.54	10.54	18.76	22.12	8.53
1995	22.54	11.03	18.30	21.94	8.51
2000	22.54	10.87	17.80	21.95	8.42
2005	25.19	12.09	20.81	22.28	8.34
2010	25.24	11.22	18.52	22.48	8.41
2015	25.55	11.37	16.91	22.78	8.94
2019	25.02	11.24	15.91	22.92	8.91

Year	Dairy cattle	Non-dairy cattle	Buffalo	Sows	Other swine
	(kg CH_4 head^{-1} year^{-1})				
2020	25.03	11.22	15.84	22.88	8.92
2021	25.04	11.26	15.85	22.89	8.85
2022	25.04	11.41	15.73	22.80	8.92

(*) These are the EFs used for estimating CH_4 emissions from manure management (for cattle and buffalo data include EFs for pasture). CH_4 reductions are not included.

Nitrous oxide emissions from manure management

Direct and indirect N_2O emissions, produced during the storage and treatment of manure before it is applied to soils, are reported separately, as indicated in the 2006 IPCC Guidelines.

Direct N_2O emissions from manure management

N_2O emissions were estimated with equation 10.25 (IPCC, 2006, Chapter 10 of Volume 4). Different parameters were used for the estimation: number of livestock species, country-specific nitrogen excretion rates per livestock category, fraction of total annual nitrogen excretion for each livestock category managed in each manure management systems and EFs for manure management systems (IPCC, 2006).

Liquid system and solid storage are considered according to their significance and major distribution in Italy. For these management systems, the same EF is used: 0.005 kg N_2O-N/kg N excreted (IPCC, 2006). Solid storage includes the chicken-dung drying process system. This system has been considered since 1995, since it has become increasingly common (CRPA, 2000; CRPA, 1997[b]). As regards the anaerobic digesters, another management system used in the country, the nitrogen quantities in livestock manure sent to anaerobic digestion were updated. Based on CRPA data on measurements of nitrogen quantities in livestock manure (downstream of releases to housing and storage) per animal category and type of manure, the nitrogen quantities in livestock manure sent to anaerobic digestion were estimated. The coefficients, expressed in g N/kg manure, were calculated gross of losses and then the losses to housing were deducted. Then, the resulting coefficients were then multiplied by the quantities of manure sent for anaerobic digestion. The whole time series was updated. N_2O emissions of the anaerobic digesters are reported as zero in line with the 2006 IPCC Guidelines (IPCC, 2006).

When estimating emissions from manure management, the amount related to manure excreted while grazing is subtracted and reported in 'Agricultural soils' under soil emissions - urine and dung deposited by grazing animals (see Table 5.25). As recommended during the 2021 UNFCCC review, N_2O direct and indirect emissions for ostriches are estimated and reported in the IPCC 'Agricultural soils' category because the manure management system for this category is pasture, range and paddock. The estimate of nitrogen excretion per manure management system is reported in CRT Table 3.B(b) (consistently with CRT Table 3.B(a)s2), in pasture range and paddock in other livestock. Further details on the estimate are given in 5.5.2 *Methodological issues* paragraph, in Direct N_2O emissions from managed soils, in *Urine and dung from grazing animals* (F_{PRP}). Different parameters such as the nitrogen excretion rates (CRPA, 2006[a]; GU, 2006; Xiccato *et al*., 2005), the slurry and solid manure production, and the average weight (CRPA, 2006[a]; GU, 2006; Regione Emilia Romagna, 2004) were updated.

In Table 5.25, nitrogen excretion rates used for the estimation of N_2O are shown. In 2022, the nitrogen excretion rate for swine is 14.92 kg head^{-1} yr^{-1}. This last parameter is a weighted average of sow (28.39 kg head^{-1} yr^{-1}) and other swine (13.45 kg head^{-1} yr^{-1}). The value for sows also includes the excreted nitrogen from piglets. The average nitrogen excretion rate for swine reported in the CRT is equal to 12.04 kg head^{-1} yr^{-1}. The figure is lower than the average rate for swine reported here since the value reported in the CRF is calculated by comparing the excreted nitrogen to the total pigs, including piglets.

Table 5.25 Average weight and nitrogen excretion rates in 2022

Livestock category	Average weight (kg)	N excreted housing (kg N head^{-1} yr^{-1})	N excreted grazing (kg N head^{-1} yr^{-1})	Total nitrogen excreted (kg N head^{-1} yr^{-1})
Non-dairy cattle	388.2	50.90	1.44	**52.34**
Dairy cattle	602.7	105.35	5.54	**110.89**
Buffalo	497.3	57.50	1.72	**59.22**
Other swine	87.4	13.35		**13.35**
Sows	172.1	28.51		**28.51**
Sheep	47.2	1.62	14.58	**16.20**
Goats	45.2	1.62	14.58	**16.20**
Horses	550.0	20.00	30.00	**50.00**
Mules and asses	300.0	20.00	30.00	**50.00**
Poultry	1.8	0.48		**0.48**
Rabbits	1.6	1.02		**1.02**
Fur animals	1.0	4.10		**4.10**

Country-specific annual nitrogen excretion rates have been set, based on the Nitrogen Balance Inter-regional Project results (nitrogen balance in animal farms); this project involved *Emilia Romagna*, *Lombardia*, *Piemonte* and *Veneto* regions, where animal breeding is concentrated. The N-balance methodology has been applied in real case farms, monitoring their normal feeding practice, without specific diet adaptation. In the project, the most relevant dairy cattle production systems in Italy have been considered. Contrary to what is normally found in European milk production systems, poor correlation between the N excretion and milk production has been found. The two possible reasons are: a) an extreme heterogeneity in the protein content of the forage and in the use of the feed; b) the non-optimisation of the protein diet of less productive cattle (De Roest and Speroni, 2005; CRPA, 2010). The N-balance methodology was followed, as suggested by the IPCC. As a result, estimations of nitrogen excretion rates[19] and net nitrogen arriving to the field[20] were obtained. In order to get reliable information on feed consumption and characteristics, and composition of the feed ratio, the project considered territorial and dimensional representativeness of Italian breeding. The final annual nitrogen excretion rates used for the UNFCCC/CLRTAP agriculture national inventory are included in a CRPA report (CRPA, 2006[a]).

In Table 5.26, nitrogen excretion rates for the main livestock categories are shown for the whole time series. For the other livestock categories, nitrogen excretion is the same for the whole time series, as shown in Table 5.25.

For the dairy cattle category, the annual average values of nitrogen excretion rates are estimated using equations 10.31-33 of the 2006 IPCC Guidelines, and therefore are calculated with the data used to estimate the enteric fermentation emissions. Following the update of the gross energy intake (GE), based on the estimation of the parameters digestibility (DE) of diet and methane conversion factor (Ym), the excreted nitrogen value of dairy cows was updated from the year 2004 onward. Excreted nitrogen is in fact calculated from GE using equations 10.31-10.33 of the 2006 IPCC Guidelines. The percentage for protein in diet is used with GE in the estimation of excreted nitrogen. As regards the percentage for protein in diet, the crude protein of the ration was updated based on data from around 500 samples of rations (unifeed) of lactating and dry dairy cows, analyzed by the CRPA's zootechnical feed service for the three-year period 2017-2019, from all over Italy. The data were obtained by weighing the values expressed as % of the dry matter of the ration with the average annual lactation period (equal to 305 days) and the dry period (equal to 60 days). The value obtained is 14.22% and it was used for the time series from 2010

[19] Nitrogen excretion = N consumed – N retained
[20] Net nitrogen to field = (N consumed – N retained) – N volatilized

onwards, as indicated by the CRPA experts. For the previous years, the previous figure of 15.32% (Bittante *et al.*, 2004) was left until 2000, and an average value of 14.5% was used for the intermediate years between 2000 and 2010. This change results in a change in the nitrogen excreted by dairy cows (which is down from the previous submission).

For non-dairy cattle, buffalo and swine categories, the average values of nitrogen excretion rates are calculated on the basis of the weight of the annual number of animal subcategories and fluctuate over the years. For the 'Less than 1 year' subcategory of the non-dairy cattle category, an average value of nitrogen excreted was calculated based on the weight of the number of animals of the subcategories calf, fattening male cattle, fattening heifer and heifer for replacement subcategories. For the sows' category, an average weighted nitrogen excretion rate is calculated taking in account the nitrogen excretion from piglets (swine less than 20 kg).

Table 5.26 Nitrogen excretion rates for main livestock categories (kg N head^{-1} yr^{-1})

Year	Dairy cattle	Non-dairy cattle	Buffalo	Other swine	Sows
			(kg N head^{-1} yr^{-1})		
1990	104.85	49.89	94.32	13.13	28.10
1995	112.58	49.89	92.84	13.10	27.86
2000	105.65	50.07	91.20	12.96	27.87
2005	105.70	49.85	95.28	12.84	28.30
2010	102.02	50.07	81.99	12.85	28.36
2015	103.48	51.37	63.57	13.48	28.36
2019	106.57	52.15	59.38	13.44	28.55
2020	109.06	52.01	59.21	13.45	28.50
2021	110.89	52.33	59.22	13.35	28.51
2022	111.81	51.67	58.91	13.45	28.39

For verification purpose, a time series reported by ISTAT in the yearbooks (animal weight before slaughter) was collected (CRPA, 2006[a]). For the specific case of sheep and goats, a detailed analysis was applied with information coming from the National Association for Sheep Farming (ASSONAPA, 2006). In order to estimate the average weight for sheep and goats, breed distribution in Italy and consistency for each breed were considered (CRPA, 2006[a]; PROINCARNE, 2005).

Slurry and solid manure production parameters are set based on Italian breeding characteristics, taking into account the slurry and solid manure effluents, housing systems and the distribution for the different animal categories (CRPA, 2006[a]; Bonazzi *et al.*, 2005; APAT, 2004[a]; APAT, 2004[b]).

Fractions of total annual nitrogen excretion for dairy cattle category managed in solid manure and liquid/slurry systems have been updated considering the distribution of housing systems resulting from the 2010 Agricultural Census.

Indirect N_2O emissions from manure management

N_2O emissions result from volatile nitrogen losses occurring primarily in the forms of ammonia and NO_x and from nitrogen leaching and run-off.

N_2O emissions due to atmospheric deposition of NH_3 and NO_x have been estimated following the IPCC Tier 2 approach (Equation 10.26 and 10.27 of the 2006 IPCC Guidelines, Volume 4, Chapter 10). The following parameters are used: total N excreted by livestock (kg head^{-1}yr^{-1}), the fraction of total annual nitrogen excretion for each livestock category managed in each manure management systems, $Frac_{GasMS}$ emission factor, which is the percentage of managed manure nitrogen that volatilises as NH_3 and NO_x in the manure management systems (see Table 5.27) and emission factor 0.01 kg N_2O-N per kg NH_3-N and

NO_x-N emitted (IPCC, 2006). The $Frac_{GasMS}$ emission factor is equal to the ratio between the amount of NH_3-N and NO_x-N emissions at housing and storage system and the total nitrogen excreted.

NH_3 and NO_x emissions are estimated on the basis of the methodology indicated in the EMEP/EEA Guidebook for transboundary air pollutants. The estimation procedure for NH_3 and NO_x emissions of the manure management category consists in successive subtractions from the quantification of nitrogen excreted annually for each livestock category. This quantity can be divided in two different fluxes, depending on whether animals are inside (housing, storage and manure application) or outside the stable (grazing). More in detail, part of the nitrogen excreted in housing volatilizes during the settle of manure in the stable and it is calculated with the relevant emission factor in housing for the different livestock; this amount is therefore subtracted from the total nitrogen excreted to derive the amount of nitrogen for storage. During storage another fraction of nitrogen is lost (calculated with the relevant emission factor for storage), and, therefore, it is subtracted to obtain the amount of nitrogen available for the agronomic spreading. Losses occurring during the spreading are finally calculated with the related emission factor for spreading. For the nitrogen excreted in the pasture, losses due to volatilization, calculated with the relevant emission factor for grazing by livestock, only occur at this stage. Ammonia and NO_x emissions coming from housing and storage by each livestock category are then summed and divided by the total nitrogen excreted for each year (CRPA, 2006[a]). Ammonia emissions related to the housing and storage by cattle, swine and laying hens categories have been updated based on ISTAT statistics such as 2010 Agricultural Census and 2013 Farm Structure Survey, on the distribution of housing and storage systems. In relation to the ammonia emissions from storage, NH_3 emissions from digesters biogas facilities (in particular due to different phases of the process: during storage of feedstock on the premises of the biogas facility; during open storage of the digestate) have been estimated taking into account the amount of excreted nitrogen feeding anaerobic digesters and the Tier 1 emission factor derived by the EMEP/EEA Guidebook (EMEP/EEA, 2023). NH_3 emissions from digesters biogas facilities have been subtracted from manure management category (only for cattle, swine and poultry categories) and allocated in the anaerobic digestion at biogas facilities (5B2 of the waste sector in the NFR classification under UNECE/LRTAP Convention). The percentage of nitrogen lost through N-NH_3 emissions from anaerobic digesters was subtracted from the percentage of nitrogen left after emissions during housing and storage, reducing the amount of nitrogen used at the spreading. The amount of nitrogen used at the spreading also includes the digestate.

For estimating of N_2O emissions due to nitrogen leaching and run-off the IPCC Tier 2 approach was followed (Equation 10.28 of the 2006 IPCC Guidelines, Volume 4, Chapter 10). The following parameters are used: total N excreted by livestock (kg $head^{-1}yr^{-1}$), the fraction of total annual nitrogen excretion for each livestock category managed in each manure management systems, $Frac_{leachMS}$ emission factor, which is the percent of managed manure nitrogen losses due to leaching and runoff during solid and liquid storage of manure (see Table 5.27) and emission factor 0.0075 kg N_2O-N per kg N leaching/runoff (IPCC, 2006).

The national legislation (as well as the regional ones) requires that the storage of liquid manure is in containers with waterproof bottom. The solid storage should have the concrete or similar materials on the bottom and the leachate collection system. Nevertheless, manure heaps near the field are permitted for limited time after storage aimed at spreading (CRPA, 2016[b]). Leaching of N during manure management is thus restricted to these manure heaps after storage. On the basis of this information, $Frac_{leachMS}$ emission factor is assumed equal to 1% (the lower bound of the typical range, reported in 2006 IPCC Guidelines) and $Frac_{leachMS}$ is applied on the amount of N after the N volatilized from manure management is subtracted, because most N will already be volatilized before installing the manure heaps near the field.

Table 5.27 Parameters used for the estimation of N_2O indirect emissions

Year	N excreted (t N)	$Frac_{GasMS}$ (%)	N volatilised as NH_3 and NO_x (t N)	N excreted housing minus N volatilised (t N)	$Frac_{LeachMS}$ (%)	N leached from manure management (t N)
1990	929,130	24.16	224,467	527,957	1.0	5,280
1995	932,041	22.64	211,049	516,582	1.0	5,166
2000	914,838	22.22	203,251	502,556	1.0	5,026
2005	813,248	22.77	185,215	473,213	1.0	4,732
2010	792,069	22.96	181,876	453,047	1.0	4,530
2015	781,253	20.99	163,980	469,616	1.0	4,696
2019	779,621	20.34	158,582	474,691	1.0	4,747
2020	785,163	20.10	157,843	480,207	1.0	4,802
2021	773,593	19.96	154,424	476,645	1.0	4,766
2022	755,421	19.88	150,182	466,138	1.0	4,661

5.3.3 Uncertainty and time-series consistency

Uncertainty of CH_4 and N_2O emissions from manure management has been estimated equal to 20.6%, as a combination of 5% and 20% for activity data and emission factors, respectively. Uncertainty of indirect N_2O emissions from manure management has been estimated equal to 50.2%, as a combination of 5% and 50% for activity data and emission factors, respectively.

In 2022, CH_4 emissions from manure management were 11.7% (171.12 Gg CH_4) lower than in 1990 (193.71 Gg CH_4). From 1990 to 2022, dairy and non-dairy cattle livestock population decreased by 38.3% and 21.7%, respectively, while swine increased by 4.0% (in particular, sows increase by 6.4% and other swine by 3.8%).

The reduction of manure management emissions has mainly driven down by the number of cattle. For cattle category until 2011, CH_4 emissions from biogas produced by anaerobic digesters fed with animal manure must be added to the emissions from manure management and not deducted because of the plant biogas losses are greater than avoided emissions due to biogas recovery. Cattle CH_4 emissions contribute for 49.6% (in 1990 for 58.6%) to total CH_4 manure management emissions and swine for 41.6% (35.2% in 1990). For cattle, swine and poultry, the reduction of manure management emissions is also due to the reduction in CH_4 because of biogas recovery.

In Table 5.28, CH_4 emission trends from manure management (including emissions from pasture) are shown. These emissions considered the reduction of CH_4 because of biogas recovery.

Table 5.28 Trend in CH_4 emissions from manure management (Gg)

Year	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Dairy cattle	59.56	46.94	46.59	46.55	44.48	46.20	40.42	40.29	39.56	40.07
Non-dairy cattle	53.88	57.33	54.25	53.52	46.28	44.55	47.85	48.02	47.08	44.79
Buffalo	1.77	2.72	3.42	4.27	6.76	6.33	6.40	6.45	6.49	6.55
Sows	14.40	15.12	15.53	15.96	15.98	13.00	12.49	12.75	12.36	15.48
Other swine	53.73	50.48	51.51	56.04	57.37	58.62	57.23	57.32	56.21	55.64
Sheep	2.07	2.52	2.60	1.88	1.90	1.86	1.84	1.84	1.76	1.72
Goats	0.21	0.23	0.23	0.16	0.17	0.17	0.19	0.19	0.19	0.18
Horses	0.50	0.55	0.49	0.48	0.65	0.71	0.70	0.70	0.70	0.69
Mules and asses	0.08	0.03	0.03	0.03	0.04	0.06	0.06	0.06	0.06	0.07

Year	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Poultry	6.10	6.84	6.48	6.61	6.54	6.25	5.79	5.75	5.64	4.88
Rabbits	1.19	1.37	1.43	1.64	1.44	1.26	0.94	0.88	0.88	1.01
Fur animals	0.22	0.15	0.16	0.14	0.09	0.12	0.09	0.03	0.01	0.01
Ostriches	0.001	0.03	0.22	0.16	0.03	0.02	0.02	0.01	0.01	0.01
Total	**193.71**	**184.32**	**182.93**	**187.43**	**181.70**	**179.17**	**174.02**	**174.30**	**170.97**	**171.12**

In Table 5.29, N_2O emissions from liquid systems, solid storage and 'other' sources are shown.

Table 5.29 Trend in N_2O emissions from manure management (Gg)

Year	Direct emissions			Indirect emissions	Total
	Liquid system	Solid storage	Other		
	Gg				
1990	2.89	3.02	0.00	3.59	**9.50**
1995	2.71	3.00	0.00	3.38	**9.09**
2000	2.53	3.01	0.00	3.25	**8.79**
2005	2.35	2.79	0.00	2.97	**8.11**
2010	2.44	2.49	0.00	2.91	**7.84**
2015	2.19	2.22	0.00	2.63	**7.05**
2019	2.16	2.12	0.00	2.55	**6.83**
2020	2.17	2.11	0.00	2.54	**6.81**
2021	2.12	2.07	0.00	2.48	**6.67**
2022	2.11	1.97	0.00	2.41	**6.50**

In 2022, N_2O emissions from manure management were 31.6% (6.50 Gg N_2O) lower than in 1990 (9.50 Gg N_2O). The major contribution of direct emissions is given by the 'liquid system' with 51.7% (in 1990 with 48.8%). In 2022, indirect N_2O emissions from manure management account for 37.2% of total N_2O emissions from manure management and were 32.7% (2.41 Gg N_2O) lower than in 1990 (3.59 Gg N_2O).

5.3.4 Source-specific QA/QC and verification

A study carried out by the CRPA in 2018 (CRPA, 2018) mentioned before also includes a survey on the digesters and the outcomes of the survey have been used to update the estimates as described in the paragraph 5.3.2.

A check was carried out on the VS values. An average of the time series of VS values was calculated for cattle. Three weighted mean values were calculated. The first was obtained using Husted values of 142.7 g VS/kg for solid manure and 47.5 g VS/kg for slurry. The second was obtained from the VS kg/head/day values calculated using Equation 10.24 of the 2006 IPCC Guidelines, which uses the data to estimate enteric emissions. The third was calculated as an average of the VS values measured by CRPA. Specifically, a crude average of VS values for manure and slurry was calculated from approximately 400 samples analysed in the period 2001-2019; from the average VS values for manure and slurry, a weighted average was calculated. The values obtained were 98.2, 93.5 and 117.4 g VS/kg manure, respectively. This verification supports the estimates made, based on the Husted factors, but further investigations will be carried out.

For verification purposes, the $Frac_{GasMS}$ parameter have been also estimated as a fraction of nitrogen recovered and stored that is emitted as N_NH_3-NO_x-N_2O-N_2. This value is equal to 0.329, for 1990, and to 0.272 in 2022.

As recommended by the 2019 UNFCCC review, starting from the data on amount of solid and slurry manure produced, used in the estimate of CH_4 emissions from manure management, the amount of straw added to the manure during housing was calculated. The estimated amount of straw for cattle and buffalo bedding was compared with the annual amount of wheat and barley straw used for various purposes. It was found that cattle and buffalo bedding is equal to 83% of the amount of wheat and barley straw.

During 2022, a verification of CH_4 estimates from manure management was conducted using provincial Census agriculture head count data from the years 2000 and 2010 and monthly average temperature data. Head count data were distinguished between animals raised in temperate and cool climate zones. Regarding temperature data, average monthly temperatures of temperate and cool climate zones were calculated separately. Average monthly temperatures for three 30-year periods (1971-2000, 1981-2010, 1991-2020) were calculated. With these data, the national methodology for estimating cattle and buffalo CH_4 emissions for the years 2000 and 2010 was replicated. For 2000, the emissions estimated with this verification were 11% lower than the methodology used. While for 2010, emissions were almost identical. The 2000 census head count (summing cattle and buffalo), used for the verification performed, is 14% lower than the annual stock figures used in the national methodology (and just under 4% for 2010). This helps in part to explain the differences obtained. As soon as the 2020 census data disaggregated at the municipal level are available, the verification will also be carried out for the year 2020.

5.3.5 Source-specific recalculations

The update of CH_4 emission factors from storage since 2015 is due to the update of temperatures for the 30-year period 1991-2020. This update resulted in updated emissions for sheep, goats, horses. The recalculation for 2021 is due to the corrected average weight for cattle less than one-year for 2021.
The change in the coefficients of N contained in manure sent to anaerobic digestion for cattle resulted in a different distribution of N between liquid, solid and digester systems. The percentage distribution of N between systems is used to calculate an average MCF, which is used to calculate the average CH_4 emission factor from storage for cows and other cattle for the years 2020 and 2021.
The 2006-2009 EFs of dairy cows were corrected because the percentages of animals by housing system were corrected. This slightly affects CH_4 emissions from dairy cow manure management.
As regards for N_2O emissions from manure management, the recalculation is due to the change in the coefficients of N contained in livestock manure sent to anaerobic digestion of cattle, swine, poultry since 1991. A minimal recalculation is also due to the correction of the N value for calves for the years 1990-2015; in addition, the average weight of the subcategory other cattle < 1 year of 2021 was corrected.

5.3.6 Source-specific planned improvements

In Table 5.30, future improvements in agreement with the QA/QC plan are presented.

Table 5.30 Improvements for manure management category according to the QA/QC plan

Category/sub category	Parameter	Year of submission 2023	2024	Activities
Livestock categories	CH_4 EFs		√	Further assessments will be made on the estimation of methane emissions from storage, considering estimating emissions according to both temperate and cool climate zones, updating temperatures and 2020 Census livestock data

Parameters used for this submission are shown in Table 5.31.

Table 5.31 Parameters used for the different livestock categories (2022)

Livestock category		Average weight (kg)	N excretion (kg N head^{-1} yr^{-1})
DAIRY CATTLE		602.7	111.81
NON- DAIRY CATTLE		393.6 (**)	51.67 (**)
Less than 1 year (*)		204.7 (**)	25.33 (**)
From 1 year - less than 2 years			
Male	for reproduction	557.0	66.8
	for slaughter	557.0	66.8
Female	for breeding	405.0	67.6
	for slaughter	444.0	53.3
From 2 years and more			
Male	for reproduction	700.0	84.0
	for slaughter and work	700.0	84.0
Female	Breeding heifer	540.0	90.2
	Slaughter heifer	540.0	64.8
	Other non-dairy cattle (***)	557.0	54.1
BUFFALO		493.9 (**)	58.91 (**)
	Cow buffalo	630.0	71.31
	Other buffaloes	319.5	43.0
OTHER SWINE		88.1 (**)	13.45 (**)
Weight less than 20 kg		10.0	
From 20 kg weight and under 50 kg		35.0	5.3
From 50 kg and more			
	Boar	200.0	30.5
	For slaughter		
	from 50 to 80 kg	65.0	9.9
	from 80 to 110 kg	95.0	14.5
	from 110 kg and more	135.0	20.6
SOWS		172.1	28.39 (**)
SHEEP	Sheep	51.1	16.2
	Other sheep	20.8	16.2
GOATS	Goats	53.8	16.2
	Other goats	14.9	16.2
EQUINE	Horses	550.0	50.0
	Mules and asses	300.0	50.0

Livestock category		Average weight (kg)	N excretion (kg N head^{-1} yr^{-1})
POULTRY	Broilers	1.2	0.36
	Layer hens	1.8	0.66
	Other poultry	4.0	0.68
RABBITS	Female rabbits	4.0	2.5
	Other rabbits	1.3	0.8
FUR ANIMALS		1.0	4.1

(*) Categories included in less than 1 year are: calf, fattening male cattle, fattening heifer and heifer for replacement; (**) values are variable for the time series; (***) Suckling cows and cows in late career.

5.4 Rice cultivation (3C)

5.4.1 Source category description

For the rice cultivation category, only CH_4 emissions are estimated, other GHGs do not occur; N_2O from fertilisation during cultivation was estimated and reported in "Agricultural soils" under direct soil emissions - synthetic fertilizers. Methane emissions from rice cultivation have been identified as a key source at level assessment with Approach 1 including LULUCF categories. In 2022, CH_4 emissions from rice cultivation were 55.3 Gg, which represent 7.4% of CH_4 emissions for the agriculture sector (8.5% in 1990) and 3.4% for national CH_4 emissions (3.8% in 1990).

In Italy, CH_4 emissions from rice cultivation are estimated only for an irrigated regime, other categories suggested by IPCC (rainfed, deep water and "other") are not present. Methane emissions, reported in the CRF tables, represent two water regimes: delay flooding (26.8 Gg) and multiple aeration (28.5 Gg).

A detailed methodology was developed in 2005/2006, in consultation with an expert in CH_4 emissions and rice cultivation (Wassmann, 2005) and following outcomes of previous UNFCCC review processes. For this purpose, an expert group on rice cultivation together with the C.R.A. – Experimental Institute of Cereal Research – Rice Research Section of Vercelli was established. Different national experts from the rice cultivation sector were also contacted[21].

In 2022/2023, national experts on rice cultivation were contacted to verify and review the historical series of emissions[22].

5.4.2 Methodological issues

For the estimation of CH_4 emissions from rice cultivation a detailed methodology in 2005/2006 was implemented following the IPCC guidelines (IPCC, 2006, volume 4, chapter 5). Country-specific circumstances have been considered. Parameters such as an adjusted integrated emission factor (kg CH_4 $m^{-2}day^{-1}$), cultivation period of rice (days) and annual harvested area (ha) cultivated under specific conditions are considered. Information of the cultivated surface is collected from rice farmers. Every year, timely data collection is ensured by the National Rice Institute (ENR, several years [b]). Activity data information is shown in Table 5.32.

21 Stefano Bocchi, Crop Science Department (University of Milan); Aldo Ferrero, Department of Agronomy, Forestry and Land Management (University of Turin); Antonino Spanu, Department of agronomic science and agriculture genetics (University of Sassari).

22 Marco Romani, Eleonora Francesca Miniotti and Elisa Cadei, Ente Nazionale Risi (Enterisi); Daniel Said-Pullicino and Lucia Crosetto, Department of Agricultural, Forestry and Food Sciences (University of Turin).

Table 5.32 Parameters used for the calculation of CH_4 emissions from rice cultivation

Parameters	Reference
Cultivated surface with "dry-seeded" technique (%)	ENR, several years [a]
Cultivated surface – national (ha)	ISTAT, several years [a],[b],[j]; ENR, several years [b]
Cultivated surface by rice varieties (ha)	ENR, several years [b]
Cultivation period of rice varieties (days)	ENR, 2011; ENR, 2014 [a],[b]; ENSE, 1999; ENSE, 2004; ENR, 2013
Methane emission factor (kg CH_4 m-2 d-1)	Peyron et al., 2016; Bertora et al., 2018; Vitali et al., 2024; Leip et al., 2002; Schutz et al., 1989[a], [b]
Crop production (t yr-1)	ISTAT, several years [a],[b],[j]
Yield (t ha-1)	Estimations based on cultivated surface and crop production data
Straw incorporation (%)	Expert judgement (Miniotti E. F., Romani M., 2023; Tinarelli, 2005; Lupotto et al., 2005)
Agronomic practices	Miniotti E. F., Romani M., 2023; ISTAT, 2006[b]; Tinarelli, 2005; Lupotto et al., 2005; Zavattaro et. al, 2004; Baldoni & Giardini, 1989; Tinarelli, 1973; 1986
Scaling factors (SFw, SFp, SFo)	IPCC, 2006; Yan et al., 2005

Rice cultivation practice

In Italy, rice is sown from mid-April to the end of May and harvested from mid-September to the end of October; the only practised system is the controlled flooding system, with variations in water regimes (Miniotti E. F., Romani M., 2023; Regione Emilia Romagna, 2005; Mannini, 2004; Tossato and Regis, 2002). Water regime trends have been estimated in collaboration with expert judgement expertise (Tinarelli, 2005; Lupotto *et al*., 2005; Miniotti E. F., Romani M., 2023) and available statistics (ENR, several years [b]). Normally, the aeration periods are very variable in number and time, depending on different circumstances, as for example, the type of herbicide, which is used (Baldoni and Giardini, 1989). Another water regime system, present in southern Italy, is the sprinkler irrigation, which exists only on experimental plots and could contribute to the diffusion of rice cultivation in areas where water availability is a limiting factor (Spanu et al., 2004; Spanu and Pruneddu, 1996). In Table 5.33, water regimes descriptions for the most common agronomic practices in Italy are presented (Miniotti E. F., Romani M., 2023).

Table 5.33 Water regimes in Italy and classification according to IPCC guidelines

Type of seeding	April	May	June	July	August	September-October	Description
Wet-seeded "classic"	15 April-15 May Flooding and <u>wet-seeded</u>		Herbicide and fertilizer treatment (1/3)	Fertilizer application (1/3). Panicle formation		Harvest	2 aeration periods during rice cultivation, as minimum, not including the final aeration. IPCC classification: Intermittently flooded – <u>multiple aeration</u>
	1/3 pre-sowing fertilizer	1° aeration-AR (dry rooting (*asciutta di radicamento*), which occurs 6-10 days after sowing and lasts several days (>3 days))	2° aeration-AA (dry for herbicide and fertilizer application at tillering (*accestimento*) (tends to occur in June, concurrent with	3° aeration-AA (*) (Fertilizer application at panicle initiation (*iniziazione pannocchia*))	Final aeration		

Type of seeding	April	May	June	July	August	September-October	Description
			herbicide treatment) (1/3))				
Wet-seeded "red rice control"	15-30 April Flooding and wet-seeded	First application of herbicides, the soil is dry. Approximately, on 15 may flooding and after some days (more or less 7) seeding	At the end of June, fertilization and herbicide treatment	Fertilizer application (1/3). Panicle formation		Harvest	2 aeration periods during rice cultivation, as minimum, not including the final aeration. IPCC classification: Intermittently flooded – multiple aeration
	2/3 Fertilizer application. There are many strategies for this type of application, so defining an unambiguous time of application is difficult: in some cases, fertilization takes place before submergence, in other cases application is postponed to post-emergence, and in still other cases, if fertilizers with inhibitors are chosen, application may be made before false seeding	1° aeration – AC Approx. after 10 days after seeding: 2° aeration - AR	3° aeration -AA	4° aeration - AA (*)	Final aeration		
Dry-seeded with delay flooding	15 April-15 May Dry-seeded	Approximately, on 15 May- 10 June flooding		Fertilizer application (1/3). Panicle formation		Harvest	1 aeration period during rice cultivation, as minimum, not including the final aeration.
		Between sowing and submergence, there is fertilizer application/herbicide treatment (2/3) in pre-sowing at the beginning of tillering (*inizio accestimento*)		1° aeration- AA (*) Fertilizer application at panicle initiation (*iniziazione pannocchia*)	Final aeration		

(*) To improve its fertilizer application efficiency, fertilizer is given on dry soil and then the field is flooded no later than 48 hours to limit losses by volatilization. Since 2020 fertilizers application at panicle initiation occurs in flooded condition. Water shortage doesn't allow to drain water from the paddy field and reflood after some days. Aeration periods last mostly between 5-15 days and are classified as follows: AC=aeration to control red rice; AR=drained, aeration in order to promote rice rooting; AA=drained, tillering aeration.

In general, rice seeds are mechanically broadcasted in flooded fields. However, in Italy for the last 15 years, the seeds are also drilled to dry soil in rows. The rice which has been planted in dry soil is generally managed as a dry crop until it reaches the 3-4 leaf stage. After this period, the rice is flooded and grows in continuous submersion, as in the conventional system (Ferrero and Nguyen, 2004; Russo, 1994). During the cultivation period, water is commonly kept at a depth of 4-8 cm and drained away 2-3 times during the season to improve crop rooting, to reduce algae growth and to allow application of fertilizers/herbicides. Rice fields are drained at the end of August to allow harvesting, once in a year (Miniotti E. F., Romani M., 2023; Ferrero and Nguyen, 2004; Baldoni and Giardini, 1989; Tinarelli, 1973; Tinarelli, 1986).

Nitrogen is generally the most limiting plant nutrient in rice production and is subject to losses because of the reduction processes (denitrification) and leaching. Table 5.33 describes the periods and amounts of fertilizer application.

Based on the guidance received from the 2022/2023 working group, the percentages of incorporated/burned straw have been changed since 2001. In addition, since 2012, the only rice-growing areas where stubble burning takes place are those in Ferrara, Rovigo, Venice, and Vicenza. On the remaining areas, residues are incorporated (Miniotti E. F., Romani M., 2023).

Methane emission factor

An analysis on recent and past literature, for the CH_4 daily EF (kg CH_4 m^{-2} d^{-1}) was done. In 2005/2006, different scientific publications related to the CH_4 daily EF measurements in Italian rice fields were revised (Marik *et al*., 2002; Leip *et al*., 2002; Dan *et al*., 2001; Butterbach-Bahl *et al*., 1997; Schutz et al., 1989[a], [b]; Holzapfel-Pschorn & Seiler, 1986). Other publications indirectly related with CH_4 production were also considered (Kruger *et al*., 2005; Weber *et al*., 2001; Dannenberg & Conrad, 1999; Roy *et al*., 1997). Butterbach-Bahl *et al*. have presented interesting results associated to the difference in EFs of two cultivation periods (1990 and 1991). Marik *et al*. have published detailed information on agronomic practices (fertilized fields) related to measurements of CH_4 emission factor for years 1998 and 1999; values are similar to those presented in previous publications (Schutz et al., 1989[a], [b]; Holzapfel-Pschorn & Seiler, 1986). Leip *et al*. have published specific CH_4 EF for the dry-seeded with delay flooding, as shown in Table 5.34. The dry–seeded technique could bring interesting benefits in emission reduction, since lower emission rates compared with normal agronomic practices, were determined experimentally.

The estimation of CH_4 emissions for the rice cultivation category considers an irrigated regime, which includes intermittently flooded with delay flooding and multiple aeration regime. The CH_4 emission factor for the years 1990-2007 is adjusted with the following parameters: a daily integrated emission factor for continuously flooded fields without organic fertilizers, a scaling factor to account for the differences in water regime in the rice growing season (*SFw*), a scaling factor to account for the differences in water regime in the preseason status (*SFp*) and a scaling factor which varies for both types and amount of amendment applied (*SFo*). Scaling factor parameters have been updated according to literature (Yan *et al*., 2005) and the IPCC 2006 Guidelines (IPCC, 2006, volume 4, chapter 5).

Based on the results that emerged from the 2022/2023 working group, emission factors were updated from 2008. The scientific studies supporting the new factors refer to field measurements carried out in the Italian rice district (an area in the Po Valley, in Northern Italy) in the years 2012, 2013, 2014, 2021 and 2022 (Peyron et al., 2016; Bertora et al., 2018; Vitali et al., 2024). Emission factors refer to conventional (water-seeded) and dry-seeded cultivation techniques. The former technique involves continuous submergence with two drainage periods for fertilizer application at tillering (*accestimento*) and panicle initiation (*iniziazione della pannocchia*) prior to final field drainage; no pre-season submergence for >180 days prior to rice cultivation; tillage with incorporation of crop residues (>30 days prior to flooding), no cover crop. The second technique involves continuous submergence after 3rd-4th leaves/early tillering (*accestimento*) with one drainage period for fertilizer application at panicle initiation (*iniziazione della pannocchia*) before final field drainage; no pre-season submergence for >180 days before rice cultivation;

tillage with incorporation of crop residues (>30 days before flooding), no cover crops (Romani M., 2023). The rooting dry (*asciutta di radicamento*) is always expected in water seeding and is additional to the other two dry described in the conventional technique (i.e., at tillering and panicle differentiation). Thus, the EF already takes this into account and it is important that it does so because methane emissions are still possible during this stage since the soil is not completely aerobic. In dry seeding, on the other hand, a single soil dry is generally expected near panicle differentiation in addition to the final drainage (Said-Pullicino D., 2023[a]). EFs for the two seeding types do not need SFs because they are already included (Said-Pullicino D., 2023[b]). The cultivation techniques used since 2012 (the scientific studies supporting the new factors refer to field measurements taken in the years 2012, 2013, 2014, 2021, and 2022) are the same as those used in previous years, therefore, it is assumed that the new emission factors can be applied since 2008 (Romani M., Said-Pullicino D. 2023, personal communication).

Assumptions of agronomic practices and parameters used for CH_4 emission estimations are shown in Table 5.33 and Table 5.34, respectively. Total CH_4 emissions for rice cultivation in 2022 were 55.25 Gg.

Table 5.34 Parameters used for estimating CH_4 emissions from rice cultivation in 2022

Rice cultivation water regimes: Intermittently flooded	Delay flooding	Multiple aeration	Multiple aeration
Type of seeding	Dry-seeded	Wet-seeded (*classic*)	Wet-seeded (*red rice control*)
Surface (ha)	145,364	32,876	40,181
Daily EF (kg CH_4 ha^{-1} d^{-1})	1.31	2.45	2.45
Days of cultivation (days)	141	159	159
Seasonal EF (kg CH_4 ha^{-1} yr^{-1})	184.3	389.5	389.5
Methane emissions (Gg)	**26.79**	**12.81**	**15.65**

5.4.3 Uncertainty and time-series consistency

Uncertainty of emissions from rice cultivation has been estimated equal to 11.2% as a combination of 5% and 10% for activity data and emissions factor, respectively. Lack of experimental data and knowledge about the occurrence and duration of drainage periods in Italy is the major cause of uncertainty. Moreover, it is not easy to quantify the surface where the traditional or the different number of aerations is practiced, which depends on the degree and the type of infestation, and the positive or negative results of the herbicide treatment application (Spanu, 2006).

In 2022, CH_4 emissions from rice cultivation were 26.4% (55.25 Gg CH_4) lower than in 1990 (75.06 Gg CH_4). In Italy, the driving force of CH_4 emissions from rice cultivation is the harvest area and the percentage of single aerated surface (lower CH_4 emission factor). From 1990-2022, the harvest area has increased by 1.4%, from 215,442 ha $year^{-1}$ (1990) to 218,421 ha $year^{-1}$ (2022). The percentage of single aerated surface has increased from 1.0% (1990) to 66.6% (2022). The dry seeded sowing (single aeration) has been widespread since the beginning of the 1990s owing to the simplification of cultivation operations and water management. Moreover, dry seeded sowing allows better production performance than sowing in water in areas with very loose soils. Data on rice cultivation including harvest area with single aeration are provided by the National Rice Institute. In Table 5.35, CH_4 emissions from rice cultivation and harvested area are shown.

Table 5.35 Harvest area and CH_4 emissions from the rice cultivation sector

Year	Harvested area (10^9 m^2 yr^{-1})	CH_4 emissions (Gg)
1990	2.15	75.06
1995	2.15	75.06
2000	2.39	79.56
2005	2.20	66.26
2010	2.24	74.23

Year	Harvested area (10^9 m^2 yr^{-1})	CH_4 emissions (Gg)
2018	2.48	80.53
2019	2.27	69.41
2020	2.20	61.45
2021	2.27	60.58
2022	2.27	59.91

5.4.4 Source-specific QA/QC and verification

Systematic quality control activities have been carried out to ensure completeness and consistency in time series and correctness in the sum of sub-categories. Data entries have been checked several times during the compilation of the inventory. Several QA activities are carried out in the different phases of the inventory process. The quality of the Italian rice emission inventory was verified with the Denitrification Decomposition model (DNDC). Initial results have found a high correspondence between the EFs used for the Italian inventory and those simulated with DNDC model (Leip and Bocchi, 2007).

In particular, the applied methodology has been presented and discussed during several national workshop and expert meeting, collecting findings and comments to be incorporated in the estimation process. All the agriculture categories have been embedded in the overall QA/QC-system of the Italian GHG inventory. In November 2014, the CH_4 emission factors used for the rice cultivation category in the Italian emissions inventory were presented at the 9th Expert Meeting on Data for the IPCC Emission Factor Database (EFDB) and the values were entered into the database.

5.4.5 Source-specific recalculations

The recalculation is due to a number of changes: emission factors were updated from 2008; the percentage of straw incorporated versus straw burned was changed from 2001; the IPCC value for CFOA to estimate SFo was changed from 2001 to 2007, from 1 to 0.29, related to the period in which straw is incorporated (before or after 30 days of tillage); the rice production figure for the years 2019-2021 was updated.

5.4.6 Source-specific planned improvements

Provincial estimations based on the relation between emissions and temperature would result in further possible improvements, even if enhancement would be limited since the largest Italian rice production is in the Po valley, where monthly temperatures of the rice paddies are similar. In 1990, *Piemonte* and *Lombardia* regions represented 95% of the national surface area of rice cultivation, while in 2016 they represented 93% (ENR, several years [b]; Confalonieri and Bocchi, 2005).

5.5 Agriculture soils (3D)

5.5.1 Source category description

In 2022, N_2O emissions from managed soils were 30.1 Gg, representing 82.2% of N_2O emissions for the agriculture sector (80.3% in 1990) and 50.7% for national N_2O emissions (42.0% in 1990). N_2O emissions from this source consist of direct emissions from managed soils (23.21 Gg) and indirect emissions from managed soils (6.88 Gg).

Direct and indirect N_2O emissions from managed soils are key sources at level assessment, both with Approach 1 and Approach 2. Direct N_2O emissions from managed soils are also key sources at trend assessment, with Approach 2 including LULUCF categories.

For direct emissions from managed soils the following sources are estimated: inorganic nitrogen fertilizers; organic nitrogen fertilizers, which include animal manure applied to soils, sewage sludge applied to soils, other organic fertilizers applied to soils (as compost and other organic amendments used as fertiliser); urine and dung deposited by grazing animals; crop residues; cultivation of organic soils (i.e. histosols). Mineralised nitrogen resulting from loss of soil organic C stocks in mineral soils through land-use change or management practices (F_{SOM}) has been assumed as not applicable; agricultural practices result in no losses of carbon in cropland remaining cropland and therefore these do not generate N_2O emissions, as reported in the 2006 IPCC Guidelines.

For indirect emissions from managed soils, atmospheric deposition and nitrogen leaching and run-off are estimated. Nitrous oxide emissions from grazing animals are calculated together with the manure management category based on nitrogen excretion and reported in agricultural soils under "Urine and dung deposited by grazing animals" (see Table 5.36).

CH_4 emissions from managed soils have not been estimated as in the IPCC Guidelines the methodology is not available.

Table 5.36 N_2O emissions from managed soils (Gg)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Direct N_2O emissions from managed soils	**29.26**	**32.39**	**31.78**	**30.13**	**25.14**	**25.80**	**25.65**	**28.47**	**27.28**	**23.21**
Inorganic N fertilizers	11.63	12.23	11.99	11.94	7.95	7.82	7.03	8.76	8.15	4.41
Organic N fertilizers	8.56	8.44	8.33	7.82	7.83	8.70	8.79	9.47	9.20	9.71
a. Animal manure applied to soils	8.22	8.03	7.80	7.33	7.02	7.25	7.34	7.43	7.37	7.21
b. Sewage sludge applied to soils	0.08	0.13	0.17	0.14	0.16	0.13	0.11	0.11	0.11	0.11
c. Other organic fertilizers applied to soils	0.26	0.28	0.35	0.35	0.65	1.31	1.34	1.93	1.73	2.39
Urine and dung deposited by grazing animals	3.09	3.50	3.60	2.71	2.71	2.57	2.55	2.56	2.49	2.43
Crop residues	5.67	7.90	7.55	7.34	6.34	6.40	6.97	7.38	7.13	6.36
Cultivation of organic soils	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Indirect N_2O emissions from managed soils	**9.56**	**10.00**	**9.82**	**9.46**	**7.77**	**7.74**	**7.89**	**8.77**	**8.43**	**6.88**
Atmospheric deposition	3.13	3.08	2.98	2.77	2.25	2.32	2.24	2.53	2.41	1.89
Nitrogen leaching and run-off	6.43	6.91	6.84	6.69	5.52	5.42	5.65	6.24	6.03	4.99

ISPRA is in charge of collecting, elaborating and reporting the UNFCCC/CLRTAP agriculture national emission inventory, thus, consistency among methodologies and parameters is ensured. The nitrogen balance, from the CLRTAP emission inventory, feeds the UNFCCC inventory, specifically for the estimation of: $Frac_{GasMS}$ parameter, used for calculating managed manure nitrogen available for application to managed soils (Equation 10.34 of 2006 IPCC Guidelines, volume 4, chapter 10) and to assess F_{AM}; $Frac_{GASM}$ and $Frac_{GASF}$ parameters, used for calculating indirect N_2O emissions from atmospheric deposition of nitrogen volatilised from managed soils (Equation 11.9 of 2006 IPCC Guidelines). Direct and indirect N_2O emissions from the use of sewage sludge in agricultural soils have been estimated and reported.

5.5.2 Methodological issues

Methodologies used for estimating N_2O emissions from "Agricultural soils" follow the IPCC approach (Tier1). IPCC emission factors (IPCC, 2006, volume 4, chapter 11) and assessed by the Research Centre on Animal Production (CRPA, 2000; CRPA, 1997[b]) are used. Activity data used for estimations are shown in Table 5.37.

Table 5.37 Data used for estimating agricultural soil emissions

Data	Reference
Fertilizer distributed (t/yr)	ISTAT, several years [a], [b], [i]
Nitrogen content (t)	ISTAT, several years [a], [b], [i]
N excretion rates (kg $head^{-1}$ yr^{-1})	CRPA, 2006[a]; GU, 2006; Xiccato *et al.*, 2005
Livestock data	ISTAT, several years [a], [b], [g]
Cultivated surface (ha yr^{-1})	ISTAT, several years [a], [b], [j]
Annual crop production (t yr^{-1})	ISTAT, several years [a], [b], [j]
Residue/crop product ratio by crop type	CESTAAT, 1988; ENEA, 1994
Crop residue production (t dry matter $ha^{-1}yr^{-1}$)	CRPA/CNR, 1992; ENEA, 1994
Dry matter of the residue and product by crop type	CESTAAT, 1988; CRPA/CNR, 1992; EPIC, 2015; IPCC, 2006
Protein content in dry matter by crop type	CESTAAT, 1988

The estimation of direct N_2O emissions from managed soils has been carried out in line with the IPCC guidelines (IPCC, 2006), taking into account country-specific peculiarities; N_2O-N emissions are estimated from the amount of: inorganic nitrogen fertilizers (F_{SN}); organic nitrogen fertilizers (F_{ON}), which include animal manure applied to soils (F_{AM}), sewage sludge applied to soils (F_{SEW}), other organic fertilizers applied to soils (as compost and other organic amendments used as fertiliser, F_{COMP} and F_{OOA} respectively); urine and dung deposited by grazing animals (F_{PRP}); crop residues (F_{CR}); cultivation of histosols (F_{OS}). Then default IPCC emission factors (IPCC, 2006, volume 4, chapter 11) are applied. Afterwards, N_2O-N emissions are converted to N_2O emissions, multiplying by the ratio of molecular weights (44/28). Urine and dung deposited by grazing animals emissions are estimated according to the methodology described in section 5.3.2 for manure management.

Direct N_2O emissions from N inputs to managed soils include also emissions related to the application of fertilizers to the short rotation forest crops, according the 2006 IPCC Guidelines (IPCC, 2006, par. 11.2.1.3, vol. 4, chapter 11) and consistently with the KP Supplement (IPCC, 2014, par. 2.4.4.2). Indirect emissions are estimated as suggested by the IPCC (IPCC, 2006).

Direct N_2O emissions from managed soils

Applied synthetic fertilizers (F_{SN})

The total use of synthetic fertilizers (expressed in t N $year^{-1}$) is estimated for each type of fertilizer (see Table 5.38). Data on synthetic fertilizers are from ISTAT as reported in paragraph 5.1.3, 5.1.4 and 5.5.2. N-N_2O emissions from synthetic fertilizers are obtained multiplying F_{SN} by the emission factor, 0.01 kg N-N_2O/kg N (IPCC, 2006). The subcategory "Other nitrogenous fertilizers" was introduced since 1998, because activity data is available from that year (ENEA, 2006).

The amount of nitrogen from synthetic fertilizers applied to areas planted with rice was also estimated. The figure used for the estimate of 127 kg N/hectare (Zavattaro *et al.*, 2004) was confirmed by the experts of the National Rice Institute (ENR). This value was multiplied by the area cultivated with rice and the result was subtracted from the quantity of N reported by ISTAT. The emission factor of 0.003 kg N-N_2O/kg N (IPCC, 2006) was used to estimate N_2O due to rice fertilization. The time series of nitrogen content of fertilizers is shown in Table 5.45. In 2022, the total use of synthetic fertilizers was 299,788 t N (see Table 5.38).

Table 5.38 Total use of synthetic fertilizer in 2022 (t N yr^{-1})

Type of fertilizers	Fertilizers distributed (t yr^{-1})	Nitrogen content (%)	Nitrogen content of synthetic fertilizers (t N yr^{-1})
Ammonium sulphate	70,131	20.3%	14,261
Calcium cyanamide	14,591	18.0%	2,628
Nitrates (*)	74,667	20.8%	15,543
CAN	117,766	27.0%	31,797
Urea	297,652	45.4%	135,156
Other nitric nitrogen	74,681 (**)	29.5%	2,224
Other ammoniacal nitrogen			6,415
Other amidic nitrogen			13,394
Phosphate nitrogen	132,080	15.1%	19,983
Potassium nitrogen	41,067	17.5%	7,181
NPK nitrogen	203,873	13.8%	28,166
Organic mineral	228,633	10.1%	23,040
Total	**1,255,141**		**299,788**

(*) includes ammonium nitrate < 27% and ammonium nitrate > 27% and calcium nitrate; (**) this amount refers to the total of other nitrogenous fertilizers, which includes other nitric, ammoniacal and amidic N fertilizers distributed. Total amount of N in these fertilizers is 22,033 t N/year, which is the sum of values reported in the column Nitrogen content of synthetic fertilizers for these three fertilizers considered. The nitrogen content (%) is calculated by dividing the total amount of N contained to the total amount of other nitrogenous fertilisers distributed.

The information on amount fertilizers distributed (tonnes/year) and nitrogen contained in the fertilizers (tonnes N/year) are collected by the ISTAT based on annual questionnaires sent to Italian companies that distribute fertilizers to wholesale and/or retail commercial structures, to farmers, cooperatives, etc. Data on nitrogen content (%) reported in table 5.38 are calculated values based on two above-mentioned amounts and are not directly used in the estimations of N_2O emissions from inorganic fertilizers applied to soils. The methodology for estimating the amount of CAN used and the nitrogen content is given in section 5.9.2.

The time series of applied synthetic fertilisers is shown in Table 5.39. A strong decrease is observed in the years from 2009 to 2011 as result from the official statistics provided by the National Institute of Statistics (ISTAT), due to the economic crisis in particular for urea applied to soils. In 2012, a recovery from the sharp decline was recorded.

Table 5.39 Trend of annual amount of synthetic fertiliser N applied to soils (t N yr-1)

Year	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
F_{SN} (t N)	759,510	799,614	782,701	779,846	528,029	517,854	466,842	577,451	538,893	299,788

Applied organic N fertilisers (F_{ON})

The amount of organic N inputs applied to soils other than by grazing animals is calculated using Equation 11.3 of the 2006 IPCC Guidelines. This includes applied animal manure (F_{AM}), sewage sludge applied to soil (F_{SEW}) and other organic amendments (F_{OOA}), which also includes compost applied to soils (F_{COMP}).

Table 5.40 Trend of applied organic N fertilisers (t N yr^{-1})

Year	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
F_{AM} (t N)	523,353	510,987	496,514	466,490	446,988	461,594	467,314	472,581	468,771	458,702
F_{SEW} (t N)	5,071	8,137	10,954	8,874	10,040	8,303	6,791	7,078	6,745	6,950
F_{OOA} (t N)	16,518	18,116	22,571	22,308	41,125	83,535	85,554	122,688	110,087	152,016

Animal manure N applied to soil (F_{AM})

The annual amount of animal manure N applied to soils is calculated using Equation 11.4 of the 2006 IPCC Guidelines (IPCC 2006, vol. 4, chapter 11). The amount of managed manure nitrogen available for soil application is calculated using Equation 10.34 (IPCC 2006, vol. 4, chapter 10). The amount of managed manure nitrogen in manure management systems is estimated as reported in paragraph 5.3.2 "Direct N_2O emissions from manure management" and country-specific nitrogen excretion rates (CRPA, 2006[a]; GU, 2006; Xiccato *et al.*, 2005) are used. $Frac_{LossMS}$ parameter of the Equation 10.34 is equal to:

- the managed manure nitrogen that volatilises as NH_3 and NO_x in the manure management systems (i.e. the $Frac_{GasMS}$ emission factor);
- the nitrogen losses from leaching and run-off at housing and storage sistems;
- the losses of N_2, that are considered in response to the 2018 ESD review process[23];
- the nitrogen lost through N-NH_3 emissions from digesters biogas facilities (during storage of feedstock on the premises of the biogas facility; during open storage of the digestate);
- the losses of N-N_2O in the manure management systems.

A description of the country specific $Frac_{GasMS}$ parameter and the nitrogen leaching and run-off is reported in paragraph 5.3.2 "Indirect N_2O emissions from manure management". On the basis of the data on the quantity of straw per day (per tonnes of live weight, per type of housing, for cattle and buffalo), contained in the Ministerial Decree of 25 February 2016 on the use of zootechnical effluents, combined with the manure production coefficients used in the estimation of methane emissions from storage, the quantity of straw used as bedding that ends up on agricultural land during the spreading of manure was estimated. The nitrogen content was considered and was added to the nitrogen input from manure applied to soils for N_2O emissions estimate. Further information and data can be found in the Annex 7.3. The description of the agricultural residues used for bedding material considered in the animal manure applied to soils (3Da2a) category, which also involves the crop residues (3Da4) and field burning of agricultural residues (3F) categories, is reported in the Annex 7.3. To enhance transparency on the total amount of crop residues generated and shares of the crop residue amounts used for different purposes (such as bedding material (3.D.a.2.a), left on fields (3.D.a.4), burnt on-site (3.F) and off-site (1.A, 5.C.2)), a flow-chart is reported in Annex 7, in Figure A.7.1.

$Frac_{FEED}$, $Frac_{FUEL}$ and $Frac_{CNST}$ parameters of the Equation 11.4 are assumed equal to zero.

The F_{AM} (t N yr^{-1}) value is estimated by summing the F_{AM} for each livestock category; then emissions are calculated with emission factor 0.01 kg N-N_2O/kg N (IPCC, 2006). In 2022, F_{AM} parameter was 458,702 t N.

Sewage sludge applied to soils (F_{SEW})

Direct and indirect N_2O emissions from the application of sewage sludge to agricultural soils were calculated using the Tier 1 methodology described in the IPCC (IPCC, 2006). Direct emissions were estimated by applying the relevant default IPCC equations, EFs and parameters (see Annex A7.3). From 1995 activity data (amount of sewage sludge) and parameters (N content) were collected from the Ministry for the Environment, Land and Sea, which is in charge of collecting and reporting data under the EU Sewage Sludge Directive 86/278/EEC (MATTM, several years). From 1990 to 1994 AD and parameters were reconstructed, description is available in the Waste Chapter. The amount of sewage N applied was calculated using the amount of sewage sludge (expressed in t dry matter) and the N content of sludge. Emission factor used was 0.01 kg N-N_2O/kg N (IPCC, 2006).

Other organic amendments applied to soils (F_{OOA}) (*including compost N applied to soils* (F_{COMP}))

[23] The 2018 annual review of the GHG emission inventory of Italy, pursuant to Article 19(2) of Regulation (EU) No 525/2013, with a view to monitoring Italy's achievement of its greenhouse gas emission reduction or limitation target pursuant to Article 3 of Decision No 406/2009/EC (the 'Effort Sharing Decision', ESD).

For the other organic fertilizers applied to soil category, the used amount, including compost and organic amendments, and N content are provided by ISTAT (as reported in the paragraph 5.1.3, 5.1.4 and 5.5.2). Data are available from 1998; for the previous years, data were reconstructed based on the trend of the available data.

Urine and dung from grazing animals (F_{PRP})

The annual amount of N deposited on pasture is calculated using Equation 11.5 (IPCC 2006, vol. 4, chapter 11). As mentioned in section 5.3.2, when estimating N_2O emissions from manure management, the amount related to manure excreted while grazing is subtracted and reported in "Agricultural soils" under urine and dung from grazing animals. In Table 5.25, nitrogen excretion rates (kg head^{-1} yr^{-1}) used for estimations are shown. N_2O emissions are estimated with the total nitrogen excreted from grazing (include all livestock categories), number of animals, an EF for cattle (dairy, non-dairy and buffalo) of 0.02 kg N_2O-N/kg N excreted and an EF for sheep and other animals (goats, horses and mules and asses) of 0.01 kg N_2O-N/kg N excreted (IPCC, 2006). As recommended during the 2021 UNFCCC review, N_2O direct emissions for ostriches are estimated and reported in the IPCC category urine and dung deposited by grazing animals because the common rearing system for ostriches is free-range outdoor housing. Activity data are provided by ISTAT for some years and for the other years the number of animals has been estimated. The default value for nitrogen excretion rate for broilers (Table 10.19 of chapter 10, volume 4 of the 2006 IPCC Guidelines) has been used. The 2006 IPCC N_2O EF for direct emissions has been used (Table 11.1 of chapter 11, volume 4 of the 2006 IPCC Guidelines).

Table 5.41 Trend of annual amount of urine and dung N deposited by grazing animals on pasture (t N yr^{-1})

Year	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
F_{PRP} (t N)	176,718	204,710	211,343	156,521	157,462	147,895	146,538	147,251	142,660	139,237

Crop residue N, including N-fixing crops and forage, returned to soils (F_{CR})

For the estimation of nitrogen input from crop residues, the IPCC methodology is used with country specific data on aboveground residue/crop product ratio, percentage of the residue fixed and dry matter content. The total amount of crop aboveground residues is estimated (t dry matter yr^{-1}) by using the following parameters: annual crop production (t yr^{-1}), aboveground residue/crop product ratio, percentage of the residue fixed and dry matter content of residue by type of crop (%), while, when cultivated surface (ha) is the available activity data, only the crop residue production (t dry matter ha^{-1} yr^{-1}) parameter is used to assess total amount of crop aboveground residues (CESTAAT, 1988; CRPA/CNR, 1992; ENEA, 1994). Data on annual crop production and cultivated surface are from ISTAT as reported in paragraph 5.1.3, 5.1.4 and 5.5.2. The description of the agricultural residues used for bedding material considered in animal manure applied to soils (3Da2a), which also involves the categories crop residues (3Da4) and field burning of agricultural residues (3F), is reported in the Annex 7.3. The description of the type of agricultural residues is also included. To enhance transparency on the total amount of crop residues generated and shares of the crop residue amounts used for different purposes (such as bedding material (3.D.a.2.a), left on fields (3.D.a.4), burnt on-site (3.F) and off-site (1.A, 5.C.2)), a flow-chart is reported in Annex 7, in Figure A.7.1.

The nitrogen content of crop aboveground residues from cereals, legumes, tubers and roots, legumes forages and other forages (t N yr^{-1}) is estimated by multiplying the total amount of crop aboveground residue as dry matter with the reincorporated fraction (1- $Frac_{BURN}$, where $Frac_{BURN}$ is the fraction of crop residue that is burned rather than left on field equal to 0.1 kg N/kg crop-N (IPCC, 1997; CRPA, 1997[b])), and the nitrogen content for each crop type, in line with the Equation 11.6 (IPCC 2006, vol. 4, chapter 11). The nitrogen content is obtained by converting protein content in dry matter (CESTAAT, 1988; Borgioli, 1981), dividing by factor 6.25 (100 g of protein/16 g of nitrogen). The contribution of the below-ground nitrogen to the total input of nitrogen from crop residues has been considered and calculated by using the Equation 11.7A (IPCC 2006, vol. 4, chapter 11) and the IPCC default values of ratio of belowground residues to above-ground biomass and N content of below-ground residues. The amount of nitrogen of crop residues from perennial grasses is calculated by using the Equation 11.7A (IPCC 2006, vol. 4, chapter 11). The values related to N content of aboveground residues, ratio of belowground residues to aboveground biomass and N content of belowground residues used for other temporary forages are weighted averages of the IPCC values in Table 11.2, weighted with the productions of the various crops included in the category other temporary forages. The values used for the $Frac_{renew}$ parameter for other temporary forages (not renewed annually) are derived from Baldoni and Giardini (Baldoni and Giardini, 2002) and the value for perennial grasses is from ISTAT (ISTAT, 2010).

The F_{CR} parameter is obtained by adding the nitrogen content of cultivars crop residues. In 2022, F_{CR} parameter was 404,650 t N (see Table 5.42). Emissions are calculated with emission factor 0.01 kg N-N_2O/kg N (IPCC, 2006).

Detailed information related to the cultivated surfaces, crops production, residues production and parameters used for emissions estimates, for each type of crop, are shown in the Annex 7 (Tables A.7.17-22).

Table 5.42 Trend of annual amount of N in crop residues (t N yr^{-1})

Year	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
F_{CR} (t N)	360,563	502,989	480,180	467,328	403,187	407,073	443,737	469,430	453,752	404,650

Area of drained/managed organic soils (F_{OS})

In Italy, the area of organic soils cultivated annually (histosols) is estimated to be 24,285 hectares for the year 2019, a substantially constant value for the whole time series (FAOSTAT database[24]). This value is multiplied by 8 kg N-N_2O ha^{-1} yr^{-1}, following IPCC 2006 Guidelines (IPCC, 2006).

The data are consistent with figures used for estimation in the LULUCF sector. Additional information may be found in paragraph *6.3.4 Methodological issues* of the LULUCF sector.

Indirect N_2O emissions from managed soils

For indirect emissions from agricultural soils the following parameters are estimated:

- Atmospheric deposition
- Nitrogen leaching and run-off

For estimating N_2O emissions due to atmospheric deposition of NH_3 and NO_x the IPCC tier 1 approach was followed (Equation 11.9 of the 2006 IPCC Guidelines). Parameters used are: total use of synthetic fertilizer F_{SN} (t N yr^{-1}), $Frac_{GASF}$ emission factor, total amount of organic N inputs applied to soils F_{ON} (t N yr^{-1}), total amount of urine and dung N deposited by grazing animals F_{PRP} (t N yr^{-1}), $Frac_{GASM}$ emission factor and the emission factor 0.01 kg N_2O-N per kg NH_3-N and NO_x-N emitted (IPCC, 2006).

$Frac_{GASF}$ parameter is estimated for the whole time series, following the IPCC definition, where the total N-NH_3 and N-NO_x emissions from fertilizers are divided by the total nitrogen content of fertilizers (see table 5.43). NH_3 EFs from the use of synthetic fertilizers for normal and high pH factors (reported in the EMEP/EEA Guidebook (EMEP/EEA, 2023)) have been updated. To calculate a weighted average of emission factors distinguished according to soil pH type, CREA-AA[25] processed the national agricultural areas distinguished according to eight soil pH classes, finally calculating the area percentages for normal

[24] http://www.fao.org/faostat/en/#data/GV

[25] Council for Agricultural Research and Analysis of Agricultural Economics - Agriculture and Environment

and high pH (Rivieccio R., 2019). NO_x emission factor for synthetic N-fertilizer (reported in the EMEP/EEA Guidebook (EMEP/EEA, 2023)) was also updated. $Frac_{GASM}$ is the fraction of applied organic N fertiliser materials (F_{ON}) and of urine and dung N deposited by grazing animals (F_{PRP}) that volatilises as NH_3 and NO_x.

$Frac_{GASM}$ is then composed of the following fractions:

- Fraction of livestock N excretion that volatilizes as NH_3 and NO_x during spreading and grazing animals - $Frac_{GASM}$ indirect (as reported in the CRF). This fraction is equal to the ratio between the amount of NH_3-N and NO_x-N emissions and the total nitrogen excreted (see table 5.43);
- Fraction of N from other organic N fertilizers applied (sewage sludge, other organic amendments applied to soils including compost) that volatilizes as NH_3 and NO_x. The volatilization factor for N-NH_3 and NO_x-N emissions is 7.8% for other organic N fertilizers and 11.9% for sewage sludge applied, as reported in table 5.43.

For $Frac_{GASM}$ indirect, the ammonia emission factors from land spreading for cattle, swine, laying hens and broilers categories have been assessed, on the basis of ISTAT statistics on spreading systems (i.e. 2010 Agricultural Census, 2013 and 2016 Farm Structure Survey). NO_x emission factors (during spreading) were also assessed based on the nitrogen mass-flow approach (Tier 2 method of the EMEP/EEA Guidebook (EMEP/EEA, 2023)). NH_3 and NO_x emission factors from other organic N fertilizers applied (sewage sludge, other organic amendments applied to soils including compost) were also updated based on the EMEP/EEA Guidebook (EMEP/EEA, 2023).

The estimation of N_2O emissions due to nitrogen leaching and run-off has followed the IPCC Tier 1 approach (Equation 11.10 of the 2006 IPCC Guidelines). Parameters used are: total use of synthetic fertilizer F_{SN} (t N yr^{-1}), total amount of organic N inputs applied to soils F_{ON} (t N yr^{-1}), total amount of urine and dung N deposited by grazing animals F_{PRP} (t N yr^{-1}), total amount of N in crop residues (above- and below-ground), including N-fixing crops and from forage F_{CR} (t N yr^{-1}), $Frac_{LEACH-(H)}$ emission factor 0.27 kg N/kg nitrogen of fertilizer or manure (see table 5.43) and the emission factor 0.0075 kg N_2O-N per kg nitrogen leaching/run-off (IPCC, 2006). As mentioned before, the $Frac_{LEACH-(H)}$ IPCC default value was compared with the country-specific $Frac_{LEACH-(H)}$ parameter (ADBPO, 2001; ADBPO, 1994).

The estimate of N lost through leaching and run-off includes the losses of N due to leaching from managed soils. As regards the $Frac_{LEACH-(H)}$, according to the 2006 IPCC Guidelines, the leached nitrogen has to be estimated only in those areas where there is a water surplus or where irrigation is employed. For the agricultural areas affected by the water surplus, the $Frac_{LEACH-(H)}$ is assumed equal to 0.3 kg N/kg N applied to soils or deposited by grazing animals, while a value equal to zero is assumed for the agricultural areas affected by the water deficit. To calculate the agricultural area affected by hydrological surplus, the following procedure was followed. The methodology involves estimating the annual hydrologic surplus of areas below 1,000 meters, which are assumed to be agricultural areas. Monthly surplus values are derived from the Big Bang model elaborated by ISPRA (Braca G. *et al*, 2023), whose data are in Ascii format and the coordinate system is ETRS_1989_LAEA (Braca G. *et al*, 2021). The calculation is made in GIS environment with the help of the raster of the altimetry and the vector files (shape files) of land use categories (Corine Land Cover 2018). The surplus in each cell (which has a size of 1 km x 1 km) was calculated by summing the values of only the rainy months (October November and December) of each year (the range of values obtained varies from 0.0001 to over 1500 millimeters) from 1990 to 2022. The sum of the three months of each year was then multiplied by a boolean raster of the elevations (values 0 if above 1000 meters, 1 if below). In this way, areas above 1000 meters were excluded from the calculation. Agricultural land corresponds to the following Corine Land Cover categories: 211, 212, 213, 221, 222, 223, 231, 241, 242, 243, 244, 321, 333, corresponding to the categories "grassland" and "cropland" defined according to the IPCC. Again, a boolean raster was created (values 0 for unselected categories, 1 for selected categories). Finally, cells where a surplus occurs were considered and the total area of these cells was calculated for each year. The result was related to the total area of land below 1000 meters of altitude. The weighted average value of $Frac_{LEACH-(H)}$ relative to the entire national agricultural area will be equal 29.0% of nitrogen applied to soils or deposited by grazing animals for 2022.

Table 5.43 Parameters used for the estimation of indirect N_2O emissions from managed soils

	Atmospheric deposition					N leaching and run-off	
Year	$Frac_{GASF}$ (1) (%)	$Frac_{GASM}$ indirect (2) (%)	Fraction of N from other organic N fertilizers applied (%) (3)	Fraction of N from from sewage sludge applied (%)(4)	N volatilised from managed soils (t N)	$Frac_{LEACH-(H)}$ (5) (kg N/kg N)	N lost through leaching and run-off (t N)
1990	13.46	10.24	7.8	11.9	199,314	0.30	545,307
1995	13.03	9.61	7.8	11.9	196,261	0.29	586,449
2000	13.12	9.08	7.8	11.9	189,364	0.29	580,756
2005	12.89	8.92	7.8	11.9	176,213	0.30	567,476
2010	12.87	8.94	7.8	11.9	143,214	0.29	468,090
2015	13.69	8.82	7.8	11.9	147,404	0.28	459,790
2019	14.09	8.88	7.8	11.9	142,551	0.30	479,332
2020	13.95	8.91	7.8	11.9	161,019	0.29	529,675
2021	13.81	8.95	7.8	11.9	153,113	0.30	511,268
2022	13.29	8.97	7.8	11.9	120,297	0.29	423,062

Note: (1) the fraction is multiplied by F_{SN} (see Table 5.39); (2) the fraction is multiplied by total N excreted (see Table 5.27); (3) the fraction is multiplied by F_{OOA} (see Table 5.40); (4) the fraction is multiplied by F_{SEW} (see Table 5.40); (5) the fraction is multiplied by F_{SN}, F_{SEW}, F_{OOA}, F_{AM} and by F_{CR} (see Table 5.42).

N_2O indirect emissions for ostriches are estimated and reported in indirect N_2O emissions from managed soils, in atmospheric deposition and nitrogen leaching and run-off. Further details on the estimate are given in 5.5.2 *Methodological issues* paragraph, in Direct N_2O emissions from managed soils, in *Urine and dung from grazing animals* (F_{PRP}). The 2006 IPCC N_2O EFs, $Frac_{GASM}$ and $Frac_{LEACH-(H)}$ for indirect emissions have been used (Table 11.3 of chapter 11, volume 4 of the 2006 IPCC Guidelines).

5.5.3 Uncertainty and time-series consistency

Uncertainty for N_2O direct and indirect emissions from managed soils has been estimated to be 53.9%, as combination of 20% and 50% for activity data and emission factor, respectively.

In Table 5.44, time series of N_2O emissions from managed soils are reported.

Table 5.44 Nitrous oxide emission trends from managed soils (Gg)

Year	Direct emissions from managed soils	Indirect emissions from managed soils	Total
		Gg	
1990	29.26	9.56	**38.82**
1995	32.39	10.00	**42.39**
2000	31.78	9.82	**41.60**
2005	30.13	9.46	**39.58**
2010	25.14	7.77	**32.90**
2015	25.80	7.74	**33.53**
2019	25.65	7.89	**33.54**
2020	28.47	8.77	**37.24**
2021	27.28	8.43	**35.71**
2022	23.21	6.88	**30.08**

In 2022, N_2O emissions from managed soils were 22.5% (30.08 Gg N_2O) lower than in 1990 (38.82 Gg N_2O). Major contributions were given by direct emissions (23.21 Gg), that come mainly (77.4%) from animal manure applied to soils (7.21 Gg), crop residues returned to soils (6.36 Gg) and inorganic N fertilizers (4.41 Gg) (see Table 5.36). Indirect emissions (6.88 Gg) are mainly (57.7%) due to N_2O emissions from nitrogen leaching and run-off from animal manure applied to soils (1.57 Gg), crop residues returned to soils (1.38 Gg) and inorganic N fertilizers (1.02 Gg) (see Table 5.36). As regards inorganic N fertilizers N_2O emissions from leaching and run-off are related to the nitrogen content in fertilizers, therefore emissions are mainly linked to the use of N fertilizers trend. Between 1996 and 1997 there was a high increase in the use of nitrogen fertilizers in Italy, thus, emissions could be identified as outlier. Between 2007/2008 (-14%) and 2008/2009 (-21%) N fertiliser distribution has decreased. In 2010 the same trend was observed. According to the Italian Fertilizer Association (AIF) the use of fertilisers is determined by their cost and particularly by the price of agricultural products. In the last years, prices have decreased and, as a result, farmers need to save costs, consequently, less fertilisers is being used (Perelli, 2007; De Corso 2008). The 12% reduction in urea used in 2021 compared to 2020 is mainly due to the increase in the cost of raw materials (natural gas), which led the main domestic producer to suspend production for some time during the year. In addition, production was suspended due to a plant shutdown for maintenance. The 2022 data are lower than annual average (for nitrogen, phosphorus pentoxide, and potassium oxide) because they follow a two-year period in which quantities purchased increased and refer to a year in which high market prices prompted operators to delay purchases in anticipation of falling prices, an event, which occurred during 2023.

5.5.4 Source-specific QA/QC and verification

Synthetic fertilizers and nitrogen content are compared with the international FAO agriculture database statistics (FAO, several years). In Table 5.45, national, FAO and EUROSTAT time series of total nitrogen applied are reported. Differences between national data and FAO database are related to the difference in data elaboration (ISTAT, 2004) and could be attributed to different factors. First, national data are more disaggregated by substance than FAO data and the national nitrogen content is considered for each substance, while FAO utilizes default values. Besides, differences could also derive from different products classification. As regards EUROSTAT data, the amount of nitrogen annually consumed for the growth of plant productions is estimated from the area and annual production of each crop and the amount of nitrogen required for the growth of a plant. In Table 5.45 the two databases are presented.

Table 5.45 Total annual N content in fertilizer applied from 1990 to 2022

Year	ISTAT National data (t N)	FAO database (Nitrous fertilizer consumption, t N) (*)	EUROSTAT database (Consumption of inorganic fertilizers, t N)
1990	759,510	878,960	
1995	799,614	875,000	
2000	782,701	828,000	599,471
2005	779,846	800,697	593,008
2010	528,029	498,605	586,130
2015	517,854	605,236	579,728
2019	466,842	598,544	574,530
2020	577,451	574,530	573,473
2021	538,893	572,105	572,105
2022	299,788	data not available	data not available

(*) Unofficial/official figures or from international organizations

In 2021, a technical report (CREA, 2021) produced by CREA (Council for Agricultural Research and Economics), in collaboration with ISPRA, on the assessment of emissions related to the use of nitrogen fertilizers was published, which contains several analyses of nitrogen fertilizer consumption data from different data sources: IFASTAT/Fertilizer Europe, FAO, EUROSTAT, Assofertilizzanti, National Integrated Production Specifications, Farm Accountancy Data Network (FADN). These analyses suggest further investigation to better understand the differences found between these data sources and the ISTAT data used for the estimates.

Data on national sales of synthetic nitrogen fertilizers (by type of fertilizers) as provided by *Assofertilizzanti* for the period 2011-2022 have been compared to official statistics provided by ISTAT. ISTAT simple mineral nitrogen fertilizers data are about 15% lower than those of *Assofertilizzanti*, for the years 2011-2022. These differences in recent years could be attributable to rising fertilizer prices. ISTAT statistics almost certainly do not take into account that farmers tend to anticipate purchases (and thus stockpile) when expectations of rising market prices are present. The 2022 data are lower than annual average (for nitrogen, phosphorus pentoxide, and potassium oxide) because they follow a two-year period in which quantities purchased increased and refer to a year in which high market prices prompted operators to delay purchases in anticipation of falling prices, an event, which occurred during 2023.

In 2015, data on crop residues and, in particular, on the relationship between crop residues and product were compared with studies and research provided by the Agricultural Research Council (CRA)[26]. However, these studies were conducted in different countries from Italy, so despite the differences, the values used in the inventory, based on national studies, have not been changed.

Following the suggestion of the CRA experts, in the estimation of N_2O emissions from crop residues, the total amount of residues has been considered, without deducting the fraction removed for purposes such as feed, bedding and construction. Therefore, the data were revised using the fixed residues/removable residues ratio for each crop considered (ENEA, 1994), also used to estimate the emissions from category 3F (see paragraph 5.6.2).

Concerning compost data, from waste sector only data on compost production are available. Official statistics provided by ISTAT on compost used in agriculture sector (considered as the green and mixed amendments) are compared to data on compost from waste sector. For the year 2015, the amount of compost used is 58.1% of the compost production only from plants that treat a selected waste.

As regards $Frac_{LEACH-(H)}$, Italy verified that the IPCC default is similar to the country-specific reference value reported from the main regional basin authority - Po Valley (ADBPO, 2001; ADBPO, 1994).

At the end of 2016, in response to the UNFCCC review process, experts on land use and wheater climate were contacted to investigate on the $Frac_{LEACH-(H)}$ fulfilment to criteria set out in the 2006 IPCC Guidelines.

As regards the sewage sludge applied, the values used are official data provided by the Ministry of the Environment which collects them at the Italian Regions under the EU Sewage Sludge Directive. The annual variations depend on the fact that some Regions prohibit the practice of spreading in certain years, on the basis of weather-climatic, soil and water conditions, and also over the years other types of sludge treatment, such as the anaerobic digestion, have been implemented, to the detriment of the spreading.

In 2020 a working group was set up with *Assofertilizzanti* and ISTAT to compare the statistics produced by these two bodies. Initial results have led to a revision of the data on nitrate consumption in the period 2009-2011 and the estimation of CAN fertiliser consumption.

5.5.5 Source-specific recalculations

As regards for N_2O emissions from agricultural soils, the changes are described below.

The recalculation is due to updating the NH_3 emission factors of synthetic fertilizers, which affects the indirect emissions of N_2O. In addition, N values of synthetics for the year 2016, N values of soil improvers

[26] CRA is a national research organization which operates under the supervision of the Ministry of Agriculture, with general scientific competence within the fields of agriculture, agro-industry, food, fishery and forestry.

for the years 2015 and 2016, N values of other organics for the year 2016 were corrected. Fracleach value from 1990 was updated, which involved recalculation of indirect emissions from leaching/runoff. Sludge data for the years 2018-2021 have been updated. Changes in NH_3 emissions from housing, storage and spreading and those from NOx from storage and spreading affect the recalculation of direct and indirect N_2O emissions from spreading and pasture.

Changes in NH_3 emissions are described below.

Major recalculations of NH_3 emissions are due to: update of NH_3 emission factors from synthetic fertilizers, reported in the EMEP/EEA Guidebook 2023; change in the coefficients of N contained in livestock manure sent to anaerobic digestion of cattle, swine, poultry since 1991; correction of NH_3 EFs from storage for cattle in the years 2003-2005; correction of NH_3 EFs from storage for cattle and pigs since 2014; correction of N values of synthetics for the year 2016, N values of soil improvers for the years 2015 and 2016, N values of other organics for the year 2016.

In addition, emissions from spreading changed throughout the time series as a result of: change in emissions from housing and storage; change in emissions of NH_3 from anaerobic digesters; change in emissions of N_2O from storage; correction of the average weight of the subcategory other cattle < 1 year of 2021 (that affects the NO_2 and N_2 emissions, N leached by manure management and N bedding); change in the distribution of dairy cow housing in the years 2006-2009 goes to affect the allocation of effluent between liquid and solid, which therefore also affects the NO_2 emissions from dairy cow storage years 2006-2009 (and thus N_2 emissions and the estimate of N bedding were also changed); N correction to calves in the years 1990-2015 goes to affect NO_2 emissions storage by non-dairy cattle category (and thus N_2 emissions were also changed).

Minor recalculations are due to: correction of NH_3 EFs from housing for dairy cows for the years 2006-2009; correction of the average weight of the subcategory other cattle < 1 year of 2021; update of the sludge data for the years 2018-2021; correction of the N value of calves (included in 'less than 1 year for the slaughter' non-dairy cattle category) for the years 1990-2015.

Changes in NO_2 emissions are described below.

The recalculation of NO_2 emissions is due to: correction of N values of synthetics for the year 2016, N values of soil improvers for the years 2015 and 2016, N values of other organics for the year 2016; changes in NH_3 emissions from spreading; update of the sludge data for the years 2018-2021; correction of the average weight of the subcategory other cattle < 1 year of 2021; correction of the N value of calves (included in 'less than 1 year for the slaughter' non-dairy cattle category) for the years 1990-2015; change in the distribution of dairy cow housing in the years 2006-2009 goes to affect the allocation of effluent between liquid and solid, which therefore also affects the NO_2 emissions from dairy cow storage years 2006-2009.

5.5.6 Source-specific planned improvements

In the coming years, the Permanent census of agriculture will provide valuable information on animal and agronomic production methods. The focus of the Permanent census is to provide a comprehensive information framework on the structure of the agricultural system and the livestock at national, regional and local level by integrating archive data and carrying out statistical support surveys. Statistical registers will be created with the aim of increasing the quantity and quality of information in order to reduce the response burden and the overall production cost of official statistics[27].

[27] https://www.istat.it/en/permanent-censuses/agriculture

5.6 Field burning of agriculture residues (3F)

5.6.1 Source category description

Methane and nitrous oxide emissions from field burning agriculture residues have not been identified as a key source. In 2022, CH_4 emissions from this source were 0.29 Gg, representing 0.04% of emissions for the agriculture sector. N_2O emissions were 0.008 Gg, representing 0.02% of emissions for the agriculture sector.

5.6.2 Methodological issues

The estimation of emissions from field burning of agriculture residues has been carried out on the basis of the IPCC methodology, using different parameters, such as the amount of residues produced, the amount of dry residues, the total biomass burned, and the total carbon and nitrogen released as reported in Table 5.46.

Table 5.46 Data used for estimating field burning of agriculture residues emissions

Data	Reference
Annual crop production	ISTAT, several years [a], [b], [j]
Removable residues/product ratio	CESTAAT, 1988
Fixed residues/removable residues ratio	ENEA, 1994
Fraction of dry matter in residues	IPCC, 1997; CRPA/CNR, 1992; CESTAAT, 1988; Borgioli, 1981
Fraction of the field where "fixed" residues are burned	IPCC, 1997; CRPA, 1997[b]; ANPA-ONR, 2001; CESTAAT, 1988
Fraction of residues oxidized during burning	IPCC, 2006
Fraction of carbon of dry matter of residues	IPCC, 2006; IPCC, 2019
Raw protein in residues (dry matter fraction)	CESTAAT, 1988; Borgioli, 1981
IPCC default emission rates (CH_4, N_2O)	IPCC, 2006

Activity data (annual crop production of cereals) used for estimating burning of agriculture residues are reported in Table 5.47.

The same methodology is used to estimate emissions from open burning of agriculture residues (burnt off-site). Emissions from fixed residues (stubble), burnt on open fields, are reported in this category (3F) while emissions from removable residues burnt off-site, are reported under the waste sector (open burning of waste - 5C2 category). The description of the agricultural residues used for bedding material considered in animal manure applied to soils (3Da2a), which also involves the categories crop residues (3Da4) and field burning of agricultural residues (3F), is reported in the Annex 7.3. The description of the type of agricultural residues is also included in the Annex 7.3. To enhance transparency on the total amount of crop residues generated and shares of the crop residue amounts used for different purposes (such as bedding material (3.D.a.2.a), left on fields (3.D.a.4), burnt on-site (3.F) and off-site (1.A, 5.C.2)), a flow-chart is reported in Annex 7, in Figure A.7.1.

Table 5.47 Time series of activity data (tons) used for 3F estimations

Year	Wheat	Barley	Maize	Oats	Rye	Rice	Sorghum
	Agricultural production (tons)						
1990	8,108,500	1,702,500	5,863,900	298,400	20,800	1,290,700	114,200
1995	7,946,081	1,387,069	8,454,164	301,322	19,780	1,320,851	214,802
2000	7,427,660	1,261,560	10,139,639	317,926	10,292	1,245,555	215,200
2005	7,717,129	1,214,054	10,427,930	429,153	7,876	1,444,818	184,915
2010	6,849,858	944,257	8,495,946	288,880	13,926	1,574,320	275,572
2015	7,394,495	955,131	7,073,897	261,366	13,183	1,505,804	294,218
2019	6,576,584	1,072,447	6,258,747	238,107	12,509	1,505,099	312,384
2020	6,553,861	1,090,630	6,771,089	242,709	11,475	1,530,921	361,694
2021	7,118,272	1,059,803	6,060,232	233,452	10,886	1,496,545	223,459
2022	6,449,773	1,124,283	4,681,925	242,282	11,409	1,236,962	191,161

The methodology for estimating emissions refers to fixed residues burnt. The same steps are followed to calculate emissions from removable residues burnt off-site reported in 5C. Parameters taken into consideration are the following:

a) Amount of "fixed" residues (t), estimated with annual crop production, removable residues/product ratio, and "fixed" residue/removable residues ratio. This last value is equal to 0.25 for all type of cereals and represents the part of the fixed residue (compared to the removable residue) that remains on the ground.
b) Amount of dry residues in "fixed" residue (t dry matter), calculated with amount of fixed residues and fraction of dry matter.
c) Amount of "fixed" dry residues oxidized (t dry matter), assessed with amount of dry residues in the "fixed" residues, fraction of the field where "fixed" residues are burned, and fraction of residues oxidized during burning.
d) Amount of carbon from stubble burning release in air (t C), calculated with the amount of "fixed" dry residue oxidized and the fraction of carbon from the dry matter of residues.
e) C-CH_4 from stubble burning (t C-CH_4), calculated with the amount of carbon from stubble burning release in air and default emissions rate for C-CH_4, equal to 0.005 (IPCC, 1997).

Data related to the removable residues/product ratio, the "fixed" residue/removable residues ratio, the fraction of dry matter, the fraction of carbon of dry matter of residues are available for each type of cereals.

Fraction of the field where "fixed" residues is burned is 10% (IPCC, 1997; CRPA, 1997[b]) for all crops except for rice, for which the fraction varies as a function of the change in annual percentage of the reincorporated rice straw into the soil (see *straw incorporation* in the methodological issues in rice cultivation (3C) paragraph). CH_4 emissions from on field burning of agriculture residues (0.29 Gg CH_4 in 2022) have been estimated multiplying the C-CH_4 value (0.218 Gg C-CH_4) by the ratio of molecular weights (16/12). In Table 5.48, parameters used for estimating of CH_4 emissions from on field burning of agriculture residues are shown.

Table 5.48 Parameters used for the estimation of CH_4 emissions from agriculture residues in 2022

Crops	Annual crop harvest production (t 1000)	Amount of "fixed" burnable residues (t 1000)	Amount of dry residue in the "fixed" residues (t 1000 dry matter)	Amount of "fixed" dry residues burnt (t 1000 dry matter)	Amount of carbon from stubble burning (t 1000 C)	C-CH_4 from stubble burning (t C-CH_4)
Wheat	6,450	1,113	949	92	35	168

Crops	Annual crop harvest production (t 1000)	Amount of "fixed" burnable residues (t 1000)	Amount of dry residue in the "fixed" residues (t 1000 dry matter)	Amount of "fixed" dry residues burnt (t 1000 dry matter)	Amount of carbon from stubble burning (t 1000 C)	C-CH_4 from stubble burning (t C-CH_4)
Rye	11	2	2	0	0	0
Barley	1,124	225	193	19	7	35
Oats	242	42	36	4	1	7
Rice	1,237	207	155	3	1	5
Maize	4,682	468	195	0	0	0
Sorghum	191	23	19	2	1	3
Total	**13,938**	**2,080**	**1,549**	**120**	**45**	**218**

For estimating N_2O emissions, the same amount of "fixed" dry residue oxidized described above were used; further parameters are:

a) Amount of nitrogen from stubble burning release in air (t N), calculated with the amount of "fixed" dry residue oxidized and the fraction of nitrogen from the dry matter of residues. The fraction of nitrogen has been calculated considering raw protein content from residues (dry matter fraction) divided by 6.25.
b) N-N_2O from stubble burning (t N-N_2O), calculated with the amount of nitrogen from stubble burning release in air and the default emissions rate for N- N_2O, equal to 0.007 (IPCC, 1997).

Data related to the raw protein content from residues (dry matter fraction) is available for each type of cereals. N_2O emissions from field burning of agriculture residues (0.008 Gg N_2O in 2022) are estimated by multiplying the N-N_2O value (0.005 Gg N) by the ratio of molecular weights (44/28).

In Table 5.49 the parameters for the estimation of N_2O emissions from field burning of agriculture residues are shown.

Table 5.49 Parameters used for the estimation of N_2O emissions from agriculture residues in 2022

Crops	Amount of "fixed" dry residues burnt (t 1000 dry matter)	Raw protein content from residues (dry matter fraction)	Fraction of nitrogen from the dry matter of residues	Amount of nitrogen from stubble burning (t 1000 N)	N-N2O from stubble burning (t N-N_2O)
Wheat	92	0.030	0.005	0.399	3.70
Rye	0	0.036	0.006	0.001	0.01
Barley	19	0.037	0.006	0.103	0.77
Oats	4	0.040	0.006	0.021	0.15
Rice	3	0.041	0.007	0.015	0.10
Maize	0	0.000	0.007	0.000	0.00
Sorghum	2	0.037	0.006	0.010	0.07
Total	**120**			**0.548**	**4.80**

5.6.3 Uncertainty and time-series consistency

Uncertainties for CH_4 and N_2O emissions from field burning of agriculture residues are estimated to be 58.3% as a result of 30% and 50% for activity data and emission factor, respectively.

In 2022, emissions from field burning of agriculture residues were 0.29 Gg CH_4 emissions and 0.008 Gg N_2O emissions (see Table 5.50). Variation in emissions trend is related to cereal production trends. In particular, in the period 1998-2003, the biomass available from wheat and barley decreases compared to the first half of the ninety years due to the sharp drop in production as a consequence of unfavorable weather conditions.

Table 5.50 CH_4 and N_2O emission trends from field burning of agriculture residues (Gg)

Year	CH_4 (Gg)	N_2O (Gg)
1990	0.543	0.014
1995	0.530	0.014
2000	0.530	0.014
2005	0.476	0.012
2010	0.337	0.009
2015	0.325	0.008
2019	0.299	0.008
2020	0.299	0.008
2021	0.314	0.008
2022	0.291	0.008

5.6.4 Source-specific QA/QC and verification

Activity data of this category were calculated based on various parameters, and in particular the fraction of carbon and nitrogen of dry matter of residues, whose values are differentiated by crops. IPCC emission factors used (IPCC, 2006) are the ratios for carbon compounds (i.e. C-CH_4), that are mass of carbon compound released (in units of C) relative to mass of total carbon released from burning (in units of C); those for the nitrogen compounds (i.e. N-N_2O) are expressed as the ratios of mass of nitrogen compounds relative to the total mass of nitrogen released from the fuel (IPCC, 2006).

In response to the 2007 review process (UNFCCC, several years) and in order to verify the national assumption, which considered that 10% of the cultivated surface (cereals) is burned in Italy, a specific elaboration of data has been carried out by ISTAT, in the framework of FSS in 2003. The information, provided by ISTAT, related to the regional practices of field burning (cereals) has confirmed the abovementioned assumption (ISTAT, 2007[c]).

5.6.5 Source-specific recalculations

The recalculation is due to updating of emission factors for CH_4, N_2O, substituted with those in the 2006 IPCC guidelines. The estimate of sorghum residue since 1990 has been changed, now aligned with the estimate of emissions from agricultural soils. The percentage of rice straw burned since 2001 has been changed, and the production of the years 2019-2021 has been updated.

5.6.6 Source-specific planned improvements

No specific improvements are planned.

5.7 Liming (3G)

5.7.1 Source category description

CO_2 emissions from application of carbonate containing lime and dolomite to agricultural soils have been estimated. In 2017 submission, in response to the UNFCCC review process, CO_2 emissions from application of carbonate containing lime and dolomite are estimated separately. In 2022, CO_2 emissions from liming were 4.22 Gg, which represents 1.8% of CO_2 emissions of the agriculture sector (0.3% in 1990) and 0.0012% of national CO_2 emissions (0.0003% in 1990). CO_2 emissions from liming have not been identified as a key source.

5.7.2 Methodological issues

Tier 1 approach, assuming that the total amount of carbonate containing lime and dolomite is applied annually to soil, has been followed. The 2006 IPCC Guidelines equation 11.12 has been used to estimate CO_2 emissions. National statistics report an aggregate annual amount of lime and dolomite, without disaggregation between calcic limestone and dolomite (ISTAT, several years [i]; ISTAT, several years [f]). Data on the disaggregation between limestone and dolomite used in agriculture are provided by the largest lime producer in the country (UNICALCE, 2016). These values are equal to 55% and 45%, respectively. Therefore, the average emission factor weighed is equal to 0.1245 t C/t limestone-dolomite (=0.12*0.55+0.13*0.45).

Data on agricultural lime application have been estimated for the period 1990-1997, since these data have not been made available for that period. Data were estimated on the basis of the ratio of the amount of limestone or dolomite applied for the year 1998 and the area planted to crops, woody and permanent forage.

5.7.3 Uncertainty and time-series consistency

Uncertainty for CO_2 emissions from additions of carbonate limes to soils has been estimated to be 22.4%, as combination of 10% and 20% for activity data and emission factor, respectively.
In 2022, CO_2 emissions from liming (4.22 Gg CO_2) were almost twenty times the figure of 1990 (1.36 Gg CO_2). An increasing trend is observed from 2002, both for limestone and dolomite application, as resulting from the official statistics published by the National Institute of Statistics (ISTAT).
In Table 5.51 activity data, emission factor and CO_2 emission trend from liming are shown.

Table 5.51 CO_2 emissions from lime application

Year	Amount of limestone and dolomite (Mg)	EF (t C (t limestone and dolomite)$^{-1}$)	C emissions (Gg)	CO_2 emissions (Gg)
1990	2,969	0.1245	0.3696	1.36
1995	3,045	0.1245	0.3791	1.39
2000	4,050	0.1245	0.5042	1.85
2005	31,451	0.1245	3.9156	14.36
2010	40,115	0.1245	4.9943	18.31
2015	29,583	0.1245	3.6831	13.50
2019	35,584	0.1245	4.4302	16.24
2020	21,860	0.1245	2.7216	9.98
2021	56,067	0.1245	6.9803	25.59
2022	9,250	0.1245	1.1516	4.22

5.7.4 Source-specific QA/QC and verification

Systematic quality control activities have been carried out in order to ensure completeness and consistency in time series and correctness in the estimation of emissions.

5.7.5 Source-specific recalculations

No specific recalculations are observed.

5.7.6 Source-specific planned improvements

No specific improvements are planned.

5.8 Urea application (3H)

5.8.1 Source category description

CO_2 emissions from application of urea to agricultural soils have been estimated. In 2022, CO_2 emissions from urea application were 218.3 Gg, which represents 92.9% of CO_2 emissions of the agriculture sector (91.2% in 1990) and 0.06% of national CO_2 emissions (0.11% in 1990). CO_2 emissions from urea application have not been identified as a key source.

5.8.2 Methodological issues

Tier 1 approach, assuming that the total amount of urea is applied annually to soil, has been followed; an overall emission factor of 0.20 t C (t urea)$^{-1}$ has been used to estimate CO_2 emissions. The 2006 IPCC Guidelines equation 11.13 has been used to estimate CO_2 emissions. The source of the activity data are national statistics (ISTAT, several years [i]).

5.8.3 Uncertainty and time-series consistency

Uncertainty for CO_2 emissions from urea application to soils has been estimated to be 22.4%, as combination of 10% and 20% for activity data and emission factor, respectively.
In 2022, CO_2 emissions from urea application were 53.0% (218.3 Gg CO_2) lower than in 1990 (464.8 Gg CO_2).
In Table 5.52 activity data, emission factor and CO_2 emission trend from urea application are shown. A strong decrease is observed in the years from 2009 to 2011 due to the economic crisis in particular for urea applied to soils. In 2012, a recovery from the sharp decline was recorded as result from the official statistics provided by the National Institute of Statistics (ISTAT). See also the explanations given in the agricultural soils chapter on trends in synthetic nitrogen fertilizer data.

Table 5.52 CO_2 emissions from urea application

Year	Amount of urea (Mg)	EF (t C (tonnes of urea)$^{-1}$)	C emissions (Gg)	CO_2 emissions (Gg)
1990	633,873	0.20	126.8	464.8
1995	698,251	0.20	139.7	512.1
2000	716,412	0.20	143.3	525.4
2005	691,255	0.20	138.3	506.9
2010	456,951	0.20	91.4	335.1

Year	Amount of urea (Mg)	EF (t C (tonnes of urea)$^{-1}$)	C emissions (Gg)	CO_2 emissions (Gg)
2015	579,444	0.20	115.9	424.9
2019	540,618	0.20	108.1	396.5
2020	643,562	0.20	128.7	471.9
2021	563,865	0.20	112.8	413.5
2022	297,652	0.20	59.5	218.3

5.8.4 Source-specific QA/QC and verification

Systematic quality control activities have been carried out to ensure completeness and consistency in time series and correctness in the estimation of emissions. Activity data are the same used in the agriculture soils (3D) category.

5.8.5 Source-specific recalculations

No specific recalculations are observed.

5.8.6 Source-specific planned improvements

No specific improvements are planned.

5.9 Other carbon-containing fertilizers (3I)

5.9.1 Source category description

CO_2 emissions from application of Calcium Ammonium Nitrate (CAN) to agricultural soils have been estimated. In 2022, CO_2 emissions from CAN application were 12.3 Gg, which represents 5.3% of CO_2 emissions of the agriculture sector (8.6% in 1990) and 0.004% of national CO_2 emissions (0.010% in 1990). CO_2 emissions from CAN application have not been identified as a key source.

5.9.2 Methodological issues

Tier 1 approach, assuming that the total amount of CAN is applied annually to soil, has been followed. Based on the data provided by *Assofertilizzanti* (personal communication) concerning the annual estimates of ammonium nitrate and CAN distributed over the country from 2011 to 2019, an annual ratio of CAN to nitrate was calculated. An overall average of these ratios was calculated for the period 2011-2019. This value was multiplied by the total amount of ammonium nitrate (<28% and >28%) distributed annually and provided by ISTAT since 1990. The carbonate content was estimated by multiplying the previously estimated series by the value 23%, which represents the average carbonate content in CAN (77% is the share of ammonium nitrate). An overall emission factor of 0.125 t C (t carbonates)$^{-1}$ has been used to estimate CO_2 emissions. The 2006 IPCC Guidelines equation 11.12 has been used to estimate CO_2 emissions. The source of the activity data are national statistics (ISTAT, several years [i]).

5.9.3 Uncertainty and time-series consistency

Uncertainty for CO_2 emissions from CAN application to soils has been estimated to be 22.4%, as combination of 10% and 20% for activity data and emission factor, respectively. In 2022, CO_2 emissions from CAN application were 71.8% (12.3 Gg CO_2) lower than in 1990 (43.7 Gg CO_2). In Table 5.53 activity data, emission factor and CO2 emission trend from CAN application are shown. See the explanations given in the agricultural soils chapter on trends in synthetic nitrogen fertilizer data.

Table 5.53 CO_2 emissions from CAN application

Year	Amount of CAN (t)	Amount of carbonates content (t)	EF (t C (tonnes of carbonates)$^{-1}$)	C emissions (Gg)	CO_2 emissions (Gg)
1990	416,907	95,293	0.125	11.9	43.7
1995	515,751	117,886	0.125	14.7	54.0
2000	416,818	95,273	0.125	11.9	43.7
2005	405,351	92,652	0.125	11.6	42.5
2010	263,930	60,327	0.125	7.5	27.6
2015	189,628	43,344	0.125	5.4	19.9
2019	161,164	36,838	0.125	4.6	16.9
2020	204,958	46,847	0.125	5.9	21.5
2021	211,607	48,367	0.125	6.0	22.2
2022	117,766	26,918	0.125	3.4	12.3

5.9.4 Source-specific QA/QC and verification

Systematic quality control activities have been carried out in order to ensure completeness and consistency in time series and correctness in the estimation of emissions. Activity data are the same used in the agriculture soils (3D) category. As recommended during the 2020 ESD review, CO_2 emissions from CAN application to soils has been estimated and reported in the category 3I Other carbon-containing fertilizers.

5.9.5 Source-specific recalculations

No specific recalculations are observed.

5.9.6 Source-specific planned improvements

No specific improvements are planned.

6 LAND USE, LAND USE CHANGE AND FORESTRY

6.1 Sector overview

CO_2 emissions and removals occur because of changes in land use and management activities as well as because of forestry activities and disturbances. The sector is responsible for 21,2 Mt of CO_2 eq. net removal from the atmosphere in 2022.

Methods applied to estimate the GHG emissions and removals from the sector are derived from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 IPCC Guidelines) and from 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2019 Refinement) for HWP estimation; similarly, all factors for which national data are not available have been taken from the 2006 IPCC Guidelines and from 2019 Refinement. For category 4A (Forest Land) estimates were supplied by a growth model, applied to national forest inventory (NFI) data, consistently with the TACCC principles implemented by IPCC methods, and with mostly country specific factors and parameters.

CO_2 emissions from forest fires are included in the net carbon stock changes reported in CRT Table 4A, instead of in CRT Table 4(IV), since C losses by forest fires are included in the carbon stock changes estimation by the For-est model (see annex 12).

Greenhouse gas removals and emissions in the main categories of the LULUCF sector in 2022 are shown in Figure 6.1.

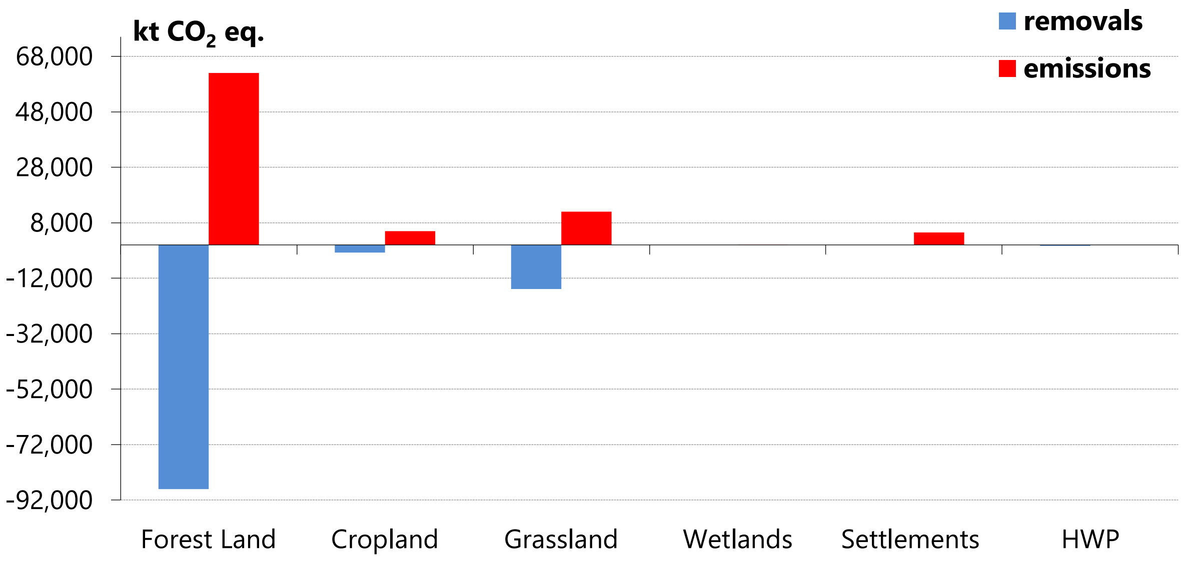


Figure 6.1 Greenhouse gas removals and emissions in LULUCF sector in 2022 [kt CO_2 eq.] by LULUCF sector categories

In Table 6.1 emissions and removals time series is reported.

Table 6.1 Trend in greenhouse gas net emissions/removals (kt) from the LULUCF sector in the period 1990-2022

GHG Source and Sink Categories	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021	2022
CO_2	**-5,292**	**-24,374**	**-21,333**	**-34,461**	**-40,303**	**-33,452**	**-24,938**	**-40,085**	**-40,755**	**-42,439**	**-41,537**	**-22,100**
A. Forest Land	-17,852	-31,122	-26,549	-35,049	-36,507	-33,260	-28,723	-38,686	-39,595	-40,417	-39,396	-24,258
B. Cropland	2,021	1,293	951	-447	339	1,778	2,860	2,403	2,253	1,740	47	296
C. Grassland	4,286	-2,116	-1,780	-5,763	-8,525	-6,629	-3,821	-8,620	-8,161	-8,431	-7,404	-3,422
D. Wetlands	NE,NO	5	8	8	130	130	130	130	130	130	32	32
E. Settlements	6,640	8,272	6,492	7,292	4,402	4,409	4,414	4,423	4,432	4,451	5,190	5,193
F. Other Land	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
G. HWP	-388	-706	-454	-503	-142	120	202	265	186	89	-6	59
H. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
CH_4	**25.72**	**6.05**	**14.29**	**5.99**	**7.00**	**11.34**	**24.00**	**3.13**	**5.49**	**5.28**	**6.13**	**30.22**
A. Forest Land	11.89	2.41	6.19	2.49	2.21	4.50	12.26	1.73	2.21	3.27	3.78	22.71
B. Cropland	0.11	0.03	0.06	0.03	0.02	0.05	0.09	0.15	0.02	0.05	0.04	0.16
C. Grassland	13.72	3.61	8.03	3.46	4.77	6.79	11.65	1.25	3.26	1.97	2.31	7.35
D. Wetlands	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
E. Settlements	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE
F. Other Land	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
G. HWP	-	-	-	-	-	-	-	-	-	-	-	-
H. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
N_2O	**3.38**	**3.00**	**2.60**	**2.22**	**1.52**	**1.73**	**2.39**	**1.21**	**1.30**	**1.26**	**1.63**	**3.04**
A. Forest Land	0.66	0.13	0.34	0.14	0.12	0.25	0.68	0.10	0.12	0.18	0.21	1.26
B. Cropland	0.22	0.35	0.14	0.13	0.13	0.11	0.09	0.06	0.03	0.00	0.06	0.13
C. Grassland	0.76	0.20	0.44	0.19	0.26	0.38	0.64	0.07	0.18	0.11	0.13	0.41
D. Wetlands	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
E. Settlements	1.70	2.25	1.65	1.72	0.97	0.97	0.97	0.97	0.97	0.97	1.22	1.22
F. Other Land	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
G. HWP	-	-	-	-	-	-	-	-	-	-	-	-
H. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
LULUCF (kt *CO_2 equivalent*)	**-3,676**	**-23,409**	**-20,244**	**-33,706**	**-39,705**	**-32,678**	**-23,632**	**-39,678**	**-40,256**	**-41,956**	**-40,934**	**-20,447**

CO_2 emissions and removals in LULUCF sector, in the period 1990-2022, are shown in Figure 6.2.

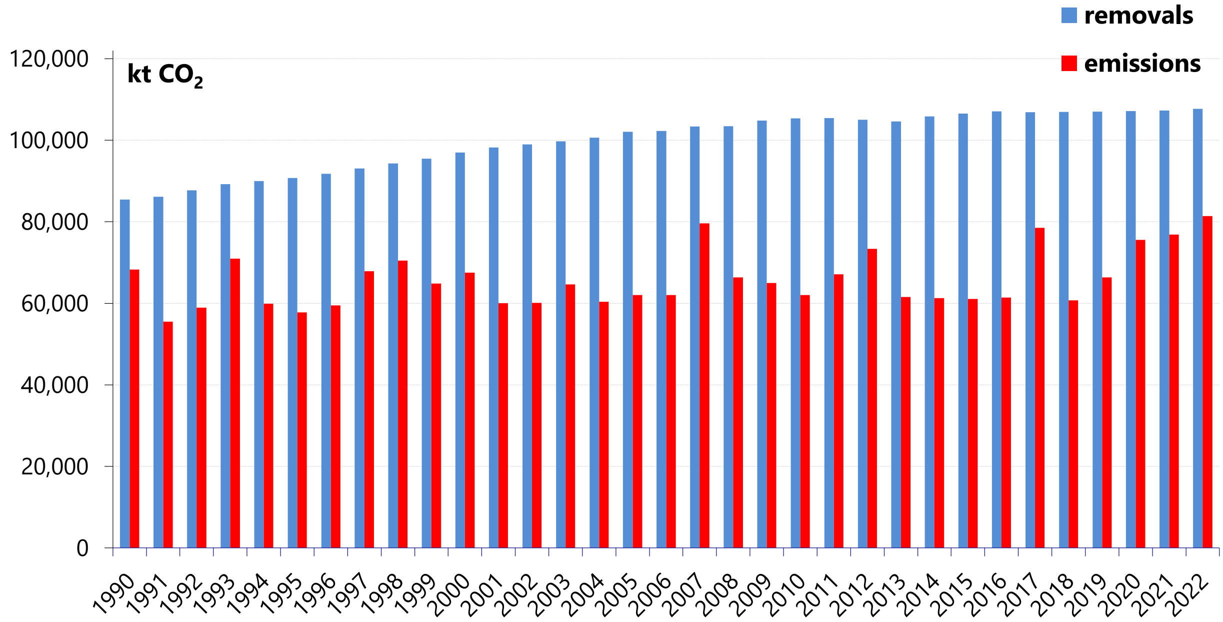


Figure 6.2 CO_2 removals and emissions in LULUCF sector in the period 1990-2022 [kt CO_2]

The outcomes of the key category analysis for 2022, for both level and/or trend assessment with IPCC Approach 1 and Approach 2, are listed in Table 6.2.

Table 6.2 Key* categories identified in the LULUCF sector

	gas	*Categories*	2022
4.A.1	CO_2	Forest land remaining forest land – Living biomass	key (L, T)
4.A.1	CO_2	Forest Land remaining Forest Land - DOM (deadwood and litter)	key (T1)
4.A.2	CO_2	Land Converted to Forest Land -Living biomass	key (L)
4.A.2	CO_2	Land Converted to Forest Land - soils	key (L, T1)
4.B.1	CO_2	Cropland Remaining Cropland - Living biomass	key (L1, T)
4.B.1	CO_2	Cropland Remaining Cropland - mineral soils	key (L1, T1)
4.C.1	CO_2	Grassland Remaining Grassland - living biomass	key (L, T)
4.C.2	CO_2	Land Converted to Grassland - mineral soils	key (L1, T1)
4.E.2	CO_2	Land converted to Settlements	key (L, T2)

* *L = key category in level assessment under both Approach 1 and 2*
T = key category in trend assessment under both Approach 1 and 2
L1, T1 = key category in level or trend assessment under Approach 1 only
L2, T2 = key category in level or trend assessment under Approach 2 only

Background data for the land representation originates from the NFIs[28] (1985, 2005, 2015) and from the National Land-Use Inventory IUTI referring to years 1990, 2000 and 2008. Additional data on non-forest categories were collected for the year 2018, through all the phases in the framework of the III NFI that was carried out on an IUTI's subgrid (i.e., 301,300 points, across the entire country territory).

Due to the technical characteristics of the IUTI assessment (i.e., classification of orthophotos), it was not possible to clearly distinguish among some subcategories included in *cropland* and *grassland* categories (e.g., annual pastures vs grazing land), and between them (e.g., annual crops and grazing land). Therefore, although the total aggregated area of the two categories *cropland* and *grassland* together is derived from the IUTI data, the area of each of their subcategories is disaggregated using as proxies the national

[28] National Forest Service, Ministry of Agricultural, Food and Forestry Policies (MIPAAF), Forest Monitoring and Planning Research Unit (CRA-MPF)

statistics (ISTAT, [b], [c]) on annual crops, perennial woody crops, grazing land, and grassland. The data from the NFI have a higher hierarchical order than that of IUTI, so that differences among the two datasets have been reconciled by adjusting[29] the grassland category (subcategory natural grassland). National statistics (ISTAT) have been used to assess the timeseries for the period 1971-1989, in relation to different land-use categories (i.e., annual statistics on forest land, annual crops and perennial woody crops, grazing lands, forage crops, permanent pastures, natural grassland and lands once used for agriculture purposes (set-aside) since 1971). National statistics do not include data for settlements and wetlands areas; for these land use categories, time series for the period 1971-1989 have been extrapolated, based on the IUTI 1990 assessment, and following the classification hierarchy.

Annual figures for areas in transition between different land uses have been derived applying a rule-based method, informed by expert judgement, based on known patterns of land-use changes in Italy, while ensuring that the total national area remains constant.

Rules applied are the following:

- when the forest land area increases, an equivalent area is transferred from grassland;
- when the cropland area increases, an equivalent area is transferred from grassland;
- when the grassland area increases, an equivalent area is transferred from cropland;
- when the forest land decreases, an equivalent area is transferred to settlements; indeed, in Italy land-use changes from forest to other uses are allowed in very limited circumstances (railways, highways constructions or other public utility projects) and only upon formal authorization, as stated in art. 4.2 of the Law Decree n. 227 of 2001. Further, land-use changes of burnt forest areas are forbidden by national legislation (Law Decree 21 November 2000, n. 353, art.10.1);
- when the settlements area increases more than the deforested area, an equivalent area is transferred from grassland, and if the grassland decreases are not larger enough, the remaining portion is transferred from cropland and, where needed, from other land (see tables 6.43, 6.44).

Based on the land use and land-use change data derived from NFIs and IUTIs classifications after the application of the rule-based approach for land representation, a time series of land-use matrices, one for each year of the period 1990–2022, have been compiled. Furthermore, land-use changes have been derived, by land-use change matrices, smoothing their area over a 5-year period, harmonizing the whole time series (i.e., the 2015–2010 difference in area for each subdivision is divided by five, and the resulting value is added, year by year, to the previous year area to deduce the current area). The smoothing period affects the assessment of the area, depending on the amount of the difference between the two reference years (i.e., 2015–2010), as well as on the number of years included in the smoothing period. The smoothing process also affects the annual land-use change data.

In addition, it has to be noted that the smoothing process is implemented at the most disaggregated level (i.e., for annual and woody crops in cropland category, grazing land and shrublands in grassland category), and that it has been implemented starting from 1971 to the last reported year (i.e., 2022).

In Tables 6.3a and 6.3b land use data with and without the smoothing are provided.

[29] Where the NFI area of forest land was larger than that of IUTI an equivalent portion of grassland area, as classified by IUTI, was reclassified as forest land while if the NFI area was smaller an equivalent area of forest land in IUTI was reclassified as grassland. Such adjustments were implemented at regional level.

Table 6.3a Land use areas before smoothing

kha	FL	CL	GL	WL	SL	OL	Total
1990	7,590	10,841	8,891	510	1,644	658	30,134
1991	7,668	10,857	8,768	511	1,672	658	30,134
1992	7,746	10,874	8,646	511	1,699	658	30,134
1993	7,824	10,891	8,523	511	1,727	658	30,134
1994	7,902	10,908	8,400	512	1,754	658	30,134
1995	7,980	10,924	8,278	512	1,782	657	30,134
1996	8,058	10,929	8,167	513	1,810	657	30,134
1997	8,136	10,919	8,071	513	1,837	657	30,134
1998	8,213	10,805	8,079	514	1,865	657	30,134
1999	8,291	10,697	8,082	514	1,892	657	30,134
2000	8,369	10,487	8,186	515	1,920	656	30,134
2001	8,447	10,351	8,216	515	1,948	656	30,134
2002	8,525	10,293	8,168	516	1,975	656	30,134
2003	8,603	10,031	8,324	516	2,003	656	30,134
2004	8,681	10,059	8,191	517	2,030	656	30,134
2005	8,759	9,879	8,265	517	2,058	656	30,134
2006	8,805	9,534	8,536	518	2,086	655	30,134
2007	8,850	9,593	8,404	518	2,113	655	30,134
2008	8,896	9,551	8,372	519	2,141	655	30,134
2009	8,941	9,069	8,787	526	2,156	655	30,134
2010	8,986	9,159	8,630	534	2,170	655	30,134
2011	9,032	8,947	8,773	541	2,185	655	30,134
2012	9,077	8,641	9,012	549	2,200	655	30,134
2013	9,123	8,977	8,609	556	2,214	655	30,134
2014	9,168	8,952	8,566	564	2,229	655	30,134
2015	9,214	8,845	8,605	571	2,244	655	30,134
2016	9,259	8,929	8,453	579	2,258	655	30,134
2017	9,304	8,982	8,333	586	2,273	655	30,134
2018	9,350	8,990	8,265	586	2,288	655	30,134
2019	9,395	9,001	8,194	586	2,302	655	30,134
2020	9,441	9,040	8,095	586	2,317	655	30,134
2021	9,486	9,029	8,046	586	2,332	655	30,134
2022	9,532	9,020	7,995	586	2,346	655	30,134

Table 6.3b Land use areas after smoothing

kha	FL	CL	GL	WL	SL	OL	Total
1990	7,590	10,841	8,891	510	1,644	658	30,134
1991	7,668	10,857	8,768	511	1,672	658	30,134
1992	7,746	10,874	8,646	511	1,699	658	30,134
1993	7,824	10,891	8,523	511	1,727	658	30,134
1994	7,902	10,908	8,400	512	1,754	658	30,134
1995	7,980	10,924	8,278	512	1,782	657	30,134
1996	8,058	10,837	8,259	513	1,810	657	30,134
1997	8,136	10,749	8,241	513	1,837	657	30,134
1998	8,213	10,662	8,223	514	1,865	657	30,134
1999	8,291	10,574	8,204	514	1,892	657	30,134
2000	8,369	10,487	8,186	515	1,920	656	30,134
2001	8,447	10,365	8,202	515	1,948	656	30,134
2002	8,525	10,244	8,218	516	1,975	656	30,134
2003	8,603	10,122	8,233	516	2,003	656	30,134
2004	8,681	10,000	8,249	517	2,030	656	30,134
2005	8,759	9,879	8,265	517	2,058	656	30,134
2006	8,805	9,769	8,301	518	2,086	655	30,134
2007	8,850	9,660	8,337	518	2,113	655	30,134
2008	8,896	9,551	8,372	519	2,141	655	30,134
2009	8,941	9,355	8,501	526	2,156	655	30,134
2010	8,986	9,159	8,630	534	2,170	655	30,134
2011	9,032	9,096	8,625	541	2,185	655	30,134
2012	9,077	9,033	8,620	549	2,200	655	30,134
2013	9,123	8,971	8,615	556	2,214	655	30,134
2014	9,168	8,908	8,610	564	2,229	655	30,134
2015	9,214	8,845	8,605	571	2,244	655	30,134
2016	9,259	8,884	8,503	574	2,258	655	30,134
2017	9,304	8,923	8,401	577	2,273	655	30,134
2018	9,350	8,962	8,299	580	2,288	655	30,134
2019	9,395	9,001	8,197	583	2,302	655	30,134
2020	9,441	9,040	8,095	586	2,317	655	30,134
2021	9,486	9,030	8,045	586	2,332	655	30,134
2022	9,532	9,020	7,995	586	2,346	655	30,134

Italy uses the IPCC default land use transition period of 20 years for each land-use change category. Consequently, to determine the area of lands converted to other land use categories for the inventory years 1990-2022, land-use change matrices have also been prepared for the period 1971-1989.

The relevant equations of 2006 IPCC Guidelines (vol. 4, chapter 2, eq. 2.15, 2.16, 2.24, 2.25) have been applied; once a land has converted to a land-use category, the annual changes in carbon stocks in mineral soils have been reported for 20 years subsequent the conversion.

In the following Table 6.4, the land use matrices are reported in two columns, for some of the reporting years. The annual matrices starting from the 1989-1990 period to 2021-2022 in the left column, while the 20-year matrices starting from the 1971-1990 period to the 2021-2022 are in the right column. Annual matrices for the years 1990-2022 are reported in CRT Tables 4.1.

Table 6.4 Land use change matrices for the years 1990-1995-2000-2010-2020-2022 [kha]

		1990						total 1989
		Forest	Grassland	Cropland	Wetlands	Settlements	Other Land	
1989	Forest	**7,511**				0.72		*7,512*
	Grassland	78.68	**8,891**	0.00	0.00	1.73	-	*8,971*
	Cropland		0	**10,841**	0.00	25	-	*10,866*
	Wetland				**510**			*510*
	Settlements					**1,616**		*1,616*
	Other Land					0.00	**658**	*658*
total 1990		*7,590*	*8,891*	*10,841*	*510*	*1,644*	*658*	30,134
	Land converted to:	78.7	0.0	0.0	0.0	27.6	0.0	

20 years matrix		1990						total 1971
		Forest	Grassland	Cropland	Wetlands	Settlements	Other Land	
1971	Forest	**6,901**				14.4		*6,916*
	Grassland	689	**8,566**	136	0.00	33	0	*9,423*
	Cropland		325	**10,704**	0.00	174	0	*11,203*
	Wetland				**510**			*510*
	Settlements					**1,423**		*1,423*
	Other Land					0.00	**658**	*658*
Total 1990		*7,589.8*	*8,890.9*	*10,840.5*	*510.1*	*1,644.0*	*658.3*	30,134
	Land converted to:	688.5	325.0	136.1	0.0	220.8	0.0	

		1995						total 1994
		Forest	Grassland	Cropland	Wetlands	Settlements	Other Land	
1994	Forest	**7,901**				0.72		*7,902*
	Grassland	78.68	**8,278**	16.77	0.47	26.70	-	*8,400*
	Cropland		0	**10,908**	0.00	0	-	*10,908*
	Wetland				**512**			*512*
	Settlements					**1,754**		*1,754*
	Other Land					0.18	**657**	*658*
total 1995		*7,980*	*8,278*	*10,924*	*512*	*1,782*	*657*	30,134
	Land converted to:	78.7	0.0	16.8	0.5	27.6	0.0	

20 years matrix		1995						total 1976
		Forest	Grassland	Cropland	Wetlands	Settlements	Other Land	
1976	Forest	**7,056**				14.4		*7,071*
	Grassland	923	**7,985**	220	2.37	166	0	*9,297*
	Cropland		292	**10,704**	0.00	150	0	*11,147*
	Wetland				**510**			*510*
	Settlements					**1,451**		*1,451*
	Other Land					0.90	**657**	*658*
Total 1995		*7,980*	*8,278*	*10,924*	*512*	*1,782*	*657*	30,134
	Land converted to:	923	292	220	2	331	0	

		2000						total 1999
		Forest	Grassland	Cropland	Wetlands	Settlements	Other Land	
1999	Forest	8,291				0.72		8,291
	Grassland	78.68	8,126	0	0.00	0.00	-	8,204
	Cropland		60.32	10,487	0.47	26.70	-	10,574
	Wetland				514			514
	Settlements					1,892		1,892
	Other Land					0.18	656	657
total 2000		8,369	8,186	10,487	515	1,920	656	30,134
	Land converted to:	78.7	60.3	0.0	0.5	27.6	0.0	

20 years matrix		2000						total 1981
		Forest	Grassland	Cropland	Wetlands	Settlements	Other Land	
1981	Forest	7,117				14.4		7,131
	Grassland	1,252	7,592	84	2.37	142	0	9,073
	Cropland		594	10,403	2.37	283	0	11,283
	Wetland				510			510
	Settlements					1,478		1,478
	Other Land					1.80	656	658
Total 2000		8,369	8,186	10,487	515	1,920	656	30,134
	Land converted to:	1,252	594	84	5	442	0	

		2005						total 2004
		Forest	Grassland	Cropland	Wetlands	Settlements	Other Land	
2004	Forest	8,678				3.69		8,681
	Grassland	81.65	8,168	-	-	-	-	8,249
	Cropland		97.46	9,879	0.47	23.73	-	10,000
	Wetland				517			517
	Settlements					2,030		2,030
	Other Land					0.18	656	656
total 2005		8,759	8,265	9,879	517	2,058	656	30,134
	Land converted to:	81.7	97.5	0.0	0.5	27.6	0.0	

20 years matrix		2005						total 1986
		Forest	Grassland	Cropland	Wetlands	Settlements	Other Land	
1986	Forest	7,183				17.4		7,200
	Grassland	1,577	7,488	84	2.37	142	0	9,293
	Cropland		777	9,795	4.74	390	0	10,966
	Wetland				510			510
	Settlements					1,506		1,506
	Other Land					2.71	656	658
Total 2005		8,759	8,265	9,879	517	2,058	656	30,134
	Land converted to:	1,577	777	84	7	552	0	

		2010						total 2009
		Forest	Grassland	Cropland	Wetlands	Settlements	Other Land	
2009	Forest	8,937				3.69		8,941
	Grassland	49.13	8,452	-	-	-	-	8,501
	Cropland		177.88	9,159	7.52	10.98	-	9,355
	Wetland				526			526
	Settlements					2,156		2,156
	Other Land					0.00	655	655
total 2010		8,986	8,630	9,159	534	2,170	655	30,134
	Land converted to:	49.1	177.9	0.0	7.5	14.7	0.0	

20 years matrix		2010						total 1991
		Forest	Grassland	Cropland	Wetlands	Settlements	Other Land	
1991	Forest	7,558				32.3		7,590
	Grassland	1,429	7,242	84	2.37	134	0	8,891
	Cropland		1,387	9,075	21.19	357	0	10,841
	Wetland				510			510
	Settlements					1,644		1,644
	Other Land					3.25	655	658
Total 2010		8,986	8,630	9,159	534	2,170	655	30,134
	Land converted to:	1,429	1,387	84	24	526	0	

		2015						total 2014
		Forest	Grassland	Cropland	Wetlands	Settlements	Other Land	
2014	Forest	9,164				3.69		9,168
	Grassland	49.13	8,561	-	-	-	-	8,610
	Cropland		44	8,845	7.52	10.98	0.00	8,908
	Wetland				564			564
	Settlements					2,229		2,229
	Other Land					0.00	655	655
total 2015		9,214	8,605	8,845	571	2,244	655	30,134
	Land converted to:	49.1	44.1	0.0	7.5	14.7	0.0	

20 years matrix		2015						total 1996
		Forest	Grassland	Cropland	Wetlands	Settlements	Other Land	
1996	Forest	7,932				47.1		7,980
	Grassland	1,281	6,997	0	0.00	0	0	8,278
	Cropland		1,608	8,845	58.79	412	0	10,924
	Wetland				512			512
	Settlements					1,782		1,782
	Other Land					2.35	655	657
Total 2015		9,214	8,605	8,845	571	2,244	655	30,134
	Land converted to:	1,281	1,608	0	59	462	0	

		2020						total 2019
		Forest	Grassland	Cropland	Wetlands	Settlements	Other Land	
2019	Forest	9,392				3.69		9,395
	Grassland	49.13	8,095	38.89	3.01	10.98	-	8,197
	Cropland		0	9,001	-	-	-	9,001
	Wetland				583			583
	Settlements					2,302		2,302
	Other Land					0.00	655	655
total 2020		9,441	8,095	9,040	586	2,317	655	30,134
	Land converted to:	49.1	0.0	38.9	3.0	14.7	0.0	

20 years matrix		2020						total 2001
		Forest	Grassland	Cropland	Wetlands	Settlements	Other Land	
2001	Forest	8,307				62.0		8,369
	Grassland	1,133	6,788	194	15.04	55	0	8,186
	Cropland		1,306	8,845	56.42	279	0	10,487
	Wetland				515			515
	Settlements					1,920		1,920
	Other Land					1.44	655	656
Total 2020		9,441	8,095	9,040	586	2,317	655	30,134
	Land converted to:	1,133	1,306	194	71	397	0	

		2022						total 2021
		Forest	Grassland	Cropland	Wetlands	Settlements	Other Land	
2021	Forest	9,483				3.69		9,486
	Grassland	49.13	7,995	0.00	0.00	0.79	-	8,045
	Cropland		0.00	9,020	-	10.18	-	9,030
	Wetland				586			586
	Settlements					2,332		2,332
	Other Land					0.00	655	655
total 2022		9,532	7,995	9,020	586	2,346	655	30,134
	Land converted to:	49.1	0.0	0.0	0.0	14.7	0.0	

20 years matrix		2022						total 2003
		Forest	Grassland	Cropland	Wetlands	Settlements	Other Land	
2003	Forest	8,457				67.9		8,525
	Grassland	1,074	6,877	194	15.04	56	0	8,218
	Cropland		1,117	8,825	55.47	246	0	10,244
	Wetland				516			516
	Settlements					1,975		1,975
	Other Land					1.08	655	656
Total 2022		9,532	7,995	9,020	586	2,346	655	30,134
	Land converted to:	1,074	1,117	194	71	371	0	

6.2 Forest Land (4A)

6.2.1 Description

Under this category, CO_2 emissions and removals from living biomass and dead organic matter, in forest land remaining forest land and from living biomass, dead organic matter (DOM) and soil organic matter (SOM) in land converted to forest land have been reported.

Forest land removals share 74.5% of total CO_2 eq. LULUCF net removals in 2022. CO_2 removals are mainly due to the living biomass, i.e., 94.2%, while DOM and SOM contribute only to 2.4% and 3.4%.

CO_2 emissions and removals from living biomass under forest land remaining forest land have been identified as key category in level and in trend assessment either with Approach 1 and Approach 2; CO_2 emissions and removals from DOM (deadwood and litter) under forest land remaining forest land and soil under land converted to forest land have been identified as key categories in level assessment either with Approach 1 and Approach and in trend assessment with Approach 1, while living biomass under land converted to forest land has been identified as key category in level assessment with either Approach 1 and Approach 2.

Management practices in the Italian forests are guided by the Legislative Decree n. 227 of 18 May 2001, although the design and implementation of specific guidelines has been carried out at regional level since, according to the Italian Constitutional Law, the forest management is a regional competence. The Legislative Decree n. 227/2001 provides general guidance on forest management:

- → protect forest ecosystem functions, genetic resources, water basins and landscape;
- → avoid conversion of forest land to other land uses, and where occurring apply compensative reforestations with endemic species;
- → avoid conversion from forest stands to coppices;
- → avoid clear-cut;
- → conserve biodiversity, including true conservation of old trees and dead wood.

6.2.2 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

The forest definition adopted under the Convention is the same used for the NFIs[30]. The forest definition includes areas where trees 1) fulfil the required threshold or 2) "have the potential to reach *in situ*" such required thresholds. For instance, *abandoned land with regenerating forest* is classified forest in consideration of the potential that vegetation has to reach the forest thresholds, while that are not expected to evolve in forests do not and will never meet the forest definition; for this reason, this kind of shrublands is included in the *grassland* category and are defined as other wooded land. The assessment of vegetation potential to meet thresholds is carried out in the field (phase 2 of the NFI), and it is mainly based on the time needed to reach the forest thresholds, which should not exceed the 20 years. This means that also shrublands that are expected to evolve to forest vegetation within such time frame are classified as forests.

Forest land area is that of the NFIs. For any forest area growth, it is assumed that new forest land area can only come from grassland.

The Italian Ministry of Agriculture and Forests (MAF) and the Experimental Institute for Forest Management (ISAFA) carried out the National Forest Inventories. The first NFI was based on a regular sampling grid of 3 km by 3 km, (MAF/ISAFA, 1988), the second NFI (INFC2005) used a grid of 1 km by 1 km, so as the third NFI (INFC2015). Complete NFI2015 results have been released in late 2022, supplying data related to current increment and stocks; in addition, the completion of NFI2015, with the on-field measurements on the plots of the sampling grid, resulted in a reassessment of 2015 area data of "Forest" and of "Other Wooded Land" have been therefore modified accordingly, resulting in a consequent recalculation carried out in 2023 submission.

6.2.3 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories

The forest definition adopted by Italy in the framework of the Kyoto Protocol has been used. This definition is in line with the definition of the Food and Agriculture Organization of the United Nations, therefore the following threshold values for tree crown cover, land area and tree height have been applied:

a. a minimum area of land of 0.5 hectares;
b. a minimum tree crown cover of 10 per cent;
c. minimum tree height of 5 meters.

[30] The detailed definition is reported on the website of the NFIs http://www.sian.it/inventarioforestale/jsp/q_features.jsp *(forest definition:* http://www.sian.it/inventarioforestale/jsp/linkmetodo/definizionilink1.jsp*)*

6.2.4 Methodological issues

Forest Land remaining Forest Land

To model C stock changes in forest land Italy uses the *For-est* model together with NFIs data, which include C pools as defined in Table 6.5.

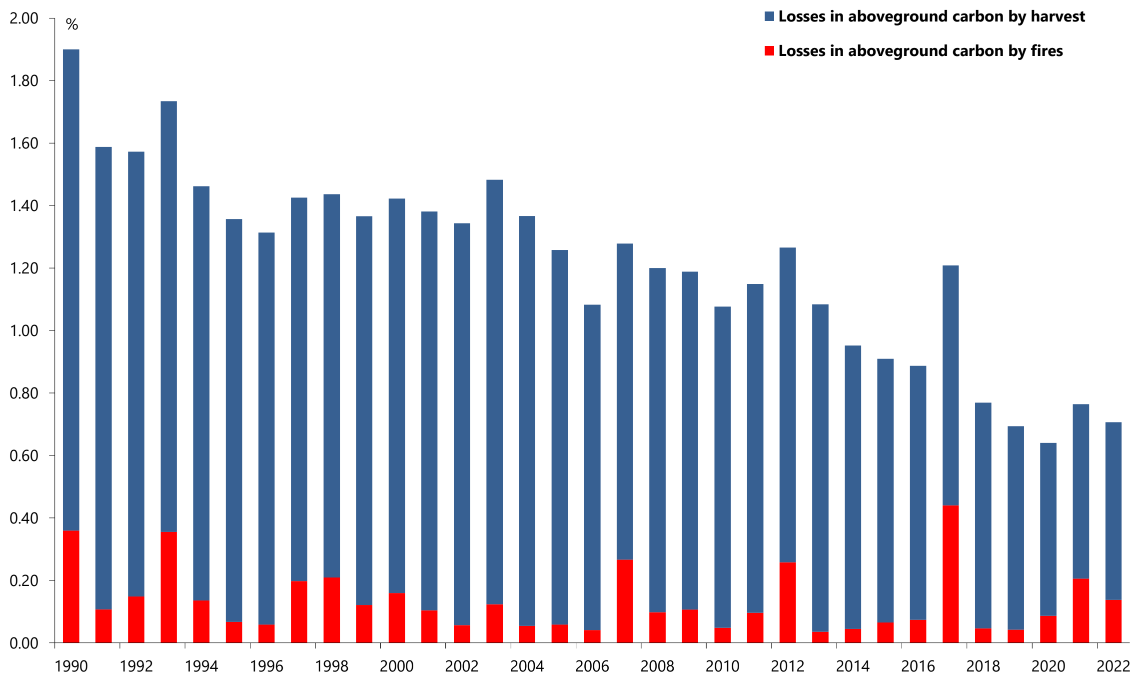
Table 6.5 Carbon pools, ecosystem components in the NFI surveys[31]

Forest carbon pools	Ordinary survey	Supplementary survey (Third phase)	Thresholds
Aboveground biomass	Biomass of trees with DBH≥4.5 cm (trees-AGB) Number or subjects of regeneration and shrubs	Ratio dry matter to wet & allometric Ratio dry matter to wet	All woody AGB included
Belowground biomass		Ratio root to shoot	ø > 2 mm
Deadwood	Volume of coarse woody debris (CWD)	Basic densities	ø ≥ 9.5 cm
	Volume of stumps	Basic densities	ø ≥ 9.5 cm
	Volume of standing dead trees (STD)	Basic densities	As for living trees
	Fine woody debris: not measured (FWD)	Wet weight per unit area; dry matter to wet ratio	2.5 ≤ ø < 9.5 cm
Litter	not measured	Wet weight per unit area; dry matter to wet ratio	Fine woody debris ø ≤ 2.5 cm, plus all other non-living biomass ø ≤ 2 mm
Soil	not measured	Organic carbon per unit area	all organic carbon for an increment of 30 cm, plus all other biomass and dead mass ø < 2 mm

The model applies the IPCC classification and definitions for C pools: living biomass, both aboveground and belowground; dead organic matter, including dead wood and litter; and soil organic matter. Information on the model is reported in Annex 12; additional information on methodological aspects can be found in Federici et al. (2008).

As described in step 3.b of Annex 12, biomass in burnt areas is assumed to have been completely lost, although not all the biomass stock is oxidized during the fire event (see also Annex 13 for the methodology used for forest fire emission estimates). In Figure 6.3, aboveground biomass losses due to harvest and forest fires, expressed as percentage on total aboveground carbon stock in forest land, are shown.

Figure 6.3 Losses by harvest and fires in relation to aboveground carbon



[31] Specific documentation and information on the definitions of the NFI pools (e.g. the diameter threshold for deadwood and how this pool is differentiated from litter, which soil horizons are included in the soil pool and which pool contains the humus layer) are available at the NFI website: https://www.inventarioforestale.org/it/node/72 (i.e., https://www.inventarioforestale.org/sites/default/files/datiinventario/manuale_fase3%2B_v4_definitiva_REGp.pdf; https://www.inventarioforestale.org/sites/default/files/datiinventario/pubb/INFC2015_Guida_per_i_rilievi_in_campo_2016-12.pdf)

CO_2 emissions due to wildfires in forest land remaining forest land are included in CRT Table 4.A.1, carbon stocks change in living biomass - losses. Non-CO_2 gases are estimated separately from the aboveground biomass loss calculated by the *For-est* model; from the aboveground biomass loss the amount of C oxidized during the fire event is estimated using oxidation factors specific of the for each fire event. CH_4 and N_2O emissions are estimated and reported (see also paragraph 6.12.2 and Annex 13). Non-CO_2 emissions from fires have been estimated and reported in CRT Table 4(IV).

Organic soils in forest land remaining forest land do not occur (NO).

CO_2 emissions due to wildfires in land converted to forest land are included in CRT Table 4.A.2, carbon stocks change in living biomass - losses.

Italy has decided not to account for the SOC changes in mineral soils from Forest land remaining Forest land, providing transparent and verifiable information to demonstrate that SOM in mineral soils is not a source.

Carbon stock changes in minerals soils, for Forest land remaining Forest land have been inferred from stock changes estimated in the aboveground biomass through linear regression i.e., SOC = $f(C_{Aboveground})$; consequently, the carbon stock changes in mineral soils are calculated as:

$$\Delta SOC = f(C_{Abovegound})_{time2} - f(C_{Abovegound})_{time1}$$

per forestry use –stands (conifers, broadleaves, mixed stands) and coppices. These equations have been calculated on data collected within the European project BioSoil[32], for SOM, and a Life+ project FutMon[33] (Further Development and Implementation of an EU-level Forest Monitoring System), for the aboveground biomass. SOC stock values in mineral soils were assessed down to 40 cm, standardized at 30 cm, with layer-based sampling (0-10, 10-20, 20-40 cm) on 227 forest plots on a 15x18 km grid. SOC stock values have been estimated in each layer using layer depths, soil carbon concentrations (704 values), bulk densities (543 measured data, 163 estimated data in the field or by means of pedotransfer functions) and volumes of coarse fragment (704 values estimated in the field). BioSoil assessed also OF and OH layers in which organic material is in various states of decomposition (down to humus) and included these in the SOC stock estimations.
In Table 6.6 the regressions calculated to infer SOC stocks [t C ha^{-1}] from the aboveground biomass [t C ha^{-1}] are shown.

[32] BioSoil project –http://www3.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/487/UT/systemPrint; http://www.inbo.be/content/page.asp?pid=EN_MON_FSCC_condition_report

[33] FutM on: Life+ project for the "Further Development and Implementation of an EU-level Forest Monitoring System"; http://www.futmon.org; http://www3.corpoforestale.it/flex/cm/pages/ServeAttachment.php/L/IT/D/D.e54313ecaf7ae893e249/P/BLOB%3AID%3D397

Table 6.6 Regressions to estimate the SOC stocks (t C ha^{-1}) in the upper 30 cm as a function of aboveground biomass in the different Italian forest typologies

	Inventory typology	Regressions aboveground biomass – SOC (t C ha-1)	R2	Standard error
stands	norway spruce	y = 0.2218x + 73.005	0.0713	40.14
	silver fir	y = 0.2218x + 73.005	0.0713	40.14
	larches	y = 0.2218x + 73.005	0.0713	40.14
	mountain pines	y = 0.2218x + 73.005	0.0713	40.14
	mediterranean pines	y = 0.2218x + 73.005	0.0713	40.14
	other conifers	y = 0.2218x + 73.005	0.0713	40.14
	european beech	y = 0.2502x + 79.115	0.0925	44.10
	turkey oak	y = 0.2502x + 79.115	0.0925	44.10
	other oaks	y = 0.2502x + 79.115	0.0925	44.10
	other broadleaves	y = 0.2502x + 79.115	0.0925	44.10
coppices	european beech	y = 0.2683x + 70.208	0.073	33.39
	sweet chestnut	y = 0.2683x + 70.208	0.073	33.39
	hornbeams	y = 0.2683x + 70.208	0.073	33.39
	other oaks	y = 0.2683x + 70.208	0.073	33.39
	turkey oak	y = 0.2683x + 70.208	0.073	33.39
	evergreen oaks	y = 0.2683x + 70.208	0.073	33.39
	other broadleaves	y = 0.2683x + 70.208	0.073	33.39
	conifers	y = 0.2218x + 73.005	0.0713	40.14
plantations	eucalyptuses coppices	y = 0.2683x + 70.208	0.073	33.39
	other broadleaves coppices	y = 0.2683x + 70.208	0.073	33.39
	poplars stands	y = 0.2502x + 79.115	0.0925	44.10
	other broadleaves stands	y = 0.2502x + 79.115	0.0925	44.10
	conifers stands	y = 0.2218x + 73.005	0.0713	40.14
protective	rupicolous forest	y = 0.3262x + 68.648	0.1338	38.96
	riparian forest	y = 0.3262x + 68.648	0.1338	38.96

Different trends in SOC stocks per hectare, for the different forest inventory typologies, have been inferred, as shown in Table 6.7.

Table 6.7 SOC stocks per hectare in the upper 30 cm, for the different forest inventory typologies

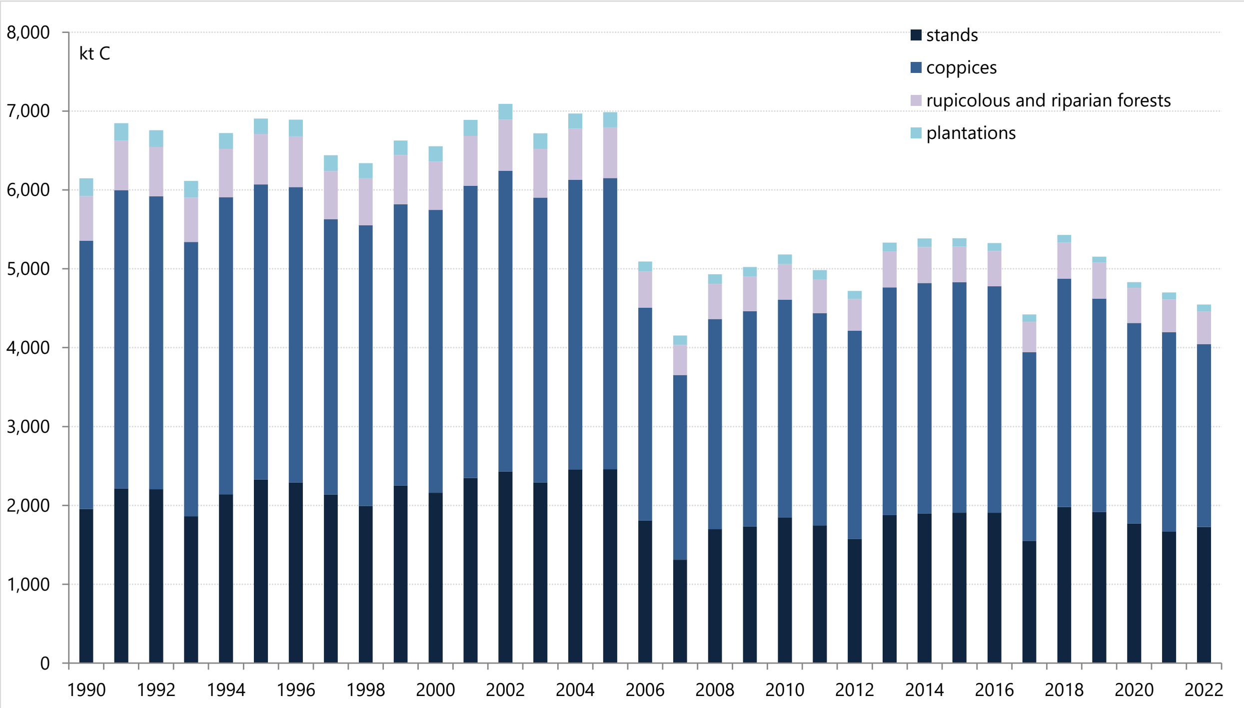
	Inventory typology	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021	2022
		SOC stocks (t C ha^{-1})										
stands	norway spruce	85.42	84.86	84.33	84.01	83.92	83.87	83.89	83.89	83.86	83.86	83.86
	silver fir	87.17	86.23	85.35	85.11	85.21	85.44	85.60	85.65	85.67	85.72	85.79
	larches	83.77	83.14	82.57	82.41	82.59	82.81	82.97	83.03	83.05	83.11	83.16
	mountain pines	83.81	84.64	85.34	86.39	87.46	88.66	89.38	89.65	89.89	90.10	90.33
	mediterranean pines	83.23	84.88	86.27	87.86	89.05	90.43	91.19	91.47	91.70	91.84	92.00
	other conifers	80.05	80.79	81.39	82.23	83.16	84.18	84.76	84.97	85.15	85.32	85.50
	european beech	98.73	98.50	98.41	98.77	99.16	99.91	100.30	100.48	100.61	100.70	100.86
	turkey oak	94.76	95.04	95.30	95.91	96.30	96.96	97.38	97.57	97.69	97.75	97.86
	other oaks	89.21	89.55	89.89	90.63	91.15	91.78	92.10	92.27	92.37	92.40	92.43
	other broadleaves	89.88	89.97	90.00	90.55	91.06	91.74	92.11	92.28	92.41	92.49	92.62
coppices	european beech	83.23	82.80	82.46	82.46	82.84	83.47	83.79	83.91	84.01	84.10	84.16
	sweet chestnut	84.10	87.09	89.55	92.16	94.93	97.99	99.62	100.16	100.63	101.09	101.40
	hornbeams	76.40	76.08	75.83	75.74	75.83	76.04	76.16	76.18	76.20	76.22	76.23
	other oaks	75.53	75.95	76.18	76.41	76.68	77.13	77.40	77.48	77.51	77.55	77.59
	turkey oak	79.18	78.68	78.26	78.03	78.01	78.23	78.39	78.44	78.45	78.46	78.44
	evergreen oaks	79.62	79.44	79.28	79.29	79.38	79.71	79.94	80.03	80.07	80.08	80.03
	other broadleaves	78.61	80.22	81.52	82.79	84.00	85.17	85.68	85.82	85.94	86.05	86.12
	conifers	80.00	80.43	80.84	81.46	82.24	83.17	83.70	83.87	84.03	84.19	84.33
plantations	eucalyptuses coppices	83.72	87.06	88.15	88.83	88.99	88.93	88.85	89.01	88.94	88.53	88.06
	other broadleaves coppices	84.15	86.95	88.27	89.17	89.80	90.19	90.37	90.43	90.41	90.36	90.24
	poplars stands	87.84	91.09	93.52	95.76	97.42	98.38	98.69	98.61	98.54	98.60	98.67
	other broadleaves stands	86.85	86.68	86.87	87.44	88.12	89.00	89.62	89.81	89.97	90.10	90.23
	conifers stands	82.30	84.01	86.25	89.32	92.46	96.02	98.18	98.91	99.60	100.16	100.65
protective	rupicolous forest	76.80	77.31	77.81	78.44	79.09	79.75	80.10	80.25	80.38	80.47	80.56
	riparian forest	83.66	83.16	82.77	82.54	82.71	82.86	82.91	82.93	82.96	82.99	82.99

From SOC stock values reported in Table 6.7 the SOC stock change values have been calculated for each forest typology group and reported in Table 6.8 and Figure 6.4.

Table 6.8 SOC stock changes in the upper 30 cm of the mineral soils at national level

Inventory typology group	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021	2022
	SOC stocks (t C)										
stands	1,954	2,327	2,161	2,460	1,849	1,907	1,979	1,915	1,772	1,669	1,727
coppices	3,403	3,742	3,584	3,692	2,758	2,924	2,897	2,708	2,541	2,528	2,319
rupicolous and riparian forests	564	641	615	642	452	451	454	456	445	415	414
plantations	227	196	194	191	122	104	98	74	73	89	89
Total	**6,149**	**6,905**	**6,554**	**6,984**	**5,181**	**5,387**	**5,429**	**5,153**	**4,831**	**4,700**	**4,548**

Figure 6.4 SOC stock changes in mineral soils of Italian forests



A comparison of the model results versus data measured in the framework of the II NFI (INFC2005) has been carried out and results are shown in the following Table 6.9.

Table 6.9 Comparison between SOC stock estimates int the upper 30 cm depth for the entire national forest land territory derived from NFI 2005 and the *For-est* model

	NFI 2005	*For-est* model	*differences*	
	t C= Mg	*t C= Mg*	*t C= Mg*	*%*
SOC stock	703,524,894	710,577,508	7,052,614	+1.00

Land converted to Forest Land

The area of land converted to forest land always comes from grassland not subject to any specific management practice (i.e., under natural conditions). It is assumed that other conversions do not occur, and there is no evidence that those do occur. Accordingly, methods and factors for grassland converted to forest land are applied to estimate C stock changes and associated GHG emissions and removals.

Italy applies a 20-years conversion period and an approach 2 for land representation, so that, in any inventory year, the area reported under this category is the cumulated area of all conversions occurred in that year plus the area converted in the 19 previous years.

As for forest land remaining forest land, carbon stock changes in living biomass are calculated using the same *For-est* model.

The DOM pools have been estimated using coefficient values for each forest inventory typology and assuming a constant, linear, accumulation rate of both dead wood and litter across the conversion time till the coefficient value is achieved when the land transfers to the category forest land remaining forest land. In practice, in each conversion year, 1/20 of the dead wood mass coefficient and of the litter mass coefficient are reported as net CO_2 removals.

The dead wood dry mass coefficients for each forest inventory typology, have been estimated using data taken for the Italian national forest inventory, in 2008 and 2009 across the country from the plots of the national forest inventory network see table 6.10, (http://www.sian.it/inventarioforestale/jsp/necromassa.jsp). The mass (wet matter) collected on the ground in those plots has been converted in dry matter using basic densities appositely calculated in a specific study (Di Cosmo et al., 2013). The data collected, aggregated at regional level, are accessible at the NFI website: http://www.sian.it/inventarioforestale/jsp/dati_carquant_tab.jsp.

The definition of the deadwood pool, coherent with the definition adopted by the NFI, is "*All non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, stumps larger than or equal to 10 cm in diameter and standing trees with DBH > 4,5 cm*".

Table 6.10 Dead-wood coefficients for dry mass (d.m.)

	Inventory typology	d.m. *t ha⁻¹*
stands	norway spruce	6.360
	silver fir	7.770
	larches	3.830
	mountain pines	4.385
	mediterranean pines	2.670
	other conifers	4.290
	european beech	3.350
	turkey oak	1.770
	other oaks	1.690
	other broadleaves	3.990
coppices	european beech	3.350
	sweet chestnut	12.990
	hornbeams	2.730
	other oaks	1.690
	turkey oak	1.770
	evergreen oaks	1.370
	other broadleaves	2.690
	Conifers	4.290
plantations	eucalyptuses coppices	0.670
	other broadleaves coppices	0.670
	poplars stands	0.480
	other broadleaves stands	0.670
	conifers stands	3.040
protective	rupicolous forest	2.730
	riparian forest	4.790

Litter mass coefficients per hectare has been estimated at regional level from data available from the NFI2005 (http://www.sian.it/inventarioforestale/jsp/dati_carquant_tab.jsp).

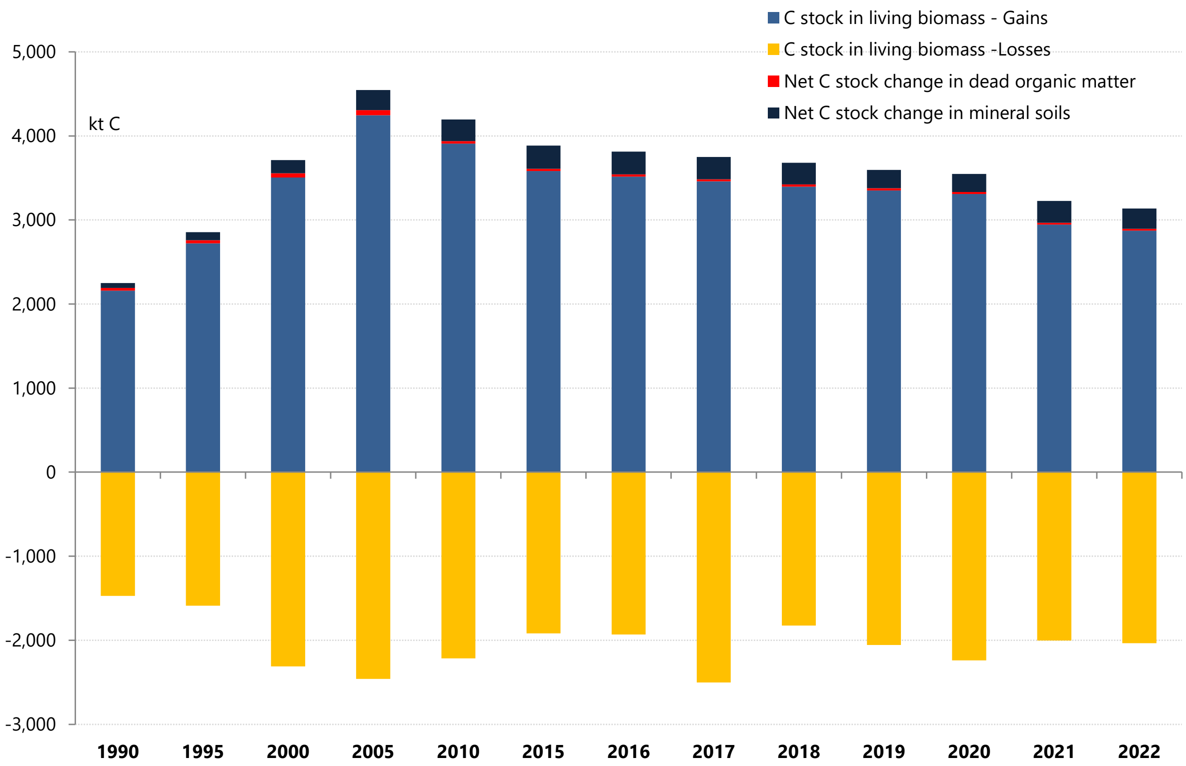
To estimate carbon stock changes in mineral soils, the IPCC default method has been applied. A country-specific SOC stock for natural grassland has been set at 78.9 t C ha^{-1}, based on a review of the literature on soil carbon in mountain meadows, pastures, set-aside lands as well as undisturbed abandoned land, in Italy (Masciandaro and Ceccanti, 1999; Del Gardo *et al.*, 2003; Benedetti *et al.*, 2004; Viaroli and Gardi, 2004; La Mantia *et al.*, 2007; Xiloyannis, 2007; IPLA, 2007; ERSAF, 2008; CRPA, 2009). For forest soils, the time series of SOC stocks is reported in table 6.11 according to the previously described methodology (forest land remining forest land).

Table 6.11 Soil Organic Carbon (SOC) stocks for *forest land remaining forest land*

years Years	SOC stock $t\ C\ ha^{-1}$
1985-1994	79.809
1995-1999	80.174
2000-2004	80.586
2005-2009	81.121
2010-2014	81.682
2015-2020	82.430
2021-2022	82.837

In Figure 6.5, the C stock changes in land converted to forest land are shown.

Figure 6.5 C stock changes in land converted to forest land (kt C)



Land converted to forest land do not occur (NO) on organic soils.

CO_2 emissions due to wildfires in land converted to forest land are included in CRT Table 4.A.2, carbon stocks change in living biomass - losses.

Non-CO_2 emissions from fires have been estimated and reported in CRT Table 4(IV); details on the methodology used to estimate emissions are reported in paragraph 6.12.2.

6.2.5 Uncertainty and time series consistency

To assess the overall uncertainty of the time series 1990–2022, Approach 1 of 2006 IPCC Guidelines (IPCC, 2006) has been applied. Input uncertainties for activity data and emission factors are derived from the country specific information and from the defaults provided in the 2006 IPCC Guidelines (IPCC, 2006).

In Table 6.12, the values of carbon stock of each pool, for the year 1985, and the associated uncertainties are reported for the entire forest land area.

Table 6.12 Carbon stocks and uncertainties for year 1985 and current increment related uncertainty

Carbon stocks *t CO_2 eq. ha^{-1}*	*Aboveground biomass*	V_{AG}	139.92
	Belowground biomass	V_{BG}	31.6
	Dead wood	V_D	3.3
	Litter	V_L	2.7
Uncertainty	*Growing stock*	E_{NFI}	3.2%
	Current increment (Richards)[34]	E_{NFI}	51.6%
	Harvest	E_H	30%
	Fires	E_F	30%
	Drain and grazing	E_D	30%
	Mortality	E_M	30%
	BEF	E_{BEF1}	30%
	R	E_R	30%
	Deadwood	E_{DEF}	4.6%
	Litter	E_L	10%
	Wood Basic Density (WDB)	E_{BD}	30%
	C Conversion Factor	E_{CF}	2%

The uncertainties of each carbon pool and the overall uncertainty for 1985 have been computed and shown in Table 6.13.

Table 6.13 C stock uncertainties for the year 1985

Aboveground biomass	E_{AG}	42.59%
Belowground biomass	E_{BG}	52.10%
Dead wood	E_D	42.84%
Litter	E_L	43.75%
Overall uncertainty	$\mathbf{E_{1985}}$	**34.85%**

The overall uncertainty related to 1985 (the year of the first National Forest Inventory) has been propagated through the years, till 2022, following Approach 1.

The uncertainties related to the carbon pools and the overall uncertainty for 2022 are shown in Table 6.14.

Table 6.14 Uncertainties for the year 2022

Aboveground biomass	E_{AG}	42.64%
Belowground biomass	E_{BG}	52.14%
Dead wood	E_D	42.89%
Litter	E_L	43.80%
Overall uncertainty	**E**	**35.43%**

Following Approach 1 and the abovementioned methodology, the overall uncertainty in the estimates produced by the described model has been quantified; in Table 6.15 the uncertainties of the 1985-2022 period are reported.

Table 6.15 Overall uncertainties 1985 – 2022 (%)

1985	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021	2022
34.9	35.0	35.1	35.2	35.2	35.3	35.4	35.4	35.4	35.4	35.4	35.4	35.4

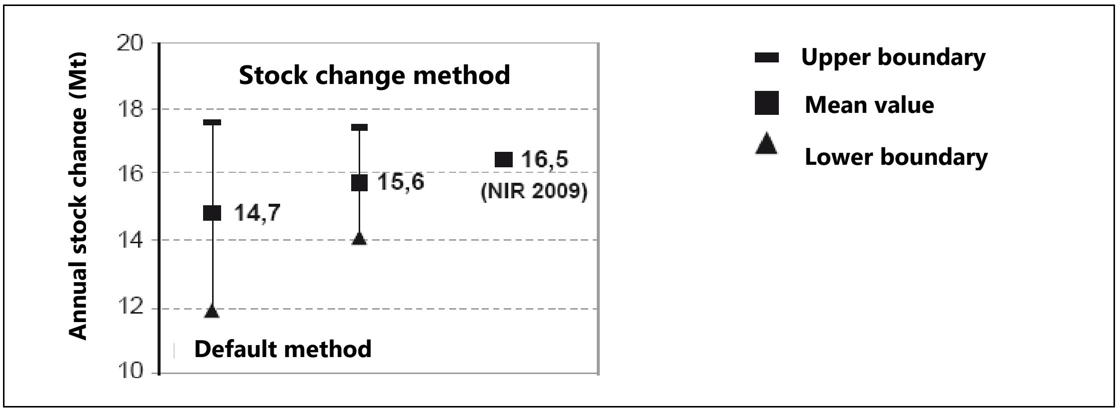
[34] The current increment is estimated by the Richards function (first derivative); uncertainty has been assessed considering the standard error of the linear regression between the estimated values and the corresponding current increment values reported in the National Forest Inventory

The overall uncertainty in the model estimates between 1990 and 2022 has been assessed subtracting uncertainties with Approach 1 (IPCC 2006, Vol.1, Ch. 3, Equation 3.2), resulting in overall uncertainty equal to 25.2%.

6.2.6 Category-specific QA/QC and verification

Systematic quality control activities have been carried out to ensure completeness and consistency in time series and correctness in the sum of sub-categories; where possible, activity data comparison among different sources (FAO database[35], ISTAT data[36]) has been made. Data entries have been checked several times during the compilation of the inventory; attention has been focused on the categories showing significant changes between two years in succession. Land use matrices have been accurately checked and cross-checked to ensure that data were properly reported. An independent verification of the living biomass net change with data from the second NFI, for the year 2005 (Tabacchi et al., 2010) was performed. In Figure 6.6 outcome of the comparison is shown.

Figure 6.6 Comparison between carbon stock changes, for living biomass pool, by the National GHG Inventory (ISPRA) and estimated data of NFI2005 (II NFI) measurements (modified from Tabacchi *et al.*, 2010)

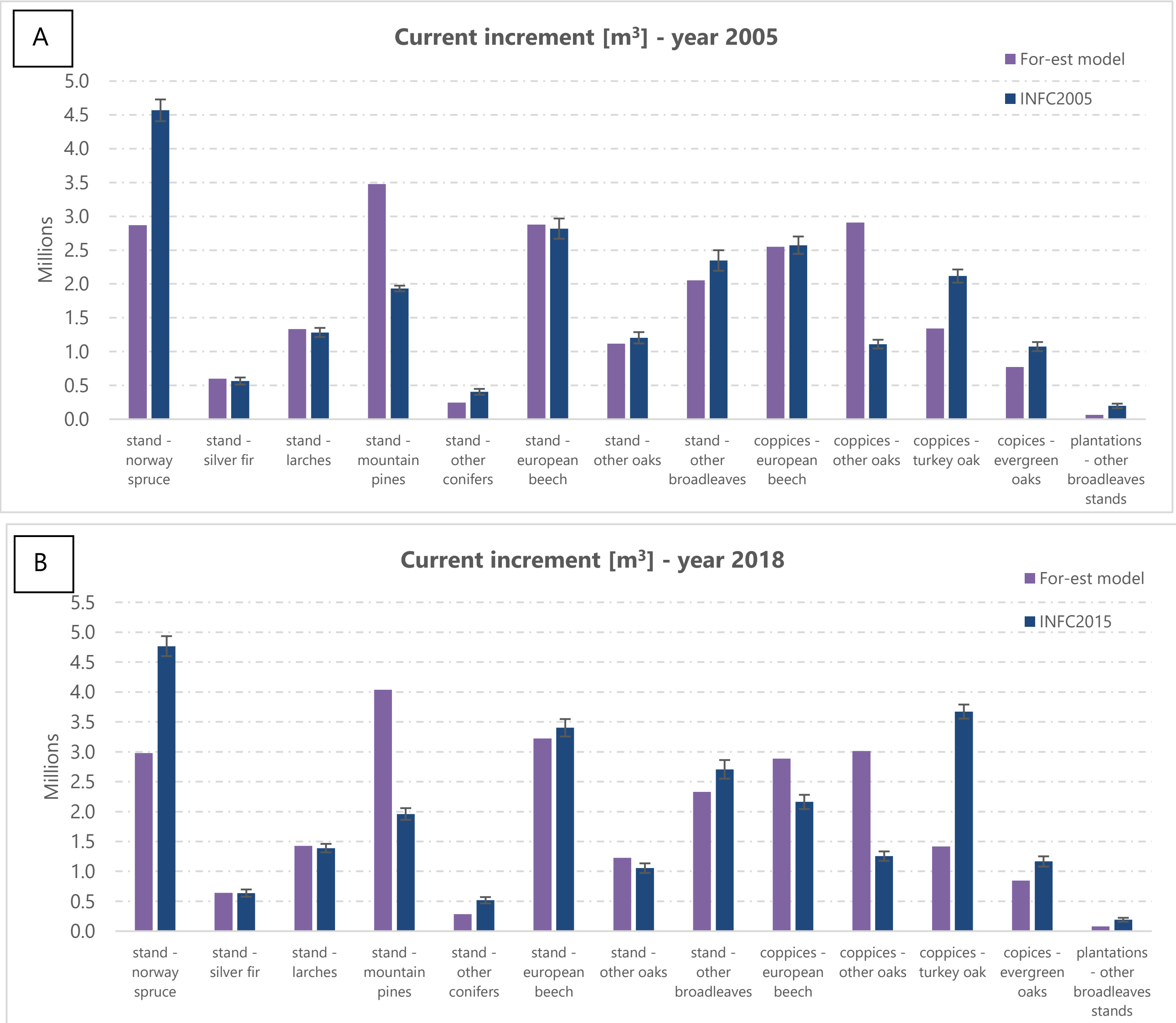


The nomenclature used in the NFI2005 and NFI2015 is different from that elaborated for the first national forest inventory. Therefore, a comparison among NFI2005-NFI2015 current increment data and *For-est* model current increment data is possible only for a not exhaustive number of inventory typologies. In the following Figure 6.7 the comparison has been reported both for NFI2005 and for NFI2015. The comparisons refer to the year 2005 and 2018, which is the mean years for the field survey of the second and third forest inventories, respectively.

[35] FAO, 2015. FAOSTAT, http://faostat3.fao.org/home/E

[36] ISTAT, several years [a], [b], [c]

Figure 6.7 Average national current increment: comparison among NFIs (INFC) data and For-est model estimates for the year 2005 (panel A – NFI2005) and for the 2018 (panel B – NFI2015)



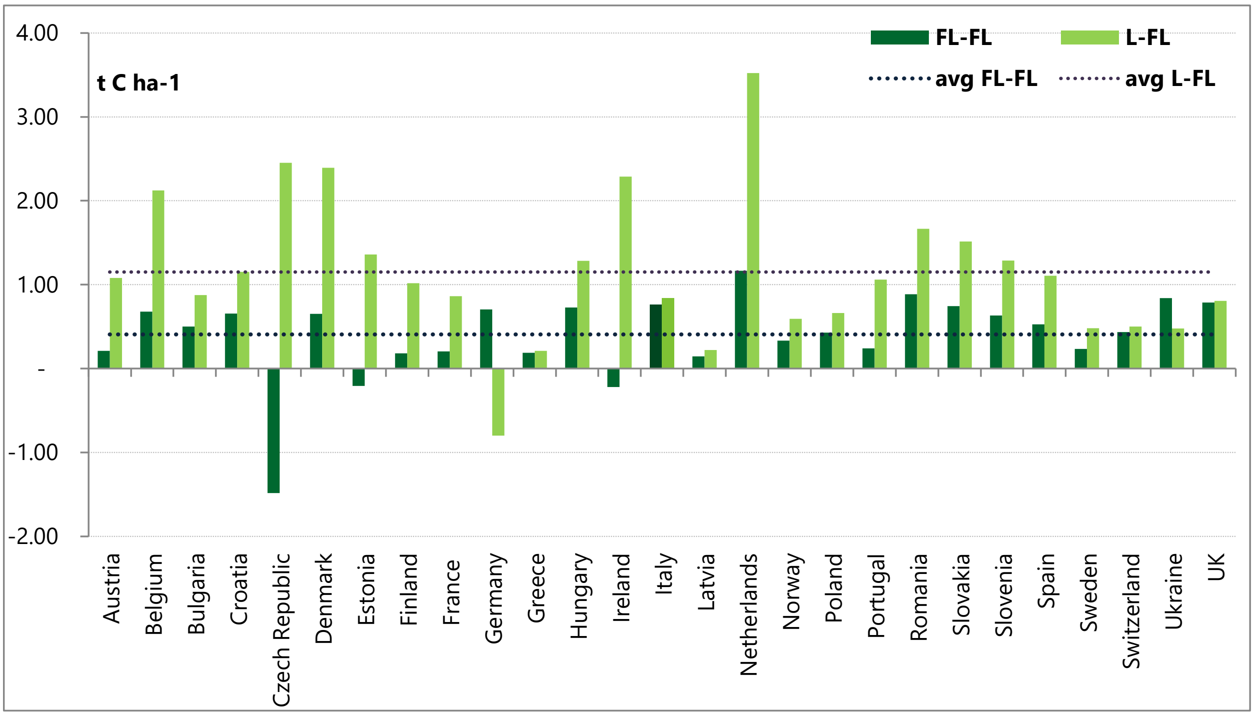
Generally, the current increment estimated with the For-est model is quite in a good agreement with the INFC measured current increments. The main differences noticeable from the comparisons refer to the different nomenclature used by the INFC and the For-est model, resulting in an assignment of some forest areas to the forest typologies by the For-est model with respect to the field data of the forest inventories. Some examples: *stand norway spuce* (with a remarkable overestimate of INFC current increment compared to For-est) while, for the *stand mountain pines*, the current increment estimated by the For-est is higher than the INFC one; similar situation with the categories *coppice other oaks – coppices turkey oak – coppices evergreen oak*s, where the mismatch may be explained with a different allocation (i.e., area) of the abovementioned categories.

An additional verification activity has been carried out, comparing the implied carbon stock change per area (IEF), related to the living biomass, with the IEFs reported by other Parties. The 2023 submission[37] has been considered to deduce the different IEFs; in figure 6.8 the comparison is showed, considering the

[37] GHG Review Tools (unfccc.int)

IEFs for both the forest land remaining forest land (FL-FL) and land converting to forest land (L-FL) subcategories, for the living biomass.

Figure 6.8 Implied carbon stock change per area for the living biomass



6.2.7 Category-specific recalculations

Recalculations, as shown in Tables 6.16 and 6.17, occurred in the 2024 submission, comparing to the 2023 submission, for the forest land remaining forest land (2.2% for the 2021 reporting year) and land converted to forest land (-0.4% for the 2021 reporting year). The recalculation is due to the update of the 2021 harvest data, updated with the data collected by the National Forestry System (SINFor[38]).

Table 6.16 Recalculation in forest land category, for carbon pool

	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021
2024 submission						*CO_2 eq. - kt*					
Forest land	**-17,852**	**-31,122**	**-26,549**	**-35,049**	**-36,507**	**-40,417**	**-39,396**	**-24,281**	**-40,734**	**-35,487**	**-30,042**
- *living biomass*	*-16,444*	*-29,579*	*-24,786*	*-32,983*	*-34,928*	*-38,759*	*-37,762*	*-22,647*	*-39,147*	*-34,048*	*-28,617*
- *dom*	*-1,191*	*-1,191*	*-1,191*	*-1,191*	*-639*	*-639*	*-639*	*-639*	*-639*	*-639*	*-639*
- *soils*	*-217*	*-353*	*-573*	*-876*	*-941*	*-1,019*	*-995*	*-995*	*-948*	*-799*	*-786*
2023 submission						*CO_2 eq. - kt*					
Forest land	**-17,852**	**-31,122**	**-26,549**	**-35,049**	**-36,507**	**-40,417**	**-39,396**	**-24,281**	**-40,734**	**-35,487**	**-30,042**
- *living biomass*	*-16,444*	*-29,579*	*-24,786*	*-32,983*	*-34,928*	*-38,759*	*-37,762*	*-22,647*	*-39,147*	*-34,048*	*-28,617*
- *dom*	*-1,191*	*-1,191*	*-1,191*	*-1,191*	*-639*	*-639*	*-639*	*-639*	*-639*	*-639*	*-639*
- *soils*	*-217*	*-353*	*-573*	*-876*	*-941*	*-1,019*	*-995*	*-995*	*-948*	*-799*	*-786*
recalculation						*%*					
Forest land	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1.80**
- *living biomass*	-	-	-	-	-	-	-	-	-	-	1.88
- *dom*	-	-	-	-	-	-	-	-	-	-	0.00
- *soils*	-	-	-	-	-	-	-	-	-	-	0.75

[38] https://sinfor-pre.sian.it/#/

Table 6.17 Recalculation in forest land category, for subcategories FL-FL e L-FL

	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021
2024 submission						*CO_2 eq. - kt*					
Forest land	**-17,852**	**-31,122**	**-26,549**	**-35,049**	**-36,507**	**-40,417**	**-24,258**	**-40,734**	**-35,487**	**-30,042**	**-28,920**
FL-FL	-15,002	-26,485	-21,420	-27,403	-29,250	-33,204	-19,681	-33,934	-29,853	-25,243	-24,430
L-FL	-2,849	-4,637	-5,130	-7,646	-7,258	-7,213	-4,576	-6,800	-5,634	-4,799	-4,489
2023 submission						*CO_2 eq. - kt*					
Forest land	**-17,852**	**-31,122**	**-26,549**	**-35,049**	**-36,507**	**-40,417**	**-24,258**	**-40,734**	**-35,487**	**-30,042**	**-28,398**
FL-FL	-15,002	-26,485	-21,420	-27,403	-29,250	-33,204	-19,681	-33,934	-29,853	-25,243	-23,893
L-FL	-2,849	-4,637	-5,130	-7,646	-7,258	-7,213	-4,576	-6,800	-5,634	-4,799	-4,505
recalculation						%					
Forest land	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1.80**
FL-FL	-	-	-	-	-	-	-	-	-	-	2.20
L-FL	-	-	-	-	-	-	-	-	-	-	0.35

6.2.8 Category-specific planned improvements

Italy is currently implementing a change in land classification system, by the use of the Oper-Foris Collect Earth tool. The new classification system is expected to supply land use and land use data for a time series, starting from 2010; the results of the abovementioned land classification will be evaluated, by comparing them against the used data and ancillary available statistics and information. The land classification system will hopefully be adopted for the reporting starting with the 2025 submission.

6.3 Cropland (4B)

6.3.1 Description

Under this category, CO_2 emissions from living biomass, and soils have been reported, for cropland remaining cropland and for land converted to cropland.

Cropland net emissions share 6.2% of total 2022 LULUCF CO_2 net emissions; in particular, the soil pools represent 6.5% of the whole cropland emissions and removals while the remaining 93.5% originates from living biomass pool.

CO_2 emissions and removals from living biomass and mineral soils under cropland remaining cropland have been identified as key category in trend assessment with Approach 1 and 2 and in level assessment with Approach 1 (living biomass) and with Approach 1 only in level and trend assessment (mineral soils).

6.3.2 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

Information on the land representation is reported in section 6.1. For the cropland category, as already discussed, it is assumed that the only conversion occurring is from grassland to cropland. The IPCC default land use transition period of 20 years has been applied.

6.3.3 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories

Cropland includes all annual and perennial crops.

Due to the technical characteristics of the IUTI assessment (i.e., classification of orthophotos), it was not possible clearly distinguish among some subcategories in *cropland* and non-woody *grassland* categories (e.g., grazing lands and unmanaged/natural grasslands). Therefore, although the total aggregated area of the 2 categories *cropland* and *grassland* together is derived from the IUTI data, the area of each of their subcategories is disaggregated using as proxies the national statistics (ISTAT, [b], [c]) on annual crops and perennial woody crops.

6.3.4 Methodological issues

Activity data for cropland remaining cropland have been subdivided into annual and perennial crops. Changes in the biomass C stock has been estimated for perennial crops in both cropland remaining cropland and land converted to cropland, while for annual crops in land converted to cropland only.

Soil carbon stock changes have been estimated and reported for annual and perennial crops in both cropland remaining cropland and land converted to cropland subcategories.

Living biomass – perennial crops

For perennial crops, biomass carbon stock changes have been estimated based on the annual rates of biomass gain and loss (IPCC 2006, Vol. 4, Chapter 2, Equation 2.7).

The annual carbon stock in living biomass and the woody crops area annually undergoing to a woody biomass removal (e.g., biomass cleared and replanted with a different crop) have been estimated; in addition, the total woody crops area has subdivided into age classes, considering three main woody crop types (i.e., olives, vineyards, and other fruit). The estimation process has been carried out at NUTS2 (regional) level, based on the available data from national statistics (ISTAT, [b], [c]) for the different woody crops' species[39] and harvest/maturity cycles.

The carbon stock change in living biomass during the plantation cycle is estimated based on an annual constant net gain (accumulation rate), per perennial crop type and age class. Table 6.18 summarises the aboveground and belowground biomass carbon stock at the end of the maturity cycle for each group of perennial crops. These values correspond to the total biomass carbon stocks removed during the harvesting. All values have been assessed based on the database collected in the framework of the LIFE project MEDINET[40].

Table 6.18 Harvest/maturity cycle, aboveground and belowground biomass carbon stock at harvest

Crops	Harvest/maturity cycle	Aboveground C stock		Belowground C stock	
	yr	*t C ha^{-1}*	*std dev (t C ha^{-1})*	*t C ha^{-1}*	*std dev (t C ha^{-1})*
olive	50	9.13	1.07	2.60	0.09
vineyards (wine grapes)	20	5.60	0.50	4.46	0.34
vineyards (for other)	30	5.62	0.50	4.48	0.35
orchards, pear, apple, cherry	25	8.91	1.32	5.75	0.32
peach, apricot	15	8.94	1.29	5.72	0.65
kiwifruit	20	8.90	1.31	5.73	0.68
other fruits	20	8.90	1.31	5.73	0.68

Net biomass carbon stock changes are equal to -316.5 kt C for 1990, and -551.2 kt C for 2022, a time series is summarised in Table 6.19.

[39] Olive, vineyard (for wine grapes and other), orchards (orange, mandarine, clementine, lemon, grapefruit, bergamot, cedar, chinotto), apple, peach, pear, apricot, cherry, kiwifruit, other fruits (carob, fig, plum, hazelnut, almond, raspberry)

[40] MEDINET (Mediterranean Network for Reporting Emissions and Removals in Cropland and Grassland): https://www.lifemedinet.com/

Table 6.19 Change in carbon stock in living biomass

	Area	aboveground biomass			belowground biomass			net change in C stock
		Gains	Losses	Net change	Gains	Losses	Net change	
	kha	*kt C*	*kt C*	*kt C*	*kt C*	*kt C*	*kt C*	*kt C*
1990	2,698	486	-693	-207	316	-425	-110	-317
1995	2,712	443	-534	-91	285	-367	-82	-173
2000	2,606	376	-693	-316	240	-533	-293	-609
2005	2,577	360	-467	-107	234	-305	-71	-178
2010	2,574	360	-441	-81	236	-320	-84	-165
2015	2,405	319	-665	-346	214	-451	-237	-582
2017	2,419	316	-407	-91	217	-274	-58	-148
2018	2,427	316	-438	-122	219	-289	-70	-192
2019	2,434	314	-375	-61	220	-240	-20	-81
2020	2,441	326	-853	-527	229	-493	-264	-791
2021	2,421	320	-613	-293	227	-382	-154	-447
2022	2,402	320	-723	-403	229	-378	-148	-551

Soils – annual and perennial crops

For mineral soils, the estimation method is based on changes in SOC stocks over a finite period due to changes in management practices. According to the 2006 IPCC Guidelines (IPCC, 2006), the change in mineral SOC stocks (vol. 4, chapter 2, eq. 2.25) is the result of a change in management practices in a unit of land across time. The SOC stock changes in annual and perennial crops have been estimated considering the following cropland management practices reported in Table 6.20.

Table 6.20 Cropland management practices

cropland subcategory	management practices	definition	CAP regulations
annual crops	Arable land (Ordinary)	A kind of agriculture that does not evidence any kind of soil carbon stock technical maintenance	
	Organic arable land	Management of waste crop; Organic manure; Extended crop rotation; Selection of better crop varieties; Cover crops	Reg. (EEC) n. 2078/92, Reg. (EC) n. 834/2007 and Reg. (EC) n. 889/2008, RDPs 2000-2006: Reg. (EC) n. 1257/99, RDPs 2007-2013: Reg. (EC) n. 1698/2005 and Reg. (EC) n. 74/2009
	Sustainable arable land	Crop rotation; Grassing; Specific erosion prevention; Cover crops; Minimum tillage	National decree on sustainable agriculture n. 2722/2008; RDPs 2000-2006: Reg. (EC) n. 1257/99; RDPs 2007-2013: Reg. (EC) n. 1698/2005 and Reg. (EC) n. 74/2009
	Set aside	Natural grassing; At least one mowing	Reg. (EEC) N. 1765/1992; National decree on cross compliance implementation n. 30125/2009 and subsequent revisions
	Conservative practices	Zero tillage; Organic manure; Grassing; Cover crops; Minimum tillage; Crop rotation	RDPs 2007-2013: Reg. (EC) n. 1698/2005 and Reg. (EC) n. 74/2009
perennial crops	Woody crops (Ordinary)	A kind of agriculture that does not evidence any kind of soil carbon stock technical maintenance	
	Organic woody crops	Management of waste crop; Organic manure; Extended crop rotation; Selection of better crop varieties; Cover crops	Reg. (EEC) n. 2078/92, Reg. (EC) n. 834/2007 and Reg. (EC) n. 889/2008, RDPs 2000-2006: Reg. (EC) n. 1257/99, RDPs 2007-2013: Reg. (EC) n. 1698/2005 and Reg. (EC) n. 74/2009

cropland subcategory	management practices	definition	CAP regulations
	Sustainable management	Crop rotation; Grassing; Specific erosion prevention; Cover crops; Minimum tillage	National decree on sustainable agriculture n. 2722/2008; RDPs 2000-2006: Reg. (EC) n. 1257/99; RDPs 2007-2013: Reg. (EC) n. 1698/2005 and Reg. (EC) n. 74/2009

In the following _Table 6.21 the data source for each management practice is listed.

Table 6.21 Cropland management practices and relative data sources

cropland subcategory	management practice	data source
annual crops	Ordinary	ISTAT
	Organic	National Information system on organic agriculture (SINAB)
	Sustainable	Annual Implementation Reports (RAE) and Annual Report on Operational Programs: 2000-2022
	Set aside	Eurostat: 1990-2016
	Conservative practices	Annual Implementation Reports (RAE): 2008-2022
perennial crops	Ordinary	ISTAT
	Organic	National Information system on organic agriculture (SINAB)
	Sustainable	Annual Implementation Reports (RAE) and Annual Report on Operational Programs: 2000-2022

The annual areas subject to the abovementioned management practices, at regional level, have been estimated, also considering the transition to and from different management practices (e.g., ordinary annual crops to organic annual crops, ordinary annual crops to sustainable annual crops, etc.). Specifically, Italy assumes that the surface increment or decrement related to each improved management practice (i.e., organic, sustainable, set aside, conservative) is due to a corresponding decrement or increment in the surface of the ordinary management practice of the same cropland subcategory (i.e., annual crops and perennial crops). Land management changes have been estimated since 1971. Changes in carbon stocks in mineral soils has been calculated by applying formulation B of equation 2.25 of the IPCC, 2006 (vol. 4, chapter 2). The IPCC default transition period, i.e., 20 years, has been considered.

The SOC_{ref} classification of the soils is based on the default reference SOC stocks for mineral soils (tC/ha in 0-30 cm) provided in Table 2.3 of the 2019 Refinement. The identification of country specific SOC_{ref} have been performed using a combination of the following map layers:

- IPCC climate zones (JRC) - http://eusoils.jrc.ec.europa.eu/projects/RenewableEnergy/
- Corine Land cover 2006 (cropland: legend codes: 2.1, 2.2 and 2.4) - http://sia.eionet.europa.eu/CLC2006
- Soil map of Italy (reclassified according to the main groups of soil types as in Table 2.3 of 2019 Refinement, vol. 4) - Carta dei suoli d'Italia[41]
- Map of Italy with administrative boundaries.

Overlapping the abovementioned layers, the Italian soils have been classified according to the IPCC soil classes (Table 2.3, vol. 4, chapter 2 of the 2019 Refinement), and their related climate zones as percentage in each region. According to the thereby defined distribution of the soil types and climate zones in each Italian region, it was possible to define the SOC_{ref}. The stock change factors (F_{LU}, F_{MG}, F_{I}), appropriate for the national circumstances, have been selected among the default values provided in Table 5.5 of the

[41] Costantini E.A.C., L'Abate G., Barbetti R., Fantappiè M., Lorenzetti R., Magini S. (2013), https://esdac.jrc.ec.europa.eu/content/carta-dei-suoli-ditalia-soil-map-italy

2019 Refinement (vol. 4, chapter 5) and have been applied considering the percentage of moist and dry climates in each administrative region. The F factors considered for each management practice are reported in the following table 6.22.

Table 6.22 Stock change factors

	Management practice	F_{LU}		F_{MG}		F_{I}	
		Moist	*Dry*	*Moist*	*Dry*	*Moist*	*Dry*
annual crops	Ordinary	0.69	0.76	1	1	0.92	0.95
	Organic	0.69	0.76	1	1	1.44	1.37
	Sustainable	0.69	0.76	1.05	0.99	1	1
	Set aside	0.82	0.93	1.10	1.04	0.92	0.95
	Conservative	0.69	0.76	1.10	1.04	1.11	1.04
perennial crops	Ordinary	0.72	0.72	1	1	1	1
	Organic	0.72	0.72	1.05	0.99	1.44	1.37
	Sustainable	0.72	0.72	1.05	0.99	0.92	0.95

The SOC stocks per hectare in the mineral soil, calculated with the previously described procedure, are shown in the table 6.23, per region and per management practices, for annual and perennial crops. Estimates of SOC stock changes in annual and perennial crops are reported in Table 6.24.

Table 6.23 SOC stocks per region and management practice

Region	annual crops					perennial crops		
	Ordinary	Organic	Sustainable	Set aside	Conservative	Ordinary	Organic	Sustainable
	SOC stock (t C ha^{-})^{1}					*SOC stock (t C ha^{-})^{1}*		
Piemonte	37.28	56.92	41.39	48.39	47.24	40.60	59.41	38.92
Valle D'Aosta	47.75	74.55	54.35	62.38	63.08	53.94	81.29	52.06
Liguria	36.83	56.62	41.21	47.90	47.28	40.57	59.92	38.97
Lombardia	42.17	65.19	47.47	54.94	54.69	46.86	69.72	45.10
Trentino – Alto Adige	46.35	72.54	52.90	60.59	61.51	52.57	79.48	50.78
Veneto	33.50	50.78	36.90	43.38	41.88	36.07	52.29	34.50
Friuli - Venezia Giulia	43.08	67.43	49.17	56.32	57.18	48.86	73.88	47.20
Emilia - Romagna	26.95	40.03	29.02	34.67	32.44	28.11	39.66	26.70
Toscana	25.32	37.42	27.11	32.51	30.19	26.21	36.73	24.85
Umbria	33.38	50.60	36.77	43.23	41.74	35.95	52.11	34.38
Marche	25.75	38.15	27.65	33.09	30.84	26.75	37.62	25.39
Lazio	29.90	44.50	32.27	38.49	36.12	31.28	44.24	29.73
Abruzzo	27.81	41.38	30.01	35.79	33.60	29.10	41.17	27.66
Molise	21.11	30.74	22.24	26.96	24.48	21.36	29.35	20.16
Campania	29.36	42.68	30.87	37.48	33.93	29.63	40.61	27.94
Puglia	17.81	25.73	18.60	22.68	20.35	17.81	24.22	16.76
Basilicata	18.96	27.45	19.85	24.16	21.76	19.03	25.95	17.92
Calabria	23.52	34.40	24.90	30.09	27.50	23.96	33.11	22.64
Sicilia	19.40	27.97	20.21	24.69	22.09	19.34	26.24	18.19
Sardegna	29.84	43.17	31.21	38.02	34.19	29.90	40.74	28.16

Table 6.24 SOC stock changes in in the mineral soil for annual and perennial crops

	area		SOC stock change		
	annual crops - mineral soil	perennial crops	annual crops	perennial crops	**total**
	kha	*kha*	*kt C*	*kt C*	*kt C*
1990	7,982.3	2,698.5	215.7	1.1	216.8
1995	7,968.5	2,712.3	385.4	17.7	403.1
2000	7,773.6	2,605.9	635.0	82.6	717.5
2005	7,193.7	2,577.4	575.6	90.9	666.4
2010	6,476.7	2,574.4	305.5	131.9	437.5
2015	6,417.1	2,404.9	221.2	127.5	348.7
2017	6,402.6	2,419.3	330.3	138.0	468.3
2018	6,395.4	2,426.5	324.0	134.5	458.5
2019	6,388.6	2,433.7	289.7	130.8	420.5
2020	6,381.5	2,440.8	228.6	135.6	364.2
2021	6,390.8	2,421.3	283.1	121.5	404.6
2022	6,400.1	2,401.9	330.4	158.4	488.8

CO_2 emissions from cultivated organic soils in cropland remaining cropland have been estimated, using default emission factor for warm temperate climate zone from Table 5.6 of the 2006 IPCC Guidelines (vol.4, chapter 5): 10 t C ha^{-1} y^{-1}. The area of organic soils is taken from the FAOSTAT[42] database that overlaps:

- the map of Histosols classes in the *Harmonized World Soil Database*[43] and

- the three "cropland" classes in the global land cover dataset, GLC2000[44].

Land converted to Cropland

In accordance with the IPCC methodology, estimates of carbon stock change in living biomass and in SOM in mineral soils have been provided. Italy applies a 20-year conversion period and an approach 2 for land representation, so that in any inventory year the area reported under this category is the cumulated area of all conversions occurred in that year plus the area converted in the 19 previous years.

Direct and indirect N_2O emissions arising from nitrogen mineralization associated with loss of soil organic matter have also been estimated and reported in CRT Table 4(III).

The biomass carbon stock change, for land converted to cropland, is estimated at Tier 1 (equation 2.16, vol. 4, chapter 2 of the 2006 IPCC Guidelines) and it is equal to the removal of biomass from the initial land use plus the carbon stocks of one year of growth in perennial crops or the average biomass stock in annual crops following the conversion. Since only conversion from grassland to cropland has occurred the biomass removal is that of grassland (i.e., managed grazing land), and the value applied, as dry matter, is the default reported in Table 6.4 of the 2006 IPCC Guidelines (vol. 4, chapter 6) for warm temperate – dry climate, i.e., 6.1 t d.m. ha^{-1}. In accordance with national expert judgement, it has been assumed that the final crop type in all land converted to cropland is ordinary perennial crop; consequently, for perennial crop, the carbon stock gain of one year of growth has been taken from Table 5.9 of the 2006 IPCC Guidelines (vol. 4, chapter 5), for temperate region i.e., 2.1 t C ha^{-1}. Conversion to cropland is a quite rare event in the time series of land matrices (Table 6.4 and CRT Tables 4.1).

Changes in carbon stocks in mineral soils in land converted to cropland have been estimated applying formulation B of the IPCC equation 2.25 (2006 IPCC Guidelines, vol. 4, chapter 2). As described for cropland remaining cropland and grassland remaining grassland (see par. 6.3), SOC_{ref} was defined according to the distribution of the soil types and climate zones in each Italian region, both for cropland

[42] FAOSTAT database: http://faostat3.fao.org/faostat-gateway/go/to/download/G1/GV/E
[43] FAO/IIASA/ISRIC/ISSCAS/JRC, 2012. Harmonized World Soil Database (version 1.2). FAO, Rome, Italy and IIASA, Laxenburg, Austria.
[44] EC-JRC. 2003. Global Land Cover 2000 database. Available at http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php

and grassland. The stock change factors (F_{LU}, F_{MG}, F_I) adapted to the national circumstances, have been derived by the default values provided in Table 5.5 of the 2019 Refinement (vol. 4, chapter 5) and Table 6.2 of the 2019 Refinement (vol. 4, chapter 6) for cropland and grassland, respectively. Then, they have been applied considering the percentage of moist and dry climates in each administrative region. SOC values for cropland are reported in table 6.23, according to the different management practices considered and disaggregated by region.

Carbon stocks changes in living biomass and soils in land converted to cropland are reported in Table 6.25.

Table 6.25 Change in carbon stock in living biomass and soil in land converted to cropland

	Conversion Area		Carbon stock	
	annual change	*20 years change*	*Living biomass*	*Soils*
year	*kha*	*kha*	*kt C*	*kt C*
1990	0	136.1	0	-204.2
1995	16.8	220.0	-12.9	-330.5
2000	0	83.8	0	-126.3
2005	0	83.8	0	-126.3
2010	0	83.8	0	-126.3
2015	0	0	0	0
2017	38.9	77.8	-29.8	-118.7
2018	38.9	116.7	-29.8	-181.2
2019	38.9	155.6	-29.8	-239.3
2020	38.9	194.5	-29.8	-295.4
2021	0	194.5	0	-295.4
2022	0	194.5	0	-295.4

6.3.5 Uncertainty and time series consistency

Uncertainty estimates for the period 1990–2022 have been assessed following Approach 1 of 2006 IPCC Guidelines (IPCC, 2006). Input uncertainties dealing with activity data and emission factors have been assessed based on the information provided in the 2006 Guidelines and 2019 Refinement (IPCC, 2006 - IPCC, 2019). For 2022, the uncertainty related to the cropland remaining cropland has been assessed to be equal to 11.8% for living biomass, to 30.4% for mineral soils and to 92.2% for organic soils. For land converted to cropland, the uncertainty has been estimated to be 70.7% for living biomass, to 56.2% for DOM (deadwood and litter pool) and to 90.1% for mineral soils. The uncertainty related to the cropland category is equal to 58.9%, for 2022.

6.3.6 Category-specific QA/QC and verification

Category-specific quality control activities include comparison with alternative data sources (FAO database[45], ISTAT data[46]). Land use matrices have been accurately checked and cross-checked to ensure that data were properly reported. Several QA activities are carried out in the different phases of the inventory process. All the LULUCF categories have been embedded in the overall QA/QC system of the Italian GHG inventory.

[45] FAO, 2005. FAOSTAT, http://faostat3.fao.org/home/E

[46] ISTAT, several years [a], [b], [c]

6.3.7 Category-specific recalculations

Recalculations occur in the 2024 submission, comparing to the 2023 submission, as shown in Tables 6.26 and 6.27, for living biomass and mineral soils, affecting both cropland remaining cropland and land converted to cropland. No recalculations occurred for the organic soils.

In the 2024 submission, the 2019 IPCC Refinement SOC_{ref} and F-factors have been used to estimate the carbon stock changes in mineral soil, resulting a significant recalculation of the CO_2 estimates from/to this pool, in both cropland remaining cropland and land converted to cropland, for the whole time series. In addition, an error related to the attribution of the SOCref to the volcanic soils (about 5% of the national territory) has been fixed, with a small revision of the whole time series.

Finally, activity data have been updated for the last reporting years, i.e., woody crops area for the 2020 and 2021 reporting years and the 2021 areas subject to the above-described management practices. These updates influenced the estimates for cropland remaining cropland subcategory: the first regards the biomass carbon pool, the latter the soil organic carbon pool.

Table 6.26 Recalculation in cropland category, for carbon pool

	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021
2024 submission					*kt C*						
- living biomass	-317	-186	-609	-178	-165	-582	-178	-222	-111	-821	-447
- mineral soils	13	73	591	540	311	349	350	277	181	69	109
2023 submission					*kt C*						
- living biomass	-317	-186	-609	-178	-165	-582	-178	-222	-111	-383	-415
- mineral soils	94	246	987	922	627	643	699	613	494	333	381
recalculation					%						
- living biomass	-	-	-	-	-	-	-	-	-	53.35	7.26
- mineral soils	-645.71	-238.26	-66.91	-70.66	-101.66	-84.40	-100.1	-121.1	-172.8	-384.6	-248.6

Table 6.27 Recalculation in cropland category, for CL-CL and L-CL

	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021
2024 submission						*CO_2 eq. - kt*					
Cropland	**2,021**	**1,293**	**951**	**-447**	**339**	**1,740**	**296**	**671**	**606**	**3,623**	**2,133**
CL-CL	1,272	34	488	-910	-124	1,740	-248	-102	-381	2,430	1,050
L-CL	749	1,259	463	463	463	NO	545	774	987	1,192	1,083
2023 submission						*CO_2 eq. - kt*					
Cropland	**1,722**	**659**	**-500**	**-1,846**	**-821**	**661**	**-987**	**-559**	**-542**	**1,047**	**1,018**
CL-CL	865	-734	-988	-2,335	-1,309	661	-1,564	-1,380	-1,593	-242	-162
L-CL	857	1,393	489	489	489	NO	577	821	1,051	1,289	1,180
recalculation						%					
Cropland	**14.8**	**49.1**	**152.6**	**-313.3**	**342.0**	**62.0**	**433.1**	**183.3**	**189.5**	**71.1**	**52.3**
CL-CL	32.0	2,266.0	302.7	-156.6	-956.5	62.0	-530.0	-1,247.9	-318.4	110.0	115.4
L-CL	-14.5	-10.6	-5.5	-5.5	-5.5	NO	-6.0	-6.1	-6.5	-8.1	-8.9

6.3.8 Category-specific planned improvements

Italy is currently implementing a change in land classification system, by the use of the Oper-Foris Collect Earth tool. The new classification system is expected to supply land use and land use data for a time series, starting from 2010; the results of the abovementioned land classification will be evaluated, by comparing them against the used data and ancillary available statistics and information. The land classification system will hopefully be adopted for the reporting starting with the 2025 submission.

6.4 Grassland (4C)

6.4.1 Description

Under this category, CO_2 emissions from living biomass, and soil organic matter, in grassland remaining grassland and land converted to grassland have been reported.

Grassland category is responsible for 1,960 kt of CO_2 net removals in 2022, sharing 6.1% of total CO_2 eq. LULUCF net removals. Living biomass pool accounts for 33.7% of the grassland CO_2 emissions and removals, while soil pool is responsible for 65.0% of the category emissions and removals and the remaining 1.3% is represented by the dead organic matter pool.

CO_2 emissions and removals from living biomass under grassland remaining grassland are key categories in trend assessment both with Approach 1 and Approach 2; soils under land converted to grassland are a key category in level and trend assessment with Approach 1.

6.4.2 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

Information on the land representation is reported in section 6.1. For the grassland category, as already discussed, it is assumed that the only conversion occurring is from cropland to grassland. The IPCC default land use transition period of 20 years is applied.

6.4.3 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories

Grassland includes all grazing land, natural grassland and other wooded land that do not fulfil the forest definition (as shrublands).

Due to the technical characteristics of the IUTI assessment (i.e., classification of orthophotos), it was not possible clearly distinguish among some subcategories in *cropland* and non-woody *grassland* categories (e.g., annual crops, annual pastures versus grazing land). Therefore, although the total aggregated area of the 2 categories *cropland* and *grassland* together is derived from the IUTI data, the area of each of their subcategories is disaggregated using as proxies the national statistics (ISTAT, [b], [c]) on grazing lands, forage crops, permanent pastures, natural grassland, and lands once used for agriculture purposes, but actually set-aside since 1971. However, the area of the subcategory other wooded land, i.e., shrublands, has been derived from the NFIs (CRA-MPF, NFI1985, NFI2005 and the NFI2015), based on IUTI data (par. 6.1), through linear interpolations for the periods 1985-2005, 2005-2015 and linear extrapolation for the period 2015-2022.

6.4.4 Methodological issues

Grassland remaining Grassland

Grazing land

This land mostly includes annual biomass so that according to IPCC Tier 1 methodological approach gain and losses in the biomass and DOM and pools are assumed at long term equilibrium, so no net C stock changes are estimated.

For mineral soils, the estimation method is based on changes in SOC stocks over a finite period following changes in management that impact soil organic C. According to the 2006 IPCC Guidelines (IPCC, 2006), the change in mineral SOC stocks (vol. 4, chapter 2, eq. 2.25) is the result of a change in management practices in a unit of land across time. The SOC stock changes have been estimated considering natural (unmanaged) grazing land and managed grazing land subcategories. The latter are reported in table 6.28.

Table 6.28 Grazing land management practices and data sources

Management practices	Definition	CAP regulations	Data source
Managed grazing land (ordinary)	Renewal and/or thickening of crops; connection to zootechnics	National decree on cross compliance implementation n. 30125/2009 and subsequent revisions	ISTAT
Organic grazing land	Renewal and/or thickening of crops; connection to zootechnics	RDPs 2000-2006: Reg. (EC) n. 1257/1999; RDPs 2007 - 2013: Reg. (EC) n. 1998/2005 and Reg. (EC) n. 74/2009; Reg. (EC) n. 834/2007 and Reg. (EC) n. 889/2008; Reg. (EC) n. 1804/2007	National Information system on organic agriculture (SINAB)

The annual areas subject to the abovementioned management practices, at regional level, have been estimated, considering the transition to and from different management practices (i.e., managed grazing land to organic grazing land and vice versa). Land management changes have been estimated since 1971. Changes in organic carbon stocks in mineral soils has been calculated by applying formulation B of equation 2.25 (IPCC GLs, 2006; vol. 4, chapter 2). The IPCC default transition period, i.e., 20 years, has been considered.

The SOC_{ref} classification of the soils is based on the default reference SOC stocks for mineral soils (tC/ha in 0-30 cm) provided in Table 2.3 of 2019 Refinement. The identification of country specific SOC_{ref} have been performed using a combination of the following map layers:

- IPCC climate zones (JRC) - http://eusoils.jrc.ec.europa.eu/projects/RenewableEnergy/
- Corine Land cover 2006 (Grassland: legend codes: 2.3 ad 3.2) - http://sia.eionet.europa.eu/CLC2006
- Soil map of Italy (reclassified according to the main groups of soil types as in Table 2.3 of 2019 Refinement, vol. 4) - Carta dei suoli d'Italia[47]
- Map of Italy with administrative boundaries.

Overlapping the abovementioned layers, the Italian soils have been classified according to the IPCC soil classes (Table 2.3, vol. 4, chapter 2 of the 2019 Refinement), and their related climate zones as percentage in each region. According to the thereby defined distribution of the soil types and climate zones in each Italian region, it was possible to define the SOC_{ref} using 2019 Refinement default values. The stock change factors (F_{LU}, F_{MG}, F_I), appropriate for the national circumstances, have been selected among the default values provided in Table 6.2 of the 2019 Refinement (vol.4, chapter 6). The F factors considered are reported in the following table 6.29.

Table 6.29 Stock change factors for grazing land subcategories

Grazing land subcategory	F_{LU}		F_{MG}		F_I	
	Moist	*Dry*	*Moist*	*Dry*	*Moist*	*Dry*
Ordinary management	1	1	1	1	1.11	1.11
Organic management	1	1	1.14	1.14	1.11	1.11
Natural (unmanaged)*	1	1	0.90	0.90	1.11	1.11

** The same factors of natural (unmanaged) grazing land subcategory are also used to estimate other wooded land SOC stock (see next section)*

[47] Costantini E.A.C., L'Abate G., Barbetti R., Fantappiè M., Lorenzetti R., Magini S. (2013), https://esdac.jrc.ec.europa.eu/content/carta-dei-suoli-ditalia-soil-map-italy

The SOC stocks per hectare in mineral soil, calculated with the abovementioned procedure, are shown in the table 6.30, per region and per management practices. Estimates of SOC stock changes in grazing land are reported in table 6.31.

Table 6.30 SOC stocks on hectares basis per region and management practice

Region	**grazing land** Ordinary management *SOC stock (t C ha^{-1})*	Organic management *SOC stock (t C ha^{-1})*	Natural (unmanaged)* *SOC stock (t C ha^{-1})*
Piemonte	75.57	86.15	61.27
Valle D'Aosta	65.73	74.93	53.29
Liguria	70.21	80.04	56.93
Lombardia	63.25	72.10	51.28
Trentino – Alto Adige	62.93	71.74	51.02
Veneto	83.77	95.50	67.92
Friuli - Venezia Giulia	81.51	92.92	66.09
Emilia - Romagna	69.60	79.34	56.43
Toscana	44.37	50.58	35.97
Umbria	67.73	77.21	54.92
Marche	68.15	77.69	55.25
Lazio	67.80	77.29	54.97
Abruzzo	79.65	90.81	64.58
Molise	62.15	70.85	50.39
Campania	64.69	73.75	52.45
Puglia	26.59	30.31	21.56
Basilicata	43.53	49.63	35.30
Calabria	46.81	53.36	37.95
Sicilia	33.99	38.75	27.56
Sardegna	56.30	64.18	45.65

** The same SOC stocks on hectares basis of natural (unmanaged) grazing land subcategory are estimated for other wooded land (see next section)*

Table 6.31 SOC stock changes in in mineral soil for grazing land

	area *kha*	**net change in C stock** *kt C*
1990	7,033	-43.6
1995	6,394	275.8
2000	5,942	326.5
2005	5,780	399.3
2010	5,404	467.2
2015	5,027	163.4
2017	4,892	43.2
2018	4,824	49.6
2019	4,756	74.5
2020	4,688	74.0
2021	4,707	13.8
2022	4,688	8.9

CO_2 emissions from drainage of organic soils in grassland remaining grassland have been estimated, using default emission factor for warm temperate climate zone from Table 6.3 of the 2006 IPCC Guidelines (vol.4, chapter 6): 2.5 t C ha^{-1} y^{-1}. The area of organic soils is taken from the FAOSTAT[48] database that overlaps:

[48] FAOSTAT database: http://faostat3.fao.org/faostat-gateway/go/to/download/G1/GV/E

- the map of Histosols classes in the *Harmonized World Soil Database*[49], and

- the grassland area in the global land cover dataset, GLC2000[50].

Other wooded land

Other wooded land includes all woody vegetation types that do not fit the forest definition as, for example, the "macchia mediterranea" (Italian translation for "Mediterranean maquis"). Other wooded lands are considered in the NFIs although they do not meet the forest minimum height threshold; this subcategory is here defined as "shrublands". In this land, the total biomass changes (aboveground and belowground) are estimated by the *For-est* model at regional scale (NUTS2). A detailed description of the model is reported in Annex 12.

In table 6.32, the biomass expansion factor (BEF) to expand growing stock volume to aboveground shrub volume, the wood basic density (WBD) conversion factor to convert volume in mass of dry matter, the root/shoot ratio (R) to estimate the belowground biomass and the carbon fraction (CF) to convert dry matter are reported.

Table 6.32 Expansion and Conversion Factors for shrublands

Inventory typology	BEF *aboveground biomass / growing stock*	WBD *dry weight t d.m./ fresh volume m^3*	R *root to shoot ratio*	CF *carbon stock t C/ biomass t d.m.*
shrublands	1.49	0.63	0.62	0.47

Almost all new other wooded land surfaces are the results of a land-cover change (from natural grassland to other wooded land) within the grassland land use category (grassland remaining grassland). The DOM pools have been estimated using coefficient values and assuming a constant, linear, accumulation rate of both dead wood and litter across the conversion time till the coefficient value is achieved when the land cover change to other wooded land. In practice, in each conversion year 1/20 of the dead wood mass coefficient and of the litter mass coefficient are reported as net CO_2 removals.

Both, the dead wood and the litter mass coefficient, see table 6.33, have been estimated from data taken for the Italian national forest inventory, in 2008 and 2009 across the country from the plots of the national forest inventory network (http://www.sian.it/inventarioforestale/jsp/necromassa.jsp). The mass (wet matter) collected on the ground in those plots has been converted in dry matter using basic densities appositely calculated in a specific study (Di Cosmo et al., 2013). The data collected, aggregated at regional level, are accessible at the NFI website: http://www.sian.it/inventarioforestale/jsp/dati_carquant_tab.jsp.

The definition of the deadwood pool, coherent with the definition adopted by the NFI, is "*All non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, stumps larger than or equal to 10 cm in diameter and standing trees with DBH > 4,5 cm*". In table 6.33 dead wood and litter coefficients are reported.

Table 6.33 Dead wood and litter coefficients [live/dead ratio]

Inventory typology	dead wood *t C ha^{-1}*	litter *t C ha^{-1}*
Shrublands	1.510	1.990

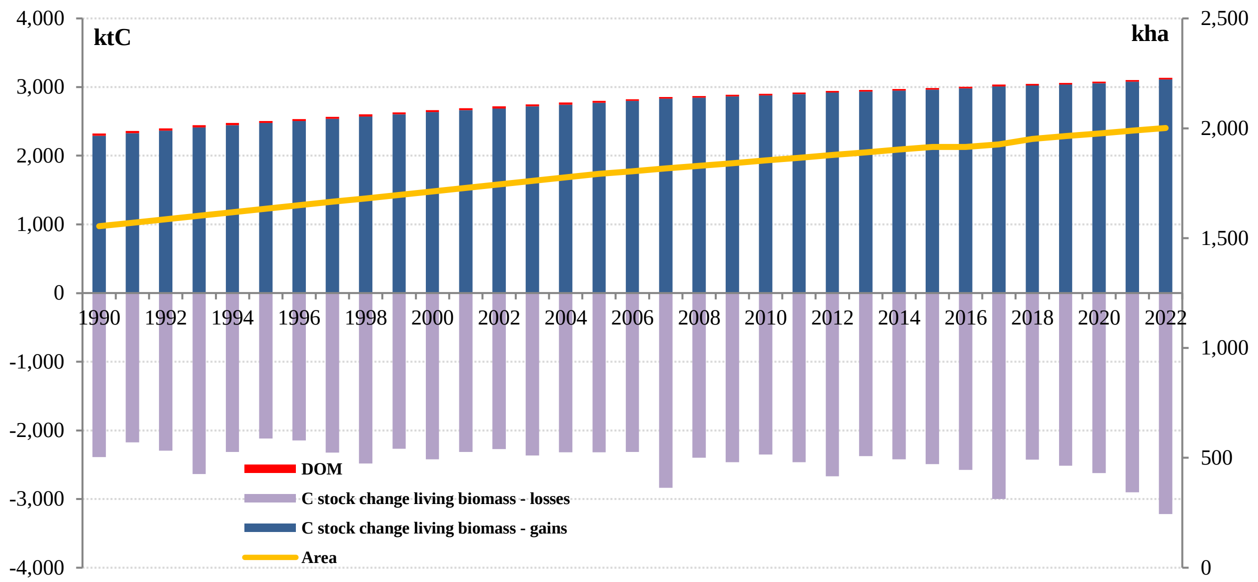
As for soils pool, following the ERT recommendation, Italy has decided to apply the IPCC Tier1, assuming that, the carbon stock in soil organic matter, for other wooded land, does not change. Land conversions from natural (unmanaged) grazing land to other wooded land are possible because of land abandonment

[49] FAO/IIASA/ISRIC/ISSCAS/JRC, 2012. Harmonized World Soil Database (version 1.2). FAO, Rome, Italy and IIASA, Laxenburg, Austria.
[50] EC-JRC. 2003. Global Land Cover 2000 database. Available at http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php

and woody encroachment. However, for these two subcategories of grassland, the same SOC stocks are estimated based on the factors of Table 6.2 of the 2019 Refinement (vol.4, chapter 6) as shown in tables 6.29 and 6.30. Therefore, carbon stock changes in soils pool, for other wooded land in grassland remaining grassland, have been not reported.

In figure 6.9, other wooded land areas and net changes in carbon stock, for the different pools, are reported, for the period 1990-2022.

Figure 6.9 Other wooded land areas and net changes in carbon stock, for the different pools



Land converted to Grassland

In accordance with the IPCC methodology, estimates of carbon stock change in living biomass and in SOC stock in mineral soils have been provided. Italy applies a 20-years conversion period and an approach 2 for land representation, so that in any inventory year the area reported under this category is the cumulated area of all conversions occurred in that year plus the area converted in the 19 previous years. As a result of conversion to grassland, it is assumed that the dominant vegetation is removed entirely, after which some type of grass is planted or otherwise established; alternatively, grassland can result from the abandonment of the preceding land use, and the area is taken over by grassland.

Three land-use changes have occurred in Italy:

1. annual crops to managed grazing land (previous vegetation removal and subsequent plantation);
2. annual crops to natural (unmanaged) grazing land (abandonment without vegetation removal);
3. woody crops to other wooded land (abandonment without vegetation removal).

The estimates of biomass C stock changes are based on the following reasonings:

1. the annual crop biomass (before) is entirely removed, and the grassland (after) is planted. Tier 1 is used with default factors:
   C_{BEFORE}: 4.7 tC ha^{-1} value before the conversion;
   C_{AFTER}: 2.867 tC ha^{-1} (6.1 t dry matter/ha) in the biomass pool in the conversion year, as suggested by IPCC 2006 (vol. 4, ch. 6, Table 6.4) for warm temperate dry climate.

2. the annual crops (before) is abandoned with no abrupt biomass change (i.e., change is not deliberate and therefore is not associated with land preparation operations like clearing and burning), and natural (unmanaged) grazing land occurs (after):
   ΔC_{growth} : 2.867 tC ha^{-1} (6.1 t d.m. ha^{-1}) in the biomass pool in the conversion year, as suggested

by IPCC 2006 (vol.4, chapter 6, Table 6.4) for warm temperate dry climate grasslands.

3. The woody crops (before) is abandoned with no abrupt biomass change (i.e., change is not deliberate and therefore is not associated with land preparation operations like clearing and burning), and other wooded land occurs (after):
   ΔC_{growth} : 2.867 tC ha^{-1} (6.1 t d.m. ha^{-1}) in the biomass pool in the conversion year, as suggested by IPCC 2006 (vol.4, chapter 6, Table 6.4) for warm temperate dry climate grasslands.

After the Second World War wide portions of cropland and managed grazing land has been abandoned in the less accessible and productive areas both in Europe and in Italy (see Pellis et al., 2019 and the references therein). The resulting conversion is generally defined as woody encroachment (specific kind of secondary succession). Generally, this type of conversion is quite slow, and its speed depends on climatic and pedological parameters. The literature on the argument is mainly based on chronosequence approaches (based on the space-for-time substitution concept) and does not measure annual C stock change in the annual transition from cropland to grassland but a general C stock change rate over a long period (generally from cropland/grassland to forest). For example, according to Alberti et al. (2008), in the Eastern Alps in Italy, the linear regression of biomass increment after agricultural abandonment is of 1.69 t C ha^{-1} yr^{-1}, but it is significantly affected by the late stages of the secondary successions identified. In a Sicilian study, Novara et al. (2013) found that annual and perennial herbs colonize abandoned perennial crops with a dry matter of 4.95 t d.m. ha^{-1}. The references suggest that in the years following the LUC there is a biomass increase. Because of the limited literature on the national territory, we therefore preferred to use the 6.1 t d.m. ha^{-1} factor suggested by the 2006 IPCC Guidelines (vol. 4, chapter 6, Table 6.4).

The total C emissions [kt C] due to change in carbon stocks in living biomass in land converted to grassland are reported in Table 6.34.

Table 6.34 Change in carbon stock in living biomass in land converted to grassland

	Conversion Area		ΔC
	annual change	*20 years change*	
year	*kha*	*kha*	*kt C*
1990	0	325.0	0
1995	0	292.5	0
2000	60	594.1	135.8
2005	97	777.0	188.0
2010	178	1,387.4	280.1
2015	44	1,608.0	124.6
2017	0	1,487.3	0
2018	0	1,427.0	0
2019	0	1,366.7	0
2020	0	1,306.4	0
2021	0	1,211.9	0
2022	0	1,117.4	0

Changes in SOC stocks in mineral soils in land converted to grassland have been estimated applying formulation B of the IPCC equation 2.25 (vol. 4, chapter 2). SOC stocks for the different subcategories of grassland are reported in the table 6.31, according to the different management practices considered and broken down by region. C emissions [kt C] due to SOC change in mineral soil in land converted to grassland, are summarized in table 6.35.

Table 6.35 Change in carbon stock in soils

	Conversion Area		Carbon stock
year	*annual change kha*	*20 years change kha*	*kt C*
1990	0	325.0	306.7
1995	0	292.5	272.0
2000	60.3	594.1	579.1
2005	97.5	777.0	846.3
2010	177.9	1,387.4	1,500.7
2015	44.1	1,608.0	1,709.5
2017	0	1,487.3	1,587.7
2018	0	1,427.0	1,528.6
2019	0	1,366.7	1,465.6
2020	0	1,306.4	1,402.4
2021	0	1,211.9	1,296.9
2022	0	1,117.4	1,182.4

6.4.5 Uncertainty and time series consistency

Uncertainty estimates for the period 1990–2022 have been assessed following Approach 1 of 2006 IPCC Guidelines (IPCC, 2006). Input uncertainties dealing with activity data and emission factors have been assessed based on the information provided in the 2006 Guidelines and 2019 Refinement (IPCC, 2006 - IPCC, 2019). For 2022, the uncertainty related to the grassland remaining grassland has been assessed to be equal to 36.3% for living biomass, to 30.7 for DOM (deadwood and litter pool), to 30.4% for mineral soils and to 92.2% for organic soils. For land converted to grassland, the uncertainty has been estimated to be 70.7% for living biomass, to 56.2% for DOM (deadwood and litter pool) and to 90.1% for mineral soils. The uncertainty related to the grassland category is equal to 84.7%, for 2022.

6.4.6 Category-specific QA/QC and verification

Systematic quality control activities have been carried out to ensure completeness and consistency in time series and correctness in the sum of sub-categories. Where possible, activity data comparison among different sources (FAO database[51], ISTAT data[52]) has been made. Data entries have been checked several times during the compilation of the inventory; attention has been focused on the categories showing significant changes between two years in succession. Land use matrices have been accurately checked and cross-checked to ensure that data were properly reported. Several QA activities are carried out in the different phases of the inventory process. The applied methodologies have been presented and discussed during several national workshops and expert meetings, collecting findings and comments to be incorporated in the estimation process. All the LULUCF categories have been embedded in the overall QA/QC-system of the Italian GHG inventory.

6.4.7 Category-specific recalculations

The recalculation resulting from the comparison of the 2024 submission with the 2023 submission is shown in table 6.36 and table 6.37, affecting both grassland remaining grassland and land converted to grassland.

In the 2024 submission, the 2019 IPCC Refinement SOC_{ref} and F-factors have been implemented to estimate the carbon stock changes in mineral soil, resulting a recalculation of the CO_2 estimates from/to this pool, for the whole time series. In addition, an error fixing in the disaggregation of the area of land converted to grassland into managed grazing land, natural grazing land and other wooded land

[51] FAO, 2005. FAOSTAT, http://faostat3.fao.org/home/E

[52] ISTAT, several years [a], [b], [c]

influenced both living biomass and carbon stock changes in the mineral soil under land converted to grassland from 2006 onward.

Table 6.36 Recalculation in grassland category, for carbon pool

	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021
2024 submission						*CO_2 - kt*					
- living biomass	5,376	17	1,665	-1,071	-1,210	-1,465	2,656	-1,986	-1,427	-884	1,586
- DOM	-114	-114	-114	-114	-88	-88	-88	-88	-88	-88	-88
- mineral soils	-975	-2,019	-3,331	-4,578	-7,226	-6,878	-5,990	-5,797	-5,657	-5,423	-4,816
2023 submission						*CO_2 - kt*					
- living biomass	5,376	17	1,665	-1,071	-1,166	-1,465	2,656	-1,986	-1,427	-884	1,752
- DOM	-114	-114	-114	-114	-88	-88	-88	-88	-88	-88	-88
- mineral soils	-1,074	-2,050	-3,519	-5,170	-8,267	-7,911	-7,059	-6,830	-6,690	-6,421	-5,665
recalculation						*%*					
- living biomass	-	-	-	-	3.66	-	-	-	-	-	-10.51
- DOM	-	-	-	-		-	-	-	-	-	-
- mineral soils	-10.18	-1.54	-5.66	-12.95	-14.40	-15.03	-17.84	-17.82	-18.26	-18.40	-17.63

Table 6.37 Recalculation in grassland category, for GL-GL and L-GL

	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021
2024 submission						*CO_2 - kt*					
Grassland	**4,307**	**-2,095**	**-1,759**	**-5,742**	**-8,504**	**-8,410**	**-3,402**	**-7,850**	**-7,153**	**-6,376**	**-3,298**
GL-GL	5,432	-1,098	862	-1,949	-1,974	-1,685	2,420	-2,245	-1,779	-1,234	1,457
L-GL	-1,124	-997	-2,621	-3,793	-6,530	-6,725	-5,822	-5,605	-5,374	-5,142	-4,755
2023 submission						*CO_2 - kt*					
Grassland	**4,187**	**-2,147**	**-1,969**	**-6,355**	**-9,521**	**-9,464**	**-4,491**	**-8,904**	**-8,205**	**-7,394**	**-4,001**
GL-GL	5,367	-1,128	771	-2,077	-2,078	-1,901	2,132	-2,523	-2,077	-1,509	1,429
L-GL	-1,180	-1,019	-2,739	-4,278	-7,443	-7,564	-6,623	-6,380	-6,128	-5,885	-5,429
recalculation						*CO_2 - kt*					
Grassland	**2.79**	**-2.48**	**-11.90**	**-10.69**	**-11.96**	**-12.53**	**-32.02**	**-13.42**	**-14.72**	**-15.96**	**-21.29**
GL-GL	1.20	-2.77	10.61	-6.59	-5.25	-12.78	11.90	-12.39	-16.77	-22.31	1.94
L-GL	-4.91	-2.17	-4.50	-12.80	-13.99	-12.47	-13.76	-13.84	-14.04	-14.44	-14.17

6.4.8 Category-specific planned improvements

Italy is currently implementing a change in land classification system, by the use of the Oper-Foris Collect Earth tool. The new classification system is expected to supply land use and land use data for a time series, starting from 2010; the results of the abovementioned land classification will be evaluated, by comparing them against the used data and ancillary available statistics and information. The land classification system will hopefully be adopted for the reporting starting with the 2025 submission.

6.5 Wetlands (4D)

6.5.1 Description

Under this category, activity data from wetlands remaining wetlands are reported. Neither wetlands remaining wetlands nor land converted to wetlands are a key category.

6.5.2 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

Wetlands area have been estimated within the national land representation applying the methodology described in section 6.1. During the period 1990-2022 conversions of annual cropland and natural grassland to wetlands have occurred.

6.5.3 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories

Wetlands includes lands covered or saturated by water, for all or part of the year (MAMB, 1992). Reservoirs or water bodies regulated by human activities have not been considered.

6.5.4 Methodological issues

Italy applies a 20-year conversion period and an approach 2 for land representation, so that in any inventory year the area reported under this category is the cumulated area of all conversions occurred in that year plus the area converted in the 19 previous years.

Only CO_2 emissions from flooded lands have been estimated. In wetlands remaining wetlands no activities are implemented. According to the equation 7.10 of the 2006 IPCC guidelines (vol. 4, chapter 7) the biomass stock after flooding is assumed to be zero, while for the biomass immediately before flooding default values reported in the 2006 IPCC guidelines have been used. For grassland (B_{before}) the value reported in Table 6.4 (vol. 4, chapter 6) for warm temperate dry climate, 6.1 t d.m. ha^{-1}, has been used; while for cropland (B_{before}) the value equal to 10 t d.m. ha^{-1} has been used (vol. 4, chapter 6) for cropland containing annual crops. The carbon fraction of 4.7 t of carbon ha^{-1} has been used.

C stocks [kt C] in living biomass are reported in table 6.38 and 6.39, for cropland converted to wetlands and grassland converted to wetlands, respectively.

Table 6.38 Change in carbon stocks in living biomass in cropland converted to wetlands

	annual change	20 years change	B after	B before	ΔC *converted*
	kha	*kha*	*t d.m. ha⁻¹*	*t d.m. ha⁻¹*	*kt C*
1990	0.00	0.00	0.00	10.00	0.00
1995	0.00	0.00	0.00	10.00	0.00
2000	0.47	2.37	0.00	10.00	-2.23
2005	0.47	4.74	0.00	10.00	-2.23
2010	7.52	21.19	0.00	10.00	-35.34
2015	7.52	58.79	0.00	10.00	-35.34
2018	0.00	57.37	0.00	10.00	0.00
2019	0.00	56.89	0.00	10.00	0.00
2020	0.00	56.42	0.00	10.00	0.00
2021	0.00	55.95	0.00	10.00	0.00
2022	0.00	55.47	0.00	10.00	0.00

Table 6.39 Change in carbon stocks in living biomass in grassland converted to wetlands

	annual change	20 years change	B after	B before	ΔC *converted*
	kha	*kha*	*t d.m. ha-1*	*t d.m. ha-1*	*kt C*
1990	0.00	0.00	0.00	6.10	0.00
1995	0.47	2.37	0.00	6.10	-1.36
2000	0.00	2.37	0.00	6.10	0.00
2005	0.00	2.37	0.00	6.10	0.00
2010	0.00	2.37	0.00	6.10	0.00
2015	0.00	0.00	0.00	6.10	0.00
2018	3.01	9.02	0.00	6.10	-8.62
2019	3.01	12.03	0.00	6.10	-8.62
2020	3.01	15.04	0.00	6.10	-8.62
2021	0.00	15.04	0.00	6.10	0.00
2022	0.00	15.04	0.00	6.10	0.00

6.5.5 Uncertainty and time series consistency

Uncertainty estimates for the period 1990–2022 have been assessed following Approach 1 of 2006 IPCC Guidelines (IPCC, 2006), resulting equal to 106% for wetlands category. Input uncertainties for activity data and emission factors have been assessed based on the information provided in the 2006 IPCC Guidelines (IPCC, 2006).

6.5.6 Category-specific QA/QC and verification

Systematic quality control activities have been carried out to ensure completeness and consistency in time series and correctness in the sum of sub-categories; where possible, activity data comparison among different sources (FAO database[53], ISTAT data[54]) has been made. Data entries have been checked several times during the compilation of the inventory; particular attention has been focused on the categories showing significant changes between two years in succession. Land use matrices have been accurately checked and cross-checked to ensure that data were properly reported. Several QA activities are carried out in the different phases of the inventory process. All the LULUCF categories have been embedded in the overall QA/QC-system of the Italian GHG inventory.

6.5.7 Category-specific recalculations

No recalculation occurs in the 2024 submission, comparing to the 2023 submission.

6.5.8 Category-specific planned improvements

Italy is currently implementing a change in land classification system, by the use of the Oper-Foris Collect Earth tool. The new classification system is expected to supply land use and land use data for a time series, starting from 2010; the results of the abovementioned land classification will be evaluated, by comparing them against the used data and ancillary available statistics and information. The land classification system will hopefully be adopted for the reporting starting with the 2025 submission.

[53] FAO, 2015. FAOSTAT, http://faostat3.fao.org/home/E
[54] ISTAT, several years [a], [b], [c]

6.6 Settlements (4E)

6.6.1 Description

Under this category, CO_2 emissions, from living biomass and soil, from land converted to settlements only have been reported. In 2022, settlements emissions share 13.6% of absolute CO_2 eq. LULUCF emissions and removals. CO_2 emissions and removals from land converted to settlements have been identified as a key category, in the level, with Approach 1 and Approach 2, and only with Approach 2 in trend assessment.

6.6.2 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

Information on the land representation is reported in section 6.1.

6.6.3 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories

All artificial surfaces, transportation infrastructures (urban and rural), power lines and human settlements of any size, including parks, have been included in this category.

6.6.4 Methodological issues

Settlements remaining Settlements

Following the 2006 IPCC Tier 1 approach no C stock changes have been estimated for any of the C pools.

Land converted to Settlements

The 2006 IPCC Guidelines equations 2.15 and 2.16 (Vol. 4, chapter 2) have been used to estimate changes in biomass and DOM carbon stocks. According to IPCC Tier 1, biomass and DOM stocks in the settlements category are assumed to be 0, which means that a complete loss of biomass and DOM stocks due to the land use change.

For the land converted to settlements, the 20-years transition period has been applied to determine the area in conversion. However, due to the characteristics of the final land use category (settlements), it is assumed that, for each carbon pool, all C stocks of the area subjected to an annual conversion are completely lost in the same conversion year, while the related CO_2 emissions are assigned to the first year the conversion has occurred.

As reported in table 6.4, in the period 1990-2022 conversions to settlements have occurred from the following categories: forest land, grassland, cropland and other land.

Carbon stock changes in forest land converted to settlements have been estimated for living biomass, dead organic matter and mineral soils, using forest land carbon stocks estimated, at regional level, by the *For-est* model described in paragraph 6.2.4 and in the Annex 12.

Concerning forest soils, the SOC stocks reported in the table 6.40 have been considered; the time range reported in the first column of the abovementioned table provides the time references for the SOC stocks' use.

Table 6.40 Soil organic carbon (SOC) stocks for *forest land*

years	**SOC stock** *t C ha⁻¹*
1985-1994	79.809
1995-1999	80.174
2000-2004	80.586
2005-2009	81.121

years	SOC stock t C ha⁻¹
2010-2014	81.682
2015-2020	82.430
2021-2022	82.837

In Table 6.41, C stocks changes [kt C] in living biomass, dead organic matter and soils in forest land converted to settlements are reported.

Table 6.41 Change in carbon stocks in forest land converted to settlements

		Forest land to settlements			Total Carbon stock
Year	conversion Area	living biomass	dead organic matter	soils	
	kha	kt C	kt C	kt C	kt C
1990	0.72	-32.09	-3.06	-57.64	-92.79
1995	0.72	-33.24	-3.05	-57.90	-94.20
2000	0.72	-34.23	-3.04	-58.20	-95.47
2005	3.69	-183.39	-15.53	-299.71	-498.63
2010	3.69	-192.82	-15.45	-301.78	-510.05
2015	3.69	-204.16	-15.37	-304.54	-524.07
2018	3.69	-210.19	-15.32	-304.54	-530.06
2019	3.69	-212.30	-15.31	-304.54	-532.15
2020	3.69	-213.87	-15.30	-304.54	-533.71
2021	3.69	-215.23	-15.28	-306.05	-536.55
2022	3.69	-216.26	-15.27	-306.05	-537.57

For cropland converted to settlements, carbon stocks changes have been estimated, for annual or perennial crops biomass, using default factors shown in the following Table 6.42 (IPCC, 2006, Table 8.4, vol. 4, chapter 8). SOC value for cropland has been set to 56.7 tC ha^{-1}, based on reviewed references.

Table 6.42 Stock change factors for cropland

	Biomass carbon stock t C ha⁻¹
Annual cropland	4.7
Perennial woody cropland	10

For grassland converted to settlements, changes in carbon stocks have been estimated for living biomass, using the IPCC default value equal to 6.1 t d.m. ha^{-1} (warm temperate dry climate, table 6.4, IPCC 2006), and for the soil pool, applying a SOC equal to 78.092 t C ha^{-1}, based on reviewed references. In table 6.43 C stocks changes [kt C] in living biomass in cropland and grassland converted to settlements are reported.

Table 6.43 Change in carbon stocks in living biomass in cropland and grassland converted to settlements

	cropland to settlements		grassland to settlements	
Year	*conversion area kha*	*carbon stock kt C*	*conversion area kha*	*carbon stock kt C*
1990	25.15	-151.84	1.73	-4.96
1995	0.00	0.00	26.70	-76.56
2000	26.70	-160.96	0.00	0.00
2005	23.73	-144.62	0.00	0.00
2010	10.98	-68.09	0.00	0.00
2015	10.98	-67.42	0.00	0.00
2018	0.00	0.00	10.98	-31.48
2019	0.00	0.00	10.98	-31.48
2020	0.00	0.00	10.98	-31.48
2021	10.18	-62.66	0.79	-2.28
2022	10.18	-62.56	0.79	-2.28

In table 6.44 SOC changes [kt C] in mineral soils in cropland and grassland converted to settlements are reported.

Table 6.44 Change in carbon stocks in soil in cropland and grassland converted to settlements

	cropland to settlements		grassland to settlements	
Year	*conversion area kha*	*carbon stock kt C*	*conversion area kha*	*carbon stock kt C*
1990	25.15	-1426.12	1.73	-135.10
1995	0.00	0.00	26.70	-2085.25
2000	26.70	-1513.98	0.00	0.00
2005	23.73	-1345.46	0.00	0.00
2010	10.98	-622.46	0.00	0.00
2015	10.98	-622.46	0.00	0.00
2018	0.00	0.00	10.98	-857.33
2019	0.00	0.00	10.98	-857.33
2020	0.00	0.00	10.98	-857.33
2021	10.18	-577.44	0.79	-62.01
2022	10.18	-577.44	0.79	-62.01

Concerning other land converted to settlements, change in carbon stocks has been not estimated, in line with the 2006 IPCC Guidelines (IPCC, 2006) as other land does not contain any significant carbon stocks.

6.6.5 Uncertainty and time series consistency

Uncertainty estimates for the period 1990–2022 have been assessed following Approach 1 of 2006 IPCC Guidelines (IPCC, 2006), resulting equal to 106% for settlements category. Input uncertainties dealing with activity data and emission factors have been assessed based on the information provided in the 2006 IPCC Guidelines (IPCC, 2006).

6.6.6 Category-specific QA/QC and verification

Systematic quality control activities have been carried out to ensure completeness and consistency in time series and correctness in the sum of sub-categories; where possible, activity data comparison among different sources (FAO database[55], ISTAT data[56]) has been made. Data entries have been checked several

[55] FAO, 2015. FAOSTAT, http://faostat3.fao.org/home/E
[56] ISTAT, several years [a], [b], [c]

times during the compilation of the inventory; particular attention has been focused on the categories showing significant changes between two years in succession. Land use matrices have been accurately checked and cross-checked to ensure that data were properly reported. Several QA activities are carried out in the different phases of the inventory process. All the LULUCF categories have been embedded in the overall QA/QC-system of the Italian GHG inventory.

6.6.7 Category-specific recalculations

Slight recalculation for the 2021 reporting year occurred in 2024 submission, comparing to the 2023 submission, as shown in table 6.45, due to the update of activity data.

Table 6.45 Recalculation in settlements category

	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021
2024 submission	*CO_2 eq. - kt*										
Settlements	7,089	8,867	6,928	7,749	4,659	4,709	5,516	5,525	5,533	5,538	4,813
2023 submission	*CO_2 eq. - kt*										
Settlements	7,089	8,867	6,928	7,749	4,659	4,709	5,516	5,525	5,533	5,538	4,749
recalculation	%										
Settlements	-	-	-	-	-	-	-	-	-	-	1.32

6.6.8 Category -specific planned improvements

Italy is currently implementing a change in land classification system, by the use of the Oper-Foris Collect Earth tool. The new classification system is expected to supply land use and land use data for a time series, starting from 2010; the results of the abovementioned land classification will be evaluated, by comparing them against the used data and ancillary available statistics and information. The land classification system will hopefully be adopted for the reporting starting with the 2025 submission.

6.7 Other Land (4F)

Under this category, CO_2 emissions, from living biomass, dead organic matter and soils, from land converted in other land should be accounted for; no data is reported since the conversion to other land is not occurring.

6.8 Direct and indirect N2O emissions from N inputs to managed soils (4(I))

N_2O emissions from N inputs to managed soils of cropland and grassland are reported in the agriculture sector; therefore, only N inputs to managed soils in forest land should be included in this section. All the related emissions are reported in the Agriculture sector, following the 2006 IPCC Guidelines (IPCC, 2006, par. 11.2.1.3, vol. 4, chapter 11).

6.9 Emissions and removals from drainage and rewetting and other management of organic and mineral soils (4(II))

N_2O emissions from N drainage of forest or wetlands soils have not been reported, since no drainage is applied to forest or wetlands soils.

6.10 Direct and indirect N_2O emissions from N mineralization/immobilization associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils (4(III))

6.10.1 Direct N_2O emissions from N mineralization/immobilization

6.10.1.1 Description

Under this category, direct N_2O emissions from N mineralization associated with loss of soil organic matter in mineral soils in land converted to cropland and to settlements are reported.

6.10.1.2 Methodological issues

N_2O emissions from mineralization of soil organic matter in mineral soils occur in land converted to cropland, from grassland remaining grassland, and land converted to settlements. The 2006 IPCC Guidelines eq. 11.1 and 11.8 (vol. 4, chapter 11) have been used to estimate the direct N_2O emissions. IPCC default values, from 2006 Guidelines have been used, namely 15 for the C/N ratio and 0.01 kg N_2O-N/kg N as EF.

In table 6.46, 6.47 and table 6.48 N_2O emissions from land-use conversion to cropland, from grassland remaining grassland, and from land-use conversion to settlements are reported, respectively.

Table 6.46 N_2O emissions from land-use conversion to cropland

	Conversion area		Carbon stock change	F_{SOM}	N_2O $_{net-min}$ -N	N_2O emissions
	annual change	*20 yrs change*				
year	*kha*	*kha*	*kt C*	*kt N*	*kt N_2O-N*	*kt N_2O*
1990	0	136.1	204.2	13.61	0.14	0.21
1995	16.8	220.0	330.5	22.03	0.22	0.35
2000	0	83.8	126.3	8.42	0.08	0.13
2005	0	83.8	126.3	8.42	0.08	0.13
2010	0	83.8	126.3	8.42	0.08	0.13
2015	0	0	0	0	0	0.00
2018	38.9	77.8	118.7	7.91	0.08	0.12
2019	38.9	116.7	181.2	12.08	0.12	0.19
2020	38.9	156	239.3	15.95	0.16	0.25
2021	38.9	194	295.4	19.69	0.20	0.31
2022	0.0	194	295.4	19.69	0.20	0.31

Table 6.47 N_2O emissions from grassland

year	Area kha	Carbon stock change kt C	F_{SOM} kt N	N_2O $_{net-min}$ -N kt N_2O-N	N_2O emissions kt N_2O
1990	7,033	43.6	2.9	0.03	0.05
1995	6,393.6	-275.8	-18.4	NO	NO
2000	5,942	-326.5	-21.8	NO	NO
2005	5,780	-399.3	-26.6	NO	NO
2010	5,404	-467.2	-31.1	NO	NO
2015	5,027	-163	-11	NO	NO
2018	4,824.0	-49.6	-3.3	NO	NO
2019	4,756.3	-74.5	-5.0	NO	NO
2020	4,688.5	-74.0	-4.9	NO	NO
2021	4,706.9	-13.8	-0.9	NO	NO
2022	4,725.4	-8.9	-0.6	NO	NO

Table 6.48 N_2O emissions from land-use conversion to settlements

	Conversion area		Carbon stock change	F_{SOM}	N_2O $_{net-min}$ -N	N_2O emissions
	annual change	*20 yrs change*				
year	*kha*	*kha*	*kt C*	*kt N*	*kt N_2O-N*	*kt N_2O*
1990	27.61	220.84	1,618.86	107.92	1.08	1.70
1995	27.61	331.26	2,143.15	142.88	1.43	2.25
2000	27.61	441.68	1,572.19	104.81	1.05	1.65
2005	27.61	552.10	1,645.16	109.68	1.10	1.72
2010	14.85	526.24	924.24	61.62	0.62	0.97
2015	14.67	461.58	927.00	61.80	0.62	0.97
2018	14.67	435.71	1,161.87	77.46	0.77	1.22
2019	14.67	422.78	1,161.87	77.46	0.77	1.22
2020	14.67	409.85	1,161.87	77.46	0.77	1.22
2021	14.67	396.92	1,161.87	77.46	0.77	1.22
2022	14.67	383.99	945.49	63.03	0.63	0.99

6.10.1.3 Category-specific recalculations

In the 2024 submission, 2019 IPCC Refinement SOCref and F-factors have been used to estimate the carbon stock changes in mineral soil in both cropland and grassland category. The estimates of direct N_2O emissions from N mineralization/immobilization associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils were affected accordingly. In addition, the direct N_2O emissions from mineral soils in 1990 for grassland remaining grassland has been reported for the first time, fixing an error that occurred in the previous submission.

Table 6.49 Recalculation in N_2O emissions from N mineralization/immobilization associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils

	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021
2024 submission	*CO_2 eq. - kt*										
GL-GL	0.05	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
L-CL	0.21	0.35	0.13	0.13	0.13	NO	0.12	0.19	0.25	0.31	0.31
L-SL	1.70	2.25	1.65	1.72	0.97	0.97	1.22	1.22	1.22	1.22	0.99
2023 submission	*CO_2 eq. - kt*										
GL-GL	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

L-CL	0.24	0.38	0.14	0.14	0.14	NO	0.13	0.20	0.27	0.34	0.34
L-SL	1.70	2.25	1.65	1.72	0.97	0.97	1.22	1.22	1.22	1.22	0.97
recalculation						%					
GL-GL	*										
L-CL	-14.46	-11.04	-5.50	-5.50	-5.50	-	-7.56	-7.09	-7.31	-8.94	-8.94
L-SL	-	-	-	-	-	-	-	-	-	-	1.96

* the direct N_2O emissions for grassland remaining grassland has been reported for the first time

6.10.2 Indirect N_2O emissions from N mineralization/immobilization

6.10.2.1 Description

Direct N_2O emissions from N inputs of synthetic and organic fertilizer to managed soils in any land use categories are reported in the agriculture sector; accordingly, the indirect N_2O emissions are reported in the agriculture sector too. In this category, only the indirect N_2O emissions from N mineralization associated with loss of soil organic matter are reported.

6.10.2.2 Methodological issues

Indirect N_2O emissions from nitrogen leaching and runoff have been estimated with method (equation 11.10) and default values (Table 11.3) from the 2006 IPCC Guidelines (vol. 4, ch. 11). In particular, 0.3 for the $Frac_{LEACH-(H)}$ and 0.0075 kg N_2O-N/kg N default values have been adopted for the EF_5. Indirect N_2O emissions are shown in Table 6.50.

Table 6.50 Indirect N_2O emissions from managed soils - Nitrogen leaching and run-off

	F_{SOM}	$Frac_{LEACH-(H)}$	EF_5	N_2Onet-min -N	N_2O emissions
year	*kt N*		*kg N_2O-N/kg N*	*kt N_2O-N*	*kt N_2O*
1990	13.61	0.30	0.008	0.03	0.05
1995	22.03	0.30	0.008	0.05	0.08
2000	8.42	0.30	0.008	0.02	0.03
2005	8.42	0.30	0.008	0.02	0.03
2010	8.42	0.30	0.008	0.02	0.03
2015	0.00	0.30	0.008	0.00	0.00
2018	12.08	0.30	0.008	0.03	0.04
2019	15.95	0.30	0.008	0.04	0.06
2020	19.69	0.30	0.008	0.04	0.07
2021	19.69	0.30	0.008	0.04	0.07
2022	19.69	0.30	0.008	0.04	0.07

6.10.2.3 Category-specific recalculations

In the 2024 submission, 2019 IPCC Refinement SOCref and F-factors have been used to estimate the carbon stock changes in mineral soil in both cropland and grassland category. The estimates of indirect N_2O emissions from managed soils were affected accordingly, as shown in Table 6.51.

Table 6.51 Recalculation in Indirect N2O emissions from managed soils

	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021
2024 submission						*N_2O - kt*					
Indirect N_2O emissions	0.05	0.08	0.03	0.03	0.03	NO	0.03	0.04	0.06	0.07	0.07
2023 submission						*N_2O - kt*					
Indirect N_2O emissions	0.06	0.09	0.03	0.03	0.03	NO	0.03	0.05	0.06	0.08	0.08

recalculation						%					
Indirect N_2O emissions	-14.46	-11.04	-5.50	-5.50	-5.50	-	-7.56	-7.09	-7.31	-8.94	-8.94

6.11 Biomass Burning (4(IV))

6.11.1 Description

Under this source category, CH_4 and N_2O emissions from wildfires occurring in forest land and CO_2, CH_4 and N_2O emissions from wildfires occurring in cropland and grassland categories are estimated. Areas affected by fires encompassed in settlements category have been reported, but no emissions are estimated, since the emissions have been assumed to be insignificant. An approximate estimate of GHG emissions from settlements has been carried out based on the 2006 IPCC (i.e., value for shrublands, Table 2.4, vol. 4, chapter 2, namely 26.7 t dm/ha). This resulted in a maximum of 7.96 kt CO_2 eq. in 2017 (3.96 kt CO_2 eq. in 2022), which is less than 500 kt CO_2 eq. and represents about 0.002 per cent of the national totals without LULUCF in 2022, which is less than 0.05 per cent of the national totals without LULUCF in 2022.

CH_4 and N_2O emissions from wildfires occurring in forest land and other wooded land under grassland have been estimated on a specific model (For-Fires) which is described in Annex 13.

Statistics related to fires occurring in other land use categories (i.e., cropland, grassland, and settlements) have been collected from the Carabinieri Force (the Armed Forces and Police Authority where the State Forestry Service is embedded, following the legislative decree 19/08/2016, n. 177), currently in charge for the data collection related to burned area.

CO_2 emissions due to forest fires in forest land remaining forest land and land converting to forest land are included in CRT Table 4.A.1, under carbon stock change in living biomass - losses.

Non-CO_2 emissions from fires have been estimated and reported in CRT Table 4(IV), while NO_x, CO and NMVOC emissions from fires have been reported in CRT Table 4.

6.11.2 Methodological issues

CO_2 emissions due to forest fires in forest land remaining forest land and land converting to forest land are included in carbon stock change in living biomass – decrease, in CRT Table 4.A.1. The total biomass loss due to forest fires has been estimated following the methodology reported in section 6.2.4.

Detailed information on the estimation process for the non-CO_2 emissions from forest fires is reported in Annex 13.

Forest, cropland, and grassland burned biomass have been estimated following the 2006 IPCC methodology (vol. 4, chapter 4, eq. 2.27), and then, multiplied by the IPCC default emission factors (Table 2.3, extra tropical forest, IPCC, 2006) to estimate CH_4, N_2O, CO and NO_x wildfire emissions.

In Table 6.52 CH_4 and N_2O emissions resulting from biomass burning in forest land category are reported.

Table 6.52 CH_4 and N_2O emissions from biomass burning in forest land category

	Forest land remaining forest land		*Land converted to forest land*	
	CH_4	N_2O	CH_4	N_2O
year	*kt*	*kt*	*kt*	*kt*
1990	10.81	0.60	1.08	0.06
1995	2.13	0.12	0.28	0.02
2000	5.26	0.29	0.93	0.05
2005	2.04	0.11	0.45	0.02
2010	1.85	0.10	0.36	0.02
2015	2.79	0.15	0.48	0.03
2018	2.11	0.12	0.34	0.02
2019	1.93	0.11	0.30	0.02
2020	4.06	0.22	0.62	0.03
2021	9.93	0.55	1.31	0.07
2022	4.06	0.22	0.86	0.05

In Table 6.53 CO_2, CH_4 and N_2O emissions resulting from biomass burning in cropland and grassland categories are reported.

Table 6.53 CO_2, CH_4 and N_2O emissions from biomass burning in cropland and grassland categories

	Cropland			*Grassland*		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
year	*kt*	*kt*	*kt*	*kt*	*kt*	*kt*
1990	39.82	0.11	0.01	5,032.03	13.72	0.76
1995	11.46	0.03	0.00	1,324.25	3.61	0.20
2000	23.18	0.06	0.00	2,945.32	8.03	0.44
2005	10.73	0.03	0.00	1,270.28	3.46	0.19
2010	8.55	0.02	0.00	1,748.79	4.77	0.26
2015	17.63	0.05	0.00	721.49	1.97	0.11
2018	8.06	0.02	0.00	214.10	0.58	0.03
2019	13.02	0.04	0.00	495.52	1.35	0.07
2020	14.65	0.04	0.00	699.92	1.91	0.11
2021	42.96	0.12	0.01	2,240.02	6.11	0.34
2022	29.23	0.08	0.00	1,876.57	5.12	0.28

6.11.3 Uncertainty and time series consistency

Uncertainty estimates for the period 1990–2022 have been assessed following Approach 1 of 2006 IPCC Guidelines (IPCC, 2006), resulting equal to 70.2% for biomass burning under forest land, to 72.8% for cropland and to 71.6% for grassland. Input uncertainties dealing with activity data and emission factors have been assessed based on the information provided in the 2006 IPCC Guidelines (IPCC, 2006).

6.11.4 Category-specific QA/QC and verification

Systematic quality control activities have been carried out to ensure completeness and consistency in time series and correctness. Data entries have been checked several times during the compilation of the inventory. Several QA activities are carried out in the different phases of the inventory process. In particular, the applied methodologies have been presented and discussed during several national workshop and expert meeting, collecting findings and comments to be incorporated in the estimation process. All the LULUCF categories have been embedded in the overall QA/QC-system of the Italian GHG inventory.

6.11.5 Category-specific recalculations

The recalculation occurred in the 2024 submission, comparing to the 2023 submission, for GHG wildfires emissions, is shown in table 6.54, both CH_4 and N_2O, for forest land, cropland, and grassland, for the whole time series. The recalculation has been due to the following causes: i) update of emission factors, used for the GHG estimation, in line with 2006 IPCC Guidelines (; ii) the carbon-to-dry matter ratio was revised, by using 0.47 instead of the 0.5 value, previously used.

Table 6.54 Recalculation of emissions from biomass burning occurring in forest land, cropland and grassland

	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021
2024 submission	*Forest land*										
CH_4 - kt	11.89	2.41	6.19	2.49	2.21	3.27	22.71	2.45	2.24	4.68	11.24
N_2O - kt	0.66	0.13	0.34	0.14	0.12	0.18	1.26	0.14	0.12	0.26	0.62
	Cropland										
CO_2 - kt	39.82	11.46	23.18	10.73	8.55	17.63	59.53	8.06	13.02	14.65	42.96
CH_4 - kt	0.11	0.03	0.06	0.03	0.02	0.05	0.16	0.02	0.04	0.04	0.12
N_2O - kt	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
	Grassland										
CO_2 - kt	5,032.03	1,324.25	2,945.32	1,270.28	1,748.79	721.49	2,696.00	214.10	495.52	699.92	2,240.02
CH_4 - kt	13.72	3.61	8.03	3.46	4.77	1.97	7.35	0.58	1.35	1.91	6.11
N_2O - kt	0.76	0.20	0.44	0.19	0.26	0.11	0.41	0.03	0.07	0.11	0.34

	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021
2023 submission	*Forest land*										
CH_4 - kt	23.77	4.82	12.38	4.99	4.42	6.54	45.41	4.90	4.47	9.36	22.48
N_2O - kt	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
	Cropland										
CO_2 - kt	39.82	11.46	23.18	10.73	8.55	17.63	59.53	8.06	13.02	14.65	42.96
CH_4 - kt	0.22	0.06	0.13	0.06	0.05	0.10	0.32	0.04	0.07	0.08	0.23
N_2O - kt	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
	Grassland										
CO_2 - kt	5,032.03	1,324.25	2,945.32	1,270.28	1,748.79	721.49	2,696.00	214.10	495.52	699.92	2,240.02
CH_4 - kt	27.45	7.22	16.07	6.93	9.54	3.94	14.71	1.17	2.70	3.82	12.22
N_2O - kt	0.86	0.23	0.50	0.22	0.30	0.12	0.46	0.04	0.08	0.12	0.38

	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021
recalculation	*Forest land*										
CH_4 - kt	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00
N_2O - kt	98.86	98.86	98.86	98.86	98.86	98.86	98.86	98.86	98.86	98.86	98.86
	Cropland										
CO_2 - kt	-	-	-	-	-	-	-	-	-	-	-
CH_4 - kt	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00
N_2O - kt	98.86	98.86	98.86	98.86	98.86	98.86	98.86	98.86	98.86	98.86	98.86
	Grassland										
CO_2 - kt	-	-	-	-	-	-	-	-	-	-	-
CH_4 - kt	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00
N_2O - kt	98.86	98.86	98.86	98.86	98.86	98.86	98.86	98.86	98.86	98.86	98.86

6.11.6 Category-specific planned improvements

No improvements are planned for the next submission.

6.12 Harvested wood products (HWP) (4G)

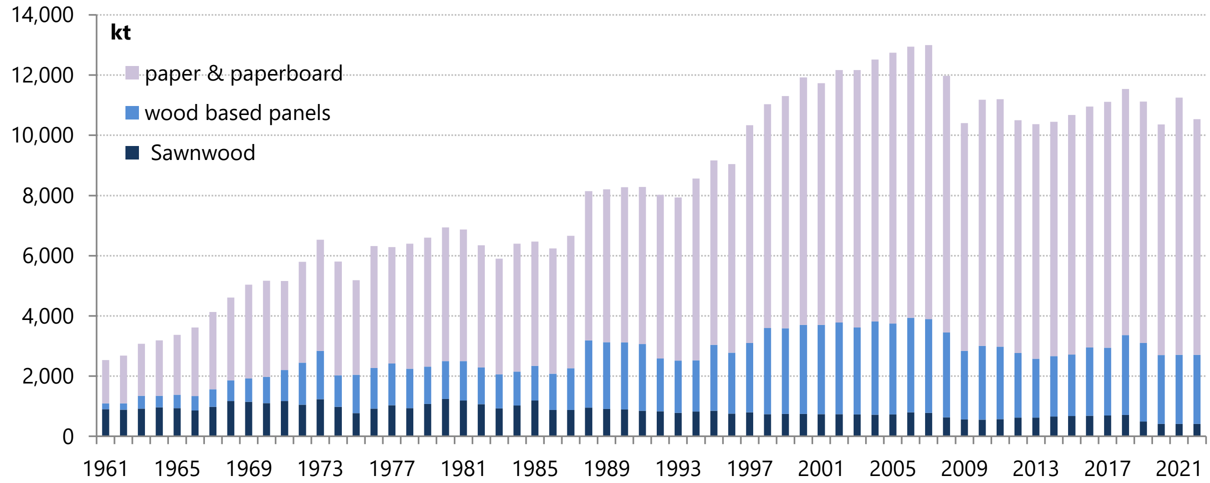
6.12.1 Description

Under this source category, annual changes in carbon stocks and associated CO_2 emissions and removals from the Harvested Wood Products (HWP) pool are estimated, following the production approach as outlined in the 2019 Refinement (IPCC, 2019), that revises and corrects errors included in the HWP chapter in the 2006 IPCC Guidelines.

6.12.2 Methodological issues

Emissions from this source are mainly influenced by the trend in forest harvest rates: in 2022, the net emissions from harvested wood products were -299.67 kt CO_2. The figure 6.10 shows the trend of HWP in use for the period 1961-2022, disaggregated into sawnwood, wood-based panels and paper & paperboard.

Figure 6.10 HWP in use for the period 1961-2022



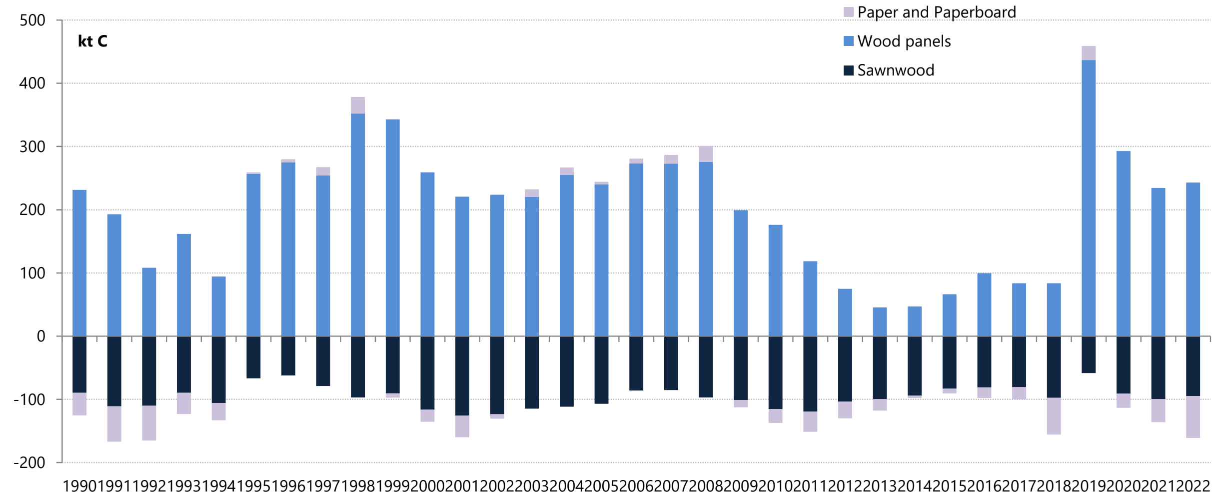
The activity data (production of sawnwood, wood-based panels and paper and paperboard) are derived from FAO forest product statistics (Food and Agriculture Organization of the United Nations: forest product statistics, http://faostat3.fao.org/download/F/FO/E).

The estimates have been carried out based on the 2019 Refinement methodology. The Tier 1 approach, first order decay, was applied to the HWP categories (sawnwood, wood-based panels and paper and paperboard) according to equation 12.2 of the 2019 Refinement (IPCC, 2019, vol. 4, ch. 12), corresponding to the equation 12.1 of the 2006 IPCC Guidelines (IPCC, 2006, vol. 4, ch. 12). Equation 12.8 of the 2019 Refinement (IPCC, 2019, vol. 4, ch. 12) has been applied to estimate the annual fraction of the feedstock coming from domestic harvest for the HWP categories sawnwood and wood-based panels.

The change in carbon stocks was estimated separately for each product category; the default values (Table 12.2 in IPCC, 2019) have been applied. Emission factors for specific product categories were calculated with default half-lives of 35 years for sawnwood, 25 years for wood panels and 2 years for paper (Table 12.3, IPCC 2019).

The annual change in stock for the period 1961-2022, disaggregated into sawnwood, wood-based panels and paper & paperboard, is reported in figure 6.11.

Figure 6.11 Annual change in stock (kt C) for the period 1990-2022



The CO_2 emissions reported in the CRT table 4Gs.1, as information item. The reported values are based on the estimates carried out with the first-order decay model, HWP sheet, from the 2006 IPCC Guidelines, implemented to estimate the long-term storage of carbon in waste disposal sites and the annual change in total long-term carbon storage in HWP waste. Therefore, the same estimates are reported in the CRT table 4Gs.1, information item, and in the memo item in CRF table 5.

6.12.3 Uncertainty and time series consistency

Uncertainty estimates for the period 1990–2022 have been assessed following Approach 1 of 2006 IPCC Guidelines (IPCC, 2006), resulting equal to 55.9% in 2022. The uncertainties of activity data and emission factors used in the estimation process have been assessed based on the uncertainties of the default factors provided in the 2019 Refinement (IPCC, 2019) and the uncertainties of used statistical data.

6.12.4 Category-specific QA/QC and verification

Systematic quality control activities have been carried out to ensure completeness and consistency in time series and correctness. Data entries have been checked several times during the compilation of the inventory. Several QA activities are carried out in the different phases of the inventory process. All the LULUCF categories have been embedded in the overall QA/QC-system of the Italian GHG inventory.

6.12.5 Category-specific recalculations

The HWP recalculation occurred in the 2024 submission, comparing to the 2023 submission, is shown in table 6.55. The recalculation is due to the revision of FAOSTAT time series for wood-based panels, for the years 2017-2021, and for paper&paperboard for 2021.

Table 6.55 Recalculation of emissions and removals from HWP category

	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021
2024 submission	*CO_2 eq. - kt*										
HWP	-388	-706	-454	-503	-142	89	59	264	-1,469	-657	-361
2023 submission	*CO_2 eq. - kt*										

HWP	-388	-706	-454	-503	-142	89	-974	-778	-3,481	-2,240	-2,035
recalculation						%					
HWP	-	-	-	-	-	-	106.09	133.96	57.79	70.65	82.28

6.12.6 Category-specific planned improvements

No improvements are planned for the next submission.

7 WASTE

7.1 Sector overview

The waste sector comprises four source categories:

1 solid waste disposal (5A);
2 biological treatment of solid waste (5B);
3 incineration and open burning of waste (5C);
4 wastewater treatment and discharge (5D).

The waste sector share of GHG emissions in the national greenhouse gas total is presently 4.86% (and was 3.65% in 1990).

The trend in greenhouse gas emissions from the waste sector is summarized in Table 7.1. It clearly shows that methane emissions from solid waste disposal sites (landfills) are by far the largest source category within this sector.

Emissions from waste incineration facilities without energy recovery are reported under category 5C, whereas emissions from waste incineration facilities, which produce electricity or heat for energetic purposes, are reported under category 1A4a.

Under 5B, CH_4, N_2O and NMVOC emissions from compost production and CH_4 emissions from anaerobic digestion of solid waste are reported.

Emissions from methane recovered, used for energy purposes, in landfills and wastewater treatment plants are estimated and reported under category 1A4a.

Table 7.1 Trend in greenhouse gas emissions from the waste sector 1990 – 2022 (Gg)

GAS/SUBSOURCE	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
CO_2 (Gg)										
5C. Waste incineration	512.01	458.23	208.26	230.15	177.21	98.72	95.62	88.68	114.24	113.58
CH_4 (Gg)	618.33	728.23	804.84	795.68	733.77	665.51	642.16	671.79	662.14	657.29
5A. Solid waste disposal on land	488.25	604.93	687.98	680.10	622.46	561.35	537.87	570.25	560.10	555.88
5B. Biological treatment of waste	0.19	0.43	1.86	3.66	4.65	4.83	4.70	4.52	4.5089	4.2706
5C. Waste incineration	1.90	2.08	2.02	2.21	2.10	2.09	1.99	2.03	2.01	1.85
5D. Wastewater treatment	127.99	120.79	112.98	109.71	104.56	97.25	97.60	94.99	95.52	95.28
N_2O (Gg)	4.42	4.38	5.10	5.82	6.22	6.04	5.97	5.88	5.89	5.79
5B. Biological treatment of waste	0.07	0.16	0.68	1.33	1.69	1.75	1.70	1.64	1.6311	1.5444
5C. Waste incineration	0.12	0.11	0.08	0.08	0.07	0.07	0.06	0.06	0.07	0.06
5D. Wastewater treatment	4.22	4.10	4.33	4.41	4.46	4.23	4.21	4.19	4.19	4.18

In the following box, key and non-key sources of the waste sector are presented based on level, trend or both. Methane emissions from landfills result as a key category at level and trend assessment calculated with Approach 1 and Approach 2; N_2O emission from biological treatment of waste is a key category at level and at trend assessment only considering the uncertainty; methane emission from wastewater treatment is a key source at level assessment with Approach 1 and Approach 2 and at trend assessment only with the uncertainty; N_2O emissions from wastewater treatment result as a key category at level and at trend assessment only with the Approach 2, taking into account the uncertainty. When including the LULUCF sector in the key source analysis, methane emissions from waste treatment and discharge is not a key category at trend assessment.

Key-source identification in the waste sector with the IPCC Approach 1 and Approach 2 (without LULUCF) for 2022

5A	CH_4	Emissions from solid waste disposal sites	Key (L, T)
5B	N_2O	Emissions from biological treatment of waste	Key (L2, T2)
5D	CH_4	Emissions from wastewater treatment	Key (L, T2)
5D	N_2O	Emissions from wastewater treatment	Key (L2, T2)
5B	CH_4	Emissions from biological treatment of waste	Non-key
5C	CO_2	Emissions from waste incineration	Non-key
5C	CH_4	Emissions from waste incineration	Non-key
5C	N_2O	Emissions from waste incineration	Non-key

7.2 Solid waste disposal on land (5A)

7.2.1 Source category description

The source category solid waste disposal on land is a key category for CH_4, both in terms of level and trend. The share of CH_4 emissions is presently 34.0% (and was about 22.2% in the base year 1990) of the CH_4 national total. For this source category, also NMVOC emissions are estimated; it has been assumed that non-methane volatile organic compounds are 1.3 weight per cent of VOC (Gaudioso et al., 1993): this assumption refers to US EPA data (US EPA, 1990).

Methane is emitted from the degradation of waste disposed of in municipal landfills, both managed and unmanaged. The main parameters that influence the estimation of emissions from landfills are, apart from the amount of waste disposed into managed landfills, the waste composition, the fraction of methane in the landfill gas and the amount of landfill gas collected and treated. These parameters are strictly dependent on the waste management policies throughout the waste streams which start from waste generation, flow through collection and transportation, separation for resource recovery, treatment for volume reduction, stabilization, recycling and energy recovery and terminate at landfill sites.

Urban waste disposal in landfill sites is still one of the main disposal practices but the percentage of waste disposed in landfills dropped from 91.1% in 1990 to 26.3% in 2022. This trend is strictly dependent on policies that have been taken in the last 25 years in waste management. In fact, at the same time, waste incineration as well as composting and mechanical and biological treatment have shown a remarkable rise due to the enforcement of legislation. Also recyclable waste collection, which at the beginning of nineties was a scarce practice and waste were mainly disposed in bulk in landfills or incineration plants, has been increasing: in 2022, the percentage of municipal solid waste separate collection is about 65.2% (the legislative targets fixed 50% in 2009), characterized by a strong growth in recent years.

In particular, in Italy the first legal provision concerning waste management was issued in 1982 (Decree of President of the Republic 10 September 1982, n.915), as a consequence of the transposition of some European Directives on waste (EC, 1975; EC, 1976; EC, 1978). In this decree, uncontrolled waste dumping as well as unmanaged landfills are forbidden, but the enforcement of these measures has been concluded only in 2000. Thus, from 2000 municipal solid wastes are disposed only into managed landfills.

For the year 2022, the non hazardous landfills in Italy disposed 5,173 kt of MSW and 2,469 kt of industrial wastes, as well as 96 kt of sludge from urban wastewater treatment plants.

Since 1999, the number of MSW landfills has decreased by more than 500 plants up to 126 in 2021 and 117 in 2022, despite the decrease of the amount of wastes disposed of is less pronounced. This because both uncontrolled landfills and small controlled landfills have been progressively closed, especially in the south of the country, where the use of modern and larger plants was opted in order to serve large territorial areas.

Concerning the composition of waste which is disposed in municipal landfills, this has been changed over the years, because of the modification of waste production due to changes in the life-style and not to a forceful policy on waste management.

The Landfill European Directive (EC, 1999) has been transposed into national decree only in 2003 by the Legislative Decree 13 January 2003 n. 36 and applied to the Italian landfills since July 2005, but the effectiveness of the policies will be significant in the future. Moreover, a following law decree (Law Decree 30 December 2008, n.208) moved to December 2009 the end of the temporary condition regarding waste acceptance criteria, thus the composition of waste accepted in landfills is expected to change slowly.

Finally, methane emissions are expected especially from non hazardous waste landfills due to biodegradability rate of the wastes disposed of; in the past, provisions by law forced only non hazardous waste landfills to have a collecting gas system.

7.2.2 Methodological issues

Emission estimates from solid waste disposal on land have been carried out using the IPCC Tier 2 methodology, through the application of the First Order Decay Model (FOD) with the start of the decay reaction on 1 January in the year after disposal.

Parameter values used in the landfill emissions model are:

1) total amount of waste disposed;
2) fraction of Degradable Organic Carbon (DOC);
3) fraction of DOC dissimilated (DOC_F);
4) fraction of methane in landfill gas (F);
5) oxidation factor (O_X);
6) methane correction factor (MCF);
7) methane generation rate constant (k);
8) landfill gas recovered (R).

It has been assumed that all the landfills, both managed and unmanaged, started operations in the same year, and have the same parameters, although characteristics of individual landfill sites can vary substantially.

Moreover, the share of waste disposed of into uncontrolled landfills has gradually decreased, as specified previously, and in the year 2000 it has been assumed equal to 0; nevertheless, emissions still have been occurring due to the waste disposed in the past years. The unmanaged sites have been considered "shallow" according to the IPCC classification.

Municipal solid waste

Basic data on waste production and landfills system are those provided by the national Waste Cadastre. The Waste Cadastre is formed by a national branch, hosted by ISPRA, and by regional and provincial branches. The basic information for the Cadastre is mainly represented by the data reported through the Uniform Statement Format (MUD), complemented by information provided by regional permits, provincial communications and by registrations in the national register of companies involved in waste management activities.

These figures have been elaborated and published by ISPRA yearly since 1999: the yearbooks report waste production data, as well as data concerning landfilling, incineration, composting and generally waste life-cycle data (ISPRA, several years).

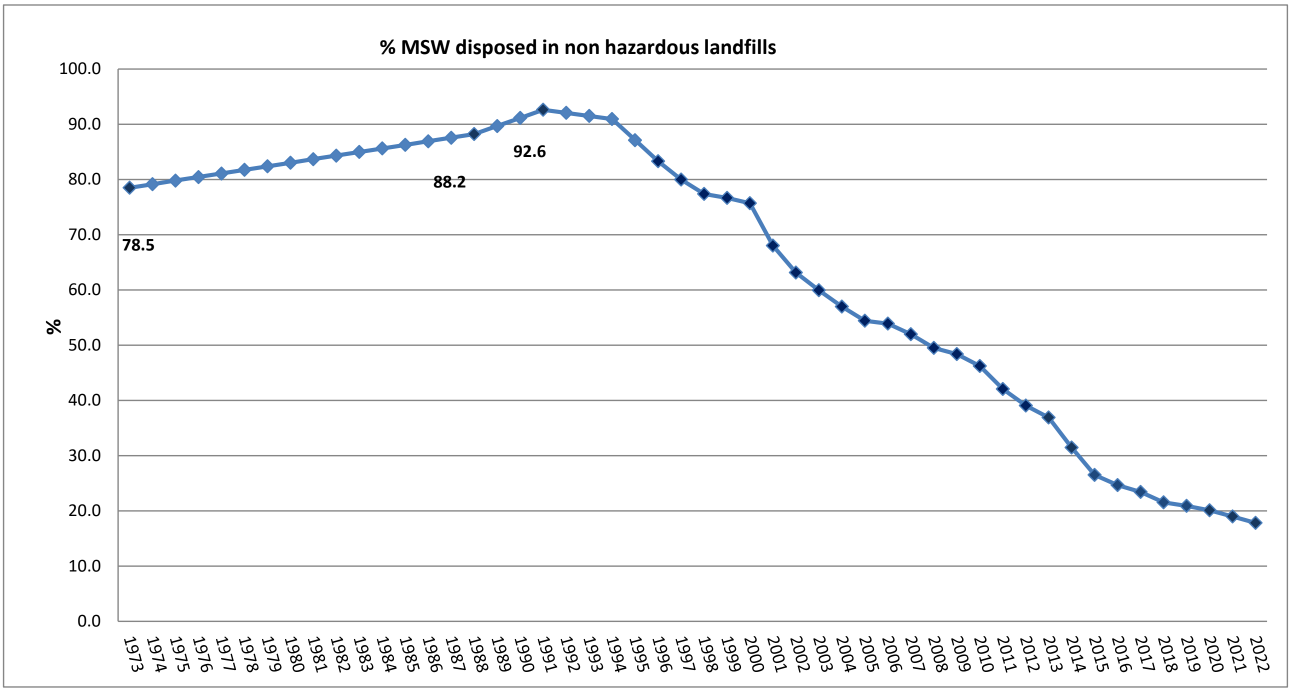
For inventory purposes, a database of waste production, waste disposal in managed and unmanaged landfills and sludge disposal in landfills was created and it has been assumed that in Italy waste landfilling started in 1950.

The complete database from 1975 of waste production, waste disposal in managed and unmanaged landfills and sludge disposal in landfills is reconstructed on the basis of different sources (MASE, several years [a]; FEDERAMBIENTE, 1992; AUSITRA-Assoambiente, 1995; ANPA-ONR, 1999 [a], [b]; APAT, 2002; ISPRA, several years), national legislation (Legislative Decree 5 February 1997, n.22), and regression models (Colombari et al, 1998).

Since waste production data are not available before 1975, they have been reconstructed on the basis of proxy variables. Gross Domestic Product data have been collected from 1950 (ISTAT, several years [a]) and a correlation function between GDP and waste production has been derived from 1975; thus, the exponential equation has been applied from 1975 back to 1950.

Consequently, the amount of waste disposed into landfills has been estimated, assuming that from 1975 backwards the percentage of waste landfilled is constant and equal to 80%; this percentage has been derived from the analysis of available data. As reported in the Figure 7.1, in the period 1973 – 1991 data are available for specific years (available data are reported in dark blue, whereas estimated data are reported in light blue). From 1973 to 1991 waste disposal has increased, because the most common practice in waste management; from early nineties, thanks to a change in national policies, waste disposal in landfill has started to decrease, in favor of other waste treatments.

Figure 7.1 Percentage of MSW disposal on land (%)



In the following Table 7.2, the time series of MSW production and MSW disposed of into non hazardous landfills from 1990 is reported. The amount of waste disposed in managed landfills is yearly provided by the national Waste Cadastre since 1995. The time series has been reconstructed backwards on the basis of several studies reporting data available for 1973, 1988, 1991, 1994 (Tecneco, 1972; MASE, several years [a]).

The amount of waste disposed in unmanaged landfills has been estimated as a percentage of the waste disposed in managed landfills. Different studies provided information about the percentage of waste in unmanaged sites for 1973, 1979, 1991 (Tecneco, 1972; ISTAT, 1984, MASE, several years [a]) and data in other years are extrapolated. These studies show that the share of waste disposed of into uncontrolled landfills has gradually decreased, from 72.8%, in 1973, to 53.4% in 1979 and 26.6% in 1991, which is a consequence of the progressive implementation of the national legislation. Since 2000 the percentage of waste in unmanaged landfills is equal to zero because of legal enforcement described in 7.2.1.

Uncontrolled landfills have been monitored since 1982 when the D.P.R. 915/82 (Decree of the President of the Republic 915/82) introduced this requirement but the effective reduction of uncontrolled landfills occurred only following the D. Lgs. 22/97 with the implementation of European Directives. From 1997 the amount of waste disposed in uncontrolled landfills (landfills not fulfilling the technological standard but allowed with special permits) strongly reduced till 2000 when they were not allowed anymore. Since 2000 police forces as Corpo Forestale dello Stato and Carabinieri (NOE - Environmental Care Command) protect and supervise the compliance with the law; if an illegal disposal of waste is revealed they proceed to the seizure and site remediation. Recently, the Law 68/2015 introduced in the Italian Penal Code a new Title entirely dedicated to crimes against the environment (Law 22 maggio 2015, n. 68).

Industrial waste

Industrial waste assimilated to municipal solid waste (AMSW) could be disposed of in non hazardous landfills. Composition of AMSW must be comparable to municipal solid waste composition. From 2001, data on industrial waste disposed of in municipal landfills are available from Waste Cadastre. For previous years, assimilated municipal solid waste production has been reconstructed, and the same percentage of MSW disposed in landfill has been applied also to AMSW. The complete database of AMSW production from 1975 to 2000 has been reconstructed starting from data available for the years 1988 (ISTAT, 1991) and 1991 (MASE, several years [a]) with a linear interpolation, and with a regression model based on Gross Domestic Product (Colombari et al, 1998). From 1975 back to 1950 AMSW production has been derived as a percentage of MSW production; this percentage has been set equal to 15%, which is approximately the value obtained from the only data available (MSW and AMSW production for the years 1988 and 1991).

The time series of AMSW and domestic sludge disposed of into non hazardous landfills from 1990 is reported is also reported in Table 7.2.

Table 7.2 Trend of MSW production and MSW, AMSW and domestic sludge disposed in landfills, 1990 – 2022.

ACTIVITY DATA	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
MSW production (Gg)	22,231	25,780	28,959	31,664	32,479	29,524	30,079	28,941	29,596	29,051
MSW disposed in landfills for non hazardous waste (Gg)	17,432	22,459	21,917	17,226	15,015	7,819	6,283	5,817	5,619	5,173
Assimilated MSW disposed in landfills for non hazardous waste (Gg)	2,828	2,978	2,825	2,914	3,508	3,222	3,256	2,910	2,963	2,469
Sludge disposed in managed landfills for non hazardous waste (Gg)	2,454	1,531	1,326	544	346	387	232	253	106	96
Total Waste to managed landfills for non hazardous waste (Gg)	16,363	21,897	26,069	20,684	18,870	11,428	9,771	8,980	8,687	7,738
Total Waste to unmanaged landfills for non hazardous waste (Gg)	6,351	5,071	0	0	0	0	0	0	0	0
Total Waste to landfills for non hazardous waste (Gg)	22,714	26,968	26,069	20,684	18,870	11,428	9,771	8,980	8,687	7,738

Sludge from urban wastewater plants

Sludge from urban wastewater treatment plants has also been considered, because it can be disposed of at the same landfills as municipal solid waste and assimilated, once it meets specific requirements. The fraction of sludge disposed in landfill sites has been estimated to be 75% in 1990, decreasing to 3% in 2022.

On the basis of their characteristics, sludge from urban wastewater treatment plants is also used in agriculture, sludge spreading on land, and in compost production, or treated in incineration plants.

The percentage of each treatment (landfilling, soil spreading, composting, incinerating and stocking) has been reconstructed within the years starting from 1990: for that year, percentages have been set based on data on tonnes of sludge treated in a given way available from a survey conducted by the National Institute of Statistics on urban wastewater plants for the year 1993 (ISTAT, 1998 [a] and [b]; De Stefanis P. et al., 1998).

From 1990 onwards each percentage has been varied on the basis of data available for specific years: in particular, data on sludge use in agriculture have been communicated by the Ministry for the Environment concerning the reference time period from 1995 (MASE, several years [a]); data on sludge used in compost production are published from 1999, while data on sludge disposed into landfills are published from 2001 (ISPRA, several years).

The total production of sludge from urban wastewater plants is communicated, every three years, by the Ministry of the Environment from 1995 (MASE, several years [b]) in the framework of the reporting commitments established by the European Sewage Sludge Directive (EC, 1986) transposed into the national Legislative Decree 27 January 1992, n. 99.

Moreover, sewage sludge production is available from different sources also for the years 1987, 1991 (MASE, several years [a]) and 1993 (ISTAT, 1998 [a] and [b]). Thus, for the missing years data have been extrapolated.

As for the waste production, also sludge production time series has been reconstructed from 1950. Starting from the number of wastewater treatment plants in Italy in 1950, 1960, 1970 and 1980 (ISTAT, 1987), the equivalent inhabitants have been derived.

To summarize, from 1987 both data on equivalent inhabitants and sludge production are available (published or estimated), thus it is possible to calculate a *per capita* sludge production: the parameter results equal on average to 80 kg $inhab.^{-1} yr^{-1}$. Consequently, this value has been multiplied to equivalent inhabitants from 1987 back to 1950.

In Table 7.3, time series of sewage sludge production and landfilling is reported.

Table 7.3 Trend of total sewage sludge production and landfilling, 1990 – 2022

ACTIVITY DATA	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Total sewage sludge production (Gg)	3,272	2,437	3,402	4,299	3,698	3,069	3,416	3,390	3,238	2,936
Sewage sludge landfilled (Gg)	2,454	1,531	1,326	544	346	387	232	253	106	96
Percentage (%)	75.0	62.8	39.0	12.7	9.4	12.6	6.8	7.5	3.3	3.3

Waste composition

One of the most important parameters that influences the estimation of emissions from landfills is the waste composition. An in-depth survey has been carried out, in order to diversify waste composition over the years.

On the basis of data available on waste composition (Tecneco, 1972; CNR, 1980; Ferrari, 1996), three slots (1950-1970; 1971-1990; 1991- 2005) have been individuated to which different waste composition has been assigned.

Waste composition used from 2005 back to 1971 (CNR, 1980; Ferrari, 1996) has been better specified, on the basis of data available from those publications. In particular, screened waste (< 20mm) has been included in emissions estimation, because the 50% of it has been assumed as organic and thus rapidly biodegradable. This assumption has been strengthened by expert judgments and sectoral studies (Regione Piemonte, 2007; Regione Umbria, 2007).

In more recent years, taking advantage of the collaboration of the branch of ISPRA that deals with waste, it has been possible to carry out characterizations of the waste based on the data collected at national level from the relevant land registry. This operation is obviously very expensive from a computational point of view, so today it is possible to carry out an in-depth analysis every 10 years, also making use of the regional studies periodically carried out at local level.

So, a fourth slot (2006- 2015) has been individuated on the basis of the analysis of several regional waste composition and the analysis of waste disposed of into non hazardous landfills specified by the European Waste Catalogue (EWC) code for the year 2007, available from Waste Cadastre database (ISPRA, 2010). Data on waste composition refer to recent years and they are representative of the national territory, deriving from the North of Italy (Regione Piemonte, 2007; Regione Veneto, 2006; Regione Emilia Romagna, 2009), the Centre (Regione Umbria, 2007; Provincia di Roma, 2008) and the South (Regione Calabria, 2002; Regione Sicilia 2004). This last waste composition, adopted from 2006, includes compost residues which are disposed into landfills because their parameters are not in compliance with those set by the law: compost residues are reported under garden and park waste component, as they are considered moderately biodegradable. The complete AD time series has been reconstructed by filling gaps with the combination of the methods provided in the 2006 IPCC guidelines (mainly overlap and interpolation). Furthermore, the consistency between the last two classifications is ensured by the high detail of the most recent data which has made it possible to univocally associate the waste deposited in landfills in the last period with those of the previous period. This also ensure the consistency in the application of the k values.

The moisture content and the organic carbon content are from national studies (Andreottola and Cossu, 1988; Muntoni and Polettini, 2002).

Finally, starting from the settings of the previous work carried out on the 2007 data, the municipal waste sent to landfill was classified into the different classes considered in the 2006 IPCC Guidelines in order to obtain the three categories mentioned above. (slowly, moderately and rapidly biodegradable). These values were compared with various regional studies conducted over the last 10 years on the characterization of waste in landfills. The studies taken into consideration were drawn from the PRGRs of Piemonte (Regione Piemonte, 2016), Emilia Romagna (Regione Emilia Romagna, 2016), Toscana (Regione Toscana, 2014), Lazio (Regione Lazio, 2020), Calabria (Regione Calabria, 2016), Campania (Regione Campania, 2016) and Sardinia (Regione Sardegna, 2016). Compared to the previous processing (based on 2007 data), the fractions of food residues (-6%) and cellulosic materials (-8%) decrease, related to the better penetration and effectiveness of separate waste collection, which are able to better intercept these fractions and subtract them from landfill disposal. On the other hand, the fraction defined here as underscreen (*sottovaglio*) and linked to the increase in TMB (Biological Mechanical Treatments) treatments of waste which has led to an increase in treatment residues. Furthermore, from various studies and hypotheses reported in the PRGRs (Regional Waste Management Plan), an increase in the organic fraction in the underscreen was noted, which was assumed to be equal to 70%.

In Tables 7.4, 7.5, 7.6, 7.7 and 7.8 waste composition of each national survey mentioned above and waste composition derived from the analysis of EWC code is reported, together with moisture content, organic carbon content and consequently degradable organic carbon both in waste type *i* and in bulk waste, DOC calculation is described in following paragraphs. Waste types containing most of the DOC and thus involved in methane emissions are highlighted in bold type.

Since sludge is not included in waste composition, because it usually refers to waste production and not to waste landfilled, it has been added to each waste composition, recalculating the percentage of waste type.

Table 7.4 Waste composition and Degradable Organic Carbon calculation, 1950 - 1970

WASTE COMPONENT	Composition by weight (wet waste)	Moisture content	Organic carbon content (dry matter)	DOC content in % of wet waste	DOC$_i$ (kgC/tMSW)
Organic	**32.7%**	**60%**	**48%**	**19%**	**62.73**
Garden and park	**3.6%**	**50%**	**48%**	**24%**	**8.71**
Paper, paperboard	**29.7%**	**9%**	**50%**	**46%**	**135.11**
Plastic	2.9%	2%	70%		
Inert	26.9%				
Sludge	**4.2%**	**75%**	**48%**	**12%**	**5.05**
DOC					**211.61**

Table 7.5 Waste composition and Degradable Organic Carbon calculation, 1971 – 1990

WASTE COMPONENT	Composition by weight (wet waste)	Moisture content	Organic carbon content (dry matter)	DOC content in % of wet waste	DOC$_i$ (kgC/tMSW)
Organic	**33.3%**	**60%**	**48%**	**19%**	**64.02**
Garden and park	**3.7%**	**50%**	**48%**	**24%**	**8.89**
Paper, paperboard, textile and wood	**19.6%**	**9%**	**50%**	**46%**	**89.29**
Plastic	6.3%	2%	70%		
Inert	6.2%				
Metal	2.6%				
Screened waste (< 2 cm)					
- organic	8.1%	**60%**	**48%**	**19%**	**15.46**
- non organic	8.1%				
Sludge	**12.0%**	**75%**	**48%**	**12%**	**14.40**
DOC					**192.06**

Table 7.6 Waste composition and Degradable Organic Carbon calculation, 1991 - 2005

WASTE COMPONENT	Composition by weight (wet waste)	Moisture content	Organic carbon content (dry matter)	DOC content in % of wet waste	DOC$_i$ (kgC/tMSW)
Organic	**24.7%**	**60%**	**48%**	**19%**	**47.36**
Garden and park	**4.2%**	**50%**	**48%**	**24%**	**10.09**
Paper, paperboard	**25.5%**	**8%**	**44%**	**40%**	**103.36**
Nappies	**2.7%**	**8%**	**44%**	**40%**	**10.98**
Textiles	**4.8%**	**10%**	**55%**	**50%**	**23.98**
Leather and rubbers	2.1%	2%	70%		
Light plastics	8.9%	2%	70%		
Rigid plastics	3.0%	2%	70%		
Inert and glasses	5.9%				
Metal	2.9%				
Bulky waste	0.5%				
Various	1.5%				
Screened waste (< 2 cm)					

WASTE COMPONENT	Composition by weight (wet waste)	Moisture content	Organic carbon content (dry matter)	DOC content in % of wet waste	DOCᵢ (kgC/tMSW)
- organic	**3.4%**	**60%**	**48%**	**19%**	**6.60**
- non organic	3.4%				
Sludge	**6.3%**	**75%**	**48%**	**12%**	**7.55**
DOC					**209.92**

Table 7.7 Waste composition and Degradable Organic Carbon calculation, 2006 – 2015

WASTE COMPONENT	Composition by weight (wet waste)	Moisture content	Organic carbon content (dry matter)	DOC content in % of wet waste	DOCᵢ (kgC/tMSW)
Organic	**21.9%**	**60%**	**48%**	**19%**	**42.07**
Garden and park	**5.6%**	**50%**	**48%**	**24%**	**13.53**
Wood	**1.6%**	**20%**	**50%**	**40%**	**6.47**
Paper, paperboard, nappies	**23.9%**	**8%**	**44%**	**40%**	**96.72**
Textiles and leather	**3.0%**	**10%**	**55%**	**50%**	**14.86**
Plastics	11.8%	2%	70%		
Metals and Aluminium	2.3%				
Inert and glasses	6.4%				
Bulky waste	2.2%				
Various	6.5%				
Screened waste (< 2 cm)					
- organic	**5.4%**	**60%**	**48%**	**19%**	**10.43**
- non organic	5.4%				
Sludge	**3.9%**	**75%**	**48%**	**12%**	**4.68**
DOC					**188.76**

Table 7.8 Waste composition and Degradable Organic Carbon calculation, 2016 – 2022

WASTE COMPONENT	Composition by weight (wet waste)	Moisture content	Organic carbon content (dry matter)	DOC content in % of wet waste	DOCᵢ (kgC/tMSW)
Organic	**15.9%**	**60%**	**48%**	**19%**	**30.61**
Garden and park	**4.3%**	**50%**	**48%**	**24%**	**10.36**
Wood	**2.1%**	**20%**	**50%**	**40%**	**8.54**
Paper, paperboard, nappies	**16.1%**	**8%**	**44%**	**40%**	**65.03**
Textiles and leather	**2.5%**	**10%**	**55%**	**50%**	**12.50**
Plastics	11.7%	2%	70%		
Metals and Aluminium	5.8%				
Inert and glasses	9.5%				
Bulky waste	0.0%				
Various	8.7%				
Screened waste (< 2 cm)					
- organic	**14.7%**	**60%**	**48%**	**19%**	**28.16**
- non organic	6.3%				
Sludge	**2.4%**	**75%**	**48%**	**12%**	**2.85**
DOC					**158.05**

On the basis of the waste composition, waste streams have been categorized in three main types: rapidly biodegradable waste, moderately biodegradable waste and slowly biodegradable waste, as reported in Table 7.9. Methane emissions have been estimated separately for each mentioned biodegradability class and the results have been consequently added up.

Table 7.9 Waste biodegradability

Waste biodegradability	Rapidly biodegradable	Moderately biodegradable	Slowly biodegradable
Food	X		
Sewage sludge	X		
Screened waste (organic)	X		
Garden and park		X	
Paper, paperboard			X
Nappies			X
Textiles, leather			X
Wood			X

Degradable organic carbon (DOC) and Methane generation potential (L_0)

Degradable organic carbon (DOC) is the organic carbon in waste that is accessible to biochemical decomposition, and should be expressed as Gg C per Gg of waste. The DOC in waste bulk is estimated based on the composition of waste and can be calculated from a weighted average of the degradable carbon content of various components of the waste stream. The following equation estimates DOC using default carbon content values.

$$DOC = \Sigma_i (DOC_i * W_i)$$

Where:

DOC = fraction of degradable organic carbon in bulk waste, kg C/kg of wet waste

DOC_i = fraction of degradable organic carbon in waste type *i*,

W_i = fraction of waste type *i* by waste category

Degradable organic carbon in waste type *i* can be calculated as following:

$$DOC_i = C_i * (1-u_i) * W_i$$

Where:

C_i = organic carbon content in dry waste type *i*, kg C/ kg of waste type *i*

u_i= moisture content in waste type *i*

W_i = fraction of waste type *i* by waste category

Once known the degradable organic carbon, the methane generation potential value (L_0) is calculated as:

$$L_0 = MCF * DOC * DOC_F * F * 16/12$$

Where:

MCF = methane correction factor

DOC_F = fraction of DOC dissimilated

F = fraction of methane in landfill gas

Fraction of degradable organic carbon (DOC_F) is an estimate of the fraction of carbon that is ultimately degraded and released from landfill, and reflects the fact that some degradable organic carbon does not degrade, or degrades very slowly, under anaerobic conditions in the landfill.

DOC_F value is dependent on many factors like temperature, moisture, pH, composition of waste: the default value 0.5 has been used. On the basis of the previous review process, Italy started an assessment of DOC_f values in order to improve the estimates and find out, if possible, separate country specific DOC_f values thanks a strict collaboration with the ISPRA branch that manage the Italian waste cadaster.

The methane correction factor (MCF) accounts for that unmanaged SWDS (solid waste disposal sites) produce less CH_4 from a given amount of waste than managed SWDS, because a larger fraction of waste decomposes aerobically in the top layers of unmanaged SWDS. The MCF should be also interpreted as the 'waste management correction factor' because it reflects the management aspects.

The MCF value used for unmanaged landfill is the default IPCC value reported for uncategorised landfills: in fact, in Italy, before 2000 the existing unmanaged landfills were mostly shallow, because they resulted in uncontrolled waste dumping instead of real deep unmanaged landfills. On the basis of the qualitative information available regarding the national unmanaged landfills, the default IPCC value used has been considered the most appropriate to represent national circumstances also in consideration of the type of waste landfilled and the humidity degree of landfills. It is assumed that landfill gas is 50% VOC. Wetlands are distinguished from dry areas by associating each type of area with landfills in their respective territories, more information are available in the following paragraph. As it is estimated that sewage sludge has been disposed of only into landfills localized in the dry zone, the values of methane generation potential for the rapidly biodegradable fraction are slightly different. The following Table 7.10 summarizes the methane generation potential values (L_0) generated, distinguished for managed and unmanaged landfills.

Table 7.10 Methane generation potential values by waste composition, landfill typology and moisture conditions

L_0 (m3CH_4/tRSU)	1950 - 1970		1971 - 1990		1991 - 2005		2006 - 2015		2016-2022	
	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet
Rapidly biodegradable										
- Managed landfill	89.7	94.6	85.4	94.6	87.2	94.6	91.4	90.2	91.4	94.6
- Unmanaged landfill	53.8	56.7	51.3	56.7	52.3	56.7	54.8	54.1	54.8	56.7
Moderately biodegradable										
- Managed landfill	118.2	118.2	118.2	118.2	118.2	118.2	118.2	118.2	118.2	118.2
- Unmanaged landfill	70.9	70.9	70.9	70.9	70.9	70.9	70.9	70.9	70.9	70.9
Slowly biodegradable										
- Managed landfill	224.1	224.1	224.1	224.1	205.9	205.9	204.0	204.0	204.6	204.6
- Unmanaged landfill	134.5	134.5	134.5	134.5	123.5	123.5	122.4	122.4	122.7	122.7

Finally, oxidation factors have been assumed equal to 0.1 for managed landfills and 0 for unmanaged according to the IPCC 2006 Guidelines where 0.1 is suggested for well managed landfills.

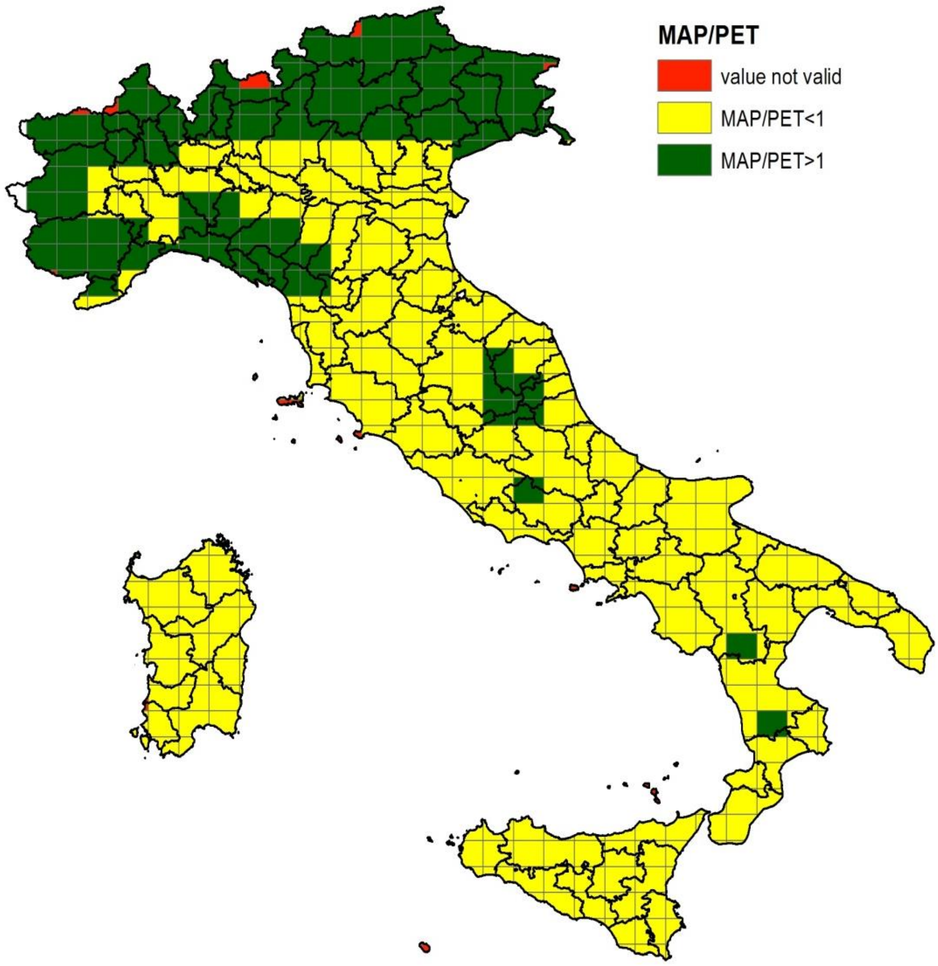
Methane generation rate constant (k)

The methane generation rate constant *k* in the FOD method is related to the time necessary for DOC in waste to decay to half its initial mass (the 'half life' or t½).

The maximum value of *k* applicable to any single SWDS is determined by a large number of factors associated with the composition of the waste and the conditions at the site. The most rapid rates are associated with high moisture conditions and rapidly degradable material such as food waste. The slowest decay rates are associated with dry site conditions and slowly degradable waste such as wood or paper. Thus, for each rapidly, moderately and slowly biodegradable fraction, and for each site conditions a different maximum methane generation rate constant has been assigned, as reported in Table 7.11. Different *k* values for rapidly, moderately and slowly biodegradable waste splitted up into dry or wet zones are applied to the different parts of the model. As above reported, consistency has been ensured in the application of a weighted average k value for slowly degradable waste but, more, Italy - applying the FOD model ith the individual k values - noted that non underestimation occurred. Furthermore, Italian experts believe that the application of the weighted average, especially for slowly biodegradable waste, constitutes a more realistic representation of the phenomenon.

The methane generation rate constant *k* values derive from the 2006 IPCC Guidelines. Italy has investigated more deeply the country specific conditions and revised the k-values considering the subdivision of the national territory in dry or wet zones on the basis of georeferenced data (30 km grid) consisting of the monthly average climatic summaries (period 1986-2015) of precipitation and evapotranspiration referring to the rainy period (October-December) and to the entire national territory provided by the Research Centre for Agriculture and Environments CREA-AA (CREA, 2017). Subsequently the ratio between precipitation (MAP = Mean Annual Precipitation) and evapotranspiration (PET = Potential Evapotranspiration) has been calculated and dry and wet zones distinguished following the 2006 Guidelines. Results have been reported in Figure 7.2., more information in (ISPRA, 2018).

Figure 7.2 Distribution of moisture conditions as defined by the 2006 IPCC GL



On the basis of the location of the solid waste disposal sites and of the distribution of dry or wet zones, the appropriate k values have been set; in particular, as reported in Table 7.10: 1) dry zones, rapidly biodegradable waste half life=12 years and k=0.06, moderately biodegradable half life=14 years and k=0.05, slowly biodegradable half life=20 years and k=0.03; 2) wet zones, rapidly biodegradable waste half life=4 years and k=0.17, moderately biodegradable half life=7 years and k=0.10, slowly biodegradable half life=14 years and k=0.05. Information and data about the fraction of waste landfilled in dry or wet zones are reported in (ISPRA, 2018). In particular, in 1990 MSW have been landfilled for 81% in dry zones and 19% in wet zones and assimilated MSW for 84% in dry and 16% in wet zones. In 2020

MSW have been landfilled for 92% in dry zones and 8% in wet zones while assimilated MSW keep the same distribution.

Table 7.11 Half-life values and related methane generation rate constant

MOISTURE CONDITIONS	WASTE TYPE	Half life	Methane generation rate constant
DRY	Rapidly biodegradable	12 year	0.06
	Moderately biodegradable	14 years	0.05
	Slowly biodegradable	20 years	0.03
WET	Rapidly biodegradable	4 year	0.17
	Moderately biodegradable	7 years	0.10
	Slowly biodegradable	14 years	0.05

Landfill gas recovered (R)

Landfill gas recovered data have been reconstructed on the basis of information on extraction plants (De Poli and Pasqualini, 1991; Acaia et al., 2004; Asja, 2003) and electricity production (TERNA, several years).

Only managed landfills have a gas collection system, and the methane extracted can be used for energy production or can be flared.

The amount of methane recovery in landfills has increased as a result of the implementation of the European Directive on the landfill of waste (EC, 1999); the amounts of methane recovered and flared have been estimated taking into account the amount of energy produced, the energy efficiency of the methane recovered, the captation efficiency and the efficiency in recovering methane for energy purposes assuming that the rest of methane captured is flared. The emissions from biogas recovered from landfills and used for energy purposes are reported in the energy sector in "1A4a biomass" category together with wood, the biomass fraction of incinerated waste and biogas from wastewater plants. In Table 7.12 consumptions and low calorific values are reported for the year 2022.

Table 7.12 1A4a biomass detailed activity data. Year 2022

Fuels		Consumption (Gg)	LCV (TJ/Gg)
Wood and similar	Wood	317.99	10.47
	Steam Wood	0.00	30.80
Incinerated waste (biomass)		2065.54	11.26
Biogas from landfills		199.16	54.34
Biogas from wastewater plants		23.28	54.34

The total CH_4 recovered is the sum of methane flared and methane used for energy purposes (see figure 7.3). Until 2000, the methane used for energy production is estimated starting from the electricity produced annually (E=GWh*3.6=TJ) by landfills (TERNA, several years) assuming an energy conversion efficiency equal to 0.3, typical efficiency value for engines that produce electricity from biogas (Colombo, 2001), and a LCV (Lower Calorific Value) equal to 50.038 TJ/Gg:

$$((E/0.3)/50.038) * 1000 = CH_4 \text{ Mg/year}$$

The LCV used for biogas derives from national experts and it is verified with energy and quantitative data about biogas production from waste supplied by TERNA (National Independent System Operator).

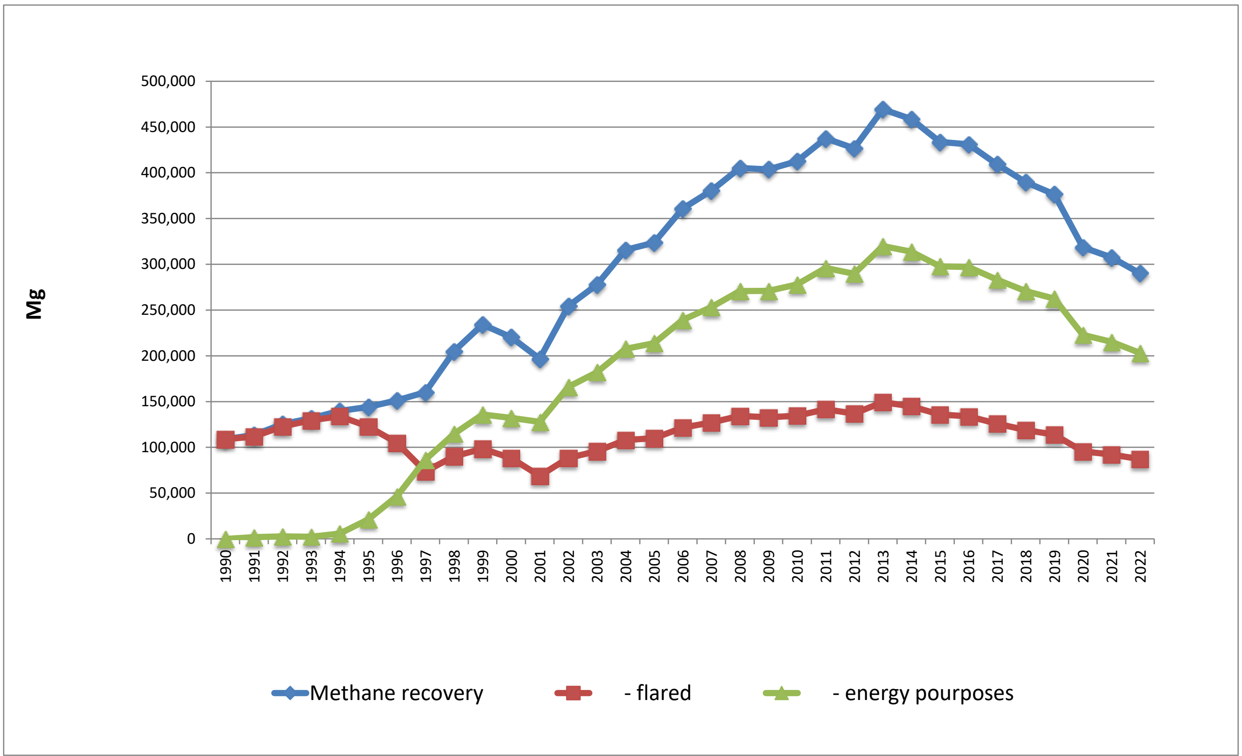
Since 2001, TERNA directly provides the amounts of biogas recovered for energy purposes, in this case the LCV has been derived from the comparison with the supplied energy data.

For the years 1987, 1988, 1989 and 1990, the methane flared is supplied by the plants (De Poli and Pasqualini, 1991); from 1991 to 1997 the methane flared has been extrapolated from the previous years; finally, for the following years the methane flared has been estimated using information based on monitored data supplied by the main operators (Asja, 2003 and Acaia, 2004) regarding the efficiency in recovering methane for energy purposes with respect to the total methane collected. This efficiency value increased from 56% of the total, in 1998, to 65% since 2002. In particular, the flared quantity of methane in 1990, reported by (De Poli and Pasqualini, 1991), is equal to 1,170,000 m^3/day which result in 108,858 Mg/y and, in 1990, this amount corresponds to the total methane recovered. Since 1991 TERNA (National Independent System Operator) supplies the amount of biogas collected with energy recovery while (ASJA, 2003) and (Acaia et al., 2004) supply the percentage (flared / with energy recovered) equal to 35% in 2000 (survey on landfills in the Lombardy region, year 2000, 32 plants) and 30% in the following years (Asja landfills produced 35% of energy from landfill gas at the national level in 2001-2002). After 2002 this value, 30 % flared of total biogas collected, has been keep constant not considering further improving in efficiency in recovering methane for energy purposes with respect to the total methane collected. Since 2002 the efficiency is estimated on the basis of an interpolation over the period 2002-2021.

Furthermore, Italy has started to collect plant data derived from IPPC permits to check data about collected and/or flared gases. There are no complete and available data bases but it is necessary to make a documentary study, plant by plant. The documents analyzed at the time (some of these are available on the website http://ippc-aia.arpa.emr.it/ippc-aia/CercaImpiantiTipo.aspx) seem to confirm current estimates (biogas flared = 30/35% of collected biogas).

Total methane collected is estimated, in 2022, equal to 32% of the total methane produced. In 2022, 70% of collected methane is used for energy purposes.

Figure 7.3 Methane recovery distinguished in flared amount and energy purposes (Mg)



CH_4 and NMVOC emission time series

The time series of CH_4 emissions is reported in Table 7.13; emissions from the amount used for energy purposes are estimated and reported under category 1A4a.

Whereas waste production continuously increases, from 2001 solid waste disposal on land has decreased as a consequence of waste management policies, although fluctuations in the amounts of industrial waste and sludge could influence this trend. At the same time, the increase in the methane-recovered percentage has led to a reduction in net emissions.

Further reduction is expected in the future because of the increasing in waste recycling.

Table 7.13 VOC produced, recovered and CH_4 and NMVOC net emissions, 1990 – 2022 (Gg)

EMISSIONS	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Managed Landfills										
VOC produced (Gg)	396.4	565.5	772.3	916.7	977.6	957.7	891.9	874.3	855.5	837.1
VOC recovered (Gg)	108.9	144.1	220.4	323.7	412.7	433.6	376.6	318.5	307.4	290.2
VOC recovered (%)	27.5	25.5	28.5	35.3	42.2	45.3	42.2	36.4	35.9	34.7
CH_4 net emissions (Gg)	255	374.3	490.3	526.7	501.8	465.5	457.8	493.7	486.8	485.8
NMVOC net emissions (Gg)	3.4	4.9	6.5	6.9	6.6	6.1	6.0	6.5	6.4	6.4
Unmanaged Landfills										
VOC produced (Gg)	235.9	233.6	200.3	155.4	122.3	97.1	81.1	77.6	74.2	71.0
VOC recovered (Gg)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CH_4 net emissions (Gg)	232.8	230.6	197.7	153.4	120.7	95.8	80.1	76.6	73.3	70.1
NMVOC net emissions (Gg)	3.1	3.0	2.6	2.0	1.6	1.3	1.1	1.0	1.0	0.9

7.2.3 Uncertainty and time-series consistency

The uncertainty in CH_4 emissions from solid waste disposal sites has been estimated both by Approach 1 and Approach 2 of the IPCC guidelines. Following Approach 1, the combined uncertainty is estimated to be 22.4%, 10% and 20% for activity data and emission factors, respectively, as suggested by the IPCC Guidelines (IPCC, 2006).

Emissions from landfills (Table 7.13) are influenced, apart from the amount of waste landfilled, also from waste composition and site conditions, as for each biodegradability class different parameters are used in the model.

The total amount of waste disposed of into managed landfills increased until 2000 (in 2000 the landfilling of waste in unmanaged landfills has stopped too), then it decreased from 2000 to 2003, while from 2003 to 2008 it is quite stable. Since 2009, due to the increase in collection and recycling, but also to the economic crisis, the amount of waste disposed of in landfills is significantly decreased. It is important to remind that the total amount of waste disposed of is the sum of municipal solid wastes (which have decreased due to the enforcement of the legislation), sludge and industrial waste (only those similar to the municipal ones), which are subjected to fluctuation.

As previously reported, five waste compositions have been used, changing from 1950 to 2022 as well as the percentage of rapidly, moderately and slowly biodegradable fraction. The combination of the amount of waste landfilled and the waste composition has led to an increase of methane production from 1990 to the period 2005-2010 and a reduction in the last years.

At the same time, biogas recovery has increased up to 2013, but from 2000 the recovery rate is higher: in 2013 the methane recovered is about 43% of the methane produced. Methane emissions for 2013 result mainly from the amount of waste landfilled in the previous three years (2010-2012) and the observed decline is explained by the sharp decrease in the amount of solid waste disposed in landfills in these years.

7.2.4 Source-specific QA/QC and verification

The National Waste cadastre is managed by ISPRA and is formed by a national branch hosted by ISPRA and regional and provincial branches hosted by the Regional Agencies for the Protection of the Environment. So the system requires continuous and systematic knowledge exchange and QA/QC checks in order to ensure homogeneity of information concerning waste production and management throughout the entire Italian territory. At central level, ISPRA provides assessment criteria and procedures for data validation, through the definition of uniform standard procedures for all regional branches. The national branch, moreover, ensures spreading of the procedures and training of technicians in each regional branch. Data are validated by ISPRA detecting potential errors and data gaps, comparing among different data sources and asking for further explanation to the regional branches whenever needed. Moreover, ISPRA has started a number of sectoral studies with a view to define specific waste production coefficients related to each production process. So through the definition of such 'production factors' and the knowledge of statistical information on production, it is possible to estimate the amount of waste originated from each sector for the selected territorial grid cell and compare the results to the statistical data on waste production.

For general QC checks on emission estimates and related parameters, each inventory expert fills in, during the inventory compilation process, a format with a list of questions to be answered which helps the compiler avoid potential errors and is also useful to prove the appropriateness of the methodological choices.

Further verifications have been carried out to check the k values for slowly degrading waste; the FOD model has been applied using the k value calculated as a weighted average between paper and wood but also imputing the different and appropriate values for paper and for wood. On the basis of 2019 submission data, the methane produced in the first case is 632,294 Mg in 1990 and 1,013,714 Mg in 2017; in the second one the methane produced is equal to 616,283 Mg in 1990 and 1,013,062 Mg in 2017. More, the sum of methane produced with the first model from 1990 to 2017 is equal to 26,943,609 Mg while using two distinct k values the sum results in 26,697,478 demonstrating that there is not an underestimation.

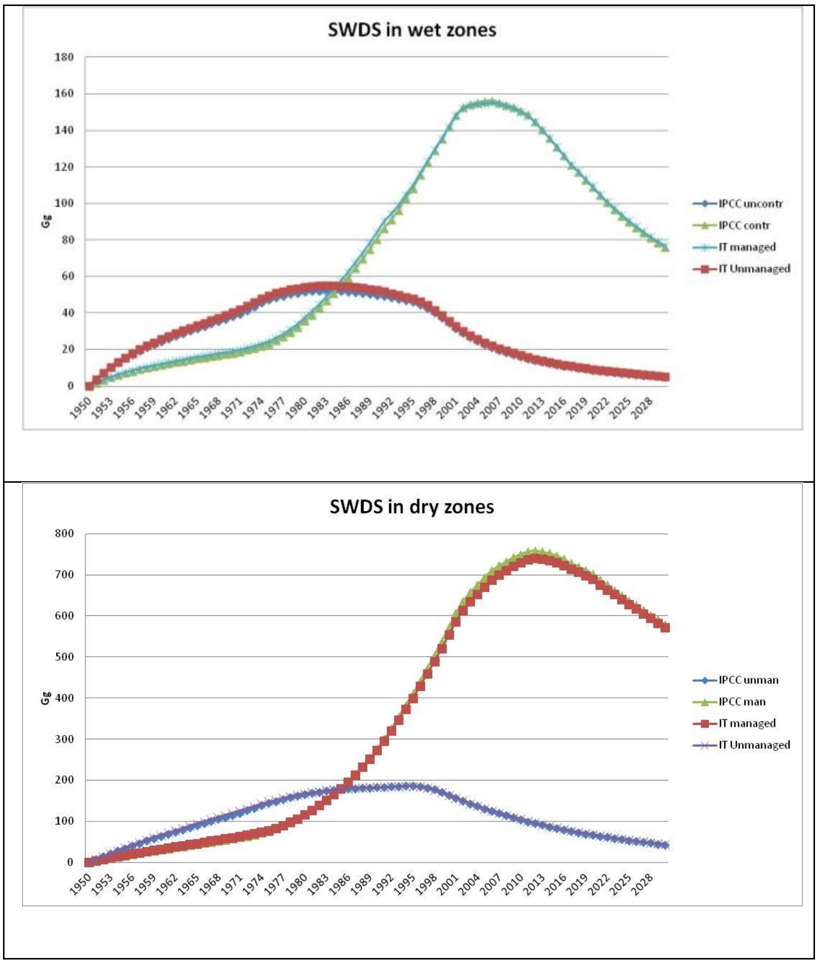
As regards the choice in k values, an in-depth survey has been conducted and results have been reported in a technical note (ISPRA, 2018).

A comparison of the IPCC waste model (MS excel) with the model used by Italy for the simulation of biogas production was carried out. To adequately compare the two calculation models, 4 outputs were created corresponding to the categories used in the Italian model: wet-managed (SWDS in wet zone and well managed), wet unmanaged (SWDS in wet zone and not managed), dry managed (SWDS in dry zone and well managed) and dry unmanaged (SWDS in dry zone and not managed). By using the same activity data and the same parameters in both models, almost identical results are obtained as can be seen from the following figures demonstrating the correct implementation of the physicochemical relationships in the Italian model. The differences shown in the table are largely within the uncertainty of the estimate.

Table 7.14 Comparison between the Italian (sub 2021) and the IPCC spreadsheet for biogas production

	IPCC model	Italian model	difference
	CH_4 Gg	CH_4Gg	%
1990			
wet managed 1990	80	84	4.4%
wet unmanaged 1990	50	53	5.8%
dry managed 1990	277	273	-1.3%
dry unmanaged 1990	183	183	0.4%
tot 1990	589	593	0.6%
2019			
wet managed 2019	113	113	0.4%
wet unmanaged 2019	9	10	8.8%
dry managed 2019	711	698	-1.8%
dry unmanaged 2019	70	71	2.0%
tot 2019	903	892	-1.1%

Figure 7.4 Comparison between the Italian (sub 2021) and the IPCC spreadsheet for biogas production



Italy investigated the possibility to estimate the emissions from certain episodes of illegal dumping. There are no quantitative data about this issue but from a qualitative point of view it was known that waste was prevalently industrial waste rich in heavy metals and inorganic chemicals, generally no or slowly biodegradable. Anyhow, the waste has been collected and temporarily stored in "ecoballe", therefore officially registered and sent to appropriate treatments resulting in the data reported by the National database (for example in the case of events in the Naples region). Moreover, an in depth analysis of EWC codes of waste disposed of in landfills has been done for the year 2007 and 2019, thanks to the complete database of Waste Cadastre kindly supplied by ISPRA Waste Office. This accurate analysis has permitted to verify the correctness of waste typology assumptions used for the estimations.

Finally, an important improvement in waste data collection has been implemented by ISPRA and the Regional Agencies for the Protection of the Environment, consequently the waste statistical report includes the urban waste data referred to last years allowing a timely reporting.

Based on the last review processes, CO_2 emissions from HWP in SWDS are under investigation. Since the previous submissions, as discussed during the review process in an intersectoral way (LULUCF and waste team), a revision of the method used to estimate the HWP in Solid Waste Disposal Sites has been applied: the waste team has implemented the HWP sheet used in the IPCC FOD model to estimate the long-term storage of C in waste disposal sites and the annual change in total long-term C storage in HWP waste. Having demonstrated in the past years the consistency of the Italian calculation model with the IPCC one, the consistency of the HWP estimates with those of the landfill (same activity data) is also ensured, pending the implementation of the calculation within the Italian model. Sharing data with LULUCF experts instead ensures consistency between the two items.

7.2.5 Source-specific recalculations

In Table 7.15, municipal and industrial (assimilated to MSW) wastes disposed into non hazardous landfills are reported also for submission 2024.

Table 7.15 MSW and AMSW disposed into landfills time series, 1990 – 2022 (t), and differences in percentage between Submission 2024 and Submission 2023.

Year	Submission 2024			Submission 2023			% MSW	% AMSW	% Total
	MSW to landfill (t)	AMSW to landfill (t)	Total waste (except sludge) to landfill (t)	MSW to landfill (t)	AMSW to landfill (t)	Total waste (except sludge) to landfill (t)			
1990	17,431,760	2,827,867	20,259,627	17,431,760	2,827,867	20,259,627	-	-	-
1995	22,458,880	2,977,672	25,436,552	22,458,880	2,977,672	25,436,552	-	-	-
2000	21,917,417	2,825,340	24,742,757	21,917,417	2,825,340	24,742,757	-	-	-
2005	17,225,728	2,913,697	20,139,425	17,225,728	2,913,697	20,139,425	-	-	-
2006	17,525,881	2,480,830	20,006,711	17,525,881	2,480,830	20,006,711	-	-	-
2007	16,911,545	2,776,637	19,688,182	16,911,545	2,776,637	19,688,182	-	-	-
2008	16,068,760	3,703,220	19,771,980	16,068,760	3,703,220	19,771,980	-	-	-
2009	15,537,822	3,180,904	18,718,726	15,537,822	3,180,904	18,718,726	-	-	-
2010	15,015,119	3,508,400	18,523,519	15,015,119	3,508,400	18,523,519	-	-	-
2011	13,205,749	2,882,686	16,088,435	13,205,749	2,882,686	16,088,435	-	-	-
2012	11,720,316	2,291,946	14,012,262	11,720,316	2,291,946	14,012,262	-	-	-
2013	10,914,353	2,511,711	13,426,064	10,914,353	2,511,711	13,426,064	-	-	-
2014	9,331,898	2,912,908	12,244,806	9,331,898	2,912,908	12,244,806	-	-	-
2015	7,818,795	3,221,646	11,040,441	7,818,795	3,221,646	11,040,441	-	-	-
2016	7,431,611	2,512,938	9,944,549	7,431,611	2,512,938	9,944,549	-	-	-
2017	6,926,548	3,899,413	10,825,961	6,926,548	3,899,413	10,825,961	-	-	-
2018	6,496,000	3,511,898	10,007,898	6,485,714	3,511,898	9,997,612	-	-	-
2019	6,283,307	3,256,299	9,539,606	6,283,307	3,256,299	9,539,606	-	-	-
2020	5,817,128	2,909,686	8,726,814	5,817,128	2,909,686	8,726,814	-	-	-
2021	5,618,640	2,962,608	8,581,248	5,618,640	2,962,608	8,581,248	-	-	-
2022	5,172,950	2,468,969	7,641,919						

In Table 7.16 differences in percentage between emissions from landfills reported in the updated time series and 2023 submission are presented. Some minor recalculations occurred since 2017 because of the correction of an error in 2016 and so differences start from 2017 considering the delay time.

Table 7.16 Differences in percentage between emissions from landfills reported in the updated time series and 2023 submission

EMISSIONS	1990	1995	2000	2005	2010	2015	2019	2020	2021
Managed Landfills									
VOC produced (Gg)	-	-	-	-	-	-	0.03%	0.03%	0.04%
VOC recovered (Gg)	-	-	-	-	-	-	-	-	-
CH4 net emissions (Gg)	-	-	-	-	-	-	0.05%	0.05%	0.07%
NMVOC net emissions (Gg)	-	-	-	-	-	-	0.05%	0.05%	0.07%
Unmanaged Landfills									
VOC produced (Gg)	-	-	-	-	-	-	-	-	-
VOC recovered (Gg)	-	-	-	-	-	-	-	-	-
CH_4 net emissions (Gg)	-	-	-	-	-	-	-	-	-
NMVOC net emissions (Gg)	-	-	-	-	-	-	-	-	-

7.2.6 Source-specific planned improvements

Currently, more recent data on the fraction of CH_4 in landfill gas and on the amount of landfill gas collected and treated are under investigation.

7.3 Biological treatment of solid waste (5B)

7.3.1 Source category description

Biological treatment of solid waste is a key category for N_2O emissions at level (for 2022) and trend assessment but only with the Approach 2. Under this source category CH_4 and N_2O emissions from compost production and CH_4 emissions from anaerobic digestion of waste have been reported. NMVOC emissions from compost production have been estimated too. The amount of waste treated in composting and digestion plants has shown a great increase from 1990 to 2022 (from 283,879 Mg to 6,435,007 Mg for composting and from 79,440 Mg to 2,195,801 Mg for anaerobic digestion).

Information on input waste to composting plants are published yearly by ISPRA since 1996, including data for 1993 and 1994 (ANPA, 1998; ISPRA, several years), while for 1987 and 1995 only data on compost production are available (MASE, several years [a]; AUSITRA-Assoambiente, 1995); based on this information the whole time series has been reconstructed. Regarding anaerobic digestion, the same sources of information have been used to reconstruct the time series until 2004 while ISPRA publishes yearly more accurate data from 2005.

7.3.2 Methodological issues

<u>Composting</u>

The composting plants are classified in two different kinds: plants that treat a selected waste (food, market, garden waste, sewage sludge and other organic waste, mainly from the agro-food industry); and mechanical-biological treatment plants, where the unselected waste is treated to produce compost, refuse derived fuel (RDF), and a waste with selected characteristics suitable for landfilling or incinerating systems.

It is assumed that 100% of the input waste to the composting plants from selected waste is treated as compost, while in mechanical-biological treatment plants 30% of the input waste is treated as compost on the basis of national studies and references (Favoino and Cortellini, 2001; Favoino and Girò, 2001).

In previous submissions, literature data (Hogg, 2001) have been used for the emission factor, 0.029 g CH_4 kg^{-1} treated waste, corresponding to the minimum of the range proposed by 2006 IPCC Guidelines on a wet weight basis. This choice has been taken because in the 2006 IPCC Guidelines the default value (4 g CH_4/kg waste treated) is clearly shifted towards high values because most of world plants does not use advanced technologies. The majority of references reported in Table 4.1 of 2006 IPCC Guidelines that have found high emission factors referred to composting time of 10-14 months, low turning frequency and no aeration system. In Italy, almost all of the plants are industrial plants (216/279 >1000 Mg/year in 2014), with enclosed areas for rotting and decomposition served by biofilters, turning when needed (to maintain the right porosity) and, above all, forced ventilation or suction system. Following the discussion started during the effort sharing decision review (EU, 2016) a specific survey on methane emission factor from composting and the relationship with technologies and management practices has been conducted (ISPRA, 2017) resulting in a new emission factor equal to 0.65 kg CH_4/Mg waste treated on a wet weight basis. As reported in the IPCC Guidelines, Table 4.1, the emission factors for dry waste are estimated from those for wet waste assuming a moisture content of 60% in wet waste.

NMVOC emissions have also been estimated: emission factor (51 g NMVOC kg^{-1} treated waste) is from international scientific literature too (Finn and Spencer, 1997). In Table 7.17 and in Figure 7.5, activity data expressed in wet weight, CH_4, N_2O and NMVOC emissions are reported.

Anaerobic digestion

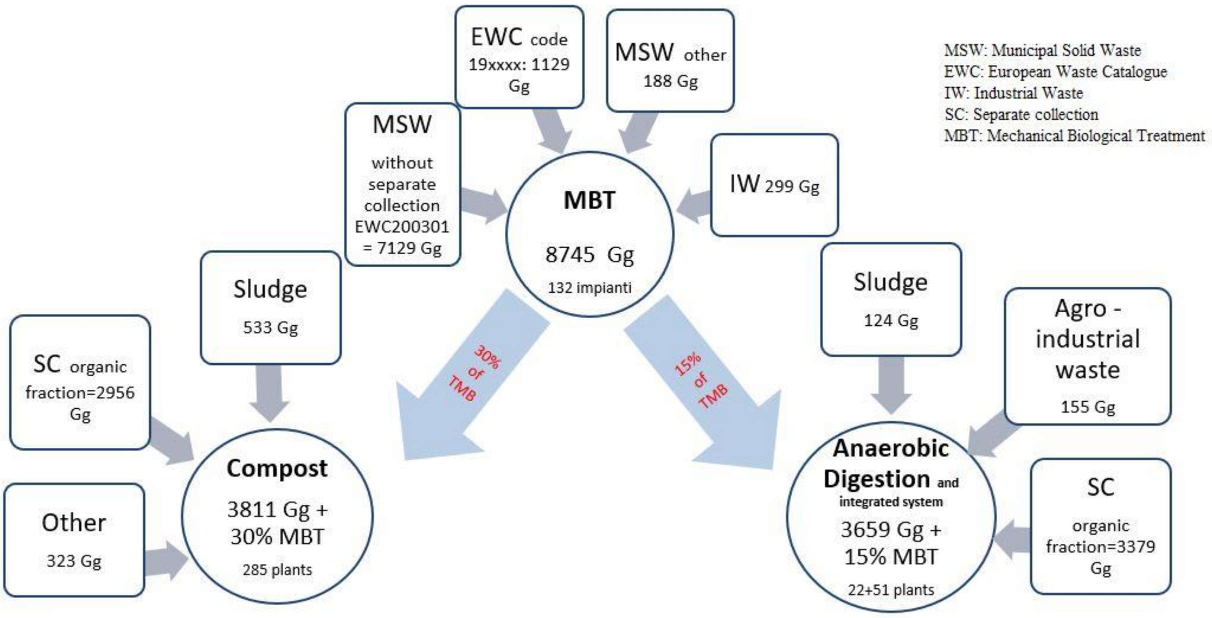
The anaerobic digestion plants too are subdivided in the same two different kinds: plants that treat a selected waste and mechanical-biological treatment plants.

It is assumed that 100% of the input waste to the plants from selected waste is treated as anaerobic digestion, while in mechanical-biological treatment plants 15% of the input waste is considered as anaerobically digested. The default IPCC 2006 emission factor has been used. Since the plants are closed systems, emissions are related to the possibility of gas leaks estimated in 5 % of potential emissions.

Table 7.17 CH_4, N_2O and NMVOC emissions from biological treatment of solid waste, 1990 – 2022

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Activity data										
Amount of waste to composting process (Gg ww)	283.88	657.22	2,834.31	5,550.89	7,030.81	7,288.30	7,085.97	6,818.91	6,796.34	6,435.01
Amount of waste to composting process (Gg dw)	113.55	262.89	1,133.72	2,220.36	2,812.32	2,915.32	2,834.39	2,727.57	2,718.53	2,574.00
Amount of waste to anaerobic digestion (Gg ww)	79.44	127.43	467.80	1,407.20	1,976.36	2,303.17	2,450.63	2,309.97	2,283.16	2,195.80
Amount of waste to anaerobic digestion (Gg dw)	31.78	50.97	187.12	562.88	790.54	921.27	980.25	923.99	913.26	878.32
CH_4										
Compost production (Gg)	0.18	0.43	1.84	3.61	4.57	4.74	4.61	4.43	4.42	4.18
Anaerobic digestion (Gg)	0.00	0.01	0.02	0.06	0.08	0.09	0.10	0.09	0.09	0.09
N_2O										
Compost production (Gg)	0.068	0.158	0.680	1.332	1.687	1.749	1.701	1.637	1.631	1.544
NMVOC										
Compost production (Gg)	0.014	0.033	0.144	0.282	0.357	0.370	0.360	0.346	0.345	0.327

Figure 7.5 Waste treated in compost and anaerobic plants in 2022



7.3.3 Uncertainty and time-series consistency

The uncertainty in CH_4 emissions from biological treatment of waste is estimated to be about 100% in annual emissions, 20% and 100% concerning activity data and emission factors respectively. The uncertainty in N_2O emissions from biological treatment of waste is estimated to be about 100% in annual emissions, 20% and 100% concerning activity data and emission factors, respectively.

7.3.4 Source-specific QA/QC and verification

This source category is covered by the general QA/QC procedures. Moreover, as concerns composting, an in depth survey has been conducted in 2017 investigating literature and plant data. Results are reported in (ISPRA, 2017).

7.3.5 Source-specific recalculations

No recalculations occur.

Table 7.18 CH_4 and N_2O recalculations for biological treatment of solid waste, 1990 – 2021

	1990	1995	2000	2005	2010	2015	2019	2020	2021
CH_4									
Compost production (Gg)	-	-	-	-	-	-	-	-	-
Anaerobic digestion (Gg)	-	-	-	-	-	-	-	-	-
N_2O	-	-	-	-	-	-	-	-	-
Compost production (Gg)	-	-	-	-	-	-	-	-	-

7.3.6 Source-specific planned improvements

Anaerobic digestion of solid waste is under investigation to collect more information about technologies and emission factors.

7.4 Waste incineration (5C)

7.4.1 Source category description

Existing incinerators in Italy are used for the disposal of municipal waste, together with some industrial waste, sanitary waste and sewage sludge for which the incineration plant has been authorized by the competent authority. Other incineration plants are used exclusively for industrial and sanitary waste, both hazardous and not, and for the combustion of waste oils, whereas there are few plants where residual waste from waste treatments, as well as sewage sludge, are treated. Since 2007, the activity of co-incineration in industrial plants, especially to produce wooden furniture, has increased significantly, resulting in an increase of the relevant emissions related to the proportion of waste burned.

Emissions from incineration of human bodies in crematoria have been estimated too.

As mentioned above, emissions from waste incineration facilities with energy recovery are reported under category 1A4a (Combustion activity, commercial/institutional sector, see Table 7.12) in the "Other fuel" and "Biomass" subcategory for the fossil and biomass fraction of wastes, respectively, whereas emissions from other types of waste incineration facilities are reported under category 5C (Waste incineration). For 2022, almost 99% of the total amount of urban waste incinerated is treated in plants with energy recovery system.

A complete database of the incineration plants is now available, updated with the information reported in the yearly report on waste production and management published by ISPRA (ISPRA, several years).

Emissions from removable residues from agricultural production are included in the IPCC category 5C: the total residues amount and carbon content have been estimated by both IPCC and national factors. The detailed methodology is reported in Chapter 5 (5.6.2).

CH_4 and N_2O emissions from biogenic, plastic and other non-biogenic wastes have been calculated.

7.4.2 Methodological issues

Regarding GHG emissions from incinerators, the methodology reported in the IPCC Good Practice Guidance (IPCC, 2000) has been applied, combined with that reported in the CORINAIR Guidebook (EMEP/CORINAIR, 2007; EMEP/EEA, 2009; EMEP/EEA, 2023). A single emission factor for each pollutant has been used combined with plant specific waste activity data. Since 2010, NO_x, SO_2 and CO emission factors for urban waste incinerators have been updated on the basis of data provided by plants (ENEA-federAmbiente, 2012; De Stefanis P., 2012).

As regard incineration plants, emissions have been calculated for each type of waste: municipal, industrial, hospital, sewage sludge and waste oils.

A complete database of these plants has been built, on the basis of various sources available for the period of the entire time series, extrapolating data for the years for which no information was available (MASE, several years [a]; ANPA-ONR, 1999 [a] and [b]; APAT, 2002; AUSITRA-Assoambiente, 1995; Morselli, 1998; FEDERAMBIENTE, 1998; FEDERAMBIENTE, 2001; AMA-Comune di Roma, 1996; ENI S.p.A., 2001; COOU, several years; Fondazione per lo sviluppo sostenibile e FISE UNIRE, 2016).

For each plant a lot of information is reported, among which the year of the construction and possible upgrade, the typology of combustion chamber and gas treatment section, if it is provided with energy recovery (thermal or electric), and the type and amount of waste incinerated (municipal, industrial, etc.).

Different procedures were used to estimate emission factors, according to the data available for each type of waste, except CH_4 and N_2O emission factor that is derived from EMEP Corinair (EMEP/CORINAIR, 2007).

Specifically:

1 for municipal waste, emission data from a large sample of Italian incinerators were used (FEDERAMBIENTE, 1998; ENEA-federAmbiente, 2012);

2 for industrial waste and waste oil, emission factors have been estimated on the basis of the allowed levels authorized by the Ministerial Decree 19 November 1997, n. 503 of the Ministry of Environment;

3 for hospital waste, which is usually disposed of alongside municipal waste, the emission factors used for industrial waste were also applied;

4 for sewage sludge, in absence of specific data, reference was made to the emission limits prescribed by the Guidelines for the authorisation of existing plants issued on the Ministerial Decree 12 July 1990.

In Table 7.19, emission factors are reported in kg per tons of waste treated, for municipal, industrial, hospital waste, waste oils and sewage sludge.

Table 7.19 Waste incineration emission factors

POLLUTANT/WASTE TYPOLOGY	NMVOC (kg/t)	CO (kg/t)	CO_2 fossil (kg/t)	N_2O (kg/t)	NO_x (kg/t)	SO_2 (kg/t)	CH_4 (kg/t)
Municipal waste 1990 - 2009	0.46	0.07	295.17	0.1	1.15	0.39	0.06
Municipal waste since 2010	0.46	0.07	467.50	0.1	0.62	0.02	0.06
Hospital waste	0.7	0.075	1200	0.1	0.604	0.026	0.06
Sewage sludge	0.25	0.6	0	0.227	3	1.8	0.06
Waste oils	7.4	0.075	3000.59	0.1	2	1.28	0.06
Industrial waste	7.4	0.56	1200	0.1	2	1.28	0.06

Here below (Tables 7.20, 7.21, 7.22, 7.23), details about data and calculation of specific emission factors are reported. Emission factors have been estimated on the basis of a study conducted by ENEA (De Stefanis, 1999), based on emission data from a large sample of Italian incinerators (FEDERAMBIENTE, 1998; AMA-Comune di Roma, 1996), legal thresholds (Ministerial Decree 19 November 1997, n. 503 of the Ministry of Environment; Ministerial Decree 12 July 1990), the last study conducted by ENEA and federAmbiente (ENEA-federAmbiente, 2012) and expert judgements.

The CO_2 implied emission factor for waste incineration varies annually and depends on the fossil carbon fraction in line with the variation of waste composition that varies yearly on the basis of the amount of annual municipal, industrial and hospital waste and the quantity of sewage sludge to burn.

In details, from 1990 to 2009 CO_2 emission factor for municipal waste has been calculated considering a carbon content equal to 23%; moreover, on the basis of the IPCC Guidelines (IPCC, 2006) and referring to the average content analysis on a national scale (De Stefanis P., 2002), a distinction was made between CO_2 from fossil fuels (generally plastics) and CO_2 from renewable organic sources (paper, wood, other organic materials). Only emissions from fossil fuels, which are equivalent to 35% for municipal waste, were included in the inventory. In the last submissions, further improvement has been carried out; with the aim to upgrade the C content in municipal waste an analysis on waste composition in recent years has been conducted resulting in a carbon content for municipal waste equal to 25.5% (ISPRA, 2010) and a subdivision between fossil and renewable fuels equal to 50-50%. These updates have been applied starting from 2010. Regarding the other waste components, C in sludge is considered completely organic, while C in industrial and hospital waste are considered completely fossil carbon according to the national definitions of these type of wastes. Mortal remains are not part of hospital waste but are included in the activity data used to estimate emissions from crematories; C in this case is considered completely organic. CO_2 emission factor for industrial, oils and hospital waste has been derived as the average of values of investigated industrial plants.

On the other hand, CO_2 emissions from the incineration of sewage sludge were not included at all, while all emissions relating to the incineration of hospital and industrial waste were considered.

In this way, the resulting CO_2 emission factor for waste incineration varies in line with the variations of waste composition as can be seen in table 5.C of the CRT tables.

In Table 7.24 activity data are reported by type of waste.

Table 7.20 Municipal waste emission factors

MUNICIPAL WASTE	Average concentration values (mg/Nm³)		Standard specific flue gas volume (Nm³/KgMSW)		E.F. (g/Mg)	
	1990-2009	2010-	1990-2009	2010-	1990-2009	2010-
SO_2	78.00	2.17	5	6.7	390	18
NO_x	230.00	97.08			1,150	621
CO	14.00	12.30			70	73
N_2O					100	100
CH_4					59.80	59.80
NMVOC					460.46	460.46
C content, % weight	23	25.5				
CO_2					843.3 (kg/Mg)	935.4(kg/Mg)

Table 7.21 Industrial waste and oils emission factors

INDUSTRIAL AND OIL WASTE	Average concentration values (mg/Nm³)	Standard specific flue gas volume (Nm³/KgMSW)	E.F. (g/t)
SO_2	160.00	8	1,280
NO_x	250.00		2,000
CO	70.00		560
N_2O			100
CH_4			59.80
NMVOC			7,400
CO_2			1,200 (kg/t)

Table 7.22 Hospital waste emission factors

HOSPITAL WASTE	Average concentration values (mg/Nm³)	Standard specific flue gas volume (Nm³/KgMSW)	E.F. (g/t)
SO_2	3.24	8	26
NO_x	75.45		604
CO	9.43		75
N_2O			100
CH_4			59.80
NMVOC			700
CO_2			1,200 (kg/t)

Table 7.23 Sewage sludge emission factors

SEWAGE SLUDGE	Average concentration values (mg/Nm³)	Standard specific flue gas volume (Nm³/KgMSW)	E.F. (g/t)
SO_2	300	6	1,800
NO_x	500		3,000
CO	100		600
N_2O			100
CH_4			59.80
NMVOC			251.16
CO_2			700 (kg/t)

Table 7.24 Amount of waste incinerated by type, 1990 – 2022 (Gg)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Total Waste incinerated	1,656	2,149	3,062	4,964	6,977	7,535	7,648	7,480	7,484	7,234
- with energy recovery	911	1,558	2,750	4,721	6,796	7,431	7,558	7,410	7,373	7,124
- without energy recovery	745	591	312	244	181	103	90	70	111	110
Total Waste incinerated - Carbon content (Gg)	439	560	773	1,309	1,970	2,123	2,187	2,143	2,136	2,067

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
MSW incinerated	1,026	1,437	2,325	3,220	4,337	4,698	4,359	4,227	4,305	4,131
- with energy recovery	626	1,185	2,161	3,168	4,284	4,698	4,359	4,227	4,305	4,131
- without energy recovery	399	251	164	52	53	0	0	0	0	0
MSW incinerated - Carbon content (Gg)	236	330	535	741	1,106	1,199	1,112	1,078	1,098	1,054
Industrial Waste incinerated										
Other waste	473	536	604	1,602	2,499	2,709	3,169	3,145	3,045	2,969
- with energy recovery	258	330	508	1,446	2,399	2,676	3,138	3,119	3,005	2,929
- without energy recovery	215	206	96	155	100	33	31	26	40	40
Other waste - Carbon content (Gg)	155	175	198	524	818	887	1,037	1,029	997	972
Hospital waste	134	152	110	126	135	102	106	107	114	113
- with energy recovery	25	41	77	106	113	57	61	64	63	63
- without energy recovery	109	111	34	21	23	45	44	44	51	51
Hospital waste-Carbon content (Gg)	44	50	36	41	44	33	35	35	37	37
Sludge	20.72	23.18	21.50	15.60	5.98	25.10	14.06	0.00	19.57	19.46
- with energy recovery	0.00	0.00	3.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- without energy recovery	20.72	23.18	18.11	15.60	5.98	25.10	14.06	0.00	19.57	19.46
Sludge - Carbon content (Gg)	3.96	4.43	4.10	2.98	1.14	4.79	2.68	0.00	3.74	3.72
Waste oil	2.66	1.41	0.82	0.67	0.18	0.46	0.23	0.29	0.40	0.20
- with energy recovery	1.77	0.94	0.55	0.54	0.18	0.46	0.23	0.29	0.40	0.20
- without energy recovery	0.89	0.47	0.27	0.12	0.00	0.00	0.00	0.00	0.00	0.00
Waste oil - Carbon content (Gg)	0.87	0.46	0.27	0.22	0.06	0.15	0.07	0.10	0.13	0.13

CH_4 and N_2O emissions from agriculture residues removed, collected and burnt 'off-site', as a way to reduce the amount of waste residues, are reported in the waste incineration sub-sector.

Removable residues from agriculture production are estimated for each crop type (cereal, green crop, permanent cultivation) taking into account the amount of crop produced, the ratio of removable residue in the crop, the dry matter content of removable residue, the ratio of removable residue burned, the fraction of residues oxidised in burning, the carbon and nitrogen content of the residues. Most of these wastes refer especially to pruning of olives and wine, because of the typical national cultivation.

Emissions due to stubble burning, which are emissions only from the agriculture residues burned on field, are reported in the agriculture sector, under 3.F, more info is also reported in the Annex 7. Under the waste sector the burning of removable agriculture residues that are collected and could be managed in different ways (disposed in landfills, used to produce compost or used to produce energy) is reported.

Different percentages of the removable agriculture residue burnt for different residues are assumed, varying from 10% to 90%, according to national and international literature. Moreover, these removable wastes are assumed to be all burned in open air (e.g. on field) taking in consideration the higher (without abatement) available CO, NMVOC, PM, PAH and dioxins emission factors. The amount of these wastes treated differently is not supplied, but they are included in the respective sectors (landfill, composting, biogas production for energy purposes, etc.).

The methodology is the same used to calculate emissions from residues burned on fields, in the category 3F, described in detail in Chapter 5.

On the basis of carbon and nitrogen content of the residues, CH_4 and N_2O emissions have been calculated, both accounting nearly for 100% of the whole emissions from waste incineration. CO_2 emissions have been calculated but not included in the inventory as biomass. All these parameters refer both to the IPCC Guidelines (IPCC, 2006) and country-specific values (CESTAAT, 1988; Borgioli, 1981).

The amount of biomass from pruning used for domestic heating is reported in the energy sector in the 1A4b category as biomass fuel.

As recommended during the 2019 UNFCCC review, to enhance transparency on the total amount of crop residues generated and shares of the crop residue amounts used for different purposes (such as bedding material (3.D.a.2.a), left on fields (3.D.a.4), burnt on-site (3.F) and off-site (1.A, 5.C.2)), a flow-chart is reported in Annex 7, in Figure A.7.1.

As regard incineration of corpses in crematoria, activity data have been supplied by a specific branch of Federutility, which is the federation of energy and water companies (SEFIT, several years).

In Table 7.25 time series of cremation as well as annual deaths and crematoria in Italy are reported.

Table 7.25 Cremation time series (activity data), 1990 – 2022

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Cremations (no. of corpses)	5,809	15,436	30,167	48,196	77,379	137,168	194,669	247,840	244,186	259,915
Deaths (no. of corpses)	543,700	555,203	560,241	567,304	587,488	653,000	634,432	746,146	709,035	713,499
Mortal remains (no.)	1,000	1,750	1,779	9,880	18,899	34,178	38,305	29,266	45,959	45,986
Cremation percentage	1.07	2.78	5.38	8.50	13.17	21.01	30.68	33.22	34.44	36.43
Crematoria (no.)	ND	31	35	43	53	70	85	87	89	91

The major emissions from crematoria are nitrogen oxides, carbon monoxide, sulphur dioxide, particulate matter, mercury, hydrogen fluoride (HF), hydrogen chloride (HCl), NMVOCs, other heavy metals, and some POPs.

In Table 7.26 emission factors for cremation are reported; all emission factors are from (SEFIT, 2015; SEFIT, 2019) except for CH_4 and N_2O, assumed equal to MSW emission factor because values were not available. CO_2 emissions have been not calculated for the inventory as human body is 'biomass'.

Table 7.26 Cremation emission factors

POLLUTANT/WASTE TYPOLOGY	NMVOC (kg/body)	CO (kg/body)	N_2O (kg/t)	NO_x (kg/body)	SO_2 (kg/body)	CH_4 (kg/t)
Cremation	0.009	0.005	0.1	0.474	0.009	0.06

CO_2 emissions from open burning of waste are also considered. Open burning of waste is forbidden in Italy but sometimes it illegally occurs. Estimates are based on 2006 IPCC Guidelines, in particular the paragraph 5.3.2 to define the amount of waste open burned using data about population, the fraction of "rural people", the per capita waste production and estimating the rate of the waste amount that is burned relative to the total amount of waste treated on the bases of recent national data (Bfrac=0.4%). In the following table activity data and CO_2 emissions have been reported. To improve the completeness, in this submission CH_4 and N_2O emissions have been estimated too. The methodology used is always that of the 2006 IPCC guidelines. The 2006 IPCC Guidelines report as default value Bfrac=0.6. In recent years the most important fires (industrial warehouses) involved 1800 Mg in Corteolona in 2018 and 8400 Mg in Pomezia in 2017 which means negligible quantities even considering an order of magnitude higher. For example, if they were 100,000 Mg of open burning waste annually, they would be equivalent, from 1990 to 2018, to approximately 0.4% to 0.3% (instead of the 60% represented by the default). More 2006GL stated that "For countries that have well functioning waste collection systems in place, it is good practice to investigate whether any fossil carbon is open-burned. In a developed country, Pfrac can be assumed to be the rural population for a rough estimate. In a region where urban population exceeds 80 percent of total population, one can assume no open burning of waste occurs." and Pfrac in Italy (Istat, 2017 "Forme, livelli e dinamiche dell'urbanizzazione in Italia") is less than 10% (9-9.4%) which means that rural population is more than 90% and open burning of urban waste can be considered negligible.

Table 7.26 Open burning of waste time series, 1990 – 2022

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Pfrac	9.4%	9.4%	9.0%	9.0%	9.0%	9.0%	9.0%	9.0%	9.0%	9.0%
Bfrac	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
MSW_B (Gg)	8.36	9.69	10.43	11.40	11.69	10.63	10.81	10.42	10.65	10.46
CO_2 (Gg) fossil	2.47	2.86	3.08	3.36	5.47	4.97	5.05	4.87	4.98	4.89
CO_2 (Gg) organic	4.58	5.31	5.71	6.25	5.47	4.97	5.05	4.87	4.98	4.89
CH_4 (Gg)	0.05	0.06	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.07
N_2O (Gg)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

7.4.3 Uncertainty and time-series consistency

The combined uncertainty in emissions from waste incineration is estimated to be about 22.4%, 10% and 20% for activity data and emission factors respectively.

The time series of activity data, distinguished in Municipal Solid Waste and other (including cremation), is shown in Table 7.28; CO_2 emission trends for each type of waste category are reported in Table 7.29, both for plants without energy recovery, reported under 5C, and plants with energy recovery, reported under 1A4a. In Table 7.30 N_2O and CH_4 emissions are summarized, including those from open burning and cremation.

In the period 1990-2022, total CO_2 emissions have increased by 442%, but whereas emissions from plants with energy recovery have increased by nearly 942%%, emissions from plants without energy recovery decreased by -79% (Table 7.28). While CO_2 emission trend reported in 5C is influenced by the amount of waste incinerated in plant without energy recovery, CH_4 and N_2O emission trend are related to the open burning, as already reported above.

Table 7.28 Waste incineration activity data, 1990 – 2022 (Gg)

Activity Data	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
MSW Production (Gg)	22,231	25,780	28,959	31,664	32,479	29,524	30,079	28,941	29,596	29,051
MSW Incinerated (%)	4.6%	5.6%	8.0%	10.2%	13.4%	15.9%	14.5%	14.6%	14.5%	14.2%
- in energy recovery plants	2.8%	4.6%	7.5%	10.0%	13.2%	15.9%	14.5%	14.6%	14.5%	14.2%
MSW to incineration (Gg)	1,026	1,437	2,325	3,220	4,337	4,698	4,359	4,227	4,305	4,131
Industrial, Sanitary, Sewage Sludge and Waste Oil to incineration (Gg)	631	712	737	1,744	2,640	2,836	3,289	3,252	3,179	3,103
Cremation (no. of corpses)	5,809	15,436	30,167	48,196	77,379	137,168	194,669	247,840	244,186	259,915

Activity Data	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Total Waste to incineration, excluding cremation (5C and 1A4a) (Gg)	1,656	2,149	3,062	4,964	6,977	7,535	7,648	7,480	7,484	7,234

Table 7.29 CO_2 emissions from waste incineration (without and with energy recovery), 1990 – 2022 (Gg)

CO_2 Emissions	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Incineration of domestic or municipal wastes (Gg)	117.83	74.12	48.26	15.32	24.74	0.00	0.00	0.00	0.00	0.00
Incineration of industrial wastes (except flaring) (Gg)	257.99	247.11	115.74	186.50	119.88	40.19	37.32	31.13	48.29	48.04
Incineration of hospital wastes (Gg)	131.07	132.73	40.36	24.61	27.12	53.57	53.25	52.68	60.97	60.65
Incineration of waste oil (Gg)	2.66	1.41	0.82	0.36	0.00	0.00	0.00	0.00	0.00	0.00
Incineration of corpses	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Waste incineration (5C) (Gg)	510	455	205	227	172	94	91	84	109	109
Waste incineration reported under 1A4a (Gg) – not biomass	530	798	1,341	2,799	5,017	5,477	5,878	5,796	5,695	5,523
Waste incineration reported under 1A4a (Gg) - biomass	343	650	1,185	1,737	2,003	2,196	2,038	1,976	2,013	1,931
Total waste incineration – fossil (Gg)	1,039	1,254	1,546	3,026	5,189	5,571	5,968	5,880	5,805	5,632

Table 7.30 N_2O and CH_4 emissions from waste incineration (cremation and open burning included), 1990 – 2022 (Gg)

GAS/SUBSOURCE	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
N_2O (Gg)										
Waste incineration (5C)	0.12	0.11	0.08	0.08	0.07	0.07	0.06	0.06	0.07	0.06
MSW incineration reported under 1A4a – not biomass	0.05	0.08	0.13	0.27	0.47	0.51	0.54	0.53	0.52	0.51
MSW incineration reported under 1A4a – biomass	0.04	0.08	0.14	0.21	0.21	0.23	0.22	0.21	0.22	0.21
CH_4 (Gg)										
Waste incineration (5C)	1.90	2.08	2.02	2.21	2.10	2.09	1.99	2.03	2.01	1.85
MSW incineration reported under 1A4a – not biomass	0.03	0.05	0.08	0.16	0.28	0.30	0.32	0.32	0.31	0.30
MSW incineration reported under 1A4a – biomass	0.02	0.05	0.08	0.12	0.13	0.14	0.13	0.13	0.13	0.12

7.4.4 Source-specific QA/QC and verification

Several verifications were carried out on the basis of the analysis of documentation supplied in the framework of IPPC permits and of environmental reports.

7.4.5 Source-specific recalculations

Generally, recalculations occur in 2021 because of the annual update of incinerators activity data: industrial, clinical and oil incinerators communicate their data one year later than those of municipal waste. Minor changes occur since 2013 because of the deletion of a single plant from the incinerators' database (from the verification processes with ETS data the plant was found to be a lime production plant whose consumption is already considered in the relevant category).

Recalculations occur in N_2O and CH_4 emissions because of the recalculation of open burning of agricultural waste emission factors. Updated IPCC values consistent with the LULUCF sector have been included. More information is reported in the agriculture chapter.

Table 7.31 Differences in percentages between time series reported in the updated time series and 2023 submission

GAS/SUBSOURCE	1990	1995	2000	2005	2010	2015	2019	2020	2021
CO_2 (Gg)									
Waste incineration (5C)	-	-	-	-	-	-	-	-	35.25%
MSW incineration reported under 1A4a - fossil	-	-	-	-	-	-0.003%	-0.0001%	0.001%	1.22%
N_2O (Gg)									
Waste incineration (5C)	0.82%	-2.39%	-2.15%	-3.55%	-4.21%	-3.20%	-2.92%	-3.62%	1.93%
MSW incineration reported under 1A4a - fossil	-	-	-	-	-	-0.002%	-0.0001%	0.001%	1.12%
CH_4 (Gg)									
Waste incineration (5C)	-5.87%	-7.46%	-7.51%	-7.16%	-7.98%	-7.99%	-8.02%	-8.24%	-6.43%
MSW incineration reported under 1A4a - fossil	-	-	-	-	-	-0.002%	-0.0001%	0.001%	1.12%

7.4.6 Source-specific planned improvements

No further improvements are planned for the next submission.

7.5 Wastewater handling (5D)

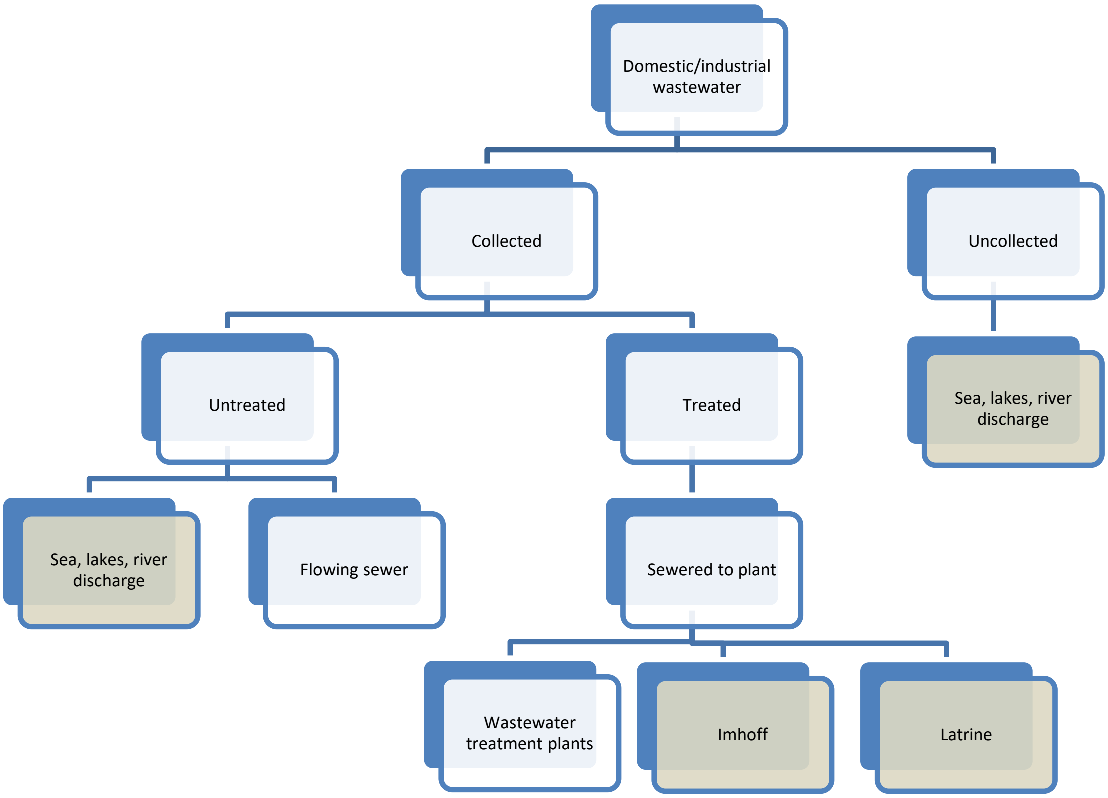
7.5.1 Source category description

Under source category 5D, CH_4, N_2O and NMVOC are estimated both from domestic and industrial wastewater. The principal by-product of the anaerobic decomposition of the organic matter in wastewater is methane gas. Normally, CH_4 emissions are not encountered in untreated wastewater because even small amounts of oxygen tend to be toxic to the organisms responsible for the production of methane. Occasionally, however, as a result of anaerobic decay in accumulated bottom deposits, methane can be produced. Again, wastewater collected in closed underground sewers is not believed to be a significant source of CH_4 (IPCC, 2006).

In 2022, the 99.6% of population is served by sewer systems, whereas 91% of population is served by wastewater treatment plants (BLUE BOOK, several years; COVIRI, several years; ISTAT [d], [e], several years). In 1990, the percentage of population served by sewer system was 57%, whereas only 52% of population was served by wastewater treatment plants (BLUE BOOK, several years; COVIRI, several years; ISTAT [d], [e], several years).

In Italy, domestic wastewaters follow the treatment systems and discharge pathways reported in Figure 7.5, whereas in brown are enhanced CH_4 sources.

Figure 7.5 Domestic wastewater treatment system and discharge pathways



Methane is produced from the anaerobic treatment process used to stabilize wastewater sludge.

The plant typology is usually distinguished in 'primary' (only physical-chemical unit operations such as sedimentation), 'secondary' (biological unit process) or 'advanced' treatments, defined as those additional treatments needed to remove suspended and dissolved substances remaining after conventional secondary treatment.

In urban areas, wastewater handling is managed mainly using a secondary treatment, with aerobic biological units: a wastewater treatment plant standard design consists of bar racks, grit chamber, primary sedimentation, aeration tanks (with return sludge), settling tank, chlorine contact chamber. The stabilization of sludge occurs in aerobic or anaerobic reactors; where anaerobic digestion is used, the reactors are covered and provided of gas recovery.

On the contrary, in rural areas, wastewaters are treated in Imhoff tanks or in other on-site systems, such as latrines.

For high strength organic waste, such as some industrial wastewater, anaerobic process is recommended also for wastewater besides sludge treatment.

It is assumed that industrial wastewaters are treated 85% aerobically and 15% anaerobically (IRSA-CNR, 1998).

Emissions from methane recovered, used for energy purposes, in wastewater treatment plants are estimated and reported under category 1A4a, as reported in Table 7.12.

7.5.2 Methodological issues

Emissions from domestic wastewater – CH_4

CH_4 emissions from domestic wastewater are estimated using a Tier 2 approach, according to the 2006 IPCC Guidelines (IPCC, 2006).

The general equation used to estimate CH_4 emissions from domestic wastewater is:

$$CH_4 \text{ emissions} = [\Sigma_{i,j} (U_i * T_{i,j} * EF_j)] * (TOW - S) - R \text{ (kg } CH_4\text{/yr)}$$

where:

TOW = total organics in wastewater in inventory year (kg BOD/yr)

S = organic component removed as sludge in inventory year (kg BOD/yr)

U_i = fraction of population in income group i in inventory year

$T_{i,j}$ = degree of utilisation of treatment/discharge pathway or system, j, for each income group fraction i in inventory year

i = income group: rural and urban high income (urban low income is not considered in national inventory, for the typical Italian urbanization)

j = each treatment/discharge pathway or system

EFj = emission factor (kg CH_4/kg BOD)

R = amount of CH_4 recovered in inventory year (kg CH_4/yr)

An in-depth analysis of national circumstances has been made, collecting many statistical data on population and on urban wastewater treatment plants (BLUE BOOK, several years; COVIRI, several years; ISTAT, 1984; ISTAT, 1987; ISTAT, 1991; ISTAT, 1993; ISTAT [a], [b], 1998; ISTAT [d], [e], several years).

Some data, such as the degree of collected or treated wastewater are available for specific year, so the entire time series has been reconstructed with interpolation of data.

In the following tables (7.32, 7.33, 7.34), domestic wastewater population data are reported.

Table 7.32 Population data for domestic wastewater, 1990 – 2022 (*1000)

Population AD	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Total Population	56,778	56,844	56,961	58,289	59,948	60,164	59,641	59,236	59,030	58,851
Urban high-income Population	52,947	53,134	53,372	54,867	56,602	56,938	56,513	56,132	55,950	55,795
Rural Population	3,831	3,710	3,589	3,422	3,347	3,225	3,129	3,104	3,080	3,056
Population served by collected wastewater systems (%)	57.0	69.8	86.0	83.0	90.1	99.4	99.5	99.5	99.6	99.6
Population served by wastewater treatment plants (%)	51.9	58.0	60.0	69.0	76.1	82.2	87.0	88.2	89.4	90.6

Table 7.33 Urban high-income Population for domestic wastewater, 1990 – 2022 (*1000)

Urban high-income Population	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Population not served by collected wastewater systems	22,761	16,042	7,472	9,327	5,588	342	283	267	252	237
Population served by collected wastewater systems	30,186	37,092	45,900	45,540	51,013	56,597	56,230	55,865	55,698	55,558
Pop. collected and treated	15,678	21,507	27,540	31,422	38,830	46,501	48,919	49,277	49,803	50,349
Pop. collected untreated	14,508	15,585	18,360	14,117	12,183	10,096	7,311	6,589	5,896	5,209
sea/lake/river discharge	8,705	9,351	11,016	8,470	7,310	6,058	4,387	3,953	3,537	3,125
flowing sewer discharge	5,803	6,234	7,344	5,647	4,873	4,038	2,925	2,635	2,358	2,084

Table 7.34 Rural Population data for domestic wastewater, 1990 – 2022 (*1000)

Rural Population	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Population not served by collected wastewater systems	1,647	1,120	502	582	330	19	16	15	14	13
Population served by collected wastewater systems	2,184	2,590	3,087	2,840	3,016	3,206	3,113	3,090	3,066	3,043
Pop. treated in Imhoff tanks	421	647	845	468	635	967	1,156	1,174	1,192	1,210
Pop. treated in latrines	1,763	1,943	2,242	2,373	2,381	2,239	1,957	1,915	1,874	1,832

The emission factor for a wastewater treatment and discharge pathway and system is a function of the maximum CH_4 production potential B_0 and the methane correction factor (MCF) for the wastewater treatment and discharge system, as indicated as following:

$$EF_j = B_0 * MCF_j$$

The default B_0 value (0.6 kg CH_4/kg BOD) and default MCF values have been used.

Type of treatment and discharge pathway or system	MCF
Untreated system	
Sea, river and lake discharge	0.1
Flowing sewer	0
Treated system	
Centralized, aerobic treatment plants	0.05
Anaerobic digester for sludge	0.8
Imhoff tanks	0.5
Latrines	0.1

The total amount of organically degradable material in the wastewater is calculated from the human population and the BOD generation per person:

$$TOW = P * BOD * 0.001 * I * 365$$

where:

TOW = total organics in wastewater in inventory year (kg BOD/yr)

P = country population in inventory year (person)

BOD = country specific per capita BOD in inventory year (g/person/day)

0.001 = conversion from grams to kg BOD

I = correction factor for additional industrial BOD discharged into sewers (I = 1.25, IPCC 2006).

The parameter I, equal to 1.25 has been applied both for collected and uncollected wastewater, in order to consider illegal wastewater spills from industry or craft activities that are not taking into account in official statistics and other industries and establishments (e.g., restaurants, butchers or grocery stores) that can co-discharged with domestic wastewater.

The organic load in biochemical oxygen demand per person is equal to 60 g BOD_5 $capita^{-1}$ d^{-1}, as defined by national legislation and expert estimations (Legislative Decree 11 May 1999, no.152; Masotti, 1996; Metcalf and Eddy, 1991).

The total organics in sludge (TOW sludge) has been estimated half of total organics in wastewater, according to international literature (Metcalf and Eddy, 1991), that states that the typical reduction in volatile solids achieved in anaerobic digestion for mixed sludge (primary plus secondary) varies from 45 to 60 percent.

In the following table 7.35, the total amount of organically degradable material expressed in tons, calculated for each treatment/discharge pathway or system is reported.

Table 7.35 Total organically degradable material in domestic wastewater, 1990 – 2022 (t BOD)

TOW (t BOD)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Urban high-income Population										
TOW uncollected wastewater	623,069	439,148	204,547	255,337	152,984	9,352	7,735	7,299	6,892	6,491
TOW wastewater treatment plant	429,195	588,761	753,901	860,185	1,062,969	1,272,957	1,339,155	1,348,948	1,363,349	1,378,295
TOW sludge	214,598	294,381	376,951	430,093	531,485	636,478	669,578	674,474	681,674	689,147
TOW untreated (sea/lake/river)	238,289	255,979	301,560	231,876	200,113	165,825	120,091	108,219	96,836	85,560
TOW untreated (flowing sewer)	158,860	170,653	201,040	154,584	133,409	110,550	80,061	72,146	64,557	57,040
Rural Population										
TOW uncollected wastewater	45,088	30,665	13,755	15,925	9,045	530	428	404	379	356
TOW Imhoff	11,535	17,705	23,129	12,799	17,378	26,467	31,646	32,143	32,640	33,136
TOW latrines	48,263	53,197	61,366	64,955	65,192	61,300	53,569	52,433	51,297	50,161

As previously reported, in Italy wastewater handling is managed mainly using a secondary treatment, with aerobic biological units. The stabilization of sludge occurs in aerobic or anaerobic reactors covered and provided of gas recovery. All the anaerobic digestion systems are equipped with systems to collect the methane produced. The methane collected is partly flared and partly used for energy purposes. The total methane recovered is estimated on the basis of the methane production and the efficiency of capture. Where anaerobic digestion of sludge is used, the reactors are covered and provided of gas recovery and the efficiency of capture is equal to 100% In fact, in Italy, anaerobic digestion tanks for sludge stabilization in wastewater treatment plants are built with fixed covered: fix covered provide a free space between the roof of the digester and the liquid surface. Gas storage is provided so that when the liquid volume is changed, gas, not air, will be drawn into the digester, and gas will not be lost by displacement.

CH_4 emissions from sludge have been subtracted from the total amount of CH_4 produced, because emissions from sludge from wastewater treatment are considered in landfills, agricultural soils and incineration.

Moreover, CH_4 recovery has been distinguished between flaring and CH_4 recovery for energy generation, which has been reported in the Energy Sector.

Emissions from domestic wastewater –N_2O

Nitrous oxide (N_2O) emissions can occur as direct and indirect emissions. Direct emissions occur from nitrification and denitrification in wastewater treatment plants, whereas indirect emissions are those from wastewater after disposal of effluent into waterways, lakes or sea.

Emissions from advanced centralized wastewater treatment plants are typically much smaller than those from effluent and are estimated using the method reported in Box 6.1 of the Volume 5, Chapter 6 of new 2006 IPCC Guidelines (IPCC, 2006).

Direct emissions

$$N_2O_{PLANTS} = P * T_{PLANT} * F_{IND-COM} * EF_{PLANT}$$

where:

N_2O_{PLANTS} = total N_2O emissions from plants in inventory year (kg N_2O/yr)

P = human population

T_{PLANT} = degree of utilization of modern, centralized wastewater treatment plants (%)

$F_{IND-COM}$ = fraction of industrial and commercial co-discharged protein (default = 1.25)

EF_{PLANT} = emission factor, 3.2 g N_2O/person/year

Indirect emissions

$$N_2O_{EMISSIONS} = N_{EFFLUENT} * EF_{EFFLUENT} * 44/28$$

where:

$N_2O_{EMISSIONS}$ = N_2O emissions in inventory year (kg N_2O/yr)

$N_{EFFLUENT}$ = nitrogen in the effluent discharged to aquatic environments (kg N/yr)

$EF_{EFFLUENT}$ = emission factor for N_2O emissions from discharged to wastewater assumed equal to 0.005 (kg N_2O-N/kg N)

Moreover:

$$N_{EFFLUENT} = N_{EFFLUENT\ TOT} - N_{SLUDGE} = (P * Protein * F_{NPR} * F_{NON-CON} * F_{IND-COM}) – N_{SLUDGE}$$

where:

$N_{EFFLUENT}$ = nitrogen in the effluent discharged to aquatic environments (kg N/yr)

P = human population

Protein = annual per capita protein consumption (kg/person/yr)

F_{NPR} = fraction of nitrogen in protein (default = 0.16 kg N/kg protein)

$F_{NON-COM}$ = fraction of non-consumed protein added to the wastewater

$F_{IND-COM}$ = fraction of industrial and commercial co-discharged protein (default = 1.25)

N_{SLUDGE} = nitrogen removed with sludge (kg N/yr)

The time series of the protein intake is from the yearly FAO Food Balance (FAO, several years) and refers to the Italian value. The estimation procedure checks for consistency with sludge produced and sludge applications, as sludge applied to agriculture soils, sludge incinerated, sludge composting and sludge deposited in solid waste disposal. Sludge spreading is subtracted from nitrogen in the effluent discharged to aquatic environments and is not accounted for twice.

For the parameter $F_{NON-COM}$ the value of 1.1 it is assumed, because, even if Italy is a developed country, garbage disposals of food that is not consumed and may be washed down the drain are not used.

Emissions from industrial wastewater – CH_4

The methane estimation concerning industrial wastewaters makes use of the IPCC method based on wastewater output and the respective degradable organic carbon for each major industrial wastewater source. Default emission factors of methane per Chemical Oxygen Demand (COD) equal to 0.25 kg CH_4 kg^{-1} COD, suggested in the 2006 IPCC Guidelines (IPCC, 2006), has been used for the whole time series.

It is assumed that industrial wastewaters are treated 85% aerobically and 15% anaerobically (IRSA-CNR, 1998).

Data has been collected for several industrial sectors (iron and steel, refineries, organic chemicals, food and beverage, paper and pulp, textiles and leather industry). The total amount of organic material, for each industry selected, has been calculated multiplying the annual production (t $year^{-1}$) by the amount of wastewater consumption per unit of product (m^3 t^{-1}) and by the degradable organic component (kg COD $(m^3)^{-1}$). Moreover, the fraction of industrial degradable organic component removed as sludge has been assumed equal to zero. The yearly industrial productions are reported in the national statistics (ISTAT, several years [a], [b] and [c]), whereas the wastewater consumption factors and the degradable organic component are either from 2006 IPCC Guidelines (IPCC, 2006) or from national references. National data have been used in the calculation of the total amount of both COD produced and wastewater output specified as follows: refineries (UNEM, several years), organic chemicals (FEDERCHIMICA, several years), beer (Assobirra, several years), wine, milk and sugar sectors (ANPA-ONR, 2001), pulp and paper sector (ANPA-FLORYS, 2001; Assocarta, several years), and leather sector (ANPA-FLORYS, 2000; UNIC, several years).

In Table 7.36 detailed references for 2022 are reported: for these national data, slight differences within the years can occur.

Emissions from industrial wastewater – N_2O

N_2O emissions from industrial wastewater have been estimated on the basis of the emission factors equal to 0.25 g N_2O/m^3 of wastewater production (EMEP/CORINAIR, 2007). EMEP/EEA Guidelines, after 2007 version, does not report any N_2O E.F but, about the methodology to estimate N_2O emissions from industrial wastewater, they refer to 2006 IPCC Guidelines. In 2006 IPCC Guidelines it is written that industrial wastewater may be treated on site or released into domestic wastewater. In the national inventory, the fraction of industrial wastewater released into domestic wastewater it is estimated because of the parameter $F_{IND\text{-}COM}$. For the fraction treated on site 0.25 g N_2O/m^3 has been applied to the volume of wastewater generated for type of industry.

The wastewater production is resulting from the model for the estimation of methane emissions from industrial wastewater.

Table 7.36 Wastewater generation and COD values, 2022

	Wastewater generation (m^3/t)	References	COD (g/l)	References
Coke	1.5	IPCC, 2000	0.1	IPCC, 2000
Petroleum Refineries	UNIONE ENERGIA PER LA MOBILITÀ supplies Total COD generated per year			
Organic Chemicals	22.3	FEDERCHIMICA, several years	3	IPCC, 2000
Paints	5.5	IPCC, 2000	5.5	IPCC, 2000
Plastics and Resins	0.6	IPCC, 2000	3.7	IPCC, 2000
Soap and Detergents	3	IPCC, 2000	0.9	IPCC, 2000
Vegetables, Fruits and Juices	20	IPCC, 2000	5.2	IPCC, 2000
Sugar Refining	4	ANPA-ONR, 2001	2.5	ANPA-ONR, 2001
Vegetable Oils	3.1	IPCC, 2000	1.2	IPCC, 2000
Dairy Products	3.87	ANPA-ONR, 2001	2.7	ANPA-ONR, 2001
Wine and Vinegar	3.8	ANPA-ONR, 2001	0.2	ANPA-ONR, 2001
Beer and Malt	420 (l/hl)	Assobirra, several years	2.9	IPCC, 2000
Alcohol Refining	24	IPCC, 2000	11.0	IPCC, 2000
Meat and Poultry	13	IPCC, 2000	4.1	IPCC, 2000
Fish Processing	13	same value of Meat and Poultry	2.5	IPCC, 2000
Paper	25	Assocarta, several years	0.1	ANPA-FLORYS, 2001; Assocarta, several years
Pulp	25	Assocarta, several years	0.1	ANPA-FLORYS, 2001; Assocarta, several years
Textiles (dyeing)	60	IPCC, 1995	1.0	IPCC, 2000
Textiles (bleaching)	350	IPCC, 1995	1.0	IPCC, 2000
Leather	0.12	UNIC, several years	4.2	UNIC, several years

In Table 7.37, N_2O emissions from industrial wastewater are reported, together with the deriving nitrogen in effluent (kt $N\text{-}N_2O$), that is reported in the CRF table 5.D. In the CRF Reporter GHG inventory software the table related to the category 5.D.2 requests, among the others, the N in effluent (kt) as well as the IEF (kg N_2O-N/kg N); N in effluent is calculated with the following formula, assuming the default emission factor 0.25 kg N_2O-N/kg N (IPCC, 2006):

N in effluent (kt) = N_2O emissions (kt) / IEF (kg N_2O-N/kg N) *28/44

As N_2O emissions from industrial wastewater are estimated on the basis of the cubic meters of wastewater produced by a specific industry and the emission factor equal to 0.25 g N_2O/m^3 (EMEP/CORINAIR, 2007), it was not possible to report this value in the CRTs: consequently, we were forced to derive the N in effluent from the N_2O emissions by multiplying for the conversion factor 28/44 and dividing for the IEF 0.25 kg N2O-N/kg N, the maximum for a cautionary reason.

Table 7.37 N_2O emissions from industrial wastewater, 1990 – 2022 (kt)

N_2O Emissions (t)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Industrial wastewater										
Industrial wastewater production (1000 m^3)	908,840	928,479	920,614	867,085	717,846	659,246	696,915	654,586	701,388	675,917
EF (g/m^3)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
N_2O Emissions (kt N_2O)	0.227	0.232	0.230	0.217	0.179	0.165	0.174	0.164	0.175	0.169
N in effluent (kt)	0.578	0.591	0.586	0.552	0.457	0.420	0.443	0.417	0.446	0.430

Emissions from domestic and industrial wastewater – NMVOC

Emissions from NMVOC has been also estimated, both from domestic and industrial wastewaters, using a default emission factor derived from Guidebook published by the European Environmental Agency with the CLRTAP Task Force on Emission Inventories and Projections (EMEP/EEA, 2016).

In Table 7.38 NMVOC emissions from domestic and industrial wastewater are reported for the whole time series.

Table 7.38 NMVOC emissions from domestic and industrial wastewater, 1990 – 2022 (kt)

NMVOC Emissions (t)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Domestic wastewater										
Equivalent inhabitants (*1000)	46,436	60,015	65,601	73,426	76,847	75,239	89,716	91,124	92,532	93,940
Domestic wastewaters production (10^6 m^3)	4,237	5,476	5,986	6,700	7,012	6,866	8,187	8,315	8,444	8,572
Per capita water supply (lt./person*die)	250	250	250	250	250	250	250	250	250	250
EF (mg/m^3)	15	15	15	15	15	15	15	15	15	15
NMVOC Emissions (t)	**63.6**	**82.1**	**89.8**	**100.5**	**105.2**	**103.0**	**122.8**	**124.7**	**126.7**	**128.6**
Industrial wastewater										
Industrial wastewaters production (1000 m^3)	908,840	928,479	920,614	867,085	717,846	659,246	696,915	654,586	701,388	675,917
EF (mg/m^3)	15	15	15	15	15	15	15	15	15	15
NMVOC Emissions (t)	**13.6**	**13.9**	**13.8**	**13.0**	**10.8**	**9.9**	**10.5**	**9.8**	**10.5**	**10.1**

7.5.3 Uncertainty and time-series consistency

The combined uncertainty in CH_4 and N_2O emissions from wastewater handling is estimated to be about 102% in annual emissions 100% and 20% for activity data and emission factor respectively, as derived by the IPCC Guidelines (IPCC, 2000; IPCC, 2006).

Concerning domestic wastewater, CH_4 emission trends are shown in Table 7.39, whereas the emission trend for N_2O emissions is shown in Table 7.40.

Table 7.39 CH_4 emissions from domestic wastewater, 1990 – 2022 (t)

CH_4 Emissions (t)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Urban high-income Population										
CH_4 uncollected wastewater	37,384	26,349	12,273	15,320	9,179	561	464	438	414	389
CH_4 wastewater treatment plant	6,438	8,831	11,309	12,903	15,945	19,094	20,087	20,234	20,450	20,674
CH_4 anaerobic digestion	103,007	141,303	180,936	206,444	255,113	305,510	321,397	323,748	327,204	330,791
CH_4 untreated (sea/lake/river)	14,297	15,359	18,094	13,913	12,007	9,950	7,205	6,493	5,810	5,134
CH_4 untreated (flowing sewer)	0	0	0	0	0	0	0	0	0	0
Rural Population										
CH_4 uncollected wastewater	2,705	1,840	825	956	543	32	26	24	23	21
CH_4 Imhoff	3,460	5,312	6,939	3,840	5,213	7,940	9,494	9,643	9,792	9,941
CH_4 latrines	2,896	3,192	3,682	3,897	3,912	3,678	3,214	3,146	3,078	3,010
CH_4 total produced	170,188	202,185	234,057	257,272	301,910	346,765	361,888	363,726	366,770	369,960
CH_4 recovered	103,007	141,303	180,936	206,444	255,113	305,510	321,397	323,748	327,204	330,791
CH_4 flared	103,007	140,583	179,473	205,802	250,613	285,108	299,834	302,042	306,196	311,488
CH_4 energy recovery	0	719	1,463	643	4,500	20,401	21,563	21,706	21,008	19,303
CH_4 total emissions	**67,181**	**60,882**	**53,121**	**50,828**	**46,798**	**41,255**	**40,491**	**39,978**	**39,566**	**39,169**

Table 7.40 N_2O emissions from domestic wastewater, 1990 – 2022 (t)

N_2O Emissions (t)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
N_2O emissions from wastewater effluent (Indirect emissions)	3,911	3,787	4,010	4,037	4,129	3,900	3,877	3,865	3,860	3,855
N_2O emissions from wastewater treatment plants (Direct emissions)	86.9	84.2	91.1	155.2	151.9	160.6	159.2	158.1	157.5	157.1
N_2O total emissions	**3,997**	**3,871**	**4,101**	**4,192**	**4,281**	**4,061**	**4,037**	**4,023**	**4,018**	**4,012**

The amount of total industrial wastewater production is reported, for each sector, in Table 7.41.

CH_4 emission trend for industrial wastewater handling for different sectors is shown in Table 7.42, whereas the emission trend for N_2O emissions from industrial wastewater handling is shown again in Table 7.43.

Concerning CH_4 emissions from industrial wastewater, neither wastewater flow nor average COD value change much over time, therefore emissions are stable and mainly related to the production data.

Table 7.41 Total industrial wastewater production by sector, 1990 – 2022 (1000 m^3)

Wastewater production (1000 m^3)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Iron and steel	9.53	7.78	6.76	6.86	6.17	2.97	2.83	2.17	2.02	2.43
Oil refinery	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Organic chemicals	210.94	212.32	215.05	214.74	214.12	213.80	213.93	213.67	213.72	213.57
Food and beverage	179.12	177.38	182.74	185.66	186.26	177.91	186.54	181.45	184.11	183.78
Pulp and paper	377.17	402.95	387.28	366.02	232.69	202.64	238.78	216.88	255.35	232.74
Textile industry	108.46	103.05	101.57	75.49	64.36	48.90	42.85	29.92	33.74	30.46
Leather industry	23.62	25.00	27.22	18.32	14.25	13.03	11.98	10.51	12.44	12.94
Total	**908.84**	**928.48**	**920.61**	**867.09**	**717.85**	**659.25**	**696.92**	**654.59**	**701.39**	**675.92**

Table 7.42 CH_4 emissions from anaerobic industrial wastewater treatment, 1990 – 2022 (kt)

CH_4 Emissions (kt)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Iron and steel	0.036	0.029	0.025	0.026	0.023	0.011	0.011	0.008	0.008	0.009
Oil refinery	5.850	5.625	4.250	4.750	4.750	4.750	4.750	4.750	4.750	4.750
Organic chemicals	23.794	23.911	24.173	24.177	24.069	23.998	24.046	24.014	24.027	24.006
Food and beverage	22.946	22.112	22.871	23.197	23.447	22.575	23.905	22.736	23.188	23.535
Pulp and paper	0.923	0.986	1.055	0.997	0.544	0.552	0.650	0.591	0.695	0.634
Textile industry	4.067	3.864	3.809	2.831	2.414	1.834	1.607	1.122	1.265	1.142
Leather industry	3.192	3.378	3.677	2.901	2.517	2.272	2.138	1.788	2.024	2.040
Total	**60.81**	**59.91**	**59.86**	**58.88**	**57.76**	**55.99**	**57.11**	**55.01**	**55.96**	**56.12**

Table 7.43 N_2O emissions from industrial wastewater, 1990 – 2022 (kt)

N_2O Emissions (kt)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Industrial wastewater	0.227	0.232	0.230	0.217	0.179	0.165	0.174	0.164	0.175	0.169

7.5.4 Source-specific QA/QC and verification

Where information is available, wastewater flows and COD concentrations are checked with those reported yearly by the industrial sectoral reports or technical documentation developed in the framework of the Integrated Pollution and Prevention Control (IPPC) Directive of the European Union (http://eippcb.jrc.es).

Moreover, in the framework of EPER/E-PRTR registry the methodology used to estimate emissions from wastewater handling can be used by the operators of wastewater treatment plants to check if their emission data exceed the reporting threshold values.

Finally, a Ph.D. thesis on GHG emissions from wastewater handling has been carried out at Environmental, Hydraulic, Infrastructures and Surveying Engineering Department (DIIAR) of Politecnico di Milano (Solini, 2010), where national methodology has been compared with that reported in 2006 IPCC Guidelines (IPCC, 2006) and with a methodology developed in the framework of a previous thesis Ph.D. for the estimation of emissions from wastewater treatment plants located in Regione Lombardia.

7.5.5 Source-specific recalculations

Minor recalculations regard the update of sludge data (production, spreading and N content) for 2018, 2019, 2020 and 2021. Moreover, yearly industrial productions for beer and meet (2021) have been update, as well as un update of parameters used for leather industry.

7.5.6 Source-specific planned improvements

According with the 2021 annual submission review process, where the ERT encouraged the Party to pursue investigation into a different methodology for estimating total biogas production and revise the amount of CH_4 flared, a draft methodology has been applied, with substantial differences in biogas production. Total gas production is estimated usually from the percentage of volatile solids reduction: typical values vary from 0.75 to 1.12 m^3/kg of volatile solids destroyed (Metcalf and Eddy, 1991): unfortunately, data on volatile solids abatement are not available at present. Gas production can also be crudely estimated on a per capita basis: the normal yield is 15 to 22 $m^3/10^3$person·day in primary plants treating normal domestic wastewater; in secondary treatment plants the gas production increase to about 28 $m^3/10^3$person·day. Applying this parameter, the total gas production and consequently the CH_4 production has been estimated as reported in the following Table 7.44. Differences are very important, thus investigations are ongoing, concerned also volatile solids destroyed.

Table 7.44 CH_4 production from anaerobic digestion of sludge, estimated with IPCC methodology and Metcalf and Eddy parameters

Total Gas Production in anaerobic digestion	1990	1995	2000	2005	2010	2015	2020	2022
TOW sludge (kg BOD/year)	214,597,690	294,380,746	376,950,614	430,092,574	531,484,619	636,478,432	674,474,078	689,147,461
CH_4 anaerobic digestion - IPCC Guidelines (kg CH_4/year)	103,006,891	141,302,758	180,936,295	206,444,436	255,112,617	305,509,647	323,747,558	330,790,782
CH_4 anaerobic digestion - Metcalf and Eddy (kg CH_4/year)	54,211,645	74,366,432	95,225,223	108,649,939	134,263,586	160,787,112	170,385,568	174,092,356

Further improvements are welcome as soon as additional data are available. We expect that environmental reports from industry will be improved each passing year. Moreover, specific survey on those industries that produce considerable amounts of wastewater with significant organic carbon levels are planned, to revise the methodology for estimating emissions from industrial wastewater, according to the 2019 IPPC Guidelines.

Moreover, Italy plans to conduct a survey on wastewater generation and COD values. The first step consists in finding the sustainability reports of the various trade associations and major industrial groups to acquire the most up-to-date but already available information. Any insights will be made in subsequent submissions through meetings and comparisons with industrial associations. ISPRA is collaborating, in the framework of other issues not specifically referred to the inventory, with Secam, a company founded in 1989, currently Italy's leading manufacturer and supplier of chemicals for industry and civil and industrial wastewater treatment services that could help us to set some parameters country specific.

8 RECALCULATIONS AND IMPROVEMENTS

8.1 Explanations and justifications for recalculations

To meet the requirements of transparency, consistency, comparability, completeness and accuracy of the inventory, the entire time series from 1990 onwards is checked and revised every year during the annual compilation of the inventory. Measures to guarantee and improve these qualifications are undertaken and recalculations should be considered as a contribution to the overall improvement of the inventory.

Recalculations are elaborated on account of changes in the methodologies used to carry out emission estimates, changes due to different allocation of emissions as compared to previous submissions, changes due to error corrections and in consideration of new available information.

The complete revised CRTs from 1990 to 2021 have been submitted as well as the CRT for the year 2022.

The revisions that lead to relevant changes in GHG emissions are pointed out in the specific sectoral chapters and summarized in the following section 8.4.1.

8.2 Implications for emission levels

The time series reported in the 2024 submission is summarised in Table 8.1 by gas; differences in emission levels due to recalculations are also reported.

Improvements in the calculation of emission estimates have led to a recalculation of the entire time series of the national inventory. Considering total GHG emissions without LULUCF, estimates show an increase in comparison with the last year submission, equal to 0.17% for 1990 and a decrease of 1.51% for 2021. Considering the national total with the LULUCF sector, the year 1990 has increased by 0.14% and the 2021 emission levels decreased by 0.93%. Detailed explanations of these recalculations are provided in the sectoral chapters.

Table 8.1 Differences in time series between the 2024 and 2023 submissions due to recalculations

	subm	1990	1995	2000	2005	2010	2015	2019	2020	2021
CO_2 net emissions/removals	2024	432,937	424,242	448,286	466,925	395,419	318,828	301,380	274,409	310,024
(kt CO_2-eq.)	2023	433,214	424,391	447,552	465,893	394,075	317,385	297,929	269,900	308,306
Differences		*-0.06%*	*-0.03%*	*0.16%*	*0.22%*	*0.34%*	*0.45%*	*1.16%*	*1.67%*	0.56%
CO_2 emissions	2024	438,208	448,596	469,598	501,366	435,701	361,246	339,641	302,614	335,920
(without LULUCF) (kt CO_2-eq.)	2023	438,904	449,430	470,524	502,347	436,534	361,936	340,403	303,281	337,230
Differences		*-0.16%*	*-0.19%*	*-0.20%*	*-0.20%*	*-0.19%*	*-0.19%*	*-0.22%*	*-0.22%*	-0.39%
CH_4 emissions	2023	55,691	57,196	58,098	54,973	53,071	49,518	46,787	47,588	47,525
(kt CO_2-eq.)	2022	56,416	57,373	58,506	55,038	53,083	49,611	46,965	47,885	48,065
Differences		*-1.28%*	*-0.31%*	*-0.70%*	*-0.12%*	*-0.02%*	*-0.19%*	*-0.38%*	*-0.62%*	-1.12%
CH_4 emissions	2024	54,971	57,026	57,698	54,806	52,874	49,370	46,685	47,402	47,036
(without LULUCF) (kt CO_2-eq.)	2023	54,975	57,034	57,706	54,703	52,690	49,316	46,762	47,513	47,087
Differences		*-0.01%*	*-0.01%*	*-0.01%*	*0.19%*	*0.35%*	*0.11%*	*-0.16%*	*-0.23%*	-0.11%
N_2O emissions	2024	25,383	27,212	27,872	26,925	18,707	17,436	17,354	18,090	18,076
(kt CO_2-eq.)	2023	24,954	26,958	27,541	26,608	18,472	17,079	17,124	17,811	17,666
Differences		*1.72%*	*0.94%*	*1.20%*	*1.19%*	*1.27%*	*2.09%*	*1.34%*	*1.57%*	2.33%
N_2O emissions	2024	24,475	26,416	27,183	26,337	18,305	17,101	16,897	17,570	17,457
(without LULUCF) (kt CO_2-eq.)	2023	24,193	26,177	26,923	26,048	18,090	16,788	16,691	17,346	17,193
Differences		*1.17%*	*0.91%*	*0.96%*	*1.11%*	*1.19%*	*1.87%*	*1.23%*	*1.29%*	1.54%
HFCs	2024	372	1,100	3,747	9,666	12,805	12,082	11,089	9,971	9,411
(kt CO_2-eq.)	2023	372	861	2,803	8,718	14,325	15,630	17,019	16,035	15,388
Differences		*0.00%*	*27.73%*	*33.71%*	*10.87%*	*-10.61%*	*-22.70%*	*-34.84%*	*-37.81%*	-38.84%
PFCs	2024	2,615	1,351	1,363	1,759	1,377	1,529	915	499	395
(kt CO_2-eq.)	2023	2,615	1,351	1,363	1,759	1,377	1,529	915	499	395
Differences			*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	0.00%
Unspecified mix	2024		24	24	24	24	24	23	22	25
(kt CO_2-eq.)	2023		24	24	24	24	24	23	22	25
Differences			*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	0.00%
SF_6	2024	421	700	621	565	405	483	438	252	282
(kt CO_2-eq.)	2023	421	700	621	565	405	485	444	257	258
Differences		*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*-0.37%*	*-1.52%*	*-2.14%*	9.65%
NF_3	2024		77	13	33	20	28	18	16	15
(Gg CO_2-eq.)	2023		77	13	33	20	28	18	16	15
Differences			*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	0.00%
Indirect CO_2	2024	1,311	1,211	1,073	1,041	860	692	786	705	740
(Gg CO_2-eq.)	2023	-	-	-	-	-	-	-	-	-
Differences										
Total	2024	518,730	513,112	541,099	561,913	482,687	400,621	378,791	351,552	386,495
(with LULUCF) (kt CO_2-eq.)	2023	517,992	511,734	538,424	558,640	481,781	401,772	380,439	352,425	390,118
Differences		*0.14%*	*0.27%*	*0.50%*	*0.59%*	*0.19%*	*-0.29%*	*-0.43%*	*-0.25%*	-0.93%
Total	2024	522,373	536,500	561,322	595,598	522,371	442,557	416,493	379,051	411,282
(without LULUCF) (kt CO_2-eq.)	2023	521,480	535,654	559,978	594,197	523,466	445,736	422,276	384,970	417,591
Differences		*0.17%*	*0.16%*	*0.24%*	*0.24%*	*-0.21%*	*-0.71%*	*-1.37%*	*-1.54%*	-1.51%

8.3 Implications for emission trends, including time series consistency

Recalculations account for an improvement in the overall emission trend and consistency in time series.

The trend 1990- 2021, without LULUCF, result in a reduction of emissions, 1990-2021, equal to 21.3% whereas it was 19.9% in the last year submission. The trend with LULUCF result in a reduction of emissions 1990-2021 equal to 25.5%, whereas the decrease was equal to 24.7% in the last year submission.

8.4 Recalculations, response to the review process and planned improvements

This chapter summarises the recalculations and improvements made to the Italian GHG inventory since the last year submission.

In addition to a new year, the inventory is updated annually by a revision of the existing activity data and emission factors in order to include new information available; the update could also reflect the revision of methodologies. Revisions always apply to the whole time series.

The inventory may also be expanded by including categories not previously estimated if sufficient information on activity data and suitable emission factors have been identified and collected.

8.4.1 Recalculations

The key differences in emission estimates occurred since last year's submission are reported in Table 8.1.

All sectors were involved in changes due to updates of activity data and some emission factor.

Specifically:

Energy. The main recalculations affected the year 2021 as a result of a joint collaboration between national energy experts and EUROSTAT for a revision of the national energy balance which should affect the entire time series. The reconstruction has started from the year 2021 to be coherent with data currently communicated for the year 2022.
The whole time series of road transport emissions has been recalculated mainly as a result of the upgrade of Copert model version used.
For navigation, CO_2 natural gas emission factor has been corrected for year 2021. Minor corrections on the figures of the gasoline engines split between 2 stroke and 4 stroke from 2014 onwards. The corrections lead to any relevant impacts on the distribution of the ratio of 2 strokes 4 strokes in the time series.
Fugitive CH4 emissions have been recalculated for the update of liquid fuel transported; and country specific emission factors for oil production. Further recalculations related to figures on natural gas imported; country specific emission factors for gas production and processing; and leakage data by one of the main distribution operators.

IPPU. Major recalculation regarded the F gas emissions, and in particular HFCs. For the Stationary air conditioning sector, recalculations are due to the revision of the estimation process of emission from containers and to the introduction of the domestic heat water machines from 2014. For commercial, industrial and transport refrigeration, major changes are due to the following issues: new estimation of the container emissions, not considered in previous submissions; availability of refrigerants consumptions by subsectors and consequently possibility to estimate separately commercial, industrial, and transport refrigeration; availability of refrigerants consumption split between first charge and service; updating of lifetimes emission factors (industrial refrigeration); update of end-of-life charge and end-of-life gas recovery rates. For Mobile air conditioning sector, recalculation is due to the revision of estimation methodology thank to the collaboration with the industrial association Assogastecnici that also provided refrigerants consumption split between first charge and service; thus, the HFC 134a stock in MAC systems is profoundly changed by causing a revision of operational and disposal emissions. Regarding the Domestic refrigeration, the recalculation is due to the new estimations for management containers emissions, as well as for refrigeration sector. CO_2 emissions from the use of solvent have been reported as indirect CO_2 emissions from this year submission and not included in the IPPU sector.

Agriculture. CH_4 emissions from rice cultivation were updated from 2008 due to the revision of EFs; N_2O emissions were recalculated because of the updating of the NH_3 emission factors of synthetic fertilizers, which affects the indirect emissions of N_2O. Moreover, Fracleach value from 1990 was updated, which involved recalculation of N_2O indirect emissions from leaching/runoff.

LULUCF. The recalculation occurred in the sector is due to the following elements reported in the table 8.3:

Table 8.3 Drivers for recalculation in the LULUCF sector

	CO_2	CH_4	N_2O
Forest land	Update of the 2021 harvest data.	- *Biomass burning* update of emission factors; revision of carbon-to-dry matter ratio (0.47 instead of the 0.5 value, previously used)	
Cropland	-Update of IPCC parameters (SOC_{ref} and F-factors from the 2019 IPCC Refinement have been used) - Update of activity data (i.e. areas subject to different management practices) and consequent recalculation of related soils C stock changes and error fixed.	- *Biomass burning* update of emission factors; revision of carbon-to-dry matter ratio (0.47 instead of the 0.5 value, previously used)	- *Biomass burning* Update of activity data (burned area) *-direct/indirect N2O emissions* Update of the FSOM values used in the estimation process (use of IPCC 2019)
Grassland	- Update of IPCC parameters (SOC_{ref} and F-factors from the 2019 IPCC Refinement have been used) - Error fixing in the disaggregation of the area of land converted to grassland into managed grazing land, natural grazing land and other wooded land.	- *Biomass burning* update of emission factors; revision of carbon-to-dry matter ratio (0.47 instead of the 0.5 value, previously used)	- *Biomass burning* Update of activity data (burned area) - *direct/indirect N2O emissions* Emissions in in 1990 for grassland remaining grassland has been reported for the first time
Wetlands	-	-	-
Settlements	Update of the activity data	-	*-direct N2O emissions* update of the FSOM values used in the estimation process (use of IPCC 2019)
HWP	Revision of FAOSTAT time series for wood-based panels for the years 2017-2021, and for paper & paperboard for 2021.	-	-

Waste. Recalculations occur in N_2O and CH_4 emissions in waste incineration because of the update of open burning of agricultural waste emission factors.

8.4.2 Response to the UNFCCC review process

A complete list of improvements following the UNFCCC review process is reported in Annex 10.

Improvements regarded the completeness and transparency of the information reported in the NIR.

Most of the recommendations has been addressed in the two last years submission. Additional information has been provided in all the sectors, more information on methodology used to estimate emissions for industrial processes (especially for F-gases estimations), estimates for the agriculture sector and LULUCF has been recalculated and the description of country specific methods and the rationale behind the choice of emission factors, activity data and other related parameters for different sector has been better detailed.

8.4.3 Planned improvements (e.g., institutional arrangements, inventory preparation)

Specific improvements are identified in the relevant chapters and specified in the 2024 QA/QC plan; they are summarized in the following.

For the energy and industrial sectors, the database where information collected in the framework of different EU legislation, Large Combustion Plant, E-PRTR and Emissions Trading, is annually updated and improved. The database has helped highlighting the main discrepancies in information and detecting potential errors leading to a better use of these data in the national inventory. Energy data submitted to the international organizations in the framework of the Joint Questionnaire OECD/IEA/EUROSTAT will be compared with the national energy statistics with the aim to reduce the differences with the international statistics. A revision of biomass and waste fuel consumption time series is planned for the next submission on the basis of energy data communicated by the Ministry of Environment to the Joint Questionnaire OECD/IEA/EUROSTAT, after a verification and comparison with data up to now used and available in the National Energy Balance reports.

Improvements for road transport sector will be connected to the availability of information regarding activity data, calculation factors and parameters, development of the methodology and update of the software.

For maritime activities further improvements will regard a verification of activity data on ship movements and emission estimates with the National Institute of Statistics. In particular we plan to build an emission estimation database which calculate every year emissions at harbor level taking in account of the information officially provided by Italy to Eurostat per type of ship, class of tonnage and movement statistics.

For the Industrial processes sector, investigations concerning the replacement of natural raw material in clinker manufacture and in lime production are planned to better explain differences of the average emission factors in the time series. Many improvements are planned for Fgases emissions estimates and in particular in the professional refrigeration sub-sector to try gathering more information and data on the equipment manufactured and sold over the years, the average charge, the operating emission factor in order to estimate the manufacturing and lifetime emissions.

For the agriculture and waste sectors, improvements will be related to the availability of new information on emission factors, activity data as well as parameters necessary to carry out the estimates. Specifically, for agriculture, further improvements are expected on information on the standard diets of cattle for fattening, for the updating of values relating to dry matter intake and Ym. Additional data and information will be collected to improve the estimation of methane emissions from sheep, in particular for the DE parameter for mature ewes and other mature sheep, as recommended during the 2019 UNFCCC review. A working group was set up with *Assofertilizzanti* and ISTAT to compare the statistics produced by these two bodies. The aim is also to revise the data collection questionnaire to detect the amount of CAN distributed throughout the country. The improvement of the waste production and management database, handled by another unit of ISPRA, is ongoing, facilitating the extrapolation and elaboration of the huge amount of information contained in the database. Analysis and elaboration e.g. on waste composition will be easier and will allow improvements in the emission estimates in the future submission.

For the LULUCF, planned improvements are related to the investigation on the end-use, the discard rates of HWP, as well as the final market use of wood in Italy. The main outcome of this investigation could be the set-up of country specific emission factors to be used in the estimation process.

Additional studies will regard the comparison between local inventories and national inventory and exchange of information with the 'local inventories' national expert group.

Further analyses will concern the collection of statistical data and information to estimate uncertainty in specific sectors by implementing Approach 2 of the IPCC guidelines. In this regards we plan to reassess the uncertainty for the same categories reported in the annex of the NIR because these are the main categories for which the analysis makes sense in consideration of the information available on parameters and underlying distributions. We will try to extend the analysis to some other key categories in the IPPU sector (chemical and mineral).

9 REFERENCES

References for the main chapters and the annexes are listed here and are organised by chapter and annex.

9.1 INTRODUCTION and TRENDS IN GREENHOUSE GAS EMISSIONS

EC, 2009. Decision No 406/2009/EC on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020.

EMEP/CORINAIR, 2007. Atmospheric Emission Inventory Guidebook. Technical report No 16/2007.

EMEP/EEA, 2019. Air Pollutant Emission Inventory Guidebook. EEA. Technical report No 13/2019.

IPCC, 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. IPCC Technical Support Unit, Kanagawa, Japan.

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

ISPRA, 2013. Quality Assurance/Quality Control plan for the Italian Emission Inventory. Procedures Manual. October 2013.

ISPRA, 2018. National Greenhouse Gas Inventory System in Italy.

ISPRA, 2022. La disaggregazione a livello provinciale dell'inventario nazionale delle emissioni. ISPRA, 369/2022.

ISPRA, 2024 [a]. Quality Assurance/Quality Control plan for the Italian Emission Inventory.

ISPRA, 2024 [b]. Dioxide Intensity Indicators. Internal document.

9.2 ENERGY

ACI, several years. Dati e statistiche. Automobile Club d'Italia, Roma. http://www.aci.it/index.php?id=54 .

AEEG, several years. Qualità del servizio gas. Autorità per l'energia elettrica e il gas. http://www.autorita.energia.it/it/dati/elenco_dati.htm .

AISCAT, several years. Aiscat in cifre. Data and reports available on website at: http://www.aiscat.it/pubb_cifre.htm?ck=1&sub=3&idl=4&nome=pubblicazioni&nome_sub=aiscat%20in%20cifre .

ANAS, several years. Osservatorio del traffico. https://www.stradeanas.it/it/le-strade/osservatorio-del-traffico.

ANCMA, several years. Data available on website at: http://www.ancma.it/statistiche.

ANPA, 2001. Redazione di inventari nazionali delle emissioni in atmosfera nei settori del trasporto aereo e marittimo e delle emissioni biogeniche. Rapporto finale. Gennaio 2001.

APAT, 2003. Analisi dei fattori di emissione di CO_2 dal settore dei trasporti. Ilacqua M., Contaldi M., Rapporti n° 28/2003.

ARPAT, several years. Monitoraggio delle aree geotermiche toscane. Also available on the website http://www.arpat.toscana.it/documentazione/report/report-geotermia.

ASSOCARTA, several years. Rapporto Ambientale dell'industria cartaria italiana. Also available on the website http://www.assocarta.it.

CNR STEMS, Innovhub SSI, 2020. Database of fuel consumption and emission factors derived from national measurements campaign. Internal documentation.

CONFETRA, several years. Il trasporto merci su strada in Italia. Data and reports available on website at: http://www.confetra.it/it/centrostudi/statistiche.htm.

EDISON, several years. Rendiconto ambientale e della sicurezza.

EEA, 2000. COPERT III, Computer Programme to Calculate Emissions from Road Transport - Methodology and Emission Factors, European Environment Agency, Technical report No 49, November 2000.

EMEP/CORINAIR, 1996. Atmospheric Emission Inventory Guidebook. February 1996.

EMEP/CORINAIR, 2007. Atmospheric Emission Inventory Guidebook. Technical report No 16/2007.

EMEP/EEA, 2009. Air Pollutant Emission Inventory Guidebook. EEA. Technical report No 9/2009.

EMEP/EEA, 2016. Air Pollutant Emission Inventory Guidebook. EEA. Technical report No 21/2016.

EMEP/EEA, 2019. Air Pollutant Emission Inventory Guidebook. EEA. Technical report No 13/2019.

EMEP/EEA, 2023. Air Pollutant Emission Inventory Guidebook. EEA.

EMISIA SA, 2024. COPERT 5 v.5.7.3, Computer programme to calculate emissions from road transport. http://www.emisia.com/copert/.

ENAC/MIT, several. Annuario Statistico. Ente Nazionale per l'Aviazione Civile, Ministero delle Infrastrutture e dei Trasporti.

ENEA-federAmbiente, 2012. Rapporto sul recupero energetico da rifiuti urbani in Italia. 3° ed.

ENEL, several years. Dati statistici sull'energia elettrica in Italia. ENEL.

ENI, several years [a]. La congiuntura economica ed energetica. ENI.

ENI, several years [b]. Health Safety Environment report. ENI.

EUROCONTROL, several years. EUROCONTROL Fuel and Emissions Inventory. Data provided to EU Member States.

Giordano R., 2007. Trasporto merci: criticità attuali e potenziali sviluppi nel contesto europeo. National road transporters central commitee.

Innovhub, 2018. Fuel consumption, regulated and unregulated exhaust emission tests on five Euro 6 b/c bifuel LPG passenger cars.

Innovhub, several years. Report on the physico-chemical characterization of fossil fuels used in Italy. Fuel Experimental Station.

IPCC, 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Emission Inventories. Three volumes: Reference Manual, Reporting Manual, Reporting Guidelines and Workbook. IPCC/OECD/IEA. IPCC WG1 Technical Support Unit, Hadley Centre, Meteorological Centre, Meteorological Office, Bracknell, UK.

IPCC, 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. IPCC National Greenhouse Gas Inventories Programme, Technical Support Unit, Hayama, Kanagawa, Japan.

IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan

IPCC 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html.

ISPRA, 2023. Aggiornamento delle modalità di calcolo delle emissioni navali con particolare riferimento all'ambito portuale a livello nazionale e locale, ISPRA 382/2023.

ISPRA, several years. Fuel Quality Monitoring Annual Report.

ISTAT, several years [a]. Annuario Statistico Italiano. Istituto Nazionale di Statistica.

ISTAT, several years [b]. Trasporto merci su strada. Istituto Nazionale di Statistica. http://www.istat.it/it/archivio/72254.

MASE, several years [a]. Bilancio Energetico Nazionale (BEN). Ministero dell'Ambiente. https://sisen.mase.gov.it/dgsaie/.

MASE, several years [b]. Bollettino Petrolifero Trimestrale (BPT). Ministero dell'Ambiente. https://sisen.mase.gov.it/dgsaie/.

MASE, several years [c]. Elenco dei pozzi idrocarburi perforati in Italia. Ministero dello Sviluppo Economico, Direzione Generale per le Risorse Minerarie ed Energetiche. https://unmig.mite.gov.it/ricerca-e-coltivazione-di-idrocarburi/pozzi-produttivi/ .

MIT, several years. Conto Nazionale delle Infrastrutture e dei Trasporti (CNIT). Ministero delle Infrastrutture e dei Trasporti. http://www.mit.gov.it/comunicazione/pubblicazioni.

Romano D., Gaudioso D., De Lauretis R., 1999. Aircraft Emissions: a comparison of methodologies based on different data availability. Environmental Monitoring and Assessment. Vol. 56 pp. 51-74.

SNAM, several years. Bilancio di sostenibilità.

STOGIT, several years, Bilancio di sostenibilità.

Techne, 2009. Stima delle emissioni in atmosfera nel settore del trasporto aereo e marittimo. Final report. TECHNE Consulting, March 2009.

TERNA, several years. Dati statistici sugli impianti e la produzione di energia elettrica in Italia. Gestore Rete Trasmissione Nazionale.
http://www.terna.it/default/Home/SISTEMA_ELETTRICO/statistiche/dati_statistici.aspx.

UCINA, several years, La nautica in cifre.

UNEM, several years. Previsioni di domanda energetica e petrolifera in Italia. Unione Energia per la Mobilità

Williams, A., 1993. Methane Emissions - Paper Presented at the 29 Consultative Conference of the Watt Committee on Energy, Edited by Professor Alan Williams, Department of Fuel and Energy, University of Leeds, UK.

9.3 INDUSTRIAL PROCESSES AND PRODUCT USE

ACI, several years. Dati e statistiche. Automobile Club d'Italia, Roma. http://www.aci.it/index.php?id=54.

AIA, several years [a]. Personal Communication. Associazione Italiana Aerosol.

AIA, several years [b]. Relazioni annuali sulla produzione italiana aerosol. Associazione Italiana Aerosol.

AIET, 2007. Impatto ambientale degli apparecchi elettrici MT ed AT. Rivista AIET n° 6, giugno 2007.

AITEC, 2004. Posizione dell'industria cementiera in merito al Piano Nazionale di Allocazione delle emissioni di gas ad effetto serra. Roma 19/03/2004.

ALCOA, 2004. Primary Aluminium in Italy. ALCOA.

ALCOA, 2010. Personal Communication. ALCOA.

ALCOA, several years. Personal Communication.

ANDIL, 2000. Primo rapporto ambientale dell'industria italiana dei laterizi. Assolaterizi, Associazione nazionale degli industriali dei laterizi.

ANDIL, several years. Indagine conoscitiva sui laterizi. Assolaterizi, Associazione nazionale degli industriali dei laterizi.

ANIE, 2001. Il gas SF_6 e l'ambiente: un impegno che continua. ANIE Federazione

ANIE, several years. Personal Communication. ANIE Federazione.

APAT, 2003. Il ciclo industriale dell'acciaio da forno elettrico. Agenzia per la Protezione dell'Ambiente e per i servizi tecnici, Rapporti 38/2003.

APEM, 1992. Air Pollution Engineering Manual. Air&Waste Management Association, 1992.

APPLiA Italia, several years. Personal Communication.

Assocandele, 2015. Personal Communication.

Assocasa, several years. Personal Communication.

Assoclima, several years [a]. Statistiche Assoclima www.anima.it/associazioni/elenco/assoclima/attivita/pubblicazioni/studi-di-mercato.kl .

Assoclima, several years [b]. Personal communication.

Assoclima, 2023. Assoclima annual statistical survey. Press release date: 05/04/2023.

Assogastecnici, several years. Personal Communication.

Assogastecnici, 2022. Personal Communication.

Assogastecnici, 2023. Personal Communication.

ASSOMET, several years. I metalli non ferrosi in Italia. Associazione nazionale industrie metalli non ferrosi.

ASSOPIASTRELLE, 2004. L'industria italiana delle piastrelle di ceramica e la Direttiva 2003/87.

ASSOPIASTRELLE, several years. Indagine statistica nazionale. Industria italiana delle piastrelle di ceramica. Assopiastrelle, Associazione nazionale dei produttori di piastrelle di ceramica e di materiali refrattari.

Assovetro, several years. Statistical data available on the official web site of the National Glass Industry Association. http://www.assovetro.it/.

ASSURE, 2005. Personal Communication. European Association for Responsible Use of HFCs in Fire Fighting.

AVISA, several years. Personal Communication.

Benndorf R., 1999. Situation in Deutschland. ACCC-Workshop 'N2O und das Kyoto-Ziel', Umweltbundesamt (Berlin), Wien.

Boehringer Ingelheim, several years. Personal Communication. Boehringer Ingelheim Istituto De Angeli.

CAGEMA, 2005. Politiche e misure per la riduzione delle emissioni di gas serra: il settore della calce. Associazione dell'industria italiana della calce, del gesso e delle malte.

CAPIEL, 2002. Switchgear and SF_6 gas. CAPIEL.

CARBITALIA S.p.A., several years. Personal Communication.

Chiesi Farmaceutici, several years. Personal Communication. Chiesi Farmaceutici S.p.A.

Clean Gas, 2001. Personal Communication. Clean Gas.

CNH, several years. Personal Communication. Case New Holland.

Co.Da.P., 2005. Personal Communication.

Confindustria Ceramica, several years. Personal Communication.

CoReVe, several years. Programma specifico di prevenzione. Risultati del riciclo.

CTN/ACE, 2000. Rassegna delle informazioni disponibili sulle emissioni di diossine e furani dal settore siderurgico e della metallurgia ferrosa. A cura di Pasquale Spezzano.

DPR 43/2012. Decreto del Presidente della Repubblica, 27 gennaio 2012, n. 43. Regolamento recante attuazione del regolamento (CE) n. 842/2006 su taluni gas fluorurati ad effetto serra.

DPR 146/2018. Decreto del Presidente della Repubblica, 16 novembre 2018, n. 146. Regolamento di esecuzione del regolamento (UE) n. 517/2014 sui gas fluorurati a effetto serra e che abroga il regolamento (CE) n. 842/2006.

EC, 1999. Council Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations. Official Journal of the European Communities 29 March 1999.

EC, 2000. Regulation (EC) n. 2037/2000 of the European Parliament and of the Council of 29 June 2000 on substances that deplete the ozone layer.

EC, 2002. Screening study to identify reduction in VOC emissions due to the restrictions in the VOC content of products. Final Report of the European Commission, February 2002.

EC, 2004. Directive 2004/42/EC of the European Parliament and of the Council of 21 April 2004 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in decorative paints and varnishes and vehicle refinishing products and amending Directive 1999/13/EC. Official Journal of the European Communities 30 April 2004.

EC, 2006. Regulation n. 842/2006 of the European Parliament and of the Council of 17 May 2006 on certain fluorinated greenhouse gases.

EDIPOWER, several years. Rapporto di Sostenibilità. EDIPOWER.

EDISON, several years. Bilancio Ambientale. EDISON.

EMEP/CORINAIR, 2007. Atmospheric Emission Inventory Guidebook. Technical report No 16/2007.

EMEP/EEA, 2009. Atmospheric Emission Inventory Guidebook. Technical report No 9/2009.

EMEP/EEA, 2013. Air Pollutant Emission Inventory Guidebook. Technical report n. 12/2013.

EMEP/EEA, 2023. Air Pollutant Emission Inventory Guidebook 2023. Technical guidance to prepare national emission inventories. EEA report 06/2023.

ENDESA, 2004. Personal Communication. ENDESA.

ENDESA, several years [a]. Rapporto ambiente e sicurezza. ENDESA.

ENDESA, several years [b]. Rapporto di sostenibilità. ENDESA.

ENEL, several years. Rapporto ambientale. ENEL.

ENEA/USLRMA, 1995. Lavanderie a secco.

Enichem, several years. Rapporto ambientale.

ENIRISORSE, several years. Statistiche metalli non ferrosi. ENIRISORSE.

EPA, 2006. Uses and air emissions of liquid PFC heat transfer fluids from the electronics sector. EPA-430-R-06-901.

EU, 2006. Directive 2006/40/EC of the European Parliament and of the Council of 17 May 2006 relating to emissions from air conditioning systems in motor vehicles and amending Council Directive 70/156/EEC

EU, 2014. Regulation n. 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) N. 842/2006 Text with EEA relevance.

FAO, several years. Food balance. http://faostat3.fao.org/home/E.

FEDERACCIAI, 2004. Personal Communication.

FEDERACCIAI, several years. La siderurgia in cifre. Federazione Imprese Siderurgiche Italiane.

FEDERBETON/AITEC [a], several years. Rapporto di Filiera. Federbeton

FEDERBETON/AITEC [b], several years. Rapporto di sostenibilità. Federbeton

FEDERCHIMICA, several years. La chimica in cifre. Federazione Nazionale dell'Industria Chimica.

FIAT, several years [a]. Personal Communication.

FIAT, several years [b]. Rendiconto Ambientale. Gruppo Fiat.

Folchi R., Zordan E., 2004. Il mercato degli esplosivi in Italia. Costruzioni, 28/1/2004.

Gastec Vesta, 2017. Personal Communication

GIADA, 2006. Progetto Giada and Personal Communication. ARPA Veneto – Provincia di Vicenza.

GSK, several years. Personal Communication. GlaxoSmithKline S.p.A.

IAI, 2003. The Aluminium Sector Greenhouse Gas Protocol (Addendum to the WBCSD/WRI Greenhouse Gas Protocol). Greenhouse Gas Emission Monitoring and Reporting by the Aluminium Industry. International Aluminium Institute, May 2003.

IAI, 2006. The Aluminium Sector Greenhouse Gas Protocol (Addendum to the WBCSD/WRI Greenhouse Gas Protocol). Greenhouse Gas Emission Monitoring and Reporting by the Aluminium Industry. International Aluminium Institute, October 2006.

ILVA, 2006. Analisi ambientale iniziale. Rev. 2, March 2006. IPPC permitting process.

INFN, several years. Personal communication.

IPCC, 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Emission Inventories. Three volumes: Reference Manual, Reporting Manual, Reporting Guidelines and Workbook. IPCC/OECD/IEA. IPCC WG1 Technical Support Unit, Hadley Centre, Meteorological Centre, Meteorological Office, Bracknell, UK.

IPCC, 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. IPCC National Greenhouse Gas Inventories Programme, Technical Support Unit, Hayama, Kanagawa, Japan.

IPPC, 2001. Best Available Techniques Reference Document on the Production of Iron and Steel. Integrated Pollution Prevention and Control. European Commission. December 2001.

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

ISPESL, 2005. Profilo di rischio e soluzioni. Metallurgia. Produzione ferroleghe. Edited by A. Borroni.

ISPRA, 2018. Studio sulle alternative agli idrofluorocarbuti (HFC) in Italia. Rapporto 286/2018

ISPRA – MATTM, 2013. Analisi del mercato della refrigerazione e del condizionamento in Italia nel periodo 1990-2013, verbale incontro Associazioni Nazionali - Roma, 7 novembre 2013

ISPRA, 2024. *Emission of fluorinated substances from ODS.* Technical Document

ISTAT, several years [a]. Annuario Statistico Italiano.

ISTAT, several years [b]. Bollettino mensile di statistica.

ISTAT, several years [c]. Statistica annuale della produzione industriale http://www.istat.it/it/archivio/73150.

ISTAT, several years [d]. Personal communication.

Istituto De Angeli, several years. Personal Communication. Istituto De Angeli.

Italghisa, 2011. Personal communication

IVECO, several years. Personal Communication.

LFoundry, several years. Personal Communication.

Linde Gas, 2015. Personal Communication.

Lusofarmaco, several years. Personal Communication. Istituto Luso Farmaco d'Italia S.p.A.

Lux, 2015. Personal Communication.

Menarini, several years. Personal Communication. Industrie farmaceutiche riunite.

MICRON, several years. Personal Communication. Micron Technology Italia S.r.l.

MSE, several years. Consuntivo produzione nazionale clinker. Ministero Sviluppo Economico.

MASE, several years. Bollettino Petrolifero Trimestrale (BPT). Ministero dell'Ambiente. https://sisen.mase.gov.it/dgsaie/bollettino-petrolifero.

Norsk Hydro, several years. Personal Communication.

Numonyx, several years. Personal Communication. Numonyx Italy S.r.l.

Offredi P., several years. Professione Verniciatore del Legno. Personal communication.

Polimeri Europa, several years. Personal Communication. Polimeri Europa S.p.A.

Radici Chimica, 1993. Progetto CORINAIR. Produzione acido adipico: descrizione del processo utilizzato da Radici Chimica. Radici Group, Novara.

Radici Chimica, 2013. Annual report to the Italian PRTR.

Radici Chimica, several years. Personal Communication.

RAEE, 2017. MANUALE PER LE AZIENDE DI TRATTAMENTO DEL CDC RAEE. Frigoriferi e Congelatori.

Regione Campania, 2005. Inventario regionale delle emissioni di inquinanti dell'aria della Regione Campania, marzo 2005.

Regione Toscana, 2001. Inventario regionale delle sorgenti di emissione in aria ambiente, febbraio 2001.

Sanofi Aventis, several years. Personal Communication. Sanofi Aventis Italia.

Shiloh Industries Italia, several years. Personal Communication.

Siemens, several years. Personal communication.

Siteb, several years. Rassegna del bitume.

Solsonica, 2015. Personal communication.

Solvay, 2003. Bilancio di Sostenibilità Solvay 2002. Solvay Solexis S.p.A.

Solvay, several years. Personal Communication. Solvay Solexis S.p.A.

Solvay, 1998. Personal communication. Solvay Solexis S.p.A.

Solvay 2006. Personal communication. Solvay Solexis S.p.A.

Solvay Fluor, several years. Personal Communication.

Sotacarbo, 2004. Progetto integrato miniera centrale. Studio di fattibilità sito di Portovesme.

Spinetta Marengo, 2011. Verbale riunione Spinetta Marengo.

ST Microelectronics, several years. Personal Communication. ST Microelectronics

Syndial, several years. Personal Communication. Syndial S.p.A. – Attività diversificate.

TECHNE, 1998. Personal communication.

TERNA, several years. Rapporto di Sostenibilità. TERNA.

UN, several years. Industrial Commodity Statistics Yearbook. United Nation.

UNEM, several years. Previsioni di domanda energetica e petrolifera italiana.

UNIPRO, several years. Rapporto Annuale - Consumi cosmetici in Italia.

UNRAE, several years. Personal Communication. Unione Nazionale Rappresentanti Autoveicoli Esteri.

USEPA, 1997. "Compilation of Air Pollutant Emission Factors". AP-42, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, North Carolina. October 1997.

USGS, several years. Mineral yearbook. Ferroalloys.

Varian, several years. Personal communication.

Versalis, several years. Personal Communication. Versalis S.p.A.

Vetrella G., 1994. Strategie ottimali per la riduzione delle emissioni di composti organici volatili. Thesis in Statistics.

WG1, 2013. Comments on Appendix A&B of the "Preparatory study for the Review of Regulation 842/2006 on certain fluorinated greenhouse gases (Working document 1).

YARA, 2007. Technical documentations from IPPC permit issuing process.

YARA, several years. Personal Communication.

9.4 AGRICULTURE

ADBPO, 1994. Piano delle direttive e degli interventi urgenti per la lotta all'eutrofizzazione delle acque interne e del mare Adriatico. Autorità di bacino del fiume Po. Parma – Italia.

ADBPO, 2001. Progetto di Piano stralcio per il controllo dell'Eutrofizzazione (PsE). Autorità di bacino del fiume Po. Relazione generale. Parma – Italia.

Agraria, 2009. Rivista di Agraria.org N. 82 del 1 giugno 2009. Publication online: Ovini tecniche di allevamento http://www.rivistadiagraria.org/articoli/anno-2009/ovini-tecniche-di-allevamento/.

AIA, several years[a]. Controlli della produttività del latte in Italia – Cattle: Median of days open for the first 5 calving intervals - Statistiche Ufficiali. Associazione Italiana Allevatori. Italia http://bollettino.aia.it/.

AIA, several years[b]. Controlli della produttività del latte in Italia – Sheep: Sex ratio in alive and dead newborn; single and double birth ratio - Statistiche Ufficiali. Associazione Italiana Allevatori. Italia http://bollettino.aia.it/.

AIA, several years[c]. Controlli della produttività del latte in Italia– Sheep: Median of lactations from 90 to 300 days by breed - Statistiche Ufficiali. Associazione Italiana Allevatori. Italia http://bollettino.aia.it/.

ANPA-ONR, 2001. I rifiuti del comparto agro-alimentare, Studio di settore. Agenzia Nazionale per la Protezione dell'Ambiente. Rapporto n. 11/2001. Roma –Italia.

APAT, 2004[a]. Linee guida per l'utilizzazione agronomica degli effluenti di allevamento, Fase 2 Effluenti zootecnici, Risultati di una indagine campionaria sulle caratteristiche degli effluenti di allevamento, a cura di CRPA. Reggio Emilia – Italia.

APAT, 2004[b]. Linee guida per l'utilizzazione agronomica degli effluenti di allevamento, Fase 2 Effluenti zootecnici, Risultati di una indagine campionaria sulle tipologie di stabulazione e di stoccaggio, a cura di CRPA. Reggio Emilia – Italia.

ARA, 2017. Associazione Regionale Allevatori della Sardegna. Publication online: Specie allevate in Sardegna – Ovini.

ASSONAPA, 2006. Database of goat and sheep animal consistency and breeds. Associazione Nazionale della Pastorizia Ufficio Centrale dei Libri Genealogici e dei Registri Anagrafici, Italy.

Baldoni R., Giardini L., 1989. Coltivazione erbacee. Editor Patron, p 1072. Bologna, Italia.

Baldoni R., Giardini L., 2002. Coltivazione erbacee. Editor Patron, Volume 3.

Barile V.L., 2005. Improving reproductive efficiency in female buffaloes. Livest. Prod. Sci. 92, 83–194.

Bertora C., Cucu M. A., Lerda C., Peyron M., Bardi L., Gorra R., Sacco D., Celi L., Said-Pullicino D., 2018. Dissolved organic carbon cycling, methane emissions and related microbial populations in temperate rice paddies with contrasting straw and water management. Agriculture, ecosystems & environment, 265, 292-306.

Bittante G., Gallo L., Schiavon S., Contiero B., Fracasso A., 2004. Bilancio dell'azoto negli allevamenti di vacche da latte e vitelloni. In (Xiccato et al., 2004) Bilancio dell'azoto in allevamenti di bovini, suini e conigli – Progetto interregionale - Legge 23/12/1999 n. 499, art. 2 - report finale, Regione Veneto.

Bonazzi G., Crovetto M., Della Casa G., Schiavon S., Sirri F., 2005, Evaluation of Nitrogen and Phosphorus in Livestock manure: Southern Europe (Italy). In Workshop: Nutrients in livestock manure, Bruxelles, 14 February 2005.

Borgioli E., 1981. Nutrizione e alimentazione degli animali domestici. Edagricole, p. 464.

Braca G., Bussettini M., Lastoria B., Mariani S., Piva F, 2023. Elaborazioni modello BIGBANG versione 7.0, Istituto Superiore per la Protezione e la Ricerca Ambientale – ISPRA http://groupware.sinanet.isprambiente.it/bigbang-data/library/bigbang_70.

Braca G., Bussettini M., Lastoria B., Mariani S., Piva F., 2021. Il Bilancio Idrologico Gis BAsed a scala Nazionale su Griglia regolare – BIGBANG: metodologia e stime. Rapporto sulla disponibilità naturale della risorsa idrica. Istituto Superiore per la Protezione e la Ricerca Ambientale, Rapporti 339/21, Roma. https://www.isprambiente.gov.it/it/pubblicazioni/rapporti/il-bilancio-idrologico-gis-based-a-scala-nazionale-su-griglia-regolare-bigbang.

Butterbach-Bahl K., Papen H., Rennenberg H., 1997. Impact of rice transport through cultivars on methane emission from rice paddy fields. Plant, Cell and Environment. 20:1175-1183.

CESTAAT, 1988. Impieghi dei sottoprodotti agricoli ed agroindustriali, Vol. 1. Centro Studi sull'Agricoltura, l'Ambiente e il Territorio, p. 311.

Confalonieri R., Bocchi S., 2005. Evaluation of CropSyst for simulating the yield of flooded rice in northern Italy. European Journal of Agronomy. 2005, 23, 315 – 326.

Consorzio per la tutela del formaggio Mozzarella di Bufala Campana, 2002. Modello di Regolamento per la gestione igienica ed alimentare dell'allevamento bufalino in relazione alla produzione della mozzarella di bufala campana DOP. Edit. Consorzio per la tutela del formaggio mozzarella di bufala campana (Campana Mozzarella Consortium).

CREA, 2020. L'agricoltura italiana conta 2020. CREA - Centro di ricerca Politiche e Bioeconomia 2020 https://www.crea.gov.it/web/politiche-e-bioeconomia/-/l-agricoltura-italiana-conta-2020.

CRPA, 1993. Manuale per la gestione e utilizzazione agronomica dei reflui zootecnici. Regione Emilia-Romagna, Assessorato agricoltura.

CRPA, 1996. Biogas e cogenerazione nell'allevamento suino. Manuale pratico. ENEL, Direzione studi e ricerche, Centro ricerche ambiente e materiali. Milano – Italia.

CRPA, 1997[a]. Piani Regionali di Risanamento e tutela della qualità dell'aria. Quadro delle azioni degli enti locali per il settore zootecnico delle aree padane. Allegato 2. Relazione di dettaglio sulla metodologia adottata per la quantificazione delle emissioni di metano. Febbraio 1997.

CRPA, 1997[b]. Piani Regionali di Risanamento e tutela della qualità dell'aria. Quadro delle azioni degli enti locali per il settore zootecnico delle aree padane. Relazione di dettaglio sulla metodologia adottata per la quantificazione delle emissioni di protossido di azoto. Settembre 1997.

CRPA, 2000. Aggiornamento dell'inventario delle emissioni in atmosfera di ammoniaca, metano e protossido di azoto dal comparto agricolo. Centro Ricerche Produzioni Animali. Gennaio 2000.

CRPA, 2004[a]. L'alimentazione della vacca da latte. Edizioni L'Informatore Agrario. Terza edizione, Centro Ricerche Produzioni Animali.

CRPA, 2004[b]. Personal communication, expert in dairy cattle feeding from the Research Centre on Animal Production (CRPA), Maria Teresa Pacchioli.

CRPA, 2004[c]. Personal communication, expert in greenhouse gases emissions from the agriculture sector from the Research Centre on Animal Production (CRPA), Laura Valli.

CRPA, 2005. Personal communication, working group with experts in animal feeding from the Research Centre on Animal Production (CRPA), Maria Teresa Pacchioli and Paola Vecchia.

CRPA, 2006[a]. Progetto MeditAIRaneo: settore Agricoltura. Relazione finale. Technical report on the framework of the MeditAIRaneo project for the Agriculture sector, Reggio Emilia – Italia.

CRPA, 2006[b]. Predisposizione di scenari di emissione finalizzati alla progettazione di interventi per la riduzione delle emissioni nazionali di ammoniaca ed alla valutazione di misure e di progetti per la tutela della qualità dell'aria a livello regionale. Final report. Reggio Emilia – Italy.

CRPA, 2008[a]. Le scelte politiche energetico-ambientali lanciano il biogas. L'Informatore Agrario 3/2008, p.28-32 (with annex).

CRPA, 2009. Valutazione dell'entità delle emissioni ammoniacali derivanti dall'applicazione al suolo dei fertilizzanti, delle loro possibilità di riduzione e individuazione degli elementi per un monitoraggio statistico delle tecniche di applicazione utilizzate. Final report. Reggio Emilia – Italy.

CRPA, 2010. Personal communication - experts Laura Valli and Maria Teresa Pacchioli from the Research Centre on Animal Production (expert consultation on N excretion and national production systems). Reggio Emilia, Italy.

CRPA, 2011. "Il biogas accelera la corsa verso gli obiettivi 2020". Supplemento a L'Informatore Agrario n. 26/2011.

CRPA, 2013. "Biogas, il settore è strutturato e continua a crescere". Supplemento a L'Informatore Agrario n. 11/2013.

CRPA, 2016[a]. Personal communication - experts Nicola Labartino and Laura Valli from the Research Centre on Animal Production (expert consultation on N excretion and national production systems). Reggio Emilia, Italy.

CRPA, 2016[b]. Personal communication – expert Laura Valli from the Research Centre on Animal Production (expert consultation on N excretion and national production systems). Reggio Emilia, Italy.

CRPA, 2018. Studio per la valutazione degli effetti sulle emissioni delle trasformazioni in corso nel settore degli allevamenti. Report. Reggio Emilia – Italy

CRPA/AIEL, 2008. Energia dal biogas prodotto da effluenti zootecnici, biomasse dedicate e di scarto. Ed. Associazione Italiana Energie Ambientali (AIEL).

CRPA/CNR, 1992. Indagine sugli scarti organici in Emilia-Romagna.

Dan J., Krüger M., Frenzel P., Conrad R., 2001. Effect of a late season urea fertilization on methane emission from a rice field in Italy. Agri. Ecos. Env. 83: 191–199.

Dannenberg S., Conrad R., 1999. Effect of rice plants on methane production and rhizospheric metabolism in paddy soil. Biogeochemistry 45: 53–71.

De Corso E., 2008. World fertilizer market between food crisis and global economy simulations with partial equilibrium models. Tesi di laurea. Facolta' di Agraria, Universita' Cattolica del Sacro Cuore. 98p.

De Roest and Speroni, 2005. Il bilancio dell'azoto negli allevamenti di latte. Agricoltura. Marzo 2005, 112-114.

De Rosa M., Trabalzi F., 2004. Technological innovation among buffalo breeders of southern lazio, Italy. Agricoltura Mediterranea. Vol. 134, 58-67.

De Rosa M., Di Francia, 2006. Personal communication.

Di Cristofaro E., several years. Procedura per la preparazione, caricamento e reporting dell'inventario nazionale delle emissioni del settore Agricoltura. Internal report ISPRA. Rome, Italy.

EMEP/EEA, 2023. Air Pollutant Emission Inventory Guidebook 2023. Technical guidance to prepare national emission inventories. EEA report 06/2023.

ENEA, 1994. Personal communication, expert in agriculture sector. Ente nazionale per l'energia, l'ambiente e le nuove tecnologie (ENEA), Andrea Sonnino.

ENEA, 2006. Valutazione della possibilità di sostituzione dell'urea con altri fertilizzanti azotati. Final report. Rome, Italy.

ENAMA, 2011. "Biomasse ed Energia - Censimento impianti, biocarburanti di seconda generazione e casi studio".

ENR, 2011. Personal communication with Ente Nazionale Risi (ENR), Enrico Losi. Information available on rice surface by variety and time of cultivation.

ENR, 2013. XLV Relazione annuale Anno 2012. Il risicoltore. Ente Nazionale Risi.

ENR, 2014 [a]. Personal communication with Ente Nazionale Risi (ENR), Elena Noja. Information available on the length of the vegetation period for some varieties of rice.

ENR, 2014 [b]. XLVI Relazione annuale Anno 2013. Il risicoltore. Ente Nazionale Risi.

ENR, several years [a]. Personal communication with Ente Nazionale Risi (ENR), Dr. Romani. Information on agronomic management of rice cultivation.

ENR, several years [b]. Data available online on rice surface by variety and production. http://www.enterisi.it/servizi/Menu/dinamica.aspx?idSezione=17505&idArea=17548&idCat=17552&ID=17552&TipoElemento=categoria.

ENSE, 1999. Caratterizzazione morfo-fisiologica delle varietà di riso iscritte al catalogo italiano dal 1992 al 1998. Quaderno numero 47 a cura di L. Tamborini. Ente Nazionale delle Sementi Elette – Milano.

ENSE, 2004. Caratterizzazione morfo-fisiologica delle varietà di riso iscritte al catalogo italiano dal 1999 al 2004. Quaderno numero 48 a cura di L. Tamborini e G. Polenghi. Ente Nazionale delle Sementi Elette – Milano.

EPIC, 2015. Environmental Policy Integrated Climate Model. User's Manual Version 0810 September 2015.

EUROSTAT, 2007[a]. Farm structure in Italy – 2005. Statistics in Focus Agriculture and Fisheries 22/2007 Product KS-SF-07-022 European Communities.

EUROSTAT, 2007[b]. Agriculture. Main statistics 2005-2006. Product Ks-ED-07-002-En-C. European Communities.

EUROSTAT, 2012. Agriculture. Main statistics 2010-2011. Product KS-FK-12-001-EN-C. European Communities.

FAO, several years. FAOSTAT, the FAO Statistical Database, http://www.fao.org/faostat/en/#data.

Ferrero A., Nguyen N.V., 2004. Constraints and opportunities for the sustainable development of rice-based production systems in Europe. In proceedings: FAO Rice Conference, 12-13 February 2004, FAO, Rome, Italy.

Gazzetta Ufficiale della Repubblica Italiana (G.U.), 2006. Criteri e norme tecniche generali per la disciplina regionale dell'utilizzazione agronomica degli effluenti di allevamento e di acque reflue di cui all'articolo 38 del decreto legislativo 11 maggio 1999 N. 152. G.U. n. 109 del 12/05/06 - Suppl. Ordinario n.120. Ministero delle Politiche Agricole e Forestali. Italy. http://www.gazzettaufficiale.it/.

Gazzetta Ufficiale della Repubblica Italiana (G.U.), 2016[a]. Ministero delle Politiche Agricole Alimentari e Forestali - Decreto 25 Febbraio 2016 - Criteri e norme tecniche generali per la disciplina regionale dell'utilizzazione agronomica degli effluenti di allevamento e delle acque reflue, nonché per la produzione ed utilizzazione agronomica del digestato (G.U. n. 90 del 18 aprile 2016).

Gazzetta Ufficiale della Repubblica Italiana (G.U.), 2016[b]. Attuazione della legge 3 maggio n. 79 in materia di ratifica ed esecuzione dell'Emendamento di Doha al Protocollo di Kyoto (G.U. n. 298 del 22 dicembre 2016).

Gislon G., Colombini S., Borreani G., Crovetto G. M., Sandrucci A., Galassi G., Tabacco E., Rapetti L., 2020. Milk production, methane emissions, nitrogen, and energy balance of cows fed diets based on different forage systems. J. Dairy Sci. 103:8048–8061 https://doi.org/10.3168/jds.2019-18134.

Greco M., Martino L., 2001. The agricultural statistical system in Italy. In: Conference on Agricultural and Environmental Application, Rome 4-8 June. Italy 46-461pp.

Holzapfel-Pschorn A., Seiler W., 1986. Methane emission during a cultivation period from an Italian Rice Paddy. Journal of Geophysical Research Vol. 91 N° D11 11,803-11,814.

Husted S., 1993. An open chamber technique for determination of methane emission from stored livestock manure. Atmospheric Environment 11 (27).

Husted S., 1994. Seasonal variation in methane emissions from stored slurry and solid manures, J. Env. Qual. 23, pp. 585-592.

Infascelli F., 2003. Nuove acquisizioni sulla nutrizione e sull'alimentazione della bufala. In: II Congresso Nazionale sull'Allevamento del Bufalo Monterotondo - Roma, pp. 1-18.

IPCC, 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Emission Inventories. Three volumes: Reference Manual, Reporting Manual, Reporting Guidelines and Workbook. IPCC/OECD/IEA. IPCC WG1 Technical Support Unit, Hadley Centre, Meteorological Centre, Meteorological Office, Bracknell, UK.

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

IPCC 2014, 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds) Published: IPCC, Switzerland.

IPCC, 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html.

ISPRA, 2020. Database SCIA - National System for the collection, processing and dissemination of climatological data of environmental interest - Spatialised monthly average temperature data of the national territory for the periods 1961-1990, 1971-2000, 1981-2010. http://www.scia.isprambiente.it/wwwrootscia/scia_eng.html.

ISPRA, 2021. Database della disaggregazione a livello provinciale dell'Inventario nazionale delle emissioni:1990-1995-2000-2005-2010-2015-2019. Istituto Superiore per la Protezione e la Ricerca Ambientale, ISPRA. http://emissioni.sina.isprambiente.it/serie-storiche-emissioni/.

ISPRA, several years [a]. Quality Assurance/Quality Control plan for the Italian Inventory.

ISPRA, several years [b]. Serie storiche delle emissioni nazionali di inquinanti atmosferici, Rete del Sistema Informativo Nazionale Ambientale - SINANET. Istituto Superiore per la Protezione e la Ricerca Ambientale. http://emissioni.sina.isprambiente.it/serie-storiche-emissioni/.

ISTAT, 1991. Caratteristiche strutturali delle aziende agricole, fascicoli provinciali, 4° Censimento generale dell'Agricoltura (20 ottobre 1990-22 febbraio 1991), Roma – Italia.

ISTAT, 2003. 5° Censimento Generale dell’Agricoltura. Caratteristiche strutturali delle aziende agricole. Fascicolo Nazionale: dati regionali, provinciali e comunali. Istituto Nazionale di Statistica, Roma – Italia.

ISTAT, 2004. Personal communication, expert in agriculture statistics- fertilizers from the National Institute of Statistics (ISTAT), Mario Adua.

ISTAT, 2006[a]. Struttura e produzioni delle aziende agricole Anno 2005. Statistiche in breve (27 dicembre 2006). Statistiche Servizio Agricoltura – Allevamenti e pesca. Istituto Nazionale di Statistica, Roma – Italia.

ISTAT, 2006[b]. Personal communication, expert in agriculture statistics from the National Institute of Statistics (ISTAT), Giampaola Bellini.

ISTAT, 2007[a]. Farm and structure survey from 2005. Information on the number of animals at a provincial level. Istituto Nazionale di Statistica, Roma –Italia.

ISTAT, 2007[b]. Annuario Statistico Italiano 2007- Capitolo 13 Agricoltura. Istituto Nazionale di Statistica, Roma –Italia.

ISTAT, 2007[c]. Personal communication with N. Mattaliano. E-mail request for elaboration Farm and structure survey 2003 data on burning residues -cereals. Istituto Nazionale di Statistica, Roma –Italia.

ISTAT, 2007[d]. Indagine sulla struttura e produzione delle aziende agricole. Anno 2005. Prodotto DCSSD1.1.1. Rapporto di qualità su SPA 2005. Istituto Nazionale di Statistica, Roma –Italia.

ISTAT, 2008[a]. Struttura e produzioni delle aziende agricole. Anno 2007 (03 Dicembre 2008). Istituto Nazionale di Statistica, Roma – Italia.

ISTAT, 2008[b]. Indagine sulla struttura e produzione delle aziende agricole. Anno 2007. Rapporto sulla Qualità. Istituto Nazionale di Statistica, Roma - Italia.

ISTAT, 2010. Istruzioni per la rilevazione. 6º Censimento Generale dell'Agricoltura. Istituto Nazionale di Statistica, Roma - Italia.

ISTAT, 2012. 6º Censimento Generale dell'Agricoltura. Istituto Nazionale di Statistica, Roma - Italia. http://dati-censimentoagricoltura.istat.it/.

ISTAT, 2013. La valutazione della qualità. Atti del 6° Censimento Generale dell'Agricoltura. Istituto Nazionale di Statistica, Roma – Italia. http://www.istat.it/it/archivio/112514.

ISTAT, 2015. Indagine sulla struttura e produzione delle aziende agricole. Anno 2013. Istituto Nazionale di Statistica, Roma - Italia.

ISTAT, 2018. Indagine sulla struttura e produzione delle aziende agricole. Anno 2016. Istituto Nazionale di Statistica, Roma - Italia.

ISTAT, several years[a]. Statistiche dell'agricoltura, zootecnia e mezzi di produzione – Annuari (1990-1993), Istituto Nazionale di Statistica, Roma – Italia.

ISTAT, several years[b]. Statistiche dell'agricoltura – Annuari (1994-2000), Istituto Nazionale di Statistica, Roma –Italia.

ISTAT, several years[c]. Struttura e produzioni delle aziende agricole – Informazione (1995- 1999), Istituto Nazionale di Statistica, Roma –Italia.

ISTAT, several years[d]. Statistiche sulla pesca e zootecnia – Informazione (1998-2001), Istituto Nazionale di Statistica, Roma –Italia.

ISTAT, several years[e]. Statistiche sulla pesca, caccia e zootecnia – Informazione (1996-1997), Istituto Nazionale di Statistica, Roma –Italia.

ISTAT, several years[f]. Annuario Statistico Italiano - Annuario (1990; 1993-1994; 1997-2003), Istituto Nazionale di Statistica, Roma –Italia.

ISTAT, several years[g]. Dati annuali sulla consistenza del bestiame. Istituto Nazionale di Statistica, Roma – Italia. http://dati.istat.it/.

ISTAT, several years[h]. Dati annuali e mensili sul settore lattiero caseario. Istituto Nazionale di Statistica, Roma – Italia. http://dati.istat.it/.

ISTAT, several years[i]. Dati congiunturali sui mezzi di produzione. Istituto Nazionale di Statistica, Roma – Italia. http://dati.istat.it/.

ISTAT, several years[j]. Dati congiunturali sulle coltivazioni. Istituto Nazionale di Statistica, Roma –Italia. http://dati.istat.it/.

ISTAT, several years[k]. Personal communication with D. Ciaccia: e-mail request of rabbit production data. Istituto Nazionale di Statistica, Roma – Italia.

ISTAT, several years[l]. Serie storiche - Agricoltura, zootecnia e pesca http://seriestoriche.istat.it/.

Kruger M., Frenzel P., Kemnitz D., Conrad R., 2005. Activity, structure and dynamics of the methanogenic archaeal community in a flooded Italian rice field. FEMS Microbiology Ecology 51: 323–331.

LAORE, 2014. Agenzia regionale per lo sviluppo in agricoltura. Opuscolo n. 3. Note tecniche sull'alimentazione degli ovini e dei caprini. LAORE Sardegna http://www.sardegnaagricoltura.it/documenti/14_43_20140205090638.pdf.

Leip A., Bocchi S., 2007. Contribution of rice production to greenhouse gas emissions in Europe. In: Proceeding of the Fourth Temperate Rice Conference. Ed. S.Bocchi, A. Ferrero, A. Porro. 25-28 June Novara –Italy.

Leip A., Russo S., Smith K.A., Conen F., Bidoglio G., 2002. Rice cultivation by direct drilling and delayed flooding reduces methane emissions. In: van Ham et al. (eds): Non-CO2 Greenhouse Gases (NCGG-3): Scientific understanding, control options and policy aspects. p. 457-458.

Lupotto E., Greppi D., Cavigiolo S., 2005. Personal communication, group of experts in rice paddy cultivation and agronomic practices from the C.R.A. – Experimental Institute of Cereal Research – Rice Research Section of Vercelli (Consiglio per la Ricerca e sperimentazione in Agricoltura, Istituto sperimentale per la Cerealicoltura, Sezione specializzata per la Risicoltura) Italia.

Mannini P., 2004. Risparmio idrico/metodi e sistemi irrigui. La sommersione. In: Supplementi di Agricoltura 18. Le buone pratiche agricole per risparmiare acqua. Assessorato Agricoltura, Ambiente e Sviluppo Sostenibile, Regione Emilia-Romagna, pp.154-157. http://agricoltura.regione.emilia-romagna.it/.

Marik T., Fischer H., Conen F., Smith K., 2002. Seasonal variations in stable carbon and hydrogen isotope ratios in methane from rice fields. Global Biogeochemical Cycles, vol. 16, N°4.

Masucci F., Di Francia A., Gioffrè F., Zullo A., Proto V., 1999. Prediction of digestibility in buffalo. In: XIII ASPA Congress, Piacenza (Italy) 21-24 June 345-347.

Masucci F., Di Francia A., Proto V., 1997. In vivo digestibility, rate of particulate passage and dry matter rumen degradability in buffaloes and sheep. In: V World Buffalo Congress, Caserta (Italy) 13-16 October, 296-301.

MATTM, 2022. Eighth National Communication under the UN Framework Convention on Climate Change Italy December 2022 https://unfccc.int/documents/624766

MATTM, several years. Personal communication with Marco Porrega: e-mails request for sewage sludge applied to agricultural soils in Italy. Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Roma –Italia.

Miniotti E. F., Romani M., 2023. Personal communication of 10/3/2023 on description of cultivation techniques of experimental fields.

Molle G., Decandia M., Cabiddu A., Landau S. Y., Cannas A., 2008. An update on the nutrition of dairy sheep grazing Mediterranean pastures. Small Ruminant Research, 77(2-3), 93-112.

Molle G., Cannas A., 2015. Tecniche di alimentazione della pecora Sarda: stato dell'arte e prospettive.

Mordenti A., Pacchioli M.T., Della Casa G., 1997. Production and nutrition techniques in the control of meat quality in heavy pigs. XXXII International Symposium on Animal Production: Advances in Technology, Accuracy and Management Milano, 29th September –1st October 1997. pag 81.

NRC, 2001. Nutrient Requirements of dairy cattle Ninth edition, Nat. Acad. Press, Washington, D.C. USA.

OSSLATTE, 2001. Annuario del latte, Edizione 2001. Capitolo 3: La produzione di latte secondo l'ISTAT e l'AIA, Osservatorio sul mercato dei prodotti lattiero-caseari del latte.

OSSLATTE/ISMEA, 2003. Il mercato del latte, rapporto 2003. Capitolo 3: La struttura degli allevamenti e la produzione di latte secondo l'ISTAT. Osservatorio sul mercato dei prodotti lattiero-caseari del latte e l'Istituto di Servizi per il Mercato Agricolo ed Alimentare.

Perelli M., 2007. Prezzi dei prodotti agricoli e fertilizzazione. Fertilizzanti Maggio 2007. Anno IX N3. 10-13pp.

Peyron M., Bertora C., Pelissetti S., Said-Pullicino D., Celi L., Miniotti E., Romani M., Sacco D., 2016. Greenhouse gas emissions as affected by different water management practices in temperate rice paddies. Agriculture, Ecosystems & Environment, 232, 17-28.

PROINCARNE, 2005. Personal communication, expert in goat and sheep breeding. Associazione Produttori Carni Bovine dell'Emilia-Romagna, Stefano Ronchi.

Regione Emilia-Romagna, 2004. L. R. 28/98 – P.S.A. 2001 - N. PROG. 3 TAB. B3 - Bilancio dell'azoto nelle specie di interesse zootecnico, Relazione finale, a cura di C.R.P.A., September 2004, Reggio Emilia, Italy.

Regione Emilia-Romagna, 2005. Disciplinari di produzione integrata 2005 Norme tecniche di coltura - Tecnica agronomica - Colture erbacee – RISO. Direzione Agricoltura, Regione Emilia-Romagna.

Rivieccio R., 2019. Tesi Dottorato "Soil database of italy at 1:250,000 scale and thematic applications for assessing environmental services" di Rosa Rivieccio, Tutor Prof. Marco Marchetti, Co-Tutor Dott. Rosario Napoli - Scienze, tecnologie e biotecnologie per la sostenibilità - XXXI Ciclo, Ecologia forestale e tecnologie ambientali. Corso congiunto di Università degli Studi della Tuscia e Università degli Studi del Molise. http://hdl.handle.net/2067/49539. Dati di riferimento utilizzati: SOIL DATABASE 250 - Banca dati nazionale dei suoli in scala 1:250.000, Responsabile dott. Rosario Napoli https://www.crea.gov.it/web/agricoltura-e-ambiente/-/soil-dababase-250-banca-dati-suoli.

Romani M., 2023. Personal communication of 06/15/2023 on description of cultivation techniques of experimental fields.

Roy R., Detlef Kluber H., Conrad R., 1997. Early initiation of methane production in anoxic rice soil despite the presence of oxidants. FEMS Microbiology Ecology 24:311-320.

Russo S., 1994. Semina interrata con sommersione ritardata: un'alternativa all'impianto della risaia tradizionale. L'informatore Agrario 12/94 p 39-46.

Safley L.M., Casada M.E., Woodbury J., Roos K.F., 1992. Global methane emissions from livestock and poultry manure. USEPA, Washington D.C., EPA/400/191/048.

Said-Pullicino D., 2023[a]. Personal communication of 06/15/2023 on description of cultivation techniques of experimental fields.

Said-Pullicino D., 2023[b]. Personal communication of 06/8/2023 on description of cultivation techniques of experimental fields.

Schütz H., Holzapfel-Pschorn A., Conrad R., Rennenberg H., Seiler W., 1989 [a]. A 3-year continuous record on the influence of daytime, season and fertilizer treatment on methane emission rates from an Italian rice padd., Journal of. Geophysical Research 94, D13, pp. 16405-16415.

Schütz H., Seiler W., Conrad R., 1989 [b]. Processes involved in formation and emission of methane in rice paddies. Biogeochemistry, 7, pp. 33-53.

Spanu A., 2006. Personal communication, expert in rice cultivation from Università degli Studi di Sassari, Sardegna – Italy.

Spanu A., Murtas A., Ledda L., Ballone F., 2004. Confronto tra varietà di riso sottoposte a irrigazione turnata. L'informatore Agrario 18/2004 p 61-62.

Spanu A., Pruneddu G., 1996. The influence of irrigation volumes on sprinkler-irrigated rice (Oryza sativa) production. Agricoltura Mediterranea, Vol 126, 377-382.

Steed Jr. J., Hashimoto A.G., 1995. Methane emissions from typical manure management systems, Bioresource Technology 50 pp. 123-130.

TERNA, several years. National production data from biogas. https://www.terna.it/it/sistema-elettrico/statistiche/pubblicazioni-statistiche.

Tinarelli A., 1973. La coltivazione del riso Editorial Edagricole, First edition p. 425.

Tinarelli A., 1986. Il riso. Editorail Edagricole, Second edition p. 426.

Tinarelli A., 2005. Personal communication, Italian expert in rice cultivation – Antonio Tinarelli, participated in the working group with the Experimental Institute of Cereal Research – Rice Research Section of Vercelli, Italia.

Tossato S., Regis F., 2002. Collana monografica di manuali naturalistico-agronomici, con riferimento alle principali colture geneticamente modificate. Volume 6. Il Riso. Agenzia Regionale per la Protezione Ambientale Piemonte (ARPA Piemonte), Piemonte, Italy.

UNAITALIA, several years. Poultry production information. Unione nazionale filiere agroalimentari delle carni e delle uova. http://www.unaitalia.com/.

UNFCCC, several years. Report of the individual review of the greenhouse gas inventories of Italy (FCCC/ARR/year/ITA) https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/inventory-review-reports-2020.

UNICALCE, 2016. Personnal communication, expert of the lime production sector. Associazione Produttori Calce, Sergio Peruta.

Vitali A., Moretti B., Bertora C., Miniotti E. F., Tenni D., Romani M., Facchi A., Martin M., Fogliatto S., Vidotto F., Celi L., Said-Pullicino D., 2024. The environmental and agronomic benefits and trade-offs linked with the adoption alternate wetting and drying in temperate rice paddies. Field Crops Research, 317, 109550.

Wassmann R., 2005. Personal communication, expert in methane from rice paddies (Forschungszentrum Karlsruhe IMK-IFU, Garmisch-Partenkirchen, Germany). E-mail communication received on 16/08/2005.

Weber S., Lueders T., Friedrich M.W., Conrad R., 2001. Methanogenic populations involved in the degradation of rice straw in anoxic paddy soil. FEMS Microbiology Ecology 38:11-20.

Xiccato G., Schiavon S., Gallo L., Bailoni L., Bittante G., 2005. Nitrogen excretion in dairy cow, beef and veal cattle, pig, and rabbit farms in Northern Italy. Italian Journal of Animal Science. vol. 4n (suppl. 3), 103-111.

Yan X., Yagi K., Akiyama H., Akimoto H., 2005. Statistical analysis of the major variables controlling methane emission from rice fields. Global Change Biology (2005) 11, 1131–1141.

Zavattaro L., Romani M., Sacco D., Bassanino M., Grignani C., 2004. Fertilization management of paddy fields in Piedmont (NW Italy) and its effects on the soil and water quality. In proceedings: Challenges and opportunities for sustainable rice-based production systems. Torino, Italy 13-15 September 2004.

Zicarelli L., 2001. Evoluzione dell'allevamento bufalino in Italia. In Proc. I Congresso Nazionale sull'Allevamento del Bufalo Eboli, Salerno, Italy, pp. 1-19.

9.5 LAND USE, LAND USE CHANGE AND FORESTRY

Adams, 1973. “The effect of organic matter on the bulk and true densities of some uncultivated podzolic soil.” J. Soil Sci. 24:10-17.

Alberti G., Peressotti A., Piussi P., Zerbi G., 2008. Forest ecosystem carbon accumulation during a secondary succession in the Eastern Prealps of Italy, Forestry: An International Journal of Forest Research, Volume 81, Issue 1, Pages 1–11, https://doi.org/10.1093/forestry/cpm026

ARPA Lombardia - Regione Lombardia, 2011 [a]. INEMAR, Inventario emissioni in atmosfera. Emissioni in Lombardia nel 2008 - revisione pubblica.

ARPA Lombardia - Regione Lombardia, 2011 [b] – Personal Communication by Federico Antognazza.

Batjes, N., 1996. Total carbon and nitrogen in the soils of the world. European Journal of Soil Science, 47: 151–163.

Benedetti A., Pompili L., Nisini L., 2004. Ruolo attivo dell’agricoltura nei processi di mitigazione del cambiamento climatico globale. Rapporto del progetto Climagri-Cambiamenti climatici e agricoltura, – CRA- Istituto Sperimentale per la Nutrizione delle Piante.

Bovio G., 2007. Method for forest fire damage level assessment based on detectable effects. In ‘Evaluation of Forest Fire Damages in Italy’. Eds Ciancio O., Corona P., Marinelli M., Pettenella D., Accademia Italiana di Scienze Forestali: Florence, Italy, pp. 55–60.

Ceccanti B., Doni S., Macci C., Cercignani G., Masciandaro G., 2008. Characterization of stable humic–enzyme complexes of different soil ecosystems through analytical isoelectric focussing technique (IEF), Soil Biology & Biochemistry 40 (2008) 2174–2177.

Chirici G., Giannetti F., Travaglini D., Nocentini S., Francini S., D’Amico G., Calvo E., Fasolini D., Broll M., Maistrelli F., Tonner J., Pietrogiovanna M., Oberlechner K., Andriolo A., Comino R., Faidiga A., Pasutto I., Carraro G., Zen S., Contarin F., Alfonsi L., Wolynski A., Zanin M., Gagliano C., Tonolli S., Zoanetti R., Tonetti R., Cavalli R., Lingua E., Pirotti F., Grigolato S., Bellingeri D., Zini E., Gianelle D., Dalponte M., Pompei E., Stefani A., Motta R., Morresi D., Garbarino M., Alberti G., Valdevit F., Tomelleri E., Torresani M., Tonon G., Marchi M., Corona P., Marchetti M. (2019). Stima dei danni della tempesta “Vaia” alle foreste in Italia. Forest@ 16: 3-9. – doi: 10.3832/efor3070-016 [online 2019-02-15]

CRA-MPF, several years. National Forestry Inventory (INFC2005, INFC2015).

CRPA, 1997. Piani Regionali di Risanamento e tutela della qualità dell’aria. Quadro delle azioni degli enti locali per il settore zootecnico delle aree padane. Relazione di dettaglio sulla metodologia adottata per la quantificazione delle emissioni di protossido di azoto. Settembre 1997.

CRPA, 2009. Progetto Salvaguardia e valorizzazione del prato stabile irriguo in area Parmigiano-Reggiano attraverso l'ottimizzazione della risorsa idrica e azotata, Personal communication.

Del Gardo I., Six J., Peressotti A., Cotrufo M.F., 2003. Assessing the impact of land-use change on soil C sequestration in agricultural soils by means of organic matter fractionation and stable C isotopes. Global Change Biology (2003) 9, 1204–1213.

Di Cosmo L., Gasparini P., Paletto A., Nocetti M., 2013. Deadwood basic density values for national-level carbon stock estimates in Italy. Forest Ecology and Management 295 (2013) 51–58.

EMEP/EEA, 2009. Air pollutant emission inventory guidebook 2009. EEA Technical report n. 9/2009.

ERSAF, 2008. Stock di carbonio nei suoli regionali. Progetto Kyoto-Ricerca sui cambiamenti climatici e il controllo dei gas serra in Lombardia - GS3.

FAO, 2016. FAOSTAT database. URL: http://faostat3.fao.org/home/E (last access 09/03/2016). Food and Agriculture Organization of the United Nations.

Federici S, Vitullo M, Tulipano S, De Lauretis R, Seufert G, 2008. An approach to estimate carbon stocks change in forest carbon pools under the UNFCCC: the Italian case. iForest 1: 86-95 URL: http://www.sisef.it/forest@/show.php?id=466.

Francaviglia R., Aromolo R., Benedetti A., Beni C., Biondi F.A., Dell'Abate M.T., Figliolia A., Mecella G., Pompili L., 2006. Qualità funzionali alla conservazione della fertilità integrale dei suoli. Rapporto del Progetto Conservazione e valorizzazione della risorsa suolo: definizione delle qualità del suolo ai fini della gestione agricola e forestale ecocompatibile – CRA- Istituto Sperimentale per la Nutrizione delle Piante.

Gardi C., Brenna S., Solaro S., Piazzi M., Petrella F., 2007. The carbon sequestration potential of soils: some data from northern italian regions" Italian Journal of Agronomy 2:163-170 http://www.agronomy.it/index.php/agro/article/view/ija.2007.143/140.

IPCC, 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. IPCC Technical Support Unit, Kanagawa, Japan.

IPCC, 2006. Guidelines for National Greenhouse Gas Inventories. IPCC Technical Support Unit, Kanagawa, Japan.

IPCC 2014, 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds) Published: IPCC, Switzerland.

IPCC 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html.

IPLA 2007, Realizzazione della parte piemontese della Carta dei Suoli nazionale a scala 1:250.000, Personal communication.

ISTAT, several years [a]. Statistiche forestali. Istituto Nazionale di statistica, Roma.

ISTAT, several years [b]. Statistiche dell'agricoltura. Istituto Nazionale di statistica, Roma.

ISTAT, several years [c]. Annuario Statistico Italiano. Istituto Nazionale di statistica, Roma.

La Mantia T, Oddo G, Rühl J, Furnari G, Scalenghe R, 2007. Variation of soil carbon stocks during the renaturation of old fields: the case study of the Pantelleria Island, Italy. Forest@ 4: 102-109. http://www.sisef.it/forest@/show.php?id=433.

Lagomarsino A., Moscatelli M.C., Di Tizio A., Mancinelli R., Grego S., Marinari S., 2009. Soil biochemical indicators as a tool to assess the short-term impact of agricultural management on changes in organic C in a Mediterranean environment. Ecological indicators 9 (2009) 518–527.

Lugato E., Berti A., 2008. Potential carbon sequestration in a cultivated soil under different climate change scenarios: A modelling approach for evaluating promising management practices in north-east Italy. Agriculture, Ecosystems and Environment 128 (2008) 97–103.

MAF/ISAFA, 1988. Inventario Forestale Nazionale. Sintesi metodologica e risultati. Ministero dell'Agricoltura e delle foreste. Istituto Sperimentale per l'assestamento forestale e per l'Alpicoltura, Trento.

MAMB, 1992. Inventario delle zone umide del territorio italiano (a cura di G. De Maria, Servizio Conservazione Natura, Ministero dell'ambiente e del territorio).

Martiniello P., 2007. Biochemical parameters in a Mediterranean soil as effected by wheat–forage rotation and irrigation. Europ. J. Agronomy 26 (2007) 198–208.

Masciandaro G., Ceccanti B., 1999. Assessing soil quality in different agro-ecosystems through biochemical and chemico-structural properties of humic substances. Soil & Tillage Research 51 (1999) 129-137.

Monaco Stefano, Hatch D. J., Sacco D., Bertora C., Grignania C., 2008. Changes in chemical and biochemical soil properties induced by 11-yr repeated additions of different organic materials in maize-based forage systems. Soil Biology & Biochemistry 40 (2008) 608–615.

Novara A., Gristina L., La Mantia T., Rühl J., 2013. Carbon dynamics of soil organic matter in bulk soil and aggregate fraction during secondary succession in a Mediterranean environment, Geoderma, Volumes 193–194, Pages 213-221, ISSN 0016-7061. https://doi.org/10.1016/j.geoderma.2012.08.036.

Pellis G., Chiti T., Rey A., Curiel Yuste J., Trotta C., Papale D., 2019. The ecosystem carbon sink implications of mountain forest expansion into abandoned grazing land: The role of subsoil and climatic factors, Science of The Total Environment, Volume 672, Pages 106-120, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2019.03.329.

Perucci P., Monaci E., Onofri A., Dischetti C., Casacci C., 2008. Changes in physico-chemical and biochemical parameters of soil following addition of wood ash: A field experiment. Europ. J. Agronomy 28 (2008) 155–161.

Puglisi E., Fragoulis G., Del Re A.A.M., Spaccini R., Piccolo A., Gigliotti G., Said-Pullicino D., Trevisan M., 2008. Carbon deposition in soil rhizosphere following amendments with compost and its soluble fractions, as evaluated by combined soil–plant rhizobox and reporter gene systems. Chemosphere 73 (2008) 1292–1299.

Rawls W.J., Brakensiek, D.L. 1985. Prediction of soil water properties for hydrologic modelling, in Proceedings of Symposium on Watershed Management, ASCE, pp. 293-299.

Scarascia Mugnozza G., Bauer G., Persson H., Matteucci G., Masci A., 2000. Tree biomass, growth and nutrient pools. In: Schulze E.-D. (edit.) Carbon and Nitrogen Cycling in European forest Ecosystems, Ecological Studies 142, Springer Verlag, Heidelberg. Pp. 49-62. ISBN 3-540-67239-7.

Somogyi Z., Teobaldelli M., Federici S., Matteucci G., Pagliari V., Grassi G., Seufert G., 2008. Allometric biomass and carbon factors database. iForest 1: 107-113. http://www.sisef.it/iforest/contents/?id=ifor0463-0010107.

Tabacchi G., De Natale F., Di Cosmo L., Floris A., Gagliano C., Gasparini P., Genchi L., Scrinzi G., Tosi V., 2007. Le stime di superficie 2005 – Parte 1. Inventario Nazionale delle Foreste e dei Serbatoi Forestali di Carbonio. MiPAF - Corpo Forestale dello Stato - Ispettorato Generale, CRA - ISAFA, TN.: 1-413, vers. 2.

Tabacchi G., De Natale F., Gasperini P., 2010. Coerenza ed entità delle statistiche forestali - Stime degli assorbimenti netti di carbonio nelle foreste italiane, Sherwood n.165/2010.

Tabacchi, G., Di Cosmo, L., Gasparini, P., 2011. Aboveground tree volume and phytomass prediction equations for forest species in Italy. Eur. J. Forest Res. 130 (6), 911–934.

Triberti L., Nastri A., Giordani G., Comellini F., Baldoni G, Toderi G., 2008. Can mineral and organic fertilization help sequestrate carbon dioxide in cropland? Europ. J. Agronomy 29 (2008) 13–20.

Viaroli P., Gardi C., 2004. Censimento e caratterizzazione pedologica e vegetazionale dei "Prati Stabili" presenti nel Parco Regionale Fluviale del Taro. Relazione tecnica - Università degli Studi di Parma - Dipartimento di Scienze Ambientali.

Xiloyannis C., 2007. La valutazione del contenuto e composizione del carbonio organico del suolo di sistemi agricoli. Relazione tecnica - Università degli Studi della Basilicata - Dipartimento di Scienze dei sistemi colturali, forestali e dell'ambiente.

9.6 WASTE

Acaia et al., 2004. Emissioni atmosferiche da discariche di rifiuti in Lombardia: stato attuale e scenari tecnologici di riduzione. RS – Rifiuti Solidi vol. XVIII n. 2, pp. 93-112.

AMA-Comune di Roma, 1996. Nuovo impianto per l'incenerimento dei rifiuti ospedalieri. Rapporto AMA.

Andreottola G., Cossu R., 1988. Modello matematico di produzione del biogas in uno scarico controllato. RS – Rifiuti Solidi vol. II n. 6, pp. 473-483.

ANPA, 1998. Il sistema ANPA di contabilità dei rifiuti, prime elaborazioni dei dati. Agenzia Nazionale per la Protezione dell'Ambiente.

ANPA-FLORYS, 2000. Industria conciaria, Studio di settore. Agenzia Nazionale per la Protezione dell'Ambiente.

ANPA-FLORYS, 2001. Industria della carta e cartone, Studio di settore. Agenzia Nazionale per la Protezione dell'Ambiente.

ANPA-ONR, 1999 [a]. Primo Rapporto sui rifiuti speciali. Agenzia Nazionale per la Protezione dell'Ambiente.

ANPA-ONR, 1999 [b]. Secondo Rapporto sui Rifiuti Urbani e sugli Imballaggi e rifiuti di imballaggio. Agenzia Nazionale per la Protezione dell'Ambiente.

ANPA-ONR, 2001. I rifiuti del comparto agro-alimentare, Studio di settore. Agenzia Nazionale per la Protezione dell'Ambiente. Rapporto n. 11/2001.

APAT, 2002. Annuario dei dati ambientali. Agenzia per la Protezione dell'Ambiente e per i servizi Tecnici. Rapporto n. 7/2002.

Asja, 2003. Dichiarazione Ambientale 2003. Asja Ambiente Italia S.p.A., 2003.

Assobirra, several years. Rapporti Annuali e Dati Statistici. Also available on the website http://www.assobirra.it.

Assocarta, several years. Rapporto Ambientale dell'industria cartaria italiana. Also available on the website http://www.assocarta.it.

AUSITRA-Assoambiente, 1995. Impianti di trattamento dei rifiuti solidi urbani e assimilabili. Indagine a cura di Merzagora W., Ferrari S.P.

BLUE BOOK, several years. I dati sul Servizio Idrico Integrato in Italia. Utilitatis, Anea.

Borgioli E., 1981. Nutrizione e alimentazione degli animali domestici. Ed Agricole, p. 464.

CESTAAT, 1988. Impieghi dei sottoprodotti agricoli ed agroindustriali, Vol. 1. Centro Studi sull'Agricoltura, l'Ambiente e il Territorio, edizione fuori commercio, p. 311.

CNR, 1980. Indagine sui Rifiuti Solidi Urbani in Italia. Consiglio Nazionale delle Ricerche, Progetto Finalizzato Energetica.

Colombari et al., 1998. Le emissioni di metano dalle discariche di rifiuti in Italia: stima e scenari futuri. ENEA RT/AMB/98/30.

Colombo, 2001. Nuovo Colombo, Manuale dell'Ingegnere, Vol. 3, 83ma edizione. Hoepli editore.

COOU, several years. Consorzio Olii Usati, also available on the web-site http://www.coou.it .

COVIRI, several years. Relazione annuale al parlamento sullo stato dei servizi idrici. Autorità di vigilanza sulle risorse idriche e sui rifuti.

CREA, 2017. Fornitura dati meteo-climatici georeferenziati nell'ambito della collaborazione CREA-AA/ISPRA. CREA - Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria Centro di ricerca Agricoltura e Ambiente (CREA-AA), delivery data mail 19/10/2017.

De Poli F., Pasqualini S., 1991. Landfill gas: the Italian situation. ENEA, atti del convegno Sardinia 91, Third International Landfill Symposium.

De Stefanis P. et al., 1998. Gestione dei rifiuti ad effetto serra. ENEA-CNR, atti della Conferenza Nazionale Energia e Ambiente, Rome 25-18 November 1998.

De Stefanis P., 1999. Personal communication.

De Stefanis P., 2002.Metodologia di stima delle emissioni di gas serra dalla combustione di rifiuti. RS Rifiuti Solidi vol.XVI n. 3 maggio - giugno 2002.

De Stefanis P., 2012. Personal communication (mail 16 November 2012).

Decree of President of the Republic 10 September 1982, n.915. Attuazione delle direttive 75/442/CEE relativa ai rifiuti e 76/403/CEE relativa ai rifiuti tossici e nocivi. G.U. 15 dicembre 1982, n. 343, S.O.

EC, 1975. Council Directive 1975/442/EC. Council Directive 75/442/EC of 15 July 1975 on waste framework. Official Journal of the European Communities 25 July 1975.

EC, 1976. Council Directive 1976/403/EC. Council Directive 76/403/EC of 6 April 1976 on treatment and disposal of PCBs and PCTs. Official Journal of the European Communities 26 April 1976.

EC, 1978. Council Directive 1978/319/EC. Council Directive 78/319/EC of 20 March 1978 on toxic and dangerous waste. Official Journal of the European Communities 31 March 1978.

EC, 1986. Council Directive 86/278/EC. Council Directive 86/278/EC of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture. Official Journal of the European Communities 4 July 1986.

EC, 1999. Council Directive 1999/31/EC. Council Directive 99/31/EC of 26 April 1999 on the landfill of waste. Official Journal of the European Communities 16 July 1999.

EMEP/CORINAIR, 2007. Atmospheric Emission Inventory Guidebook. Technical report No 16/2007.

EMEP/EEA, 2009. Air Pollutant Emission Inventory Guidebook. Technical report No 9/2009.

EMEP/EEA, 2016. Air Pollutant Emission Inventory Guidebook. Technical report No 21/2016.

EMEP/EEA, 2023. Air Pollutant Emission Inventory Guidebook. Technical report No 6/2023.

ENEA-federAmbiente, 2012. Rapporto sul recupero energetico da rifiuti urbani in Italia. 3° ed.

ENI S.p.A. 2001. Rapporto Salute Sicurezza Ambiente.

EU, 2016. 2016 comprehensive review of national greenhouse gas inventory data pursuant to Article 19(1) of Regulation (EU) No 525/2013. Final review report. Italy. 28 August 2016.

FAO, several years. Food balance, available on the website http://faostat.fao.org (last access 26/11/2015).

Favoino E., Cortellini L., 2001. Composting and biological treatment in southern European countries: an overview. Conference Proceedings Soil and Biowaste in Southern Europe. Rome 18-19 January, 2001.

Favoino E., Girò F., 2001. An assessment of effective, optimised schemes for source separation of organic waste in Mediterranean districts. Conference Proceedings Soil and Biowaste in Southern Europe. Rome 18-19 January, 2001.

FEDERAMBIENTE, 1992. Analisi dei principali sistemi di smaltimento dei rifiuti solidi urbani.

FEDERAMBIENTE, 1998. Impianti di smaltimento: analisi sui termocombustori RSU – prima edizione. Indagine a cura di Motawi A..

FEDERAMBIENTE, 2001. Impianti di smaltimento: analisi sui termoutilizzatori RU. Indagine a cura di Morabito L., GEA n. 5/2001.

FEDERCHIMICA, several years. Rapporto Responsible Care. Federazione Nazionale dell'Industria Chimica.

Ferrari G., 1996. I rifiuti città per città. GEA, July 1996.

Finn L., Spencer R., 1997. Managing biofilters for consistent odor and VOC treatment. Biocycle, January 1997 Vol. 38 Iss.1.

Fondazione per lo sviluppo sostenibile e FISE UNIRE, 2016. L'Italia del riciclo, 2016. http://www.fondazionesviluppsostenibile.org/wp-content/uploads/dlm_uploads/2016/12/rapporto_Italia_del_Riciclo_2016.pdf.

Gaudioso et al., 1993. Emissioni in atmosfera dalle discariche di rifiuti in Italia. RS, Rifiuti Solidi vol. VII n. 5, Sept.-Oct. 1993.

Hogg D., 2001. Biological treatment of waste: a solution for tomorrow. ISWA Beacon Conference.

IPCC, 1995. IPCC Guidelines for National Greenhouse Gas Emission Inventories. Three volumes: Reference Manual, Reporting Manual, Reporting Workbook. IPCC/OECD/IEA. IPCC WG1 Technical Support Unit, Hadley Centre, Meteorological Centre, Meteorological Office, Bracknell, UK.

IPCC, 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. IPCC National Greenhouse Gas Inventories Programme, Technical Support Unit, Hayama, Kanagawa, Japan.

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

IRSA-CNR, 1998. Personal Communication.

ISPRA, several years. Rapporto Rifiuti. Istituto Superiore per la Protezione e la Ricerca Ambientale.

ISPRA, 2010. Personal Communication. Waste Cadastre database, year 2007.

ISPRA, 2017. Update of CH_4 emission factor from composting. Technical note n.1/2017.

ISPRA, 2018. Update of CH_4 emission from landfills. Technical note n.1/2018.

ISTAT, 1984. Statistiche ambientali 1984. Istituto nazionale di statistica.

ISTAT, 1987. Approvvigionamento idrico, fognature e impianti di depurazione in Italia – anno 1987. Collana d'informazione n. 20, ed. 1991.

ISTAT, 1991. Statistiche ambientali 1991. Istituto nazionale di statistica.

ISTAT, 1993. Statistiche ambientali 1993. Istituto nazionale di statistica.

ISTAT, 1998 [a]. Il processo di depurazione e la qualità delle acque reflue urbane. Indagine sugli impianti di depurazione delle acque reflue urbane, anno 1993. Istituto nazionale di statistica.

ISTAT, 1998 [b]. Caratteristiche strutturali degli impianti di depurazione delle acque reflue urbane. Indagine sugli impianti di depurazione delle acque reflue urbane, anno 1993. Istituto nazionale di statistica.

ISTAT, 2017. Forme, livelli e dinamiche dell'urbanizzazione in Italia.

ISTAT, several years [a]. Annuario Statistico. Istituto Nazionale di Statistica.

ISTAT, several years [b]. Bollettino mensile di statistica. Istituto Nazionale di Statistica.

ISTAT, several years [c]. Banche dati ISTAT, http://www.istat.it/it/prodotti/banche-dati.

ISTAT, several years [d]. Sistema di Indagini sulle Acque, SIA.Istituto nazionale di statistica, also available at website http://www.istat.it.

ISTAT, several years [e]. Censimento delle acque per uso civile. Istituto nazionale di statistica, also available at website http://www.istat.it.

Law 22 maggio 2015, n. 68 Disposizioni in materia di delitti contro l'ambiente. (G.U. 28 maggio 2015, n. 122)

Law Decree 30 December 2008, n.208. Misure straordinarie in materia di risporse idriche e protezione dell'ambiente. G.U. 31 dicembre 2008, n. 304, S.O.

Legislative Decree 27 January 1992 n. 99 Attuazione della direttiva 86/278/CEE concernente la protezione dell'ambiente, in particolare del suolo, nell'utilizzazione dei fanghi di depurazione in agricoltura. G.U.15 febbraio 1992 n. 38, S.O.

Legislative Decree 11 May 1999, n. 152. Disposizioni sulla tutela delle acque dall'inquinamento e recepimento della direttiva 91/271/CEE concernente il trattamento delle acque reflue urbane e della direttiva 91/676/CEE relativa alla protezione delle acque dall'inquinamento provocato dai nitrati provenienti da fonti agricole. G.U. 29 maggio 1999, n. 124, S.O.

Legislative Decree 13 January 2003 n. 36. Attuazione della direttiva 1999/31/EC relativa alle discariche di rifiuti. G.U. 12 marzo 2003, n. 59 – S.O. 40/L.

Legislative Decree 5 February 1997, n. 22. Attuazione delle direttive 91/156/CEE sui rifiuti 91/698/CEE sui rifiuti pericolosi e 94/62/CEE sugli imballaggi e sui rifiuti di imballaggio. G.U. 15 febbraio 1997, n. 38, S.O.

Masotti L., 1996. Depurazione delle acque. Edizioni Calderoni.

MASE, several years [a]. RSA - Rapporto sullo stato dell'ambiente 1989, 1992, 1997, 2001. Ministero dell'Ambiente e della Tutela del Territorio e del Mare.

MASE, several years [b]. Personal communication with Marco Porrega: E-mail request for sewage sludge applied to agricultural soils in Italy. *Ministero dell'Ambiente e della Tutela del Territorio e del Mare*, Roma –Italia.

Metcalf and Eddy, 1991. Wastewater engineering: treatment, disposal and reuse. Mc Graw Hill, third edition.

Ministerial Decree 12 July 1990. Linee Guida per il contenimento delle emissioni inquinanti degli impianti industriali e la fissazione dei valori minimi di emissione. G.U. 30 luglio 1990, n. 176.

Ministerial Decree 19 November 1997, n. 503. Regolamento recante norme per l'attuazione delle Direttive 89/369/CEE e 89/429/CEE concernenti la prevenzione dell'inquinamento atmosferico provocato dagli impianti di incenerimento dei rifiuti urbani e la disciplina delle emissioni e delle condizioni di combustione degli impianti di incenerimento di rifiuti urbani, di rifiuti speciali non pericolosi, nonché di taluni rifiuti sanitari. G.U. 29 gennaio 1998, n. 23.

Morselli L., 1998. L'incenerimento dei rifiuti, ricognizione sulla realtà regionale. Università degli Studi di Bologna, Dipartimento di chimica industriale e dei materiali e Regione Emilia Romagna, Assessorato Territorio, Programmazione e Ambiente.

Muntoni A., Polettini A., 2002. Modelli di produzione del biogas - limiti di applicazione e sensitività. Conference proceedings, Università degli Studi di Roma La Sapienza "Gestione del biogas da discarica: controllo, recupero e monitoraggio. Rome, December 2002.

Provincia di Roma, 2008. Documento di indirizzo per la riduzione della produzione di rifiuti urbani e l'implementazione delle raccolte differenziate nel territorio della provincia di Roma. Dipartimento Ambiente della Provincia di Roma, 12 febbraio 2008.

Regione Calabria, 2002. Piano regionale di gestione rifiuti. Supplemento straordinario al Bollettino Ufficiale Regione Calabria 30 novembre 2002, n. 22.

Regione Calabria, 2016. Piano Regionale Gestione Rifiuti. Parte 1 – Quadro conoscitivo.

Regione Campania, 2016. Aggiornamento del Piano Regionale per la Gestione dei Rifiuti Urbani della Regione Campania. Dicembre 2016.

Regione Emilia Romagna, 2009. La gestione dei rifiuti in Emilia Romagna. Regione Emilia Romagna – ARPA Emilia Romagna, Report 2009.

Regione Emilia Romagna, 2016. Piano Regionale di Gestione dei Rifiuti. Quadro conoscitivo. Aggiornamento dei dati.

Regione Lazio, 2020. Deliberazione del Consiglio Regionale 5 agosto 2020, n. 4. Piano regionale di gestione dei rifiuti della regione Lazio.

Regione Piemonte, 2007. L'evoluzione merceologica dei Rifiuti Urbani: la storia e le prospettive. Recycling Prix proceedings. Turin, October 2007.

Regione Piemonte, 2016. Deliberazione del Consiglio regionale 19 aprile 2016, n. 140 – 14161. Piano regionale di gestione dei rifiuti urbani e dei fanghi di depurazione.

Regione Sardegna, 2016. Piano regionale di gestione dei rifiuti sezione rifiuti urbani – aggiornamento.

Regione Sicilia, 2004. Programma regionale per la riduzione dei rifiuti biodegradabili da avviare in discarica. Ordinanza 25 marzo 2004, n. 323 del Commissario delegato per l'emergenza rifiuti e la tutela delle acque in Sicilia.

Regione Toscana, 2014. PRB - Parte Prima – Sezione Conoscitivo-Programmatica - Allegato di Piano 1.

Regione Umbria, 2007. Programma regionale per la riduzione dei rifiuti biodegradabili da avviare in discarica. Bollettino Ufficiale Regione Umbria 31 gennaio 2007, n. 5.

Regione Veneto, 2006. Programma regionale per la riduzione dei rifiuti biodegradabili da avviare in discarica. Bollettino Ufficiale Regione Veneto 21 luglio 2006, n. 65.

SEFIT, 2015. Emissioni inquinanti in atmosfera per i crematori italiani. Indagine conoscitiva ed elaborazione dati. Novembre 2015.

SEFIT, 2019. Emissioni inquinanti in atmosfera per i crematori italiani. Indagine conoscitiva ed elaborazione dati.

SEFIT, several years. Personal Communication with Daniele Fogli: E-mail request for activity data regarding cremation of corpses in Italy.

Solini, 2010. Emissioni di gas serra dallo scarico e trattamento di acque reflue. PhD thesis.

Tecneco, 1972. Indagine Nazionale sullo smaltimento dei Rifiuti Solidi Urbani. Dispense 1995 Prof. Liuzzo, Università degli Studi di Roma "La Sapienza".

TERNA, several years. Dati statistici sull'energia elettrica in Italia. Rete Elettrica Nazionale.

UNIC, several years. Rapporto Ambientale. Unione Nazionale Industria Conciaria.

UNEM, several years. Statistiche economiche, energetiche e petrolifere. Unione Energia per la Mobilità.

US EPA, 1990. Air emissions Species Manual, vol. I: Volatile Organic Compound Species Profiles, Second Edition. EPA-450/2-90-001a (United States Environmental Protection Agency – Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711), January 1990.

9.7 ANNEX 1

IPCC, 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. IPCC National Greenhouse Gas Inventories Programme, Technical Support Unit, Hayama, Kanagawa, Japan.

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

9.8 ANNEX 2

ENI, several years. La congiuntura economica ed energetica. ENI.

TERNA, several years. Dati statistici sull'energia elettrica in Italia. Rete Elettrica Nazionale.

UNAPACE, several years. Data from the association of industrial electricity producers. http://www.assoelettrica.it/.

9.9 ANNEX 3

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

9.10 ANNEX 4

ENEA/MAP/APAT, 2004. Energy data harmonization for CO_2 emission calculations: the Italian case. Rome 23/02/04. EUROSTAT file n. 200245501004.

MASE, several years. Bilancio Energetico Nazionale (BEN). Ministero dell'Ambiente e della Sicurezza Energetica, https://sisen.mase.gov.it/dgsaie/bilancio-energetico-nazionale.

9.11 ANNEX 5

MASE, several years. Bilancio Energetico Nazionale (BEN). Ministero dell'Ambiente e della Sicurezza Energetica. https://sisen.mase.gov.it/dgsaie/bilancio-energetico-nazionale.

EUROSTAT, 2022. https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_bal_c&lang=en.

9.12 ANNEX 6

APAT, 2003. Analisi dei fattori di emissione di CO_2 dal settore dei trasporti. Ilacqua M., Contaldi M., Rapporti n° 28/2003.

EMISIA SA, 2012. COPERT 4 v 10.0, Computer programme to calculate emissions from road transport, November 2012. http://www.emisia.com/copert/.

EMEP/CORINAIR, 2007. Atmospheric Emission Inventory Guidebook. Technical report No 16/2007.

Innovhub, several years. Report on the physico-chemical characterization of fossil fuels used in Italy. Fuel Experimental Station.

IPCC, 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Emission Inventories. Three volumes: Reference Manual, Reporting Manual, Reporting Guidelines and Workbook. IPCC/OECD/IEA. IPCC WG1 Technical Support Unit, Hadley Centre, Meteorological Centre, Meteorological Office, Bracknell, UK.

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

MASE, several years [a]. Bilancio Energetico Nazionale (BEN). Ministero dell'Ambiente e della Sicurezza Energetica https://sisen.mase.gov.it/dgsaie/bilancio-energetico-nazionale.

MASE, several years [b]. Bollettino Petrolifero Trimestrale (BPT). Ministero dell'Ambiente e della Sicurezza Energetica. https://sisen.mase.gov.it/dgsaie/bollettino-petrolifero.

Snam Rete Gas, several years. Bilancio di sostenibilità.

TERNA, several years. Dati statistici sull'energia elettrica in Italia. Rete Elettrica Nazionale.

9.13 ANNEX 7

ANABORAPI, 2022. Associazione degli Allevatori della Razza Bovina Piemontese. Provincia di Torino e APA Torino. https://anaborapi.it/.

Bittante G., Gallo L., Schiavon S., Contiero B., Fracasso A., 2004. Bilancio dell'azoto negli allevamenti di vacche da latte e vitelloni. In (Xiccato et al., 2004) Bilancio dell'azoto in allevamenti di bovini, suini e conigli – Progetto interregionale - Legge 23/12/1999 n. 499, art. 2 - report finale, Regione Veneto.

Borgioli E., 1981. Nutrizione e alimentazione degli animali domestici. Edagricole, p. 464.

CESTAAT, 1988. Impieghi dei sottoprodotti agricoli ed agroindustriali, Vol. 1. Centro Studi sull'Agricoltura, l'Ambiente e il Territorio, p. 311.

Cevolani D. et al, 2021. "Alimenti per la vacca da latte e il bovino da carne", pp 461-472. Edagricole, Milano, 2021.

Cevolani D. et al, 2022. "Alimenti per la vacca da latte e il bovino da carne", pp 453-466. Edagricole, Milano, 2022.

Cozzi G., 2007. Present situation and future challenges of beef cattle production in Italy and the role of research. Italian Journal of Animal Science, 6, (suppl 1), 389-396.

CRPA, 1997[a]. Piani Regionali di Risanamento e tutela della qualità dell'aria. Quadro delle azioni degli enti locali per il settore zootecnico delle aree padane. Allegato 2. Relazione di dettaglio sulla metodologia adottata per la quantificazione delle emissioni di metano. Febbraio 1997.

CRPA, 1997[b]. Piani Regionali di Risanamento e tutela della qualità dell'aria. Quadro delle azioni degli enti locali per il settore zootecnico delle aree padane. Relazione di dettaglio sulla metodologia adottata per la quantificazione delle emissioni di protossido di azoto. Settembre 1997.

CRPA, 2006[a]. Progetto MeditAIRaneo: settore Agricoltura. Relazione finale. Technical report on the framework of the MeditAIRaneo project for the Agriculture sector, Reggio Emilia – Italia.

CRPA, 2008[a]. Le scelte politiche energetico-ambientali lanciano il biogas. L'Informatore Agrario 3/2008, p.28-32.

CRPA, 2008[b]. "Biogas: l'analisi di fattibilità tecnico-economica". Opuscolo CRPA n. 4/2008.

CRPA, 2011[a]. "Il biogas accelera la corsa verso gli obiettivi 2020". Supplemento a L'Informatore Agrario n. 26/2011.

CRPA, 2011[b]. "Carne bovina: l'impatto della Pac dopo il 2013", analisi del CRPA realizzata su incarico di INTERCARNEPRO, 2011 - https://agriregionieuropa.univpm.it/it/content/article/31/27/effetti-della-riforma-pac-sugli-allevamenti-di-carne-bovina-italia.

CRPA, 2012. "Bovini da latte e biogas – Linee guida per la costruzione e la gestione degli impianti".

CRPA, 2013. "Biogas, il settore è strutturato e continua a crescere". Supplemento a L'Informatore Agrario n. 11/2013.

CRPA, 2016. Personal communication - experts Nicola Labartino and Laura Valli from the Research Centre on Animal Production (expert consultation on N excretion and national production systems). Reggio Emilia, Italy.

CRPA, 2018. Studio per la valutazione degli effetti sulle emissioni delle trasformazioni in corso nel settore degli allevamenti. Report. Reggio Emilia – Italy.

CRPA/AIEL, 2008. Energia dal biogas prodotto da effluenti zootecnici, biomasse dedicate e di scarto. Ed. Associazione Italiana Energie Ambientali (AIEL).

CRPA/CNR, 1992. Indagine sugli scarti organici in Emilia-Romagna.

Ellis J. L., Kebreab E., Odongo N. E., McBride B. W., Okine E. K., France J., 2007. Prediction of Methane Production from Dairy and Beef Cattle. Article in Journal of Dairy Science - August 2007.

EMEP/EEA, 2023. Air Pollutant Emission Inventory Guidebook 2023. Technical guidance to prepare national emission inventories. EEA report 06/2023.

ENAMA, 2011. "Biomasse ed Energia - Censimento impianti, biocarburanti di seconda generazione e casi studio".

ENEA, 1994. Personal communication, expert in agriculture sector. Ente nazionale per l'energia, l'ambiente e le nuove tecnologie (ENEA), Andrea Sonnino.

Fabbri C., Shams-Eddin S., Bondi F., Piccinini S., 2011. "Efficienza e problematiche di un impianto a digestione anaerobica a colture dedicate". IA – Ingegneria Ambientale, Vol. XL n.1 Gennaio-Febbraio 2011.

Grossi S., Massa V., Giorgino A., Rossi L., Dell'Anno M., Pinotti L., Avidano F., Compiani R., Sgoifo Rossi C. A., 2022. "Feeding Bakery Former Foodstuffs and Wheat Distiller's as Partial Replacement for Corn and Soybean Enhances the Environmental Sustainability and Circularity of Beef Cattle Farming." Sustainability.

IPCC, 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Emission Inventories. Three volumes: Reference Manual, Reporting Manual, Reporting Guidelines and Workbook. IPCC/OECD/IEA. IPCC WG1 Technical Support Unit, Hadley Centre, Meteorological Centre, Meteorological Office, Bracknell, UK.

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

ISMEA, 2022. Bovino da carne. ISMEA, Febbraio 2022.

MASE, several years. Personal communication with Marco Porrega: e-mails request for sewage sludge applied to agricultural soils in Italy. Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Roma –Italia.

Mazzenga A., Brscic M., Cozzi G., 2007. The use of corn silage in diets for beef cattle of different genotype. Italian Journal of Animal Science, 6 (suppl. 1), 321-323.

Pacchioli M.T., Bortolazzo E., Franzoni A., Carteri F., Balestra R., Di Pasquale F., 2023. Alimentare "precisamente" il bovino da carne. Tecnica bovini. Allevatori Top, n° 03 | marzo 2023.

Regione Veneto, 2008. Allegato A del Decreto della Direzione Agroambiente e Servizi per l'Agricoltura n. 308 del 7.8.2008. Dipartimento di Scienze Animali, Università degli Studi di Padova - Relazione sui modelli di bilancio dell'azoto e del fosforo proposti nell'allegato D del DGR del Veneto n. 2439 del 7 Agosto 2007.

UBA, 2014. National Inventory Report for the German Greenhouse Gas Inventory 1990 – 2012.

Xiccato G., Bailoni L., Bittante G., Gallo L., Gottardo F. Mantovani R., Schiavon S., 2004. "Bilancio dell'azoto in allevamenti di bovini, suini e conigli" Progetto interregionale - Legge 23/12/1999 n. 499, art. 2 - report finale, Regione Veneto, Italia.

Xiccato G., Schiavon S., Gallo L., Bailoni L., Bittante G., 2005. Nitrogen excretion in dairy cow, beef and veal cattle, pig, and rabbit farms in Northern Italy. Italian Journal of Animal Science. vol. 4n (suppl. 3), 103-111.

9.14 ANNEX 12

APAT - ARPA Lombardia, 2007. Stima dei consumi di legna da ardere per riscaldamento ed uso domestico in Italia, Rapporto Finale.

Corona P, Giuliarelli D, Lamonaca A, Mattioli W, Tonti D, Chirici G, Marchetti M, 2007. Confronto sperimentale tra superfici a ceduo tagliate a raso osservate mediante immagini satellitari ad alta risoluzione e tagliate riscontrate amministrativamente. Forest@ 4 (3): 324-332. URL: http://www.sisef.it/forest@/show.php?id=468.

Di Cosmo L., Gasparini P., Paletto A., Nocetti M., 2013. Deadwood basic density values for national-level carbon stock estimates in Italy. Forest Ecology and Management 295 (2013) 51–58.

Federici S, Vitullo M, Tulipano S, De Lauretis R, Seufert G, 2008. An approach to estimate carbon stocks change in forest carbon pools under the UNFCCC: the Italian case. iForest 1: 86-95 URL: http://www.sisef.it/forest@/show.php?id=466.

Giordano G., 1980. Tecnologia del legno. Hoepli. Milano.

ISAFA, 2004. RiselvItalia Project, Personal communication.

MAF/ISAFA, 1988. Inventario Forestale Nazionale. Sintesi metodologica e risultati. Ministero dell'Agricoltura e delle foreste. Istituto Sperimentale per l'assestamento forestale e per l'Alpicoltura, Trento.

Tabacchi G., De Natale F., Gasperini P., 2010. Coerenza ed entità delle statistiche forestali - Stime degli assorbimenti netti di carbonio nelle foreste italiane, Sherwood n.165/2010.

UNECE – FAO, Timber Committee, 2008 - Italian statement on potential wood supply, communication by national correspondent, March 2008.

9.15 ANNEX 13

Bovio G., 2007. Method for forest fire damage level assessment based on detectable effects. In 'Evaluation of Forest Fire Damages in Italy'. Eds Ciancio O., Corona P., Marinelli M., Pettenella D., Accademia Italiana di Scienze Forestali: Florence, Italy, pp. 55–60.

EMEP/EEA, 2023. Air Pollutant Emission Inventory Guidebook. Technical guidance to prepare nationa emission inventories. EEA Report 06/2023. ISBN: 978-92-9480-598.

IPCC, 2006. Guidelines for National Greenhouse Gas Inventories. IPCC Technical Support Unit, Kanagawa, Japan.

ISTAT, several years [a]. Statistiche forestali. Istituto Nazionale di statistica, Roma.

ANNEX 1: KEY CATEGORIES AND UNCERTAINTY

A1.1 Introduction

The 2006 IPCC Guidelines (IPCC, 2006) recommend as good practice the identification of *key categories* in national GHG inventories. A *key category* is defined as an emission source that has a significant influence on a country's GHG inventory in terms either of the absolute/relative level of emissions or the trend in emissions, or both. Two different approaches are reported in the guidelines according to whether or not a country has performed an uncertainty analysis of the inventory: Approach 1 and Approach 2.

When using Approach 1, key categories are identified by means of a pre-determined cumulative emissions threshold, usually fixed at 95% of the total. If an uncertainty analysis is carried out at category level for the inventory, Approach 2 can be used to identify key categories. Approach 2 is a more detailed analysis that builds on Approach 1; in fact, the results of Approach 1 are multiplied by the relative uncertainty of each source/sink category. Key categories are those that represent 90% of the uncertainty contribution. So the factors which make a source or a sink a key category have a high contribution to the total, a high contribution to the trend and a high uncertainty. If both the approaches are applied, it is good practice to use the results of the Approach 2 analysis.

For the Italian inventory, a key category analysis has been carried out according to both the methods, excluding and including the LULUCF sector. National emissions have been disaggregated, as far as possible, into the categories proposed in the IPCC guidelines; other categories have been added to reflect specific national circumstances. Both level and trend analysis have been applied. For the base year, the level assessment has been carried out.

Summary of the results of the key category analysis, for the base year and 2022, is reported in Tables 1.3–1.6 of chapter 1. The tables indicate whether a key category derives from the level assessment or the trend assessment, according to Approach 1, Approach 2 or both.

For the base year, 27 categories were individuated according to Approach 1, whereas 30 categories were carried out by Approach 2. Including the LULUCF sector in the analysis, 35 categories were selected according to Approach 1 and 38 with Approach 2.

For the year 2022, 25 categories were individuated by the Approach 1 accounting for 95% of the total emissions, without LULUCF; for the trend 28 key categories were selected. Repeating the key category analysis for the full inventory, including the LULUCF sector, 33 categories were individuated accounting for 95% of the total emissions and removals in 2022, and 37 key categories in trend assessment.

The application of the Approach 2 to the 2022 emission levels gives as a result 27 key categories accounting for the 90% of the total levels with uncertainty, when applying the trend analysis the number of the key categories is equal to 35. The application of the Approach 2 including the LULUCF categories results in 34 key categories, for the year 2022, accounting for the 90% of the total levels with uncertainty; for the trend analysis including LULUCF categories, the results were 43 key categories.

A1.2 Approach 1 key category assessment

As described in the 2006 IPCC Guidelines (IPCC, 2006), the Approach 1 for identifying key categories assesses the impact of various categories on the level and on the trend of the national emission inventory. Both level and trend assessments should be applied to an emission GHG inventory.

As regards the level assessment, the contribution of each source or sink category to the total national inventory level is calculated as follows:

$$\text{Category Level Assessment} = \frac{|\text{Source or Sink Category Estimate}|}{\text{Total Contribution}}$$

$$L_{x,t} = \frac{|E_{x,t}|}{\sum_y |E_{y,t}|}$$

where

$L_{x,t}$ = level assessment for source or sink *x* in year *t*;

$|E_{x,t}|$ = absolute value of emission and removal estimate of source or sink category *x* in year *t*;

$\sum_y |E_{y,t}|$ = total contribution, which is the sum of the absolute values of emissions and removals in year *t*.

The contribution of all categories (including the LULUCF sector) is entered as absolute values.

Therefore, key categories are those which, when summed in descending order of magnitude, add up to over 95% of the total emissions.

As far as the trend assessment is concerned, the contribution of each source and sink category's trend can be assessed by the following equation:

Category Trend Assessment = Category Level Assessment * | Category Trend - Total Trend |

$$T_{x,t} = |E_{x,0}| \Big/ \sum_y |E_{y,0}| \cdot \left| \left[(E_{x,t} - E_{x,0}) \Big/ |E_{x,0}| \right] - \left[(E_t - E_0) \Big/ \sum_y |E_{y,0}| \right] \right|$$

where

$T_{x,t}$ = trend assessment, contribution of the category trend to the overall inventory trend;

$|E_{x,0}|$ = absolute value of emissions and removals of category *x* in the base year (year *0*);

$\sum_y |E_{y,0}|$ = total contribution, sum of the absolute values of emissions and removals in year 0;

$E_{x,t}$ *and* $E_{x,0}$ = real values of estimates of category x in years t and 0, respectively;

E_t *and* $E_0 = \sum_y E_{y,t}$ *and* $\sum_y E_{y,0}$ = total inventory estimates in years t and 0, respectively.

The source or sink category trend is the change in the category emissions over time, computed by subtracting the base year estimate for a generic category from the latest inventory year estimate and dividing by the absolute value of the latest inventory year estimate; the total trend is the change in the total inventory emissions over time, computed by subtracting the base year estimate for the total inventory from the current year estimate and dividing by the current year estimate.

In circumstances where the base year emissions for a given category are zero, the expression is reformulated to avoid zero in the denominator:

$$T_{x,t} = \left| E_{x,t} \Big/ |E_{x,0}| \right|$$

As differences in trend are more significant to the overall inventory level for larger categories, the results of the trend difference is multiplied by the results of the level assessment to provide appropriate weighting.

Thus, key categories are those for which the category trend diverges significantly from the total trend, weighted by the emission level of the category.

Both level and trend assessments have been carried out for the Italian GHG inventory. For the base year, a level assessment is computed.

The results of Approach 1 are shown in Table A1.1 and Table A1.2, level and trend assessments without LULUCF categories. Results of the key category analysis with the LULUCF are reported in Table A1.3 and Table A1.4.

Table A1.1 Results of the key category analysis without LULUCF. Approach 1 Level assessment, year 2022

CATEGORIES	2022 *kt CO_2 eq*	Level assessment	Cumulative Percentage
Transport - CO2 Road transportation	99,435	0.241	0.24
Energy industries - CO2 gaseous fuels	52,566	0.127	0.37
Other sectors - CO2 commercial, residential, agriculture gaseous fuels	50,221	0.122	0.49
Manufacturing industries and construction - CO2 gaseous fuels	31,746	0.077	0.57
Energy industries - CO2 solid fuels	23,427	0.057	0.62
Energy industries - CO2 liquid fuels	18,299	0.044	0.67
Solid waste disposal - CH4	15,565	0.038	0.71
Manufacturing industries and construction - CO2 liquid fuels	15,518	0.038	0.74
Enteric Fermentation- CH4	14,487	0.035	0.78
Other sectors - CO2 commercial, residential, agriculture liquid fuels	12,592	0.030	0.81
Mineral industry- CO2 Cement production	7,093	0.017	0.83
Product uses as substitutes for ozone depleting substances - HFCs Refrigeration and Air conditioning	6,868	0.017	0.84
Direct N2O Emissions from Managed soils	6,150	0.015	0.86
Manufacturing industries and construction - CO2 solid fuels	6,034	0.015	0.87
Transport - CO2 Waterborne navigation	5,718	0.014	0.89
Other sectors - CO2 commercial, residential, agriculture other fossil fuels	5,523	0.013	0.90
Manure Management - CH4	4,791	0.012	0.91
Wastewater treatment and discharge - CH4	2,668	0.006	0.92
Fugitive - CH4 Oil and natural gas - Natural gas	2,596	0.006	0.92
Transport - CO2 Civil Aviation	2,485	0.006	0.93
Other sectors - CH4 commercial, residential, agriculture biomass	2,465	0.006	0.94
Indirect N2O Emissions from Managed soils	1,822	0.004	0.94
Mineral industry- CO2 Lime production	1,815	0.004	0.94
Manure Management - N2O	1,722	0.004	0.948
Product uses as substitutes for ozone depleting substances - HFCs Fire protection	1,641	0.004	0.952
Rice cultivations - CH4	1,547	0.004	0.956
Metal industry- CO2 Iron and steel production	1,392	0.003	0.96

Table A1.2 Results of the key category analysis without LULUCF. Approach 1 Trend assessment base year-2022

CATEGORIES	Contribution to trend (%)	Cumulative Percentage
Energy industries - CO2 liquid fuels	0.186	0.19
Energy industries - CO2 gaseous fuels	0.159	0.35
Transport - CO2 Road transportation	0.107	0.45
Other sectors - CO2 commercial, residential, agriculture gaseous fuels	0.087	0.54
Other sectors - CO2 commercial, residential, agriculture liquid fuels	0.072	0.61
Manufacturing industries and construction - CO2 solid fuels	0.058	0.67
Manufacturing industries and construction - CO2 liquid fuels	0.042	0.71
Energy industries - CO2 solid fuels	0.029	0.74
Product uses as substitutes for ozone depleting substances - HFCs Refrigeration and Air conditioning	0.028	0.77
Manufacturing industries and construction - CO2 gaseous fuels	0.025	0.79
Mineral industry- CO2 Cement production	0.022	0.82
Other sectors - CO2 commercial, residential, agriculture other fossil fuels	0.021	0.84
Solid waste disposal - CH4	0.019	0.86
Fugitive - CH4 Oil and natural gas - Natural gas	0.019	0.88
Chemical industry- N2O Adipic acid production	0.013	0.89
Product uses as substitutes for ozone depleting substances - HFCs Fire protection	0.007	0.89
Other sectors - CH4 commercial, residential, agriculture biomass	0.006	0.90
Metal industry- PFCs Aluminium production	0.006	0.91
Transport - CO2 Waterborne navigation	0.006	0.91
Chemical industry- N2O Nitric acid production	0.006	0.92
Mineral industry- CO2 Other processes uses of carbonates	0.006	0.92
Transport - CO2 Civil Aviation	0.005	0.93
Chemical industry- CO2 Ammonia production	0.005	0.93
Metal industry- CO2 Iron and steel production	0.004	0.94
Enteric Fermentation- CH4	0.004	0.94
Other sectors - CO2 commercial, residential, agriculture solid fuels	0.003	0.945
Other sectors - N2O commercial, residential, agriculture biomass	0.003	0.948
Transport - CO2 Other transportation - pipelines	0.003	0.950
Fugitive - CO2 Oil and natural gas - Oil	0.003	0.95
Transport - CH4 Road transportation	0.002	0.96

Table A1.3 Results of the key category analysis with LULUCF. Approach 1 Level assessment, year 2022

CATEGORIES	2022 *kt CO_2 eq*	Level assessment	Cumulative Percentage
Transport - CO2 Road transportation	99,435	0.217	0.22
Energy industries - CO2 gaseous fuels	52,566	0.115	0.33
Other sectors - CO2 commercial, residential, agriculture gaseous fuels	50,221	0.110	0.44
Manufacturing industries and construction - CO2 gaseous fuels	31,746	0.069	0.51
Energy industries - CO2 solid fuels	23,427	0.051	0.56
Forest Land remaining Forest Land - Living biomass -CO2	-21,767	0.048	0.61
Energy industries - CO2 liquid fuels	18,299	0.040	0.65
Solid waste disposal - CH4	15,565	0.034	0.68
Manufacturing industries and construction - CO2 liquid fuels	15,518	0.034	0.72
Enteric Fermentation- CH4	14,487	0.032	0.75
Other sectors - CO2 commercial, residential, agriculture liquid fuels	12,592	0.028	0.78
Mineral industry- CO2 Cement production	7,093	0.015	0.79
Product uses as substitutes for ozone depleting substances - HFCs Refrigeration and Air conditioning	6,868	0.015	0.81
Direct N2O Emissions from Managed soils	6,150	0.013	0.82

Manufacturing industries and construction - CO2 solid fuels	6,034	0.013	0.83
Transport - CO2 Waterborne navigation	5,718	0.012	0.85
Other sectors - CO2 commercial, residential, agriculture other fossil fuels	5,523	0.012	0.86
Manure Management - CH4	4,791	0.010	0.87
Land Converted to Settlements - CO2	4,553	0.010	0.88
Land Converted to Grassland - mineral soils- CO2	-4,335	0.009	0.89
Land Converted to Forest Land -Living biomass - CO2	-3,078	0.007	0.90
Wastewater treatment and discharge - CH4	2,668	0.006	0.90
Fugitive - CH4 Oil and natural gas - Natural gas	2,596	0.006	0.91
Transport - CO2 Civil Aviation	2,485	0.005	0.91
Other sectors - CH4 commercial, residential, agriculture biomass	2,465	0.005	0.92
Grassland Remaining Grassland - living biomass - CO2	2,267	0.005	0.92
Cropland Remaining Cropland - Living biomass - CO2	2,050	0.004	0.93
Indirect N2O Emissions from Managed soils	1,822	0.004	0.93
Mineral industry- CO2 Lime production	1,815	0.004	0.93
Cropland Remaining Cropland - mineral soils - CO2	-1,792	0.004	0.94
Manure Management - N2O	1,722	0.004	0.94
Product uses as substitutes for ozone depleting substances - HFCs Fire protection	1,641	0.004	0.946
Rice cultivations - CH4	1,547	0.003	0.950
Metal industry- CO2 Iron and steel production	1,392	0.003	0.953
Fugitive - CO2 Oil and natural gas - Oil	1,268	0.003	0.96
Wastewater treatment and discharge - N2O	1,108	0.002	0.96

Table A1.4 Results of the key category analysis with LULUCF. Approach 1 Trend assessment, base year-2022

CATEGORIES	% Contribution to trend	Cumulative Percentage
Energy industries - CO2 liquid fuels	0.165	0.17
Energy industries - CO2 gaseous fuels	0.153	0.32
Transport - CO2 Road transportation	0.114	0.43
Other sectors - CO2 commercial, residential, agriculture gaseous fuels	0.088	0.52
Other sectors - CO2 commercial, residential, agriculture liquid fuels	0.063	0.58
Manufacturing industries and construction - CO2 solid fuels	0.052	0.63
Manufacturing industries and construction - CO2 liquid fuels	0.036	0.67
Product uses as substitutes for ozone depleting substances - HFCs Refrigeration and Air conditioning	0.028	0.70
Manufacturing industries and construction - CO2 gaseous fuels	0.028	0.73
Energy industries - CO2 solid fuels	0.022	0.75
Solid waste disposal - CH4	0.020	0.77
Other sectors - CO2 commercial, residential, agriculture other fossil fuels	0.020	0.79
Mineral industry- CO2 Cement production	0.019	0.81
Forest Land remaining Forest Land - Living biomass -CO2	0.017	0.82
Fugitive - CH4 Oil and natural gas - Natural gas	0.017	0.84
Chemical industry- N2O Adipic acid production	0.011	0.85
Land Converted to Grassland - mineral soils- CO2	0.011	0.86
Grassland Remaining Grassland - living biomass -CO2	0.007	0.87
Product uses as substitutes for ozone depleting substances - HFCs Fire protection	0.007	0.88

CATEGORIES	% Contribution to trend	Cumulative Percentage
Other sectors - CH4 commercial, residential, agriculture biomass	0.006	0.88
Transport - CO2 Waterborne navigation	0.006	0.89
Enteric Fermentation- CH4	0.006	0.90
Transport - CO2 Civil Aviation	0.005	0.90
Metal industry- PFCs Aluminium production	0.005	0.91
Chemical industry- N2O Nitric acid production	0.005	0.91
Mineral industry- CO2 Other processes uses of carbonates	0.005	0.92
Chemical industry- CO2 Ammonia production	0.005	0.92
Cropland Remaining Cropland - Living biomass - CO2	0.004	0.93
Metal industry- CO2 Iron and steel production	0.004	0.93
Cropland Remaining Cropland - mineral soils - CO2	0.003	0.93
Forest Land remaining Forest Land - DOM (deadwood+litter) - CO2	0.003	0.94
Manure Management - CH4	0.003	0.94
Other sectors - N2O commercial, residential, agriculture biomass	0.003	0.94
Other sectors - CO2 commercial, residential, agriculture solid fuels	0.003	0.94
Transport - CO2 Other transportation - pipelines	0.003	0.946
Land Converted to Forest Land - soils -CO2	0.002	0.948
Transport - CH4 Road transportation	0.002	0.950
Fugitive - CO2 Oil and natural gas - Oil	0.002	0.952
Land Converted to Cropland - soils CO2	0.002	0.95

The application of Approach 1, excluding LULUCF categories, gives as a result 25 key categories accounting for the 95% of the total levels; when applying the trend analysis, excluding LULUCF categories, the number of key categories is equal to 28 (Tables A1.1, A1.2). The Approach 1 level assessment repeated for the full inventory, including the LULUCF, results in 33 key categories (sources and sinks), and 37 key categories outcome from the trend analysis (Tables A1.3, A1.4).

For the base year, the results are reported in the following tables, including and excluding LULUCF.

Table A1.5 Results of the key category analysis without LULUCF. Approach 1 Level assessment, base year

CATEGORIES	Base year kt CO_2 eq	Level assessment	Cumulative Percentage
Transport - CO2 Road transportation	92,332	0.18	0.18
Energy industries - CO2 liquid fuels	81,197	0.16	0.33
Energy industries - CO2 solid fuels	38,647	0.07	0.41
Other sectors - CO2 commercial, residential, agriculture liquid fuels	38,274	0.07	0.48
Other sectors - CO2 commercial, residential, agriculture gaseous fuels	36,338	0.07	0.55
Manufacturing industries and construction - CO2 liquid fuels	32,806	0.06	0.61
Manufacturing industries and construction - CO2 gaseous fuels	32,234	0.06	0.67
Manufacturing industries and construction - CO2 solid fuels	25,732	0.05	0.72
Enteric Fermentation- CH4	17,093	0.03	0.76
Energy industries - CO2 gaseous fuels	16,954	0.03	0.79
Mineral industry- CO2 Cement production	15,846	0.03	0.82
Solid waste disposal - CH4	13,671	0.03	0.84
Fugitive - CH4 Oil and natural gas - Natural gas	9,225	0.02	0.86

CATEGORIES	Base year	Level assessment	Cumulative Percentage
Direct N2O Emissions from Managed soils	7,755	0.01	0.88
Transport - CO2 Waterborne navigation	5,470	0.01	0.89
Manure Management - CH4	5,424	0.01	0.90
Chemical industry- N2O Adipic acid production	3,914	0.01	0.91
Wastewater treatment and discharge - CH4	3,584	0.01	0.91
Metal industry- CO2 Iron and steel production	3,124	0.01	0.92
Mineral industry- CO2 Other processes uses of carbonates	2,544	0.00	0.92
Indirect N2O Emissions from Managed soils	2,533	0.00	0.93
Manure Management - N2O	2,515	0.00	0.93
Fugitive - CO2 Oil and natural gas - Oil	2,402	0.00	0.94
Rice cultivations - CH4	2,102	0.00	0.94
Chemical industry- CO2 Ammonia production	1,892	0.00	0.94
Mineral industry- CO2 Lime production	1,877	0.00	0.948
Chemical industry- N2O Nitric acid production	1,783	0.00	0.952
Metal industry- PFCs Aluminium production	1,778	0.00	0.955
Transport - CO2 Civil Aviation	1,493	0.00	0.958

Table A1.6 Results of the key category analysis with LULUCF. Approach 1 Level assessment, base year

CATEGORIES	Base year kt CO_2 eq	Level assessment	Cumulative Percentage
Transport - CO2 Road transportation	92,332	0.17	0.17
Energy industries - CO2 liquid fuels	81,197	0.15	0.31
Energy industries - CO2 solid fuels	38,647	0.07	0.38
Other sectors - CO2 commercial, residential, agriculture liquid fuels	38,274	0.07	0.45
Other sectors - CO2 commercial, residential, agriculture gaseous fuels	36,338	0.06	0.51
Manufacturing industries and construction - CO2 liquid fuels	32,806	0.06	0.57
Manufacturing industries and construction - CO2 gaseous fuels	32,234	0.06	0.63
Manufacturing industries and construction - CO2 solid fuels	25,732	0.05	0.67
Enteric Fermentation- CH4	17,093	0.03	0.71
Energy industries - CO2 gaseous fuels	16,954	0.03	0.74
Mineral industry- CO2 Cement production	15,846	0.03	0.76
Forest Land remaining Forest Land - Living biomass -CO2	-13,919	0.02	0.79
Solid waste disposal - CH4	13,671	0.02	0.81
Fugitive - CH4 Oil and natural gas - Natural gas	9,225	0.02	0.83
Direct N2O Emissions from Managed soils	7,755	0.01	0.84
Land Converted to Settlements - CO2	6,640	0.01	0.86
Transport - CO2 Waterborne navigation	5,470	0.01	0.87
Manure Management - CH4	5,424	0.01	0.88
Grassland Remaining Grassland - living biomass -CO2	5,376	0.01	0.88
Chemical industry- N2O Adipic acid production	3,914	0.01	0.89
Wastewater treatment and discharge - CH4	3,584	0.01	0.90
Metal industry- CO2 Iron and steel production	3,124	0.01	0.90
Mineral industry- CO2 Other processes uses of carbonates	2,544	0.00	0.91
Indirect N2O Emissions from Managed soils	2,533	0.00	0.91
Land Converted to Forest Land -Living biomass - CO2	-2,525	0.00	0.92
Manure Management - N2O	2,515	0.00	0.92
Fugitive - CO2 Oil and natural gas - Oil	2,402	0.00	0.93
Rice cultivations - CH4	2,102	0.00	0.93
Chemical industry- CO2 Ammonia production	1,892	0.00	0.93
Mineral industry- CO2 Lime production	1,877	0.00	0.94
Chemical industry- N2O Nitric acid production	1,783	0.00	0.94

Metal industry- PFCs Aluminium production	1,778	0.00	0.943
Transport - CO2 Civil Aviation	1,493	0.00	0.946
Indirect CO2	1,311	0.00	0.948
Cropland Remaining Cropland - Living biomass - CO2	1,200	0.00	0.9502
Land Converted to Grassland - mineral soils- CO2	-1,124	0.00	0.95
Wastewater treatment and discharge - N2O	1,120	0.00	0.95
Transport - CO2 Road transportation	92,332	0.17	0.17

The application of Approach 1 to the base year, excluding LULUCF categories, gives as a result 27 key categories accounting for the 95% of the total levels; when applying the base year assessment, including the LULUCF, the number of key categories increases to 35 (Tables A1.5, A1.6).

A1.3 Uncertainty assessment (IPCC Approach 1)

Approach 2 for the identification of key categories implies the assessment of the uncertainty analysis to an emission inventory. As already mentioned, the IPCC Approach 1 has been applied to the Italian GHG inventory to estimate uncertainties for the base year and the last submitted year. In this section, detailed results are reported for the 2022 inventory. The uncertainty analysis has also been implemented both excluding and including the LULUCF sector in the national totals.

Results are reported in Table A1.7, for the year 2022, excluding the LULUCF sector and in Table A1.8 figures of inventory total uncertainty, including the LULUCF sector, are shown.

Details on the method used for LULUCF are described in chapter 6.

Table A1.7 Results of the uncertainty analysis excluding LULUCF (Approach 1). Year 2022

IPCC category	Gas	Emissions		Uncertainty				Sensitivity		Uncertainty in trend		
		Base year	2022	AD	EF	Combined	Contribution to variance	Type A	Type B	introduced by EF uncertainty	introduced by AD uncertainty	in total national emissions
Energy industries - CO2 liquid fuels	CO2	81,197	18,299	3%	3%	0.042	0.000	0.088	0.035	0.003	0.001	0.0000091
Energy industries - CO2 solid fuels	CO2	38,647	23,427	3%	3%	0.042	0.000	0.014	0.045	0.000	0.002	0.0000038
Energy industries - CO2 gaseous fuels	CO2	16,954	52,566	3%	3%	0.042	0.000	0.075	0.101	0.002	0.004	0.0000233
Energy industries - CO2 other fuels	CO2	143	117	3%	3%	0.042	0.000	0.000	0.000	0.000	0.000	0.0000000
Energy industries - N2O liquid fuels	N2O	256	127	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Energy industries - N2O solid fuels	N2O	145	94	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Energy industries - N2O gaseous fuels	N2O	8	26	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Energy industries - N2O other fuels	N2O	1	1	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Energy industries - N2O biomass	N2O	14	84	20%	50%	0.539	0.000	0.000	0.000	0.000	0.000	0.0000000
Energy industries - CH4 liquid fuels	CH4	82	13	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Energy industries - CH4 solid fuels	CH4	147	16	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Energy industries - CH4 gaseous fuels	CH4	13	37	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Energy industries - CH4 other fuels	CH4	0	0	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Energy industries - CH4 biomass	CH4	11	64	20%	50%	0.539	0.000	0.000	0.000	0.000	0.000	0.0000000
Manufacturing industries and construction - CO2 liquid fuels	CO2	32,806	15,518	3%	3%	0.042	0.000	0.020	0.030	0.001	0.001	0.0000019
Manufacturing industries and construction - CO2 solid fuels	CO2	25,732	6,034	3%	3%	0.042	0.000	0.027	0.012	0.001	0.000	0.0000009
Manufacturing industries and construction - CO2 gaseous fuels	CO2	32,234	31,746	3%	3%	0.042	0.000	0.012	0.061	0.000	0.003	0.0000068
Manufacturing industries and construction - CO2 other fuels	CO2	0	403	3%	3%	0.042	0.000	0.001	0.001	0.000	0.000	0.0000000
Manufacturing industries and construction - N2O liquid fuels	N2O	823	442	3%	50%	0.501	0.000	0.000	0.001	0.000	0.000	0.0000000
Manufacturing industries and construction - N2O solid fuels	N2O	216	37	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Manufacturing industries and construction - N2O gaseous fuels	N2O	146	150	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Manufacturing industries and construction - N2O other fuels	N2O	0	20	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Manufacturing industries and construction - N2O biomass	N2O	6	64	20%	50%	0.539	0.000	0.000	0.000	0.000	0.000	0.0000000
Manufacturing industries and construction - CH4 liquid fuels	CH4	47	29	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000

IPCC category	Gas	Emissions		Uncertainty			Contribution to variance	Sensitivity		Uncertainty in trend		
		Base year	2022	AD	EF	Combined		Type A	Type B	introduced by EF uncertainty	introduced by AD uncertainty	in total national emissions
Manufacturing industries and construction - CH4 solid fuels	CH4	120	38	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Manufacturing industries and construction - CH4 gaseous fuels	CH4	16	15	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Manufacturing industries and construction - CH4 other fuels	CH4	0	0	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Manufacturing industries and construction - CH4 biomass	CH4	4	233	20%	50%	0.539	0.000	0.000	0.000	0.000	0.000	0.0000001
Transport - CO2 Road transportation	CO2	92,332	99,435	3%	3%	0.042	0.000	0.051	0.190	0.002	0.008	0.0000675
Transport - N2O Road transportation	N2O	745	850	3%	40%	0.401	0.000	0.000	0.002	0.000	0.000	0.0000000
Transport - CH4 Road transportation	CH4	969	176	3%	40%	0.401	0.000	0.001	0.000	0.000	0.000	0.0000002
Transport - CO2 Waterborne navigation	CO2	5,470	5,718	3%	3%	0.042	0.000	0.003	0.011	0.000	0.000	0.0000002
Transport - N2O Waterborne navigation	N2O	34	38	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Transport - CH4 Waterborne navigation	CH4	39	19	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Transport - CO2 Civil Aviation	CO2	1,493	2,485	3%	3%	0.042	0.000	0.002	0.005	0.000	0.000	0.0000000
Transport - N2O Civil Aviation	N2O	11	18	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Transport - CH4 Civil Aviation	CH4	1	1	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Transport - CO2 Railways	CO2	613	35	3%	5%	0.058	0.000	0.001	0.000	0.000	0.000	0.0000000
Transport - N2O Railways	N2O	64	4	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Transport - CH4 Railways	CH4	1	0	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Transport - CO2 Other transportation - pipelines	CO2	411	982	3%	3%	0.042	0.000	0.001	0.002	0.000	0.000	0.0000000
Transport - N2O Other transportation - pipelines	N2O	6	13	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Transport - CH4 Other transportation - pipelines	CH4	1	1	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Other sectors - CO2 commercial, residential, agriculture liquid fuels	CO2	38,274	12,592	3%	3%	0.042	0.000	0.034	0.024	0.001	0.001	0.0000021
Other sectors - CO2 commercial, residential, agriculture solid fuels	CO2	899	0	3%	3%	0.042	0.000	0.001	0.000	0.000	0.000	0.0000000
Other sectors - CO2 commercial, residential, agriculture gaseous fuels	CO2	36,338	50,221	3%	3%	0.042	0.000	0.041	0.096	0.001	0.004	0.0000182
Other sectors - CO2 commercial, residential, agriculture other fossil fuels	CO2	530	5,523	3%	3%	0.042	0.000	0.010	0.011	0.000	0.000	0.0000003
Other sectors - N2O commercial, residential, agriculture liquid fuels	N2O	885	634	3%	50%	0.501	0.000	0.000	0.001	0.000	0.000	0.0000000
Other sectors - N2O commercial, residential, agriculture solid fuels	N2O	4	0	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Other sectors - N2O commercial, residential, agriculture gaseous fuels	N2O	173	226	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000

IPCC category	Gas	Emissions		Uncertainty			Contribution to variance	Sensitivity		Uncertainty in trend		
		Base year	2022	AD	EF	Combined		Type A	Type B	introduced by EF uncertainty	introduced by AD uncertainty	in total national emissions
Other sectors - N2O commercial, residential, agriculture other fossil fuels	N2O	13	134	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Other sectors - N2O commercial, residential, agriculture biomass	N2O	473	1,050	3%	50%	0.501	0.000	0.001	0.002	0.001	0.000	0.0000004
Other sectors - CH4 commercial, residential, agriculture liquid fuels	CH4	103	17	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Other sectors - CH4 commercial, residential, agriculture liquid fuels	CH4	105	0	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Other sectors - CH4 commercial, residential, agriculture solid fuels	CH4	11	60	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Other sectors - CH4 commercial, residential, agriculture gaseous fuels	CH4	46	8	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Other sectors - CH4 commercial, residential, agriculture other fossil fuels	CH4	1	2,465	3%	50%	0.501	0.000	0.003	0.005	0.002	0.000	0.0000023
Other sectors - CH4 commercial, residential, agriculture biomass	CH4	1,116	511	3%	5%	0.058	0.000	0.001	0.001	0.000	0.000	0.0000000
Other non specified - CO2 military mobile - liquid fuels	CO2	1,071	10	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Other non specified - N2O military mobile - liquid fuels	N2O	60	2	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Other non specified - CH4 military mobile - liquid fuels	CH4	5	0	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.0000000
Fugitive - CO2 Solid fuels	CO2	0	30	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Fugitive - CH4 Solid fuels	CH4	148	1,268	3%	10%	0.104	0.000	0.001	0.002	0.000	0.000	0.0000000
Fugitive - CO2 Oil and natural gas - Oil	CO2	2,402	79	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Fugitive - CH4 Oil and natural gas - Oil	CH4	347	0	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000
Fugitive - N2O Oil and natural gas - Oil	N2O	0	4	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.0000000
Fugitive - CO2 Oil and natural gas - Natural gas	CO2	9	2,596	3%	50%	0.501	0.000	0.009	0.005	0.004	0.000	0.0000202
Fugitive - CH4 Oil and natural gas - Natural gas	CH4	9,225	336	50%	10%	0.510	0.000	0.001	0.001	0.000	0.000	0.0000002
Fugitive - CO2 Oil and natural gas - venting and flaring	CO2	956	1	50%	50%	0.707	0.000	0.000	0.000	0.000	0.000	0.0000000
Fugitive - N2O Oil and natural gas - venting and flaring	N2O	1	57	50%	50%	0.707	0.000	0.000	0.000	0.000	0.000	0.0000000
Fugitive - CH4 Oil and natural gas - venting and flaring	CH4	199	192	50%	10%	0.510	0.000	0.001	0.000	0.000	0.000	0.0000001
Fugitive - CO2 Oil and natural gas - Other - flaring in refineries	CO2	681	134	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.0000000

IPCC category	Gas	Emissions		Uncertainty			Contribution to variance	Sensitivity		Uncertainty in trend		
		Base year	2022	AD	EF	Combined		Type A	Type B	introduced by EF uncertainty	introduced by AD uncertainty	in total national emissions
Fugitive - N2O Oil and natural gas - Other - flaring in refineries	N2O	10	7	50%	50%	0.707	0.000	0.000	0.000	0.000	0.000	0.0000000
Fugitive - CH4 Oil and natural gas - Other - flaring in refineries	CH4	226	482	50%	50%	0.707	0.000	0.001	0.001	0.000	0.001	0.0000005
Mineral industry- CO2 Cement production	CO2	15,846	7,082	3%	10%	0.104	0.000	0.010	0.014	0.001	0.001	0.0000014
Mineral industry- CO2 Lime production	CO2	1,877	1,815	3%	10%	0.104	0.000	0.001	0.003	0.000	0.000	0.0000000
Mineral industry- CO2 Glass production	CO2	453	623	3%	10%	0.104	0.000	0.001	0.001	0.000	0.000	0.0000000
Mineral industry- CO2 Other processes uses of carbonates	CO2	2,544	644	3%	10%	0.104	0.000	0.003	0.001	0.000	0.000	0.0000001
Chemical industry- CO2 Ammonia production	CO2	1,892	247	3%	10%	0.104	0.000	0.002	0.000	0.000	0.000	0.0000001
Chemical industry- N2O Nitric acid production	N2O	1,783	21	3%	10%	0.104	0.000	0.003	0.000	0.000	0.000	0.0000001
Chemical industry - CO2 Adipic acid production	CO2	1	2	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.0000000
Chemical industry- N2O Adipic acid production	N2O	3,914	15	3%	10%	0.104	0.000	0.006	0.000	0.001	0.000	0.0000003
Chemical industry- Caprolactam, Glyoxal and Glyoxylic Acid production -N2O	N2O	10	0	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.0000000
Chemical industry- CO2 Carbide production	CO2	26	3	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.0000000
Chemical industry- CO2 Titanium dioxide production	CO2	0	0	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.0000000
Chemical industry- CO2 Soda ash production	CO2	183	261	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.0000000
Chemical industry - CO2 Petrochemical and carbon black production	CO2	422	581	3%	10%	0.104	0.000	0.000	0.001	0.000	0.000	0.0000000
Chemical industry - CH4 Petrochemical and carbon black production	CH4	69	3	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.0000000
Chemical industry- HFCs Fluorochemical production	HFCs	372	1	5%	50%	0.502	0.000	0.001	0.000	0.000	0.000	0.0000001
Chemical industry- PFCs Fluorochemical production	PFCs	837	300	5%	50%	0.502	0.000	0.001	0.001	0.000	0.000	0.0000001
Chemical industry- SF6 Fluorochemical production	SF6	118	0	5%	50%	0.502	0.000	0.000	0.000	0.000	0.000	0.0000000
Metal industry- CO2 Iron and steel production	CO2	3,124	1,392	3%	10%	0.104	0.000	0.002	0.003	0.000	0.000	0.0000001
Metal industry- CH4 Iron and steel production	CH4	76	35	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.0000000
Metal industry- CO2 Ferroalloys production	CO2	395	0	3%	10%	0.104	0.000	0.001	0.000	0.000	0.000	0.0000000
Metal industry- CO2 Aluminium production	CO2	359	0	3%	20%	0.202	0.000	0.001	0.000	0.000	0.000	0.0000000
Metal industry- PFCs Aluminium production	PFCs	1,778	0	3%	20%	0.202	0.000	0.003	0.000	0.001	0.000	0.0000003
Metal industry- HFCs Magnesium production	HFCs	0	3	3%	20%	0.202	0.000	0.000	0.000	0.000	0.000	0.0000000
Metal industry- CO2 Zinc production	CO2	500	197	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.0000000
Non-Energy products from Fuels and Solvent Use - CO2	CO2	370	287	30%	50%	0.583	0.000	0.000	0.001	0.000	0.000	0.0000001

IPCC category	Gas	Emissions		Uncertainty			Contribution to variance	Sensitivity		Uncertainty in trend		
		Base year	2022	AD	EF	Combined		Type A	Type B	introduced by EF uncertainty	introduced by AD uncertainty	in total national emissions
Electronics Industry - HFCs	HFCs	0	30	5%	20%	0.206	0.000	0.000	0.000	0.000	0.000	0.0000000
Electronics Industry - PFCs	PFCs	0	139	5%	20%	0.206	0.000	0.000	0.000	0.000	0.000	0.0000000
Electronics Industry - SF6	SF6	0	40	5%	20%	0.206	0.000	0.000	0.000	0.000	0.000	0.0000000
Electronics Industry - NF3	NF3	0	20	5%	20%	0.206	0.000	0.000	0.000	0.000	0.000	0.0000000
Product uses as substitutes for ozone depleting substances - HFCs Refrigeration and Air conditioning	HFCs	0	6,868	30%	50%	0.583	0.000	0.013	0.013	0.007	0.006	0.0000743
Product uses as substitutes for ozone depleting substances - HFCs Foam blowing agents	HFCs	0	412	30%	50%	0.583	0.000	0.001	0.001	0.000	0.000	0.0000003
Product uses as substitutes for ozone depleting substances - HFCs Fire protection	HFCs	0	1,641	30%	50%	0.583	0.000	0.003	0.003	0.002	0.001	0.0000042
Product uses as substitutes for ozone depleting substances - HFCs Aerosols	HFCs	0	152	30%	50%	0.583	0.000	0.000	0.000	0.000	0.000	0.0000000
Other Product Manufacture and Use - SF6	SF6	303	350	5%	20%	0.206	0.000	0.000	0.001	0.000	0.000	0.0000000
Other Product Manufacture and Use - N2O	N2O	694	444	5%	10%	0.112	0.000	0.000	0.001	0.000	0.000	0.0000000
Enteric Fermentation- CH4	CH4	17,093	14,487	3%	20%	0.202	0.000	0.002	0.028	0.000	0.001	0.0000015
Manure Management - CH4	CH4	5,424	4,791	5%	20%	0.206	0.000	0.001	0.009	0.000	0.001	0.0000005
Manure Management - N2O	N2O	2,515	1,722	5%	20%	0.206	0.000	0.000	0.003	0.000	0.000	0.0000001
Field burning of agricultural residues - CH4	CH4	15	8	30%	50%	0.583	0.000	0.000	0.000	0.000	0.000	0.0000000
Field burning of agricultural residues - N2O	N2O	4	2	30%	50%	0.583	0.000	0.000	0.000	0.000	0.000	0.0000000
Liming and other carbon containing fertilisers - CO2	CO2	45	17	10%	20%	0.224	0.000	0.000	0.000	0.000	0.000	0.0000000
Urea application - CO2	CO2	465	218	10%	20%	0.224	0.000	0.000	0.000	0.000	0.000	0.0000000
Direct N2O Emissions from Managed soils	N2O	7,755	6,150	20%	50%	0.539	0.000	0.000	0.012	0.000	0.003	0.0000111
Indirect N2O Emissions from Managed soils	N2O	2,533	1,822	20%	50%	0.539	0.000	0.000	0.003	0.000	0.001	0.0000010
Indirect N2O Emissions from Manure Management	N2O	3	0	5%	50%	0.502	0.000	0.000	0.000	0.000	0.000	0.0000000
Rice cultivations - CH4	CH4	2,102	1,547	5%	10%	0.112	0.000	0.000	0.003	0.000	0.000	0.0000000
Solid waste disposal - CH4	CH4	13,671	15,565	10%	20%	0.224	0.000	0.009	0.030	0.002	0.004	0.0000212
Biological treatment of Solid waste - CH4	CH4	5	120	20%	100%	1.020	0.000	0.000	0.000	0.000	0.000	0.0000001
Biological treatment of Solid waste - N2O	N2O	18	409	20%	100%	1.020	0.000	0.001	0.001	0.001	0.000	0.0000006
Incineration and open burning of waste - CO2	CO2	512	114	10%	20%	0.224	0.000	0.001	0.000	0.000	0.000	0.0000000
Incineration and open burning of waste - CH4	CH4	53	52	10%	20%	0.224	0.000	0.000	0.000	0.000	0.000	0.0000000
Incineration and open burning of waste - N2O	N2O	33	17	10%	20%	0.224	0.000	0.000	0.000	0.000	0.000	0.0000000
Wastewater treatment and discharge - CH4	CH4	3,584	2,668	20%	100%	1.020	0.000	0.000	0.005	0.000	0.001	0.0000022
Wastewater treatment and discharge - N2O	N2O	1,120	1,108	20%	100%	1.020	0.000	0.000	0.002	0.000	0.001	0.0000006

		Emissions		Uncertainty				Sensitivity		Uncertainty in trend		
IPCC category	Gas	Base year	2022	AD	EF	Combined	Contribution to variance	Type A	Type B	introduced by EF uncertainty	introduced by AD uncertainty	in total national emissions
Indirect CO2	Indirect CO2	1,311	728	30%	50%	0.583	0.000	0.001	0.001	0.000	0.001	0.0000004
TOTAL		**522,373**	**413,041**				**0.001**					**0.0003**
						Percertage uncertainty in total inventory	**2.4%**				Trend uncertainty	**1.7%**

Table A1.8 Results of the uncertainty analysis including LULUCF (Approach 1). Year 2022

IPCC category	Gas	Emissions		Uncertainty			Contribution to variance	Sensitivity		Uncertainty in trend		
		Base year	2022	AD	EF	Combined		Type A	Type B	introduced by EF uncertainty	introduced by AD uncertainty	in total national emissions
Energy industries - CO2 liquid fuels	CO2	81,197	18,299	3%	3%	0.042	0.000	0.083	0.035	0.002	0.001	0.000
Energy industries - CO2 solid fuels	CO2	38,647	23,427	3%	3%	0.042	0.000	0.011	0.045	0.000	0.002	0.000
Energy industries - CO2 gaseous fuels	CO2	16,954	52,566	3%	3%	0.042	0.000	0.077	0.101	0.002	0.004	0.000
Energy industries - CO2 other fuels	CO2	143	117	3%	3%	0.042	0.000	0.000	0.000	0.000	0.000	0.000
Energy industries - N2O liquid fuels	N2O	256	127	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Energy industries - N2O solid fuels	N2O	145	94	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Energy industries - N2O gaseous fuels	N2O	8	26	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Energy industries - N2O other fuels	N2O	1	1	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Energy industries - N2O biomass	N2O	14	84	20%	50%	0.539	0.000	0.000	0.000	0.000	0.000	0.000
Energy industries - CH4 liquid fuels	CH4	82	13	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Energy industries - CH4 solid fuels	CH4	147	16	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Energy industries - CH4 gaseous fuels	CH4	13	37	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Energy industries - CH4 other fuels	CH4	0	0	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Energy industries - CH4 biomass	CH4	11	64	20%	50%	0.539	0.000	0.000	0.000	0.000	0.000	0.000
Manufacturing industries and construction - CO2 liquid fuels	CO2	32,806	15,518	3%	3%	0.042	0.000	0.018	0.030	0.001	0.001	0.000
Manufacturing industries and construction - CO2 solid fuels	CO2	25,732	6,034	3%	3%	0.042	0.000	0.026	0.012	0.001	0.000	0.000
Manufacturing industries and construction - CO2 gaseous fuels	CO2	32,234	31,746	3%	3%	0.042	0.000	0.014	0.061	0.000	0.003	0.000
Manufacturing industries and construction - CO2 other fuels	CO2	0	403	3%	3%	0.042	0.000	0.001	0.001	0.000	0.000	0.000
Manufacturing industries and construction - N2O liquid fuels	N2O	823	442	3%	50%	0.501	0.000	0.000	0.001	0.000	0.000	0.000
Manufacturing industries and construction - N2O solid fuels	N2O	216	37	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Manufacturing industries and construction - N2O gaseous fuels	N2O	146	150	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Manufacturing industries and construction - N2O other fuels	N2O	0	20	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Manufacturing industries and construction - N2O biomass	N2O	6	64	20%	50%	0.539	0.000	0.000	0.000	0.000	0.000	0.000
Manufacturing industries and construction - CH4 liquid fuels	CH4	47	29	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000

IPCC category	Gas	Emissions		Uncertainty			Contribution to variance	Sensitivity		Uncertainty in trend		
		Base year	2022	AD	EF	Combined		Type A	Type B	introduced by EF uncertainty	introduced by AD uncertainty	in total national emissions
Manufacturing industries and construction - CH4 solid fuels	CH4	120	38	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Manufacturing industries and construction - CH4 gaseous fuels	CH4	16	15	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Manufacturing industries and construction - CH4 other fuels	CH4	0	0	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Manufacturing industries and construction - CH4 biomass	CH4	4	233	20%	50%	0.539	0.000	0.000	0.000	0.000	0.000	0.000
Transport - CO2 Road transportation	CO2	92,332	99,435	3%	3%	0.042	0.000	0.057	0.192	0.002	0.008	0.000
Transport - N2O Road transportation	N2O	745	850	3%	40%	0.401	0.000	0.001	0.002	0.000	0.000	0.000
Transport - CH4 Road transportation	CH4	969	176	3%	40%	0.401	0.000	0.001	0.000	0.000	0.000	0.000
Transport - CO2 Waterborne navigation	CO2	5,470	5,718	3%	3%	0.042	0.000	0.003	0.011	0.000	0.000	0.000
Transport - N2O Waterborne navigation	N2O	34	38	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Transport - CH4 Waterborne navigation	CH4	39	19	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Transport - CO2 Civil Aviation	CO2	1,493	2,485	3%	3%	0.042	0.000	0.003	0.005	0.000	0.000	0.000
Transport - N2O Civil Aviation	N2O	11	18	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Transport - CH4 Civil Aviation	CH4	1	1	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Transport - CO2 Railways	CO2	613	35	3%	5%	0.058	0.000	0.001	0.000	0.000	0.000	0.000
Transport - N2O Railways	N2O	64	4	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Transport - CH4 Railways	CH4	1	0	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Transport - CO2 Other transportation - pipelines	CO2	411	982	3%	3%	0.042	0.000	0.001	0.002	0.000	0.000	0.000
Transport - N2O Other transportation - pipelines	N2O	6	13	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Transport - CH4 Other transportation - pipelines	CH4	1	1	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Other sectors - CO2 commercial, residential, agriculture liquid fuels	CO2	38,274	12,592	3%	3%	0.042	0.000	0.031	0.024	0.001	0.001	0.000
Other sectors - CO2 commercial, residential, agriculture solid fuels	CO2	899	0	3%	3%	0.042	0.000	0.001	0.000	0.000	0.000	0.000
Other sectors - CO2 commercial, residential, agriculture gaseous fuels	CO2	36,338	50,221	3%	3%	0.042	0.000	0.044	0.097	0.001	0.004	0.000
Other sectors - CO2 commercial, residential, agriculture other fossil fuels	CO2	530	5,523	3%	3%	0.042	0.000	0.010	0.011	0.000	0.000	0.000
Other sectors - N2O commercial, residential, agriculture liquid fuels	N2O	885	634	3%	50%	0.501	0.000	0.000	0.001	0.000	0.000	0.000
Other sectors - N2O commercial, residential, agriculture solid fuels	N2O	4	0	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Other sectors - N2O commercial, residential, agriculture gaseous fuels	N2O	173	226	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000

IPCC category	Gas	Emissions		Uncertainty			Contribution to variance	Sensitivity		Uncertainty in trend		
		Base year	2022	AD	EF	Combined		Type A	Type B	introduced by EF uncertainty	introduced by AD uncertainty	in total national emissions
Other sectors - N2O commercial, residential, agriculture other fossil fuels	N2O	13	134	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Other sectors - N2O commercial, residential, agriculture biomass	N2O	473	1,050	3%	50%	0.501	0.000	0.001	0.002	0.001	0.000	0.000
Other sectors - CH4 commercial, residential, agriculture liquid fuels	CH4	105	17	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Other sectors - CH4 commercial, residential, agriculture solid fuels	CH4	11	0	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Other sectors - CH4 commercial, residential, agriculture gaseous fuels	CH4	46	60	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Other sectors - CH4 commercial, residential, agriculture other fossil fuels	CH4	1	8	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Other sectors - CH4 commercial, residential, agriculture biomass	CH4	1,116	2,465	3%	50%	0.501	0.000	0.003	0.005	0.002	0.000	0.000
Other non specified - CO2 military mobile - liquid fuels	CO2	1,071	511	3%	5%	0.058	0.000	0.001	0.001	0.000	0.000	0.000
Other non specified - N2O military mobile - liquid fuels	N2O	60	10	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Other non specified - CH4 military mobile - liquid fuels	CH4	5	2	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Fugitive - CO2 Solid fuels	CO2	0	0	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.000
Fugitive - CH4 Solid fuels	CH4	148	30	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Fugitive - CO2 Oil and natural gas - Oil	CO2	2,402	1,268	3%	10%	0.104	0.000	0.001	0.002	0.000	0.000	0.000
Fugitive - CH4 Oil and natural gas - Oil	CH4	347	79	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Fugitive - N2O Oil and natural gas - Oil	N2O	0	0	3%	50%	0.501	0.000	0.000	0.000	0.000	0.000	0.000
Fugitive - CO2 Oil and natural gas - Natural gas	CO2	9	4	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.000
Fugitive - CH4 Oil and natural gas - Natural gas	CH4	9,225	2,596	3%	50%	0.501	0.000	0.008	0.005	0.004	0.000	0.000
Fugitive - CO2 Oil and natural gas - venting and flaring	CO2	956	336	50%	10%	0.510	0.000	0.001	0.001	0.000	0.000	0.000
Fugitive - N2O Oil and natural gas - venting and flaring	N2O	1	1	50%	50%	0.707	0.000	0.000	0.000	0.000	0.000	0.000
Fugitive - CH4 Oil and natural gas - venting and flaring	CH4	199	57	50%	50%	0.707	0.000	0.000	0.000	0.000	0.000	0.000
Fugitive - CO2 Oil and natural gas - Other - flaring in refineries	CO2	681	192	50%	10%	0.510	0.000	0.001	0.000	0.000	0.000	0.000
Fugitive - N2O Oil and natural gas - Other - flaring in refineries	N2O	10	7	50%	50%	0.707	0.000	0.000	0.000	0.000	0.000	0.000

IPCC category	Gas	Emissions		Uncertainty			Contribution to variance	Sensitivity		Uncertainty in trend		
		Base year	2022	AD	EF	Combined		Type A	Type B	introduced by EF uncertainty	introduced by AD uncertainty	in total national emissions
Fugitive - CH4 Oil and natural gas - Other - flaring in refineries	CH4	226	482	50%	50%	0.707	0.000	0.001	0.001	0.000	0.001	0.000
Mineral industry- CO2 Cement production	CO2	15,846	7,093	3%	10%	0.104	0.000	0.009	0.014	0.001	0.001	0.000
Mineral industry- CO2 Lime production	CO2	1,877	1,815	3%	10%	0.104	0.000	0.001	0.003	0.000	0.000	0.000
Mineral industry- CO2 Glass production	CO2	453	623	3%	10%	0.104	0.000	0.001	0.001	0.000	0.000	0.000
Mineral industry- CO2 Other processes uses of carbonates	CO2	2,544	644	3%	10%	0.104	0.000	0.002	0.001	0.000	0.000	0.000
Chemical industry- CO2 Ammonia production	CO2	1,892	247	3%	10%	0.104	0.000	0.002	0.000	0.000	0.000	0.000
Chemical industry- N2O Nitric acid production	N2O	1,783	21	3%	10%	0.104	0.000	0.003	0.000	0.000	0.000	0.000
Chemical industry - CO2 Adipic acid production	CO2	1	2	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.000
Chemical industry- N2O Adipic acid production	N2O	3,914	15	3%	10%	0.104	0.000	0.006	0.000	0.001	0.000	0.000
Chemical industry- Caprolactam, Glyoxal and Glyoxylic Acid production -N2O	N2O	10	0	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.000
Chemical industry- CO2 Carbide production	CO2	26	3	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.000
Chemical industry- CO2 Titanium dioxide production	CO2	0	0	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.000
Chemical industry- CO2 Soda ash production	CO2	183	261	3%	10%	0.104	0.000	0.000	0.001	0.000	0.000	0.000
Chemical industry - CO2 Petrochemical and carbon black production	CO2	422	581	3%	10%	0.104	0.000	0.001	0.001	0.000	0.000	0.000
Chemical industry - N2O Petrochemical and carbon black production	N2O	69	3	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.000
Chemical industry- HFCs Fluorochemical production	HFCs	372	1	5%	50%	0.502	0.000	0.001	0.000	0.000	0.000	0.000
Chemical industry- PFCs Fluorochemical production	PFCs	837	300	5%	50%	0.502	0.000	0.001	0.001	0.000	0.000	0.000
Chemical industry- SF6 Fluorochemical production	SF6	118	0	5%	50%	0.502	0.000	0.000	0.000	0.000	0.000	0.000
Metal industry- CO2 Iron and steel production	CO2	3,124	1,392	3%	10%	0.104	0.000	0.002	0.003	0.000	0.000	0.000
Metal industry- CH4 Iron and steel production	CH4	76	35	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.000
Metal industry- CO2 Ferroalloys production	CO2	395	0	3%	10%	0.104	0.000	0.001	0.000	0.000	0.000	0.000
Metal industry- CO2 Aluminium production	CO2	359	0	3%	20%	0.202	0.000	0.001	0.000	0.000	0.000	0.000
Metal industry- PFCs Aluminium production	PFCs	1,778	0	3%	20%	0.202	0.000	0.003	0.000	0.001	0.000	0.000
Metal industry- HFCs Magnesium production	HFCs	0	3	3%	20%	0.202	0.000	0.000	0.000	0.000	0.000	0.000
Metal industry- CO2 Zinc production	CO2	500	197	3%	10%	0.104	0.000	0.000	0.000	0.000	0.000	0.000
Non-Energy products from Fuels and Solvent Use - CO2	CO2	370	287	30%	50%	0.583	0.000	0.000	0.001	0.000	0.000	0.000
Electronics Industry - HFCs	HFCs	0	30	5%	20%	0.206	0.000	0.000	0.000	0.000	0.000	0.000
Electronics Industry - PFCs	PFCs	0	139	5%	20%	0.206	0.000	0.000	0.000	0.000	0.000	0.000
Electronics Industry - SF6	SF6	0	40	5%	20%	0.206	0.000	0.000	0.000	0.000	0.000	0.000
Electronics Industry - NF3	NF3	0	20	5%	20%	0.206	0.000	0.000	0.000	0.000	0.000	0.000

IPCC category	Gas	Emissions		Uncertainty			Contribution to variance	Sensitivity		Uncertainty in trend		
		Base year	2022	AD	EF	Combined		Type A	Type B	introduced by EF uncertainty	introduced by AD uncertainty	in total national emissions
Product uses as substitutes for ozone depleting substances - HFCs Refrigeration and Air conditioning	HFCs	0	6,868	30%	50%	0.583	0.000	0.013	0.013	0.007	0.006	0.00008
Product uses as substitutes for ozone depleting substances - HFCs Foam blowing agents	HFCs	0	412	30%	50%	0.583	0.000	0.001	0.001	0.000	0.000	0.00000
Product uses as substitutes for ozone depleting substances - HFCs Fire protection	HFCs	0	1,641	30%	50%	0.583	0.000	0.003	0.003	0.002	0.001	0.00000
Product uses as substitutes for ozone depleting substances - HFCs Aerosols	HFCs	0	152	30%	50%	0.583	0.000	0.000	0.000	0.000	0.000	0.00000
Other Product Manufacture and Use - SF6	SF6	303	350	5%	20%	0.206	0.000	0.000	0.001	0.000	0.000	0.00000
Other Product Manufacture and Use - N2O	N2O	694	444	5%	10%	0.112	0.000	0.000	0.001	0.000	0.000	0.00000
Enteric Fermentation- CH4	CH4	17,093	14,487	3%	20%	0.202	0.000	0.003	0.028	0.001	0.001	0.00000
Manure Management - CH4	CH4	5,424	4,791	5%	20%	0.206	0.000	0.001	0.009	0.000	0.001	0.00000
Manure Management - N2O	N2O	2,515	1,722	5%	20%	0.206	0.000	0.000	0.003	0.000	0.000	0.00000
Field burning of agricultural residues - CH4	CH4	15	8	30%	50%	0.583	0.000	0.000	0.000	0.000	0.000	0.00000
Field burning of agricultural residues - N2O	N2O	4	2	30%	50%	0.583	0.000	0.000	0.000	0.000	0.000	0.00000
Liming - CO2	CO2	45	17	10%	20%	0.224	0.000	0.000	0.000	0.000	0.000	0.00000
Urea application - CO2	CO2	465	218	10%	20%	0.224	0.000	0.000	0.000	0.000	0.000	0.00000
Direct N2O Emissions from Managed soils	N2O	7,755	6,150	20%	50%	0.539	0.000	0.001	0.012	0.000	0.003	0.00001
Indirect N2O Emissions from Managed soils	N2O	2,533	1,822	20%	50%	0.539	0.000	0.000	0.004	0.000	0.001	0.00000
Indirect N2O Emissions from Manure Management	N2O	3	0	5%	50%	0.502	0.000	0.000	0.000	0.000	0.000	0.00000
Rice cultivations - CH4	CH4	2,102	1,547	5%	10%	0.112	0.000	0.000	0.003	0.000	0.000	0.00000
Solid waste disposal - CH4	CH4	13,671	15,565	10%	20%	0.224	0.000	0.010	0.030	0.002	0.004	0.00002
Biological treatment of Solid waste - CH4	CH4	5	120	20%	100%	1.020	0.000	0.000	0.000	0.000	0.000	0.00000
Biological treatment of Solid waste - N2O	N2O	18	409	20%	100%	1.020	0.000	0.001	0.001	0.001	0.000	0.00000
Incineration and open burning of waste - CO2	CO2	512	114	10%	20%	0.224	0.000	0.001	0.000	0.000	0.000	0.00000
Incineration and open burning of waste - CH4	CH4	53	52	10%	20%	0.224	0.000	0.000	0.000	0.000	0.000	0.00000
Incineration and open burning of waste - N2O	N2O	33	17	10%	20%	0.224	0.000	0.000	0.000	0.000	0.000	0.00000
Wastewater treatment and discharge - CH4	CH4	3,584	2,668	20%	100%	1.020	0.000	0.000	0.005	0.000	0.001	0.00000
Wastewater treatment and discharge - N2O	N2O	1,120	1,108	20%	100%	1.020	0.000	0.001	0.002	0.001	0.001	0.00000
Forest Land remaining Forest Land - Living biomass - CO2	CO2	-13,919	-21,767	19%	31%	0.363	0.000	0.022	0.042	0.007	0.012	0.00018
Forest Land remaining Forest Land - DOM (deadwood+litter) - CO2	CO2	-1,083	-567	17%	26%	0.307	0.000	0.000	0.001	0.000	0.000	0.00000
Forest Land remaining Forest Land - CH4	CH4	303	189	5%	70%	0.702	0.000	0.000	0.000	0.000	0.000	0.00000
Forest Land remaining Forest Land - N2O	N2O	158	99	5%	70%	0.702	0.000	0.000	0.000	0.000	0.000	0.00000
Land Converted to Forest Land -Living biomass - CO2	CO2	-2,525	-3,078	19%	31%	0.363	0.000	0.002	0.006	0.001	0.002	0.00000

IPCC category	Gas	Emissions		Uncertainty			Contribution to variance	Sensitivity		Uncertainty in trend		
		Base year	2022	AD	EF	Combined		Type A	Type B	introduced by EF uncertainty	introduced by AD uncertainty	in total national emissions
Land Converted to Forest Land - DOM (deadwood+litter) CO2	CO2	-108	-72	17%	26%	0.307	0.000	0.000	0.000	0.000	0.000	0.00000
Land Converted to Forest Land - soils -CO2	CO2	-217	-892	20%	46%	0.500	0.000	0.001	0.002	0.001	0.000	0.00000
Land Converted to Forest Land - CH4	CH4	30	24	5%	70%	0.702	0.000	0.000	0.000	0.000	0.000	0.00000
Land Converted to Forest Land - N2O	N2O	16	13	5%	70%	0.702	0.000	0.000	0.000	0.000	0.000	0.00000
Cropland Remaining Cropland - Living biomass - CO2	CO2	1,200	2,050	5%	11%	0.117	0.000	0.002	0.004	0.000	0.000	0.00000
Cropland Remaining Cropland - mineral soils - CO2	CO2	-795	-1,792	5%	30%	0.304	0.000	0.002	0.003	0.001	0.000	0.00000
Cropland Remaining Cropland - organic soils - CO2	CO2	867	851	20%	90%	0.922	0.000	0.000	0.002	0.000	0.000	0.00000
Cropland Remaining Cropland - CH4	CH4	3	2	20%	70%	0.728	0.000	0.000	0.000	0.000	0.000	0.00000
Cropland Remaining Cropland - N2O	N2O	2	1	20%	70%	0.728	0.000	0.000	0.000	0.000	0.000	0.00000
Land Converted to Cropland - soils CO2	CO2	749	1,083	50%	75%	0.901	0.000	0.001	0.002	0.001	0.001	0.00000
Land Converted to Cropland - N2O	N2O	57	82	50%	70%	0.860	0.000	0.000	0.000	0.000	0.000	0.00000
Grassland Remaining Grassland - living biomass -CO2	CO2	5,376	2,267	19%	31%	0.363	0.000	0.003	0.004	0.001	0.001	0.00000
Grassland Remaining Grassland - DOM (deadwood+litter) CO2	CO2	-114	-88	17%	26%	0.307	0.000	0.000	0.000	0.000	0.000	0.00000
Grassland Remaining Grassland - mineral soils-CO2	CO2	160	-33	5%	30%	0.304	0.000	0.000	0.000	0.000	0.000	0.00000
Grassland Remaining Grassland - organic soils-CO2	CO2	10	10	20%	90%	0.922	0.000	0.000	0.000	0.000	0.000	0.00000
Grassland Remaining Grassland - CH4	CH4	384	143	15%	70%	0.716	0.000	0.000	0.000	0.000	0.000	0.00000
Grassland Remaining Grassland - N2O	N2O	213	75	15%	70%	0.716	0.000	0.000	0.000	0.000	0.000	0.00000
Land Converted to Grassland - mineral soils- CO2	CO2	-1,124	-4,335	50%	75%	0.901	0.000	0.007	0.008	0.005	0.006	0.00006
Land Converted to Wetland - CO2	CO2	0	0	75%	75%	1.061	0.000	0.000	0.000	0.000	0.000	0.00000
Land Converted to Settlements - CO2	CO2	6,640	4,553	75%	75%	1.061	0.000	0.001	0.009	0.001	0.009	0.00009
Land Converted to Settlements - N2O	N2O	449	262	75%	75%	1.061	0.000	0.000	0.001	0.000	0.001	0.00000
Harvest Wood Products - CO2	CO2	-388	-300	25%	50%	0.559	0.000	0.000	0.001	0.000	0.000	0.00000
Indirect N2O from Managed soils - LULUCF	N2O	13	18	75%	75%	1.061	0.000	0.000	0.000	0.000	0.000	0.00000
Indirect CO2	Indirect CO2	1,311	728	30%	50%	0.583	0.000	0.000	0.001	0.000	0.001	0.00000
TOTAL		**518,730**	**391,842**				**0.001**					**0.001**
						Percentage uncertainty in total inventory	**3.6%**				**Trend uncertainty**	**2.5%**

Emission sources of the Italian inventory are disaggregated into a detailed level, 128 sources, according to the IPCC list in the guidelines and taking into account national circumstances and importance. Considering also the LULUCF sector, sources and sinks of the Italian inventory are disaggregated into 161 categories. Uncertainties are therefore estimated for these categories. To estimate uncertainty for both activity data and emission factors, information provided in the IPCC Guidelines, as well as expert judgement have been used; standard deviations have also been considered whenever measurements were available.

The assumptions on which uncertainty estimations are based on are documented for each category. Figures to draw up uncertainty are checked with the relevant analyst experts and literature references and they are consistent with the IPCC Good Practice Guidance and the 2006 IPCC Guidelines (IPCC, 2000; IPCC, 2006).

The general approach followed for quantifying a level of uncertainty to activity data and emission factors is to set values within a range low, medium and high according to the confidence the expert relies on the value. For instance, a low value (e.g. 3-5%) has been attributed to activity data derived from the energy balance and statistical yearbooks, medium-high values within a range of 20-50% for all the data which are not directly or only partially derived from census or sample surveys or data which are simple estimations. For emission factors, the uncertainties set are usually higher than those for activity data; figures suggested by the IPCC good practice guidance and guidelines (IPCC, 2000; IPCC, 2006) are used when the emission factor is a default value or when appropriate, low values are attributed to measured data whereas the uncertainty values are high in all other cases.

For the base year, the uncertainty estimated by Approach 1 is equal to 2.1%; if considering the LULUCF sector the overall uncertainty increases to 2.8%.

In 2022, the results of Approach 1 suggest an uncertainty of 2.4% in the combined GWP total emissions. The analysis also estimates an uncertainty of 1.7% in the trend.

Including the LULUCF sector in the total uncertainty assessment, Approach 1 shows an uncertainty of 3.6% in the combined GWP total emissions for the year 2022, whereas the uncertainty in the trend is equal to 2.5%. Results are shown in Table A1.8

Further investigation is needed to better quantify the uncertainty values for some specific source, nevertheless it should be noted that a conservative approach has been followed.

A1.4 Approach 2 key category assessment

Approach 2 can be used to identify key categories when an uncertainty analysis has been carried out on the inventory. It is helpful in prioritizing activities to improve inventory quality and to reduce overall uncertainty. Under Approach 2, the source or sink category uncertainties are incorporated by weighting the Approach 1 level and trend assessment results with the source category's relative uncertainty.

Therefore, the following equations:

Level Assessment, with Uncertainty = Approach 1 Level Assessment · Relative Category Uncertainty

Trend Assessment, with Uncertainty = Approach 1 Trend Assessment · Relative Category Uncertainty

Approach 2 has been applied both to the base and the current year submission.

The results of the Approach 2 key category analysis, without LULUCF categories, are provided in Table A1.9, for 2022, while in Table A1.11 results, including LULUCF categories, are shown. For the base year, results of the analysis excluding and including LULUCF categories are reported in Table A1.13 and Table A1.14. The results of the trend analysis are reported in Table A1.10 and in Table A1.12, excluding LULUCF and including LULUCF, respectively.

The application of Approach 2 to the base year gives as a result 30 key categories accounting for the 90% of the total levels uncertainty. Including the LULUCF categories, 38 key categories result accounting for 90% of the total uncertainty levels.

For the year 2022, 27 key categories accounting for the 90% of the total uncertainty levels were identified; when applying the trend analysis the key categories increased to 35.

The application of Approach 2 to the inventory, including the LULUCF categories, results in 34 key categories which account for the 90% of the total levels uncertainty; for the trend analysis, with LULUCF, the number of key categories is 43.

Table A1.9 Results of the key category analysis without LULUCF. Approach 2 Level assessment, year 2022

CATEGORIES	Share	Uncertainty	L*U	Level assessment with uncertainty	Cumulative Percentage
Transport - CO2 Road transportation	0.24	0.0424	0.0102	0.0964	0.10
Product uses as substitutes for ozone depleting substances - HFCs Refrigeration and Air conditioning	0.02	0.5831	0.0097	0.0915	0.19
Solid waste disposal - CH4	0.04	0.2236	0.0084	0.0795	0.27
Direct N2O Emissions from Managed soils	0.01	0.5385	0.0080	0.0757	0.34
Enteric Fermentation- CH4	0.04	0.2022	0.0071	0.0670	0.41
Wastewater treatment and discharge - CH4	0.01	1.0198	0.0066	0.0622	0.47
Energy industries - CO2 gaseous fuels	0.13	0.0424	0.0054	0.0510	0.52
Other sectors - CO2 commercial, residential, agriculture gaseous fuels	0.12	0.0424	0.0052	0.0487	0.57
Manufacturing industries and construction - CO2 gaseous fuels	0.08	0.0424	0.0033	0.0308	0.60
Fugitive - CH4 Oil and natural gas - Natural gas	0.01	0.5009	0.0031	0.0297	0.63
Other sectors - CH4 commercial, residential, agriculture biomass	0.01	0.5009	0.0030	0.0282	0.66
Wastewater treatment and discharge - N2O	0.00	1.0198	0.0027	0.0258	0.69
Energy industries - CO2 solid fuels	0.06	0.0424	0.0024	0.0227	0.71
Manure Management - CH4	0.01	0.2062	0.0024	0.0226	0.73
Indirect N2O Emissions from Managed soils	0.00	0.5385	0.0024	0.0224	0.75
Product uses as substitutes for ozone depleting substances - HFCs Fire protection	0.00	0.5831	0.0023	0.0219	0.78
Energy industries - CO2 liquid fuels	0.04	0.0424	0.0019	0.0177	0.79
Mineral industry- CO2 Cement production	0.02	0.1044	0.0018	0.0169	0.81
Manufacturing industries and construction - CO2 liquid fuels	0.04	0.0424	0.0016	0.0150	0.83
Other sectors - CO2 commercial, residential, agriculture liquid fuels	0.03	0.0424	0.0013	0.0122	0.84
Other sectors - N2O commercial, residential, agriculture biomass	0.00	0.5009	0.0013	0.0120	0.85
Indirect CO2	0.00	0.5831	0.0010	0.0097	0.86
Biological treatment of Solid waste - N2O	0.00	1.0198	0.0010	0.0095	0.87
Manure Management - N2O	0.00	0.2062	0.0009	0.0081	0.88
Fugitive - CH4 Oil and natural gas - Other - flaring in refineries	0.00	0.7071	0.0008	0.0078	0.89
Transport - N2O Road transportation	0.00	0.4011	0.0008	0.0078	0.89
Other sectors - N2O commercial, residential, agriculture liquid fuels	0.00	0.5009	0.0008	0.0073	0.9002
Manufacturing industries and construction - CO2 solid fuels	0.01	0.0424	0.0006	0.0059	0.91
Transport - CO2 Waterborne navigation	0.01	0.0424	0.0006	0.0055	0.91

Table A1.10 Results of the key category analysis without LULUCF. Approach 2 Trend assessment, base year- 2022

CATEGORIES	Trend assessment with uncertainty	Uncertainty	T*U	Relative trend assessment with uncertainty	Cumulative Percentage
Product uses as substitutes for ozone depleting substances - HFCs Refrigeration and Air conditioning	0.01	0.5831	0.0077	0.163	0.16
Fugitive - CH4 Oil and natural gas - Natural gas	0.01	0.5009	0.0045	0.095	0.26
Energy industries - CO2 liquid fuels	0.09	0.0424	0.0037	0.078	0.34
Energy industries - CO2 gaseous fuels	0.08	0.0424	0.0032	0.068	0.40
Product uses as substitutes for ozone depleting substances - HFCs Refrigeration and Air conditioning	0.01	0.5831	0.0077	0.164	0.16
Fugitive - CH4 Oil and natural gas - Natural gas	0.01	0.5009	0.0045	0.096	0.26
Energy industries - CO2 liquid fuels	0.09	0.0424	0.0037	0.080	0.34
Energy industries - CO2 gaseous fuels	0.07	0.0424	0.0032	0.068	0.41
Transport - CO2 Road transportation	0.05	0.0424	0.0021	0.046	0.45
Solid waste disposal - CH4	0.01	0.2236	0.0020	0.043	0.50
Product uses as substitutes for ozone depleting substances - HFCs Fire protection	0.00	0.5831	0.0018	0.039	0.54
Other sectors - CO2 commercial, residential, agriculture gaseous fuels	0.04	0.0424	0.0017	0.037	0.57
Other sectors - CH4 commercial, residential, agriculture biomass	0.00	0.5009	0.0015	0.032	0.61
Other sectors - CO2 commercial, residential, agriculture liquid fuels	0.03	0.0424	0.0014	0.031	0.64
Manufacturing industries and construction - CO2 solid fuels	0.03	0.0424	0.0012	0.025	0.66
Mineral industry- CO2 Cement production	0.01	0.1044	0.0011	0.023	0.68
Manufacturing industries and construction - CO2 liquid fuels	0.02	0.0424	0.0008	0.018	0.70
Biological treatment of Solid waste - N2O	0.00	1.0198	0.0008	0.016	0.72
Other sectors - N2O commercial, residential, agriculture biomass	0.00	0.5009	0.0006	0.014	0.73
Chemical industry- N2O Adipic acid production	0.01	0.1044	0.0006	0.013	0.75
Energy industries - CO2 solid fuels	0.01	0.0424	0.0006	0.012	0.76
Metal industry- PFCs Aluminium production	0.00	0.2022	0.0005	0.012	0.77
Manufacturing industries and construction - CO2 gaseous fuels	0.01	0.0424	0.0005	0.011	0.78
Product uses as substitutes for ozone depleting substances - HFCs Foam blowing agents	0.00	0.5831	0.0005	0.010	0.79
Transport - CH4 Road transportation	0.00	0.4011	0.0005	0.010	0.80
Wastewater treatment and discharge - N2O	0.00	1.0198	0.0004	0.009	0.81
Other sectors - CO2 commercial, residential, agriculture other fossil fuels	0.01	0.0424	0.0004	0.009	0.82
Fugitive - CH4 Oil and natural gas - Other - flaring in refineries	0.00	0.7071	0.0004	0.009	0.83
Fugitive - CO2 Oil and natural gas - venting and flaring	0.00	0.5099	0.0004	0.009	0.84
Enteric Fermentation- CH4	0.00	0.2022	0.0004	0.008	0.84
Chemical industry- PFCs Fluorochemical production	0.00	0.5025	0.0003	0.007	0.85
Indirect CO2	0.00	0.5831	0.0003	0.007	0.86
Fugitive - CO2 Oil and natural gas - Other - flaring in refineries	0.00	0.5099	0.0003	0.007	0.87
Wastewater treatment and discharge - CH4	0.00	1.0198	0.0003	0.007	0.87
Chemical industry- HFCs Fluorochemical production	0.00	0.5025	0.0003	0.006	0.88
Chemical industry- N2O Nitric acid production	0.00	0.1044	0.0003	0.006	0.88
Mineral industry- CO2 Other processes uses of carbonates	0.00	0.1044	0.0003	0.006	0.89
Chemical industry- CO2 Ammonia production	0.00	0.1044	0.0002	0.005	0.896
Manufacturing industries and construction - CH4 biomass	0.00	0.5385	0.0002	0.005	0.901
Biological treatment of Solid waste - CH4	0.00	1.0198	0.0002	0.005	0.91

CATEGORIES	Trend assessment with uncertainty	Uncertainty	T*U	Relative trend assessment with uncertainty	Cumulative Percentage
Metal industry- CO2 Iron and steel production	0.00	0.1044	0.0002	0.005	0.91

Table A1.11 Results of the key category analysis with LULUCF. Approach 2 Level assessment, year 2022

CATEGORIES	Share	Uncertainty	L*U	Level assessment with uncertainty	Cumulative Percentage
Forest Land remaining Forest Land - Living biomass -CO2	0.05	0.3630	0.0173	0.1188	0.12
Land Converted to Settlements - CO2	0.01	1.0607	0.0106	0.0726	0.19
Transport - CO2 Road transportation	0.22	0.0424	0.0092	0.0634	0.25
Product uses as substitutes for ozone depleting substances - HFCs Refrigeration and Air conditioning	0.02	0.5831	0.0087	0.0602	0.32
Land Converted to Grassland - mineral soils- CO2	0.01	0.9014	0.0085	0.0588	0.37
Solid waste disposal - CH4	0.03	0.2236	0.0076	0.0523	0.43
Direct N2O Emissions from Managed soils	0.01	0.5385	0.0072	0.0498	0.48
Enteric Fermentation- CH4	0.03	0.2022	0.0064	0.0441	0.52
Wastewater treatment and discharge - CH4	0.01	1.0198	0.0059	0.0409	0.56
Energy industries - CO2 gaseous fuels	0.11	0.0424	0.0049	0.0335	0.59
Other sectors - CO2 commercial, residential, agriculture gaseous fuels	0.11	0.0424	0.0047	0.0320	0.63
Manufacturing industries and construction - CO2 gaseous fuels	0.07	0.0424	0.0029	0.0203	0.65
Fugitive - CH4 Oil and natural gas - Natural gas	0.01	0.5009	0.0028	0.0196	0.67
Other sectors - CH4 commercial, residential, agriculture biomass	0.01	0.5009	0.0027	0.0186	0.68
Wastewater treatment and discharge - N2O	0.00	1.0198	0.0025	0.0170	0.70
Land Converted to Forest Land -Living biomass - CO2	0.01	0.3630	0.0024	0.0168	0.72
Energy industries - CO2 solid fuels	0.05	0.0424	0.0022	0.0149	0.73
Manure Management - CH4	0.01	0.2062	0.0022	0.0149	0.75
Indirect N2O Emissions from Managed soils	0.00	0.5385	0.0021	0.0148	0.76
Land Converted to Cropland - soils CO2	0.00	0.9014	0.0021	0.0147	0.78
Product uses as substitutes for ozone depleting substances - HFCs Fire protection	0.00	0.5831	0.0021	0.0144	0.79
Grassland Remaining Grassland - living biomass -CO2	0.00	0.3630	0.0018	0.0124	0.80
Cropland Remaining Cropland - organic soils - CO2	0.00	0.9220	0.0017	0.0118	0.82
Energy industries - CO2 liquid fuels	0.04	0.0424	0.0017	0.0117	0.83
Mineral industry- CO2 Cement production	0.02	0.1044	0.0016	0.0111	0.84
Manufacturing industries and construction - CO2 liquid fuels	0.03	0.0424	0.0014	0.0099	0.85
Cropland Remaining Cropland - mineral soils - CO2	0.00	0.3041	0.0012	0.0082	0.86
Other sectors - CO2 commercial, residential, agriculture liquid fuels	0.03	0.0424	0.0012	0.0080	0.87
Other sectors - N2O commercial, residential, agriculture biomass	0.00	0.5009	0.0011	0.0079	0.873
Land Converted to Forest Land - soils -CO2	0.00	0.5000	0.0010	0.0067	0.880
Indirect CO2	0.00	0.5831	0.0009	0.0064	0.887
Biological treatment of Solid waste - N2O	0.00	1.0198	0.0009	0.0063	0.893
Manure Management - N2O	0.00	0.2062	0.0008	0.0053	0.898
Fugitive - CH4 Oil and natural gas - Other - flaring in refineries	0.00	0.7071	0.0007	0.0051	0.903
Transport - N2O Road transportation	0.00	0.4011	0.0007	0.0051	0.91

Table A1.12 Results of the key category analysis with LULUCF. Approach 2 Trend assessment, base year-2022

CATEGORIES	Trend assessment	Uncertainty	T*U	Relative trend assessment with uncertainty	Cumulative Percentage
Product uses as substitutes for ozone depleting substances - HFCs Refrigeration and Air conditioning	0.01	0.5831	0.0077	0.13	0.13
Land Converted to Grassland - mineral soils- CO2	0.01	0.9014	0.0047	0.08	0.22
Fugitive - CH4 Oil and natural gas - Natural gas	0.01	0.5009	0.0039	0.07	0.28
Energy industries - CO2 liquid fuels	0.08	0.0424	0.0033	0.06	0.34
Energy industries - CO2 gaseous fuels	0.07	0.0424	0.0030	0.05	0.39
Forest Land remaining Forest Land - Living biomass -CO2	0.01	0.3630	0.0029	0.05	0.44
Transport - CO2 Road transportation	0.05	0.0424	0.0023	0.04	0.48
Solid waste disposal - CH4	0.01	0.2236	0.0021	0.04	0.52
Product uses as substitutes for ozone depleting substances - HFCs Fire protection	0.00	0.5831	0.0018	0.03	0.55
Other sectors - CO2 commercial, residential, agriculture gaseous fuels	0.04	0.0424	0.0017	0.03	0.58
Other sectors - CH4 commercial, residential, agriculture biomass	0.00	0.5009	0.0015	0.03	0.61
Other sectors - CO2 commercial, residential, agriculture liquid fuels	0.03	0.0424	0.0012	0.02	0.63
Grassland Remaining Grassland - living biomass -CO2	0.00	0.3630	0.0012	0.02	0.65
Manufacturing industries and construction - CO2 solid fuels	0.02	0.0424	0.0010	0.02	0.66
Mineral industry- CO2 Cement production	0.01	0.1044	0.0009	0.02	0.68
Land Converted to Settlements - CO2	0.00	1.0607	0.0009	0.02	0.70
Land Converted to Cropland - soils CO2	0.00	0.9014	0.0008	0.01	0.71
Biological treatment of Solid waste - N2O	0.00	1.0198	0.0007	0.01	0.72
Manufacturing industries and construction - CO2 liquid fuels	0.02	0.0424	0.0007	0.01	0.73
Other sectors - N2O commercial, residential, agriculture biomass	0.00	0.5009	0.0006	0.01	0.75
Enteric Fermentation- CH4	0.00	0.2022	0.0006	0.01	0.76
Manufacturing industries and construction - CO2 gaseous fuels	0.01	0.0424	0.0006	0.01	0.77
Land Converted to Forest Land - soils -CO2	0.00	0.5000	0.0006	0.01	0.77
Chemical industry- N2O Adipic acid production	0.01	0.1044	0.0005	0.01	0.78
Metal industry- PFCs Aluminium production	0.00	0.2022	0.0005	0.01	0.79
Wastewater treatment and discharge - N2O	0.00	1.0198	0.0005	0.01	0.80
Product uses as substitutes for ozone depleting substances - HFCs Foam blowing agents	0.00	0.5831	0.0005	0.01	0.81
Energy industries - CO2 solid fuels	0.01	0.0424	0.0004	0.01	0.82
Cropland Remaining Cropland - mineral soils - CO2	0.00	0.3041	0.0004	0.01	0.82
Forest Land remaining Forest Land - DOM (deadwood+litter) - CO2	0.00	0.3071	0.0004	0.01	0.83
Transport - CH4 Road transportation	0.00	0.4011	0.0004	0.01	0.84
Fugitive - CH4 Oil and natural gas - Other - flaring in refineries	0.00	0.7071	0.0004	0.01	0.85
Other sectors - CO2 commercial, residential, agriculture other fossil fuels	0.01	0.0424	0.0004	0.01	0.85
Fugitive - CO2 Oil and natural gas - venting and flaring	0.00	0.5099	0.0004	0.01	0.86
Cropland Remaining Cropland - organic soils - CO2	0.00	0.9220	0.0003	0.01	0.86
Chemical industry- PFCs Fluorochemical production	0.00	0.5025	0.0003	0.01	0.87
Fugitive - CO2 Oil and natural gas - Other - flaring in refineries	0.00	0.5099	0.0003	0.01	0.87
Direct N2O Emissions from Managed soils	0.00	0.5385	0.0003	0.00	0.88
Indirect CO2	0.00	0.5831	0.0003	0.00	0.884
Manure Management - CH4	0.00	0.2062	0.0003	0.00	0.888
Chemical industry- HFCs Fluorochemical production	0.00	0.5025	0.0003	0.00	0.89

CATEGORIES	Trend assessment	Uncertainty	T*U	Relative trend assessment with uncertainty	Cumulative Percentage
Chemical industry- N2O Nitric acid production	0.00	0.1044	0.0002	0.00	0.897
Cropland Remaining Cropland - Living biomass - CO2	0.00	0.1173	0.0002	0.00	0.901
Mineral industry- CO2 Other processes uses of carbonates	0.00	0.1044	0.0002	0.00	0.91

Table A1.13 Results of the key category analysis without LULUCF. Approach 2 Level assessment, base year

CATEGORIES	Share	Uncertainty	L*U	Level assessment with uncertainty	Cumulative Percentage
Fugitive - CH4 Oil and natural gas - Natural gas	0.02	0.5009	0.0088	0.0899	0.09
Direct N2O Emissions from Managed soils	0.01	0.5385	0.0080	0.0812	0.17
Transport - CO2 Road transportation	0.18	0.0424	0.0075	0.0762	0.25
Wastewater treatment and discharge - CH4	0.01	1.0198	0.0070	0.0711	0.32
Enteric Fermentation- CH4	0.03	0.2022	0.0066	0.0672	0.39
Energy industries - CO2 liquid fuels	0.16	0.0424	0.0066	0.0670	0.45
Solid waste disposal - CH4	0.03	0.2236	0.0059	0.0594	0.51
Mineral industry- CO2 Cement production	0.03	0.1044	0.0032	0.0322	0.54
Energy industries - CO2 solid fuels	0.07	0.0424	0.0031	0.0319	0.58
Other sectors - CO2 commercial, residential, agriculture liquid fuels	0.07	0.0424	0.0031	0.0316	0.61
Other sectors - CO2 commercial, residential, agriculture gaseous fuels	0.07	0.0424	0.0030	0.0300	0.64
Manufacturing industries and construction - CO2 liquid fuels	0.06	0.0424	0.0027	0.0271	0.66
Manufacturing industries and construction - CO2 gaseous fuels	0.06	0.0424	0.0026	0.0266	0.69
Indirect N2O Emissions from Managed soils	0.00	0.5385	0.0026	0.0265	0.72
Wastewater treatment and discharge - N2O	0.00	1.0198	0.0022	0.0222	0.74
Manure Management - CH4	0.01	0.2062	0.0021	0.0217	0.76
Manufacturing industries and construction - CO2 solid fuels	0.05	0.0424	0.0021	0.0212	0.78
Indirect CO2	0.00	0.5831	0.0015	0.0149	0.80
Energy industries - CO2 gaseous fuels	0.03	0.0424	0.0014	0.0140	0.81
Other sectors - CH4 commercial, residential, agriculture biomass	0.00	0.5009	0.0011	0.0109	0.82
Manure Management - N2O	0.00	0.2062	0.0010	0.0101	0.83
Fugitive - CO2 Oil and natural gas - venting and flaring	0.00	0.5099	0.0009	0.0095	0.84
Other sectors - N2O commercial, residential, agriculture liquid fuels	0.00	0.5009	0.0008	0.0086	0.85
Chemical industry- PFCs Fluorochemical production	0.00	0.5025	0.0008	0.0082	0.86
Manufacturing industries and construction - N2O liquid fuels	0.00	0.5009	0.0008	0.0080	0.87
Chemical industry- N2O Adipic acid production	0.01	0.1044	0.0008	0.0079	0.88
Transport - CH4 Road transportation	0.00	0.4011	0.0007	0.0076	0.88
Metal industry- PFCs Aluminium production	0.00	0.2022	0.0007	0.0070	0.89
Fugitive - CO2 Oil and natural gas - Other - flaring in refineries	0.00	0.5099	0.0007	0.0068	0.90
Metal industry- CO2 Iron and steel production	0.01	0.1044	0.0006	0.0063	0.903
Transport - N2O Road transportation	0.00	0.4011	0.0006	0.0058	0.91
Mineral industry- CO2 Other processes uses of carbonates	0.00	0.1044	0.0005	0.0052	0.91

Table A1.14 Results of the key category analysis with LULUCF. Approach 2 Level assessment, base year

CATEGORIES	Share	Uncertainty	L*U	Level assessment with uncertainty	Cumulative Percentage
Land Converted to Settlements - CO2	0.0119	1.0607	0.0126	0.0987	0.10

CATEGORIES	Share	Uncertainty	L*U	Level assessment with uncertainty	Cumulative Percentage
Forest Land remaining Forest Land - Living biomass -CO2	0.0249	0.3630	0.0090	0.0708	0.17
Fugitive - CH4 Oil and natural gas - Natural gas	0.0165	0.5009	0.0083	0.065	0.23
Direct N2O Emissions from Managed soils	0.0139	0.5385	0.0075	0.0585	0.29
Transport - CO2 Road transportation	0.1651	0.0424	0.0070	0.0549	0.35
Wastewater treatment and discharge - CH4	0.0064	1.0198	0.0065	0.0512	0.40
Enteric Fermentation- CH4	0.0306	0.2022	0.0062	0.0484	0.45
Energy industries - CO2 liquid fuels	0.1452	0.0424	0.0062	0.048	0.50
Solid waste disposal - CH4	0.0244	0.2236	0.0055	0.043	0.54
Grassland Remaining Grassland - living biomass -CO2	0.0096	0.3630	0.0035	0.0273	0.57
Mineral industry- CO2 Cement production	0.0283	0.1044	0.0030	0.0232	0.59
Energy industries - CO2 solid fuels	0.0691	0.0424	0.0029	0.0230	0.61
Other sectors - CO2 commercial, residential, agriculture liquid fuels	0.0684	0.0424	0.0029	0.0228	0.63
Other sectors - CO2 commercial, residential, agriculture gaseous fuels	0.0650	0.0424	0.0028	0.0216	0.66
Manufacturing industries and construction - CO2 liquid fuels	0.0587	0.0424	0.0025	0.0195	0.68
Manufacturing industries and construction - CO2 gaseous fuels	0.0576	0.0424	0.0024	0.0192	0.69
Indirect N2O Emissions from Managed soils	0.0045	0.5385	0.0024	0.0191	0.71
Wastewater treatment and discharge - N2O	0.0020	1.0198	0.0020	0.0160	0.73
Manure Management - CH4	0.0097	0.2062	0.00	0.0157	0.75
Manufacturing industries and construction - CO2 solid fuels	0.0460	0.0424	0.0020	0.0153	0.76
Land Converted to Grassland - mineral soils- CO2	0.0020	0.9014	0.0018	0.0142	0.78
Land Converted to Forest Land -Living biomass - CO2	0.0045	0.3630	0.0016	0.0128	0.788
Cropland Remaining Cropland - organic soils - CO2	0.0015	0.9220	0.0014	0.0112	0.80
Indirect CO2	0.0023	0.5831	0.0014	0.0107	0.81
Energy industries - CO2 gaseous fuels	0.0303	0.0424	0.00	0.0101	0.82
Land Converted to Cropland - soils CO2	0.0013	0.9014	0.0012	0.009	0.83
Other sectors - CH4 commercial, residential, agriculture biomass	0.0020	0.5009	0.0010	0.0078	0.84
Manure Management - N2O	0.0045	0.2062	0.0009	0.0073	0.84
Fugitive - CO2 Oil and natural gas - venting and flaring	0.0017	0.5099	0.0009	0.0068	0.85
Land Converted to Settlements - N2O	0.0008	1.0607	0.0009	0.0067	0.86
Other sectors - N2O commercial, residential, agriculture liquid fuels	0.0016	0.5009	0.0008	0.0062	0.86
Chemical industry- PFCs Fluorochemical production	0.0015	0.5025	0.00	0.0059	0.87
Manufacturing industries and construction - N2O liquid fuels	0.0015	0.5009	0.00	0.0058	0.88
Chemical industry- N2O Adipic acid production	0.0070	0.1044	0.00	0.0057	0.88
Transport - CH4 Road transportation	0.0017	0.4011	0.00	0.0054	0.89
Metal industry- PFCs Aluminium production	0.0032	0.2022	0.00	0.0050	0.89
Fugitive - CO2 Oil and natural gas - Other - flaring in refineries	0.0012	0.5099	0.0006	0.0049	0.90
Forest Land remaining Forest Land - DOM (deadwood+litter) - CO2	0.0019	0.3071	0.0006	0.0047	0.902
Metal industry- CO2 Iron and steel production	0.0056	0.1044	0.0006	0.0046	0.91
Transport - N2O Road transportation	0.0013	0.4011	0.0005	0.0042	0.91

ANNEX 2: ENERGY CONSUMPTION FOR POWER GENERATION

A2.1 Source category description

The main source of data on fuel consumption for electricity production is the annual report “Statistical data on electricity in Italy - Production” (“Dati statistici sull’energia elettrica in Italia - Produzione”), edited from 1999 by the Italian Independent System Operator (TERNA, several years), a public company that runs the high voltage transmission grid. For the period 1990-1998 the same data were published by ENEL (ENEL, several years), former monopolist of electricity distribution. The time series is available since 1963. In these publications, consumptions of all power plants are reported, either public or privately owned.

Detailed data are collected at plant level. They include electricity production and estimation of physical quantities of fuels and the related energy content The Terna Statistical Office, a member of the National Statistical System, is legally responsible for preparing the official statistics of the electricity sector and for managing the survey in its various phases, starting from data acquisition, control and correction of inconsistent data, processing and final publication. In particular, as regards production, the report indicates hydroelectric, thermoelectric and renewable energy production, broken down by plant type and region. In Table A2.1 the time series of fuel consumptions for power sector production is reported.

Table A2.1 Time series of power sector production by fuel, Gg or Mm^3

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
national coal	58	-	Solids 9,633	Solids 16,253	Solids 14,998	Solids 16,245	Solids 7,175	Solids 5,274	Solids 5,590	Solids 8,936
imported coal	10,724	8,216								
lignite	1,501	380								
Natural gas, Mm^3	9,731	11,277	22,334	30,544	29,630	20,365	26,065	24,689	26,356	25,502
BOF (steel converter) gas, Mm^3	509	633	Coal Gases 8,690	Coal-Gases 12,104	Coal-Gases 8,822	Coal-Gases 3,658	Coal Gases 3,801	Coal Gases 2,527	Coal Gases 3,624	Coal Gases 2,791
Blast furnace gas, Mm^3	6,804	6,428								
Coke gas, Mm^3	693	540								
Light distillate	5	6	Oil products 19,352	Oil products 7,941	Oil products 2,152	Oil products 1,133	Oil products 617	Oil products 549	Oil products 761	Oil products 945
Diesel oil	303	184								
Heavy fuel oil	21,798	25,355								
Refinery gas	211	378								
Petroleum coke	186	189								
Gases from chemical processes	444	803	Others	Others	Others	Others	Others	Others	Others	Others
Other fuels	344	697	5,153	Mm^3= 978 Gg= 15,460	Mm^3= 1,501 Gg= 18,160	Mm^3= 3,509 Gg= 16,257	Mm^3= 3,568 Gg= 16,012	Mm^3= 3,478 Gg= 15,884	Mm3= 3,449 Gg=14,632	Mm3=3,337 Gg=17,324
Tar	2	-	-							
Heat recovered from Pyrite	146	3	-							

Source: TERNA, several years

Figures reported in the table show that natural gas has substituted oil products, from 1990 to 2022, becoming the main fuel for electricity production while coal consumption, decreased until 2020, seems to show an upward trend in the last two years.

For the purpose of calculating GHG emissions, a detailed list of 25 fuels was delivered to ISPRA by TERNA for the years from 2000 to 2007. From 2008 the list of the fuels used to estimate emissions was expanded by TERNA, up to 40 different types in 2012. The list includes different varieties of renewable sources according to their composition and origin, useful to estimate the percentage of renewable sources for electricity generation and to comply with national regulations of waste derived fuels. These figures include also the amount of fuels used to cogenerate heat and electricity in some power plants.

The detailed information is confidential and only the elaboration applied to calculate emissions at an aggregated level is reported in Table A2.2. The consumption of municipal solid waste (MSW) / industrial wastes is separated from the biomass consumption, and reported under other fuels, since the use of this fuel for electricity generation is expanding and emission factors are different.

Terna is responsible for compiling the IEA-EUROSTAT-UNECE questionnaire on electricity and heat that is transmitted by MASE, together with other questionnaires on other energy vectors, to EUROSTAT which produces the national energy balances for the member countries of the European Union. In the past, also the association of the industrial electricity producers (UNAPACE, several years) up to the year 1998, and ENI, the former national oil company up to the year 2000, published production data with the associated fuel consumptions (ENI, several years).

A2.2 Methodological issues

The inventory estimates are based directly on the data provided by Terna rather than on the energy balances produced by Eurostat based on the same data since they are available earlier and therefore allow compliance with deadlines. Furthermore, the questionnaire is more detailed and has more information than the Eurostat energy balances and, finally, Eurostat uses conversion factors (e.g. lower calorific values) standardized at European level while on the other hand, where possible, national values are reported. This last circumstance may be the basis of differences between the national data and the Eurostat data.

Table A2.2 shows all energy and emissions summarized by fuel and split in two main categories of producers: public services and industrial producers for the year 2022, according to the reporting in the CRT. Since 1998, expansion of industrial cogeneration of electricity and splitting of national monopoly has transformed many industrial producers into "independent producers", regularly supplying the national grid. So, part of the energy/emissions of the industrial producers are added to Table 1.A.1.a of the CRT, according to the best information available, including those available at plant level from the EU ETS scheme.

Table A2.2 Power sector, Energy/CO_2 emissions in CRT format, year 2022

	TJ	CO_2, Gg
Public Electricity and Heat Production - Table 1.A.1a		
Liquid fuels	27,253	2,099
Solid fuels	219,412	20,456
Natural gas	828,810	48,832
Refinery gases		
Coal gases		
Biomass	91,283	8,115
Other fuels (incl.waste)		
Total	**1,166,759**	**71,388**
Industrial producers and auto-producers - Tables 1.A.1b, 1.A.1c and 1.A.2		
Liquid fuels	20,627	1,460
Solid fuels	6,651	659
Natural gas	207,729	12,239
Refinery gases	30,228	1,709

	TJ	CO_2, Gg
Other refinery products	57,934	5,740
Coal gases	16,634	2,957
Biomass	107,732	9,582
Other fuels (incl.waste)	44,369	4,016
Total	**491,903**	**28,780**
General total	**1,658,662**	**100,167**

Source: ISPRA elaborations

Currently, a review process of the national energy balance is underway with Eurostat and involves the various interested parties (TERNA, GSE, MASE). In a first step, those responsible for the National Energy Balance implemented methodological changes for 2022 and subsequently applied these changes to 2021 to make it consistent. ISPRA is following this process closely in order to know the details and optimize the estimates. It will probably take a few years to also reconstruct the historical series of fuels according to the new definitions.

A2.3 Uncertainty and time-series consistency

The combined uncertainty in CO_2 emissions from electricity production is estimated to be about 4.2% in annual emissions; a higher uncertainty, equal to 50.1%, is calculated for CH_4 and N_2O emissions on account of the uncertainty levels attributed to the related emission factors.

In Table A2.3, the time series of the total CO_2 emissions from electricity generation activities is reported, including total electricity produced and specific indicators of CO_2 emissions for the total energy production and for the thermoelectric production respectively, expressed in grams of CO_2 per kWh. The emission factors are reported excluding the electricity produced from pumped storage units using water that has previously been pumped uphill, as requested by Directive 2009/28/EC of the European Parliament and of the Council promoting the electricity renewable sources.

The time series clearly shows that although the specific carbon content of the kWh generated in Italy has constantly improved over the years, total emissions have raised till 2006 due to the even bigger increase of electricity production. The decreasing trend starting from 2007 results from an increase in energy production from renewable sources, combined with a further reduction in the use of oil products for electricity production. In the last years emissions are quite stable notwithstanding the increase of total energy demand and production, as a consequence of the shift from coal to natural gas.

Table A2.3 Time series of CO_2 emissions from electricity production

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Total electricity produced (gross), TWh	216.9	241.5	276.6	303.7	302.1	283.0	293.9	280.5	289.1	284.0
Total CO_2 emitted, Mt	126.4	133.5	139.8	144.6	120.9	93.7	81.2	72.4	76.9	85.6
g CO_2/kwh (gross thermo-electric production)	709	682	636	574	524	489	416	400	407	431
G CO_2/kwh of total gross production*	593	562	518	487	405	333	278	260	268	303

* excluding electricity production from pumped storage units using water that has previously been pumped uphill
Source: ISPRA elaborations

The trend of CO_2 emissions for thermoelectric production is the result of an increase of natural gas share due to the entry into service of more efficient combined cycle plants. The downward trend takes also into account the general increase in efficiency of the power plants.

A2.4 Source-specific QA/QC and verification

Basic activity data to estimate emissions from all operators are annually collected and reported by the national grid administrator (TERNA, several years). Other data are collected directly from operators for plants bigger than 20 MWh, with a yearly survey since 2005 and communicated at international level in the framework of the EU ETS scheme. Activity data and other parameters, as net calorific values, are compared every year at an aggregate level, by fuel; differences and problems have been identified, analysed in detail and solved with sectoral experts.

A2.5 Source-specific recalculations

Minor recalculations occur because of the update of the whole time series of EFs of residual gas of chemical processes and only in 2010 and 2013-2020 because of the update of data about synthesis gas not applied in the previous submission.

A2.6 Source-specific planned improvements

As reported above, Italy, in agreement with Eurostat, is updating some methodologies relating to the national energy balance and therefore the plan for improving the estimates is strictly linked to the application of these methodologies.

ANNEX 3: ESTIMATION OF CARBON CONTENT OF COALS USED IN INDUSTRY

Care should be exercised to avoid double counting of carbon dioxide (CO_2) emissions in both IPPU and Energy Sector, or, in omitting CO_2 emissions since CO_2 emissions resulting from carbon's role as process reactant and as a heat source to drive the chemical reactions involved in the metallurgical processes are closely related in many cases. Any methodology considering CO_2 capture should consider that CO_2 emissions captured in the process may be both combustion and process related. In cases where combustion and process emissions are to be reported separately, e.g., for iron and steel production, inventory compilers should ensure that the same quantities of CO_2 are not double counted.

Iron and steel integrated production has only taken place in two sites in Italy since the year 2005, with integrated steel plants, coke ovens and electricity self-production and just in one site since 2015. Only pig iron has been produced also in one additional location up to 2020. This has allowed for careful check of the processes involved and the emissions estimates at site level and, with reference to other countries, may or may not have exacerbated the unbalances in carbon emissions due to the use of standard emission factor developed for other industrial sites.

In estimating emissions from this source category: coke production (Energy) and iron and steel production (IPPU), there is a risk of double counting or omission in either the Industrial Processes or the Energy Sector. According to the 2006 Guidelines, since the primary use of carbon sources (predominantly coke, but also coal, oil, natural gas, limestone, etc.) is to produce pig iron, the CO_2 and CH_4 emissions from iron and steel production including sinter production are considered industrial process emissions and should be reported as such. The CO_2 and CH_4 emissions from coke production (both fuel consumption and conversion losses) are categorized as energy production and should be reported as such. However, for integrated production and iron and steel with onsite coke production, there may be flows of by-products (e.g., coke oven gas, blast furnace gas, coke oven by-products) between the coke production facility and the iron and steel production facility, creating potential double counting issues. Carbon consumed in the form of coke oven gas at an iron and steelmaking facility and the resulting CO_2 and CH_4 emissions would be categorized as IPPU emissions and reported as such. Carbon consumed in the form of blast furnace gas at an onsite coke production facility and the resulting CO_2 and CH_4 emissions would be categorized as Energy emissions and should reported as such. Tracking of such carbon flows will require good knowledge of the inventory in that source category. Because of the dominant role of coke, it is important to consider the existence of coke making at a facility and define the boundary limits of a carbon balance at an iron and steelmaking facility to assure that CO_2 emissions are not double counted. CO_2 and CH_4 emissions associated with onsite and offsite coke making are to be reported under the Energy Sector.

Consistent with the IPCC good practice guidance, Italy provides the energy and carbon balance in the iron and steel category. However, CO_2 emissions due to the consumption of coke, coal and other reducing agents used in the iron and steel industry have been accounted for as fuel consumption and reported under the energy sector when the IPCC good practice guidance shows a preference for including these emissions under the industrial processes sector rather than the energy sector.

But it is necessary to take into account that carbon serves a dual purpose in the iron making process, primarily as a reducing agent to convert iron oxides to iron, but also as an energy source to provide heat when carbon and oxygen react exothermically.

The choice between several reducing agents is not determined by costs alone. Apart from being a reducing agent, coke also serves as a carrier of the bulk column in the blast furnace. Without this carrying capacity, blast furnace operation would not be possible (coke is highly porous).

The coke primarily serves as a reducing agent, but also as a fuel and it is not possible to distinguish between the two functions of the material.

A balance is made between the coal used for coke production and the quantities of derived fuels used in various sectors. The iron and steel sector gets the resulting quantities of energy and carbon after subtraction of what is used for electricity generation, non-energy purposes and other industrial sectors.

To avoid the double counting a specific methodology has been developed: it balances energy and carbon content of coking coals used by steelworks, industry, for non-energy purposes and coal gasses used for electricity generation.

The balance is made between the coal used for coke production and the quantities of derived fuels used in various sectors. The iron and steel sector gets the resulting quantities of energy and carbon after subtraction of what is used for electricity generation, non-energy purposes and other industrial sectors. According to the 2006 IPCC Guidelines (IPCC, 2006), the use of reductants is also included in this balance because no sufficient information to detail emissions between the energy and industrial processes sectors is available. The carbon balance methodology does not imply separate off input between the energy and industrial sectors but ensures no double counting occurs.

Table A3.1 summarizes the quantities of coal and coal by-products used by the energy system in the year 2022; all the data mentioned are those provided by the Ministry of Environment to the Joint Questionnaire IEA/OECD/EUROSTAT for the same year.

In Table A3.1 the quantities of coke, coke gas and blast furnace gas used by the different sectors are detailed as well as the quantities of the same energy carriers that are self-used, used to produce coke or wasted. Inputs are indicated in the blue cells while outputs are reported in the orange ones.

Table A3.1 Energy balance, 2022, TJ

	TJ input	TJ output	
steam coal	251,925	600	clinker/industry
		236,847	thermoelectric power plants
		14,478	blast furnace
anthracite	2,113	2,113	steel plants
sub bituminous and lignite	3	3	clinker/industry
coking coal	57,933	0	coking coal consumption
		0	Non-energy use in other sectors
Coke import/export/stock change	-913		
coke		0	other industry and domestic
			ferroalloys
		11,250	blast furnace consumption
coke oven gas		308	coke oven gas in coke oven and blast furnace
		2,857	coke oven gas reheating
		5,871	coke oven gas thermoelectric
blast furnace gas		0	BF gas in coke oven
		10,673	BF gas thermoelectric
		0	BF gas reheating
BOF gas		90	coal gasses in thermoelectric + reheating
			carbon stored in products
tot	**311,061**	**285,088**	**Input – output= 26,973 TJ → 9.1%**

In Table A3.2, the same energy data of Table A3.1 evaluated for their carbon content are reported, according to the emission factors reported in Table 3.12 of the NIR.

The balance is the resulting quantity of emissions after subtraction of carbon emissions estimated for coke ovens, electricity production, other coal uses and non-energy uses.

The low implied emission factors in CRT and annual variations in the average CO_2 emission factor for solid fuel are due to the fact that both activity data and emissions reported under this category include the results of the carbon balance.

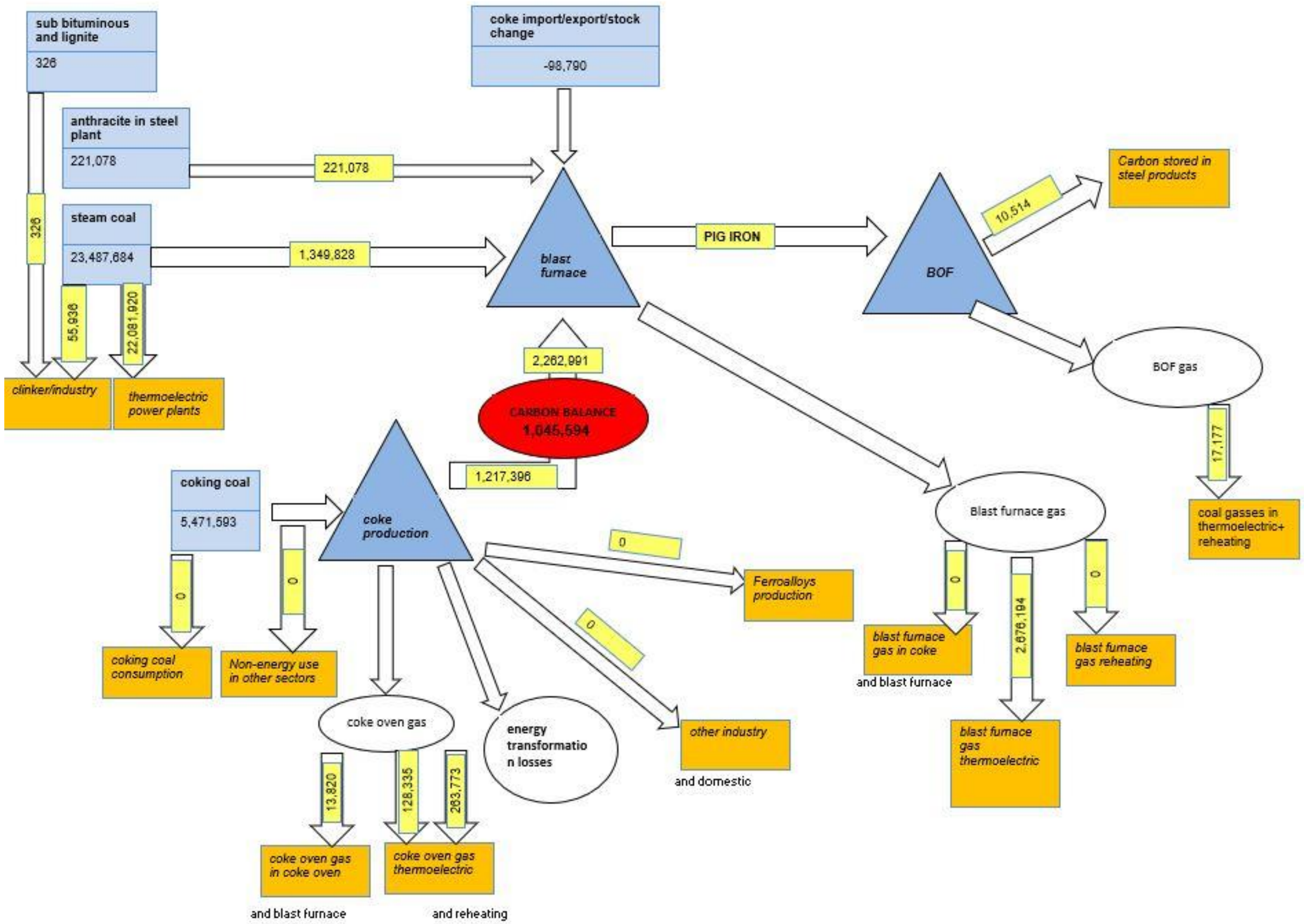
All main installations of the iron and steel sector are included in EU ETS, but not all sources of emission. Only part of the processes of integrated steel making is subject to EU ETS, in particular the manufacturing process after the production of row steel was excluded up to 2007 and only the lamination processes have been included from 2008 onwards. Additional information from the operators on fuel consumptions and average emission factors is used to verify our calculation and CO_2 emissions at plant level and to calculate average CO_2 emission factors for coal and derived gases from 2005; obviously from the 2015 submission emission factors have been updated on the basis of 2006 IPCC Guidelines, see Annex 6 for further details.

Table A3.2 Carbon balance, 2022, Gg CO_2

	input	output	
steam coal	23,487,684	55,936	clinker/industry
		22,081,920	thermoelectric power plants
		1,349,828	blast furnace
anthracite	221,078	221,078	steel plants
sub bituminous and lignite	326	326	clinker/industry
coking coal	5,471,593	0	coking coal consumption
		0	Non-energy use in other sectors
coke import/export/stock change	-98,790		
coke		0	other industry and domestic
		0	ferroalloys
		1,217,396	blast furnace consumption
coke oven gas		13,820	coke oven gas in coke oven and blast furnace
		128,335	coke oven gas reheating
		263,773	coke oven gas thermoelectric
blast furnace gas		0	BF gas in coke oven
		2,676,194	BF gas thermoelectric
		0	BF gas reheating
BOF gas		17,177	coal gasses in thermoelectric + reheating
		10,514	carbon stored in products
tot	**29,081,892**	**28,036,298**	**Input-output=1,045 Gg CO_2 unbalance 3.73%**

In 2022 the unbalance in terms of CO_2 is equal to 1,045 Gg; this amount has been subtracted from the total to avoid double counting of carbon. The flowchart of carbon - cycle for the year 2022 is reported below. CO_2 emissions from primary input fuels and from final fuel consumptions are compared. Emissions related to fuel input data are enhanced in light-blue whereas emissions estimated from final fuel consumptions are highlighted in orange. Emissions from the use of coke in blast furnaces result from differences between emissions from final consumption of coke and the value of the carbon balance for 2022. The amount of carbon stored in steel produced was estimated and subtracted from the balance to avoid the subsequent overestimation of CO_2.. The amount of coke used for ferroalloys production has also been subtracted to avoid a double counting of emissions already estimated and reported in the industrial processes sector.

CO_2 emission calculation (Gg) Year 2022



ANNEX 4: CO_2 REFERENCE APPROACH

A4.1 Introduction

The IPCC Reference Approach is a 'top down' inventory based on data on production, imports, exports and stock changes of crude oils, feedstock, natural gas and solid fuels. Estimates are made of the carbon stored in manufactured products, the carbon consumed as international bunker fuels and the emissions from biomass combustion.

It is good practice to apply both a sectoral approach and the reference approach to estimate a country's CO_2 emissions from fuel combustion and to compare the results of these two independent estimates. Significant differences may indicate possible problems with the activity data, net calorific values, carbon content, excluded carbon calculation, etc. The Reference Approach is designed to calculate the emissions of CO_2 from fuel combustion, starting from high level energy supply data. The assumption is that carbon is conserved so that, for example, carbon in crude oil is equal to the total carbon content of all the derived products. The Reference Approach does not distinguish between different source categories within the energy sector and only estimates total CO2 emissions from Source category 1A, Fuel Combustion. Emissions derive both from combustion in the energy sector, where the fuel is used as a heat source in refining or producing power, and from combustion in final consumption of the fuel or its secondary products.

For the reference approach, as for the inventory, data submitted by the Ministry of Environment to the Joint Questionnaire IEA/OECD/EUROSTAT have been used for solid fuels, natural gas, liquid fuels and the update is ongoing for other fuels.

Starting from those data and using the emission factors reported in chapter 3, Table 3.12, it is possible to estimate the total carbon entering the national energy system.

The carbon stored in products is estimated according to the procedure illustrated in paragraph 3.8 and directly subtracted to the emission balance.

With reference to table 1.A(b) of the CRT, we make reference to the tables reported in Annex 5. In particular the following data are reported and used for the *Reference Approach*:

1. all liquid fuels as available in the Joint Questionnaire IEA/ EUROSTAT/UNECE;
2. all coal data as available in the Joint Questionnaire IEA/ EUROSTAT/UNECE;
3. natural gas data as available in the Joint Questionnaire IEA/ EUROSTAT/UNECE;
4. waste production data;
5. biomass fuel data as available in the Joint Questionnaire IEA/ EUROSTAT/UNECE.

The following additional information is needed to complete table 1.A(b) of CRT and it is found in other sources:

1) Orimulsion, this fuel is mixed up with imported fuel oil (on the base of the energy content), the quantities used for electricity generation are reported by ENEL (ENEL, several years), the former electricity monopoly, presently the only user of this fuel, in their environmental report. This fuel is not used any more since 2004.
2) No energy products from refineries.

   Data on those materials are mixed up in the no energy use by the joint questionnaire, while detailed data are available in BPT (MASE, several years [b]). The quantities of those materials are quite relevant for the no energy use of oil.

A4.2 Comparison of the sectoral approach with the reference approach

The detailed inventory contains sources not accounted for in the IPCC Reference Approach, as offshore flaring and well testing and non-fuel industrial processes, and so gives a higher estimate of CO_2 emissions from 1A categories.

First of all, the IPCC Reference total CO_2 can be compared with the CRT Table 1A total. Results show the IPCC Reference totals are between –1.28 and –4.27 percent with respect to the comparable 'bottom up' totals.

Differences are observed both for energy and emissions. Quality control activities have been done and a detail explanation of them will require specific meetings and additional verification activities with the energy experts responsible for the official communication of the energy statistics in order to make the transition to the new data format for the whole time series.

As above mentioned, sectoral approach considers sources not considered in the Reference approach, so negative differences occur between CO_2 emissions from reference approach and the sectoral one. The highest difference is observed for 1999.

Differences between emissions estimated by the reference and sectoral approach are reported in Table A4.1.

Table A4.1 Reference and sectoral approach CO_2 emission estimates 1990-2022 (Mt) and percentage differences

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Sectoral approach	405.1	417.5	440.8	470.4	412.0	343.8	322.1	287.0	318.9	325.6
Reference approach	396.4	407.1	423.0	457.5	399.7	330.1	315.8	283.3	312.5	319.2
Δ %	-2.16	-2.50	-4.04	-2.73	-2.99	-3.97	-1.95	-1.28	-2.01	-1.96

There are a number of reasons why the totals differ, and these arise from differences in the methodologies and the statistics used.

Explanations for the discrepancies:

1. The IPCC Reference Approach is based on statistics of production, imports, exports and stock changes of fuels whilst the 'bottom-up' approach uses fuel consumption data. The two sets of statistics can be related using mass balances (MASE, several years), but these show that some fuel is unaccounted for. This fuel is reported under 'statistical differences' which consist of measurement errors and losses. A significant proportion of the discrepancy between the IPCC Reference approach and the 'bottom up' approach arises from these statistical differences particularly with liquid fuels.
2. In the power sector, in the detailed approach, statistics from producers are used, whereas for the reference approach the IEA/EUROSTAT/UNECE questionnaires data are used. The two data sets are not connected; in the questionnaires sections used, only the row data of imports-exports are contained.
3. The 'bottom up' approach only includes emissions from the no energy use of fuel where they can be specifically identified and estimated such as with fertilizer production and iron and steel production. The IPCC Reference approach implicitly treats the non-energy use of fuel as if it were combustion. A correction is then applied by deducting an estimate of carbon stored from non-energy fuel use. The result is that the IPCC Reference approach is based on a higher estimate of non-energy use emissions than the 'bottom-up' approach.

The IPCC Reference Approach uses data on primary fuels such as crude oil and natural gas liquids which are then corrected for imports, exports and stock changes of secondary fuels. Thus, the estimates obtained will be highly dependent on the default carbon contents used for the primary fuels.

A4.3 Comparison of the sectoral approach with the reference approach and international statistics

A verification of national energy balance and CO_2 emissions with data communicated to the joint EUROSTAT/IEA/UNECE questionnaire was carried out in 2004 and results are reported in the document "Energy data harmonization for CO_2 emission calculations: the Italian case" (ENEA/MAP/APAT, 2004).

From 2004 some improvements were implemented both in the national and international statistics also through the revision of the questionnaire but differences in apparent consumptions still occur.

Specifically, for Italy, major discrepancies identified were only related to the consumption of refinery feedstocks which differs considerably between annual Eurostat data and the CRT: annual Eurostat consumption is 30% and 40% lower than the CRT for 2008 and 2009 respectively. The judgment of the energy balance experts indicated the introduction of backflows as a correct allocation with respect to the EUROSTAT balance. From our point of view, the issue regards the allocation of refinery feedstocks which, in addition to production, import and export, also include the item "backflows".

In order to improve transparency and comparability backflows and feedstock are reported in the following table.

Table A4.2 Refinery feedstock, data for to the Joint Questionnaire IEA/OECD/EUROSTAT (kt)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Imports	11,553	8,571	6,628	5,855	6,856	6,136	2,533	2,704	2,330	1,791
Exports	1,706	261	521	805	1,382	545	1,005	952	897	1,801
Stock changes	-111	69	-53	399	-479	28	18	-755	28	-186
Backflows	3,678	4,410	2,626	2,080	1,732	1,641	1,789	1,758	1,804	2,279

ANNEX 5: NATIONAL ENERGY BALANCE, YEAR 2022

Currently, a review process of the national energy balance is underway with Eurostat and involves the various interested parties (TERNA, GSE, MASE) in Italy.

In 2024 submission, some recalculations occurred as in the following. In a first step, those responsible for the National Energy Balance implemented methodological changes for 2022 and subsequently applied these changes to 2021 to make it consistent. ISPRA is following this process closely in order to know the details and optimize the estimates. This change in methodology has caused a break in the series for some fuels and it is necessary further work to improve the time series consistency and it will probably take a few years to also reconstruct the historical series of fuels according to the new definitions.

The official national energy balance (BEN) from the year 1998 to 2020 is available, in Italian, on the website of the Italian Ministry of the Environment (MASE, several years): https://sisen.mase.gov.it/dgsaie/bilancio-energetico-nazionale. At the same web address data communicated by Italy to the Joint Questionnaire OECD/IEA/EUROSTAT are available in the format revisited by EUROSTAT. Some differences between data communicated to the international organizations and EUROSTAT publication have been observed and are under investigation; they should mainly due to the use of default instead of country specific energy conversion factors and different classification criteria of fuels.

The energy balances of the entire times series are reported on the Eurostat website: Energy Balances (europa.eu).

From 2016, data submitted by the Ministry of Environment to the Joint Questionnaire IEA/OECD/EUROSTAT have been used for solid, liquid and gaseous fuel consumptions (EUROSTAT, 2022). The entire time series was not reconstructed and data from national energy balance (BEN) have been also used for the inventory. In fact, some inconsistencies were found in data communicated to Eurostat and referring to the ninety years, especially in the sectoral distribution of fuels; in these cases the information already available in the national energy balances has been maintained because considered more reliable and consistent in the time series.

ANNEX 6: NATIONAL EMISSION FACTORS

Monitoring of the carbon content of the fuels used nationally is an ongoing activity at ISPRA. The purpose is to analyse regularly the chemical composition of the used fuel or relevant commercial statistics to estimate the carbon content / emission factor (EF) of the fuels. For each primary fuel (natural gas, oil, coal) a specific procedure has been established.

Starting from 2021 submission the updated atomic weights of Carbon and Oxygen (NIST Chemistry WebBook, SRD 69 - National Institute of Standard and Technology, USA) have been used since 2005 (National Institute of Standard and Technology, USA) to convert carbo content to CO_2 content and viceversa.

A6.1 Natural gas

The national market is characterized by the commercialization of gases with different chemical composition in variable quantities from one year to the other. Since 1990 natural gas has been produced in Italy and imported by pipelines from Russia, Algeria and the Netherlands. Moreover, an NGL facility is importing gas from Algeria and Libya. From 2003-2004 onwards Norway and Libya have also been added to the supply list, through new pipeline connections, and from 2008 a new NGL facility has entered into service, using mainly liquefied gas from Oman. There are also sizeable underground storage facilities and additional pipelines/NGL facilities are planned.

The estimation of an average EF for natural gas is the only way to calculate total emissions from this source in Italy, because the origin of the gas used by final consumers cannot be tracked trough the national statistics and it is subject to variations during the year, according to supply. Only the main industrial installations perform routine checks to estimate the average chemical composition / energy content of natural gas used.

Another task connected to the use of natural gases of different origin and composition is linked to the estimation of an average content of methane to estimate fugitive emissions of this gas from the transmission / distribution network. Since the beginning of the inventory estimations, the average EF of the used gas in Italy has been estimated by the inventory team and it changes every year.

From 2008 in the energy balance, BEN 2008, (MASE, several years [a]) some modifications have occurred; a new average lower heat value has been derived from Eurostat methodology. This new conversion factor did imply a methodological revision to estimate the average national EF. Additionally, the IPCC 2006 guidelines, see table A6.1, contain important information to consider: the recognition of a certain variability of the EF for this source; the estimation of a lower and upper bound for the EFs; the link between energy content and EF; the statement that, by converting to energy units all EFs, their variability can be reduced. Moreover default oxidation factor is estimated to be equal to 1 (full oxidation) (IPCC, 2006).

Each of natural gases transmitted by the grid operator is regularly analyzed at import gates, for budgetary reasons. Energy content for cubic meters, percentage of methane and other substances are calculated. For example, methane content can considerably vary: national produced gas sold to the grid is almost 99% methane (% moles), the one coming from Algeria has less than 85% of methane and significant quantities of propane-butane. Also carbon content varies significantly.

Natural gas properties are more stable referring to the country of origin, with small variations in chemical composition from year to year. Speciation of gas from each import manifold is regularly published by national transmission grid operator (Snam Rete Gas, several years). Other information is also available from the main final users (TERNA, several years).

So, for each year, the average methane and carbon content of the natural gas used in Italy are estimated, using international trade statistical data, and a national emission factor is estimated.

The list of factors for the years of interest is reported in Table A6.1.

As shown in the table, the ranges of national EFs are within the lower and upper threshold of the IPCC 2006 guidelines.

With regard the oxidation factors, increasing values have been used from 0.995 in the 1990 to 1.000 in 2005 according to the improvement of combustion efficiency in the nineties.

Table A6.1 Natural gas carbon emission factors

	t CO_2 / TJ (stechiometric)	t CO_2 / TJ	t CO_2 / 10^3 std cubic mt	t CO_2 / toe
Natural gas (dry) IPCC '96	55.820	55.820	1.928	2.337
Natural gas, IPCC '06 average	56.100	56.100	1.932	2.349
lower	54.300			
upper	58.300			
National Emission Factors				
Natural gas , 1990	56.103	55.822	1.935	2.337
Natural gas, 1995	56.236	55.955	1.947	2.343
Natural gas , 2000	56.415	56.258	1.955	2.355
Natural gas , 2001	56.337	56.212	1.946	2.353
Natural gas , 2002	56.914	56.819	1.985	2.379
Natural gas, 2003	56.483	56.420	1.974	2.362
Natural gas, 2004	56.450	56.418	1.973	2.362
Natural gas, 2005	56.475	56.475	1.978	2.365
Natural gas, 2006	56.553	56.553	1.979	2.368
Natural gas, 2007	56.444	56.444	1.976	2.363
Natural gas, 2008, with 8190 lhv	57.732	57.732	1.980	2.417
Natural gas, 2009, with 8190 lhv	57.914	57.914	1.986	2.425
Natural gas, 2010, with 8190 lhv	57.945	57.945	1.987	2.426
Natural gas, 2011, with 8190 lhv	57.427	57.427	1.969	2.404
Natural gas, 2012, with 8190 lhv	57.702	57.702	1.979	2.416
Natural gas, 2013, with 8190 lhv	57.447	57.447	1.970	2.405
Natural gas, 2014, with 8190 lhv	57.473	57.473	1.971	2.406
Natural gas, 2015, with 8190 lhv	57.633	57.633	1.976	2.413
Natural gas, 2016, with 8190 lhv	58.140	58.140	1.994	2.434
Natural gas, 2017, with 8190 lhv	58.000	58.000	1.989	2.428
Natural gas, 2018, with 8190 lhv	57.846	57.846	1.984	2.422
Natural gas, 2019, with 8190 lhv	57.746	57.746	1.980	2.418
Natural gas, 2020, with 8190 lhv	57.910	57.910	1.986	2.425
Natural gas, 2021, with 8190 lhv	58.504	58.504	2.006	2.449
Natural gas, 2022, with 8190 lhv	58.918	58.918	2.020	2.467

Source: ISPRA elaborations

The methodology used to estimate the EF is based on the available data. Each year the quantities of natural gas imported or produced in Italy are published on the web by the MASE https://sisen.mase.gov.it/dgsaie/bilancio-gas-naturale.Those data are produced by the national grid operator and are concerned on all imported gas by point of entrance in the country and all natural gas produced. To compare quantities of different gases, the physical quantities of imported/produced gas are normalized to a higher heat value (hhv) equal to 9100 kcal/m^3 and standard conditions. Other data input used in the estimation are the average chemical composition and the hhv of the gas at each import "gate" and for the national production. Those data are published by Snam in its yearly "Bilancio di Sostenibilità" (Snam Rete Gas, several years) and with them it is possible to estimate the average carbon content of the fuel. Those data are referred to the physical quantities of imported / produced gas.

So the total quantities of imported gas (normalized at the hhv of 9100) published by MASE are transformed back to the physical quantities of actually imported gas using the hhv ratio and then average carbon content of the total gas imported or produced in Italy can be estimated. Those data are then referred back to the normalized quantities of gas used in national statistics.

Data on final consumption of gas refers to the lower heat value (lhv). In particular the electricity production companies regularly estimate the actual lhv of the gas they are using and this figure is published yearly by TERNA. Operator's data are used to verify the calculation results.

As mentioned above, in the BEN 2008 the average lhv has been changed from 8250 kcal/m^3 (historical value) to 8190 kcal/m^3, to harmonize national data with Eurostat methodology. Eurostat considers the lhv as being 10% less than hhv, regardless of the actual value. This change influences the EF if it is referred to the energy content (lhv) of the fuel, but it has no influence if the EF is referred to cubic meters.

A6.2 Diesel oil, petrol and LPG

ISPRA set periodical investigations on the carbon content of the main transportation fuels sold in Italy, petrol, diesel and LPG, with the aim of testing the average fuels. The goal of this work is the verification of CO_2 emission factors of Italian energy system, with a particular focus on the transportation sector. The results of analysis of fuel samples performed by "Stazione Sperimentale Combustibili" (APAT, 2003; Innovhub, several years) were compared with emission factors used in Reference Approach of the Intergovernmental Panel for Climate Change (IPCC, 1997; IPCC, 2006).

These two methodologies are widely used to prepare data at the international level but, when applied to the Italian data set produce results with significant differences, around 2- 4%. The reason has been traced back to the emission factors that are referred to the energy content of the fuel for IPCC.

The results of the study link the chemical composition to the lhv for a series of fuels representative of the national production, allowing for more precise evaluations of the emission factors.

IPCC 1996 emission factors for diesel fuels and IPCC-Europe for LPG are almost identical to the experimental results (less than 1% difference), and it has been decided to use IPCC emission factors for the period 1990-1999 and the measured EF from the year 2000 onwards. The figures from the last surveys have been used for the years 2017-2020.

Concerning petrol, instead, IPCC 1996 emission factors is quite low and it has to be updated, the reason may be linked to the extensive use of additives in recent years to reach a high octane number after the lead has been phased out. For 2000 and the following years the experimental factor are used, for the period 1990-1999 it has been decided to use an interpolate factor between IPCC emission factors and the measured value, using the lhv as the link between the national products and the international database.

The list of emission factors used is reported in Table A6.2.

Table A6.2 Fuels, national production, carbon emission factors

	t CO_2 / TJ	t CO_2 / t	t CO_2 / toe
Petrol, IPCC / OECD	68.559	3.071	2.870
Petrol, IPCC Europe	72.270	3.148	3.026
Petrol (Italian National Energy Balance), interpolated emission factor 1990-1999	71.034	3.123	2.974
Petrol, experimental averages 2000-2011	71.864	3.143	3.009
Petrol, experimental averages 2012-2016	73.338	3.140	3.071
Petrol, experimental averages 2017-2020	73.081	3.152	3.060
Gas oil, IPCC / OECD	73.274	3.175	3.068
Gas oil, IPCC Europe	73.260	3.108	3.067
Gas oil, 1990 – 1999	73.274	3.129	3.068
Gas oil, engines, experimental averages 2000-2011	73.892	3.171	3.094
Gas oil, engines, experimental averages 2012-2016	73.648	3.151	3.084
Gas oil, engines, experimental averages 2017-2020	73.510	3.150	3.078
Gas oil, heating, experimental averages 2000-2011	74.438	3.175	3.117
Gas oil, heating, experimental averages 2012-2016	73.578	3.155	3.081
Gas oil, heating, experimental averages 2017-2020	73.927	3.169	3.095
LPG, IPCC / OECD	62.392	2.952	2.612
LPG, IPCC / Europe	64.350	3.000	2.694
LPG, 1990 – 1999	62.392	2.873	2.612
LPG, experimental averages 2000-2016	65.592	3.026	2.746
LPG, experimental averages 2017-2020	65.984	3.026	2.763
Biodiesel, experimental averages 2017-2020	74.938	2.803	3.137

Source: ISPRA elaborations

A6.3 Fuel oil

The main information available nationally of fuel oil EF is a sizable difference in carbon content between high sulphur and light sulphur brands. The data were elaborated from literature and from an extensive series of samples (more than 400) analysed by ENEL and made available to ISPRA. Carbon content varies to a certain extent also between the medium sulphur content and the very low sulphur products, but the main discrepancies refer to the high sulphur type. According to the available statistical data, it was possible to trace back to the year 1990 the produced and imported quantities of fuel oil divided between high and low sulphur products and to estimate the average carbon emission factor for the years of interest, see Table A6.3 for details.

Table A6.3 Fuel oil, average of national and imported products, carbon emission factors

	t CO_2 / TJ (stechiometric)	t CO_2 / TJ	t CO_2 / t	t CO_2 / toe
Fuel oil , IPCC, 1996	77.400	76.626	3.154	3.208
Fuel oil , IPCC, 2006 average	77.400	77.400	3.127	3.241
lower	75.500			
upper	78.800			
National emission factors				
Fuel oil, average 1990	77.339	76.565	3.113	3.206
Fuel oil, average 1995	77.425	76.650	3.129	3.209
Fuel oil, average 2000	76.665	76.239	3.140	3.192
Fuel oil, average 2001	76.655	76.315	3.141	3.195
Fuel oil, average 2002	76.709	76.454	3.148	3.201
Fuel oil, average 2003	76.921	76.750	3.158	3.213
Fuel oil, average 2004	76.939	76.853	3.162	3.218
Fuel oil, average 2005	75.877	75.877	3.144	3.177
Fuel oil, average 2006	75.955	75.955	3.144	3.180
Fuel oil, average 2007	76.328	76.328	3.147	3.196
Fuel oil, average 2008	76.682	76.682	3.145	3.211
Fuel oil, average 2009	76.635	76.635	3.145	3.209
Fuel oil, average 2010	76.865	76.865	3.145	3.218

Fuel oil, average 2011	77.063	77.063	3.147	3.226
Fuel oil, average 2012	76.507	76.507	3.145	3.203
Fuel oil, average 2013	76.695	76.695	3.145	3.211
Fuel oil, average 2014	76.698	76.698	3.145	3.211
Fuel oil, average 2015	76.606	76.606	3.144	3.207
Fuel oil, average 2016	76.606	76.606	3.144	3.207
Fuel oil, average 2017	76.690	76.690	3.144	3.211
Fuel oil, average 2018	76.692	76.692	3.144	3.211
Fuel oil, average 2019	76.594	76.594	3.143	3.207
Fuel oil, average 2020	76.497	76.497	3.143	3.203
Fuel oil, average 2021	76.501	76.501	3.143	3.203
Fuel oil, average 2022	76.609	76.609	3.144	3.207

Source: ISPRA elaborations

Data for all years are within IPCC 2006 ranges, but it can be noticed that are on the lower side from year 2000 onwards. The change from an average to a low EF is due to the harmful emissions limits and fuel regulations introduced in Italy between 1990 and 2000. Most of the fuel used from 2000 onwards is not heavy, high sulphur, fuel oil but light type, low sulphur. With regard the oxidation factors, increasing values have been used from 0.99 in the 1990 to 1.00 in 2005 according to the improvement of combustion efficiency in the nineties.

A6.4 Coal

Italy has only negligible national production of coal; most part is imported from various countries and there are differences in carbon content of coal mined in different parts of the world. The variations in carbon content can be linked to the hydrogen content and to the LHV of the coal.

An additional national circumstance refers to the absence of long term import contracts. The quantities shipped by the main exporters change considerably from year to year. Detailed data are available in BPT (MASE, several years [b]) supplied by the Ministry of Environment and reported for the submission year in Table A6.4.

Table A6.4 – Coal imported by country in 2022 (Mg)

Country	Coaking coal	Coke	Anthracite	Steam coal	Lignite	Total Coal	TAR	Petroleum coke
CZECH REPUBLIC		509				509		
GERMANY					308	308		
GREECE						0		9,950
POLAND		63,807	126			63,933		24
SLOVAKIA			764			764		
SPAIN				1,088,963		1,088,963		23,609
BELGIUM			552			552		
BULGARIA			5,144			5,144		
NETHERLANDS						0	1,262	32,200
TOTAL EU	**0**	**64,316**	**6,586**	**1,088,963**	**308**	**1,160,173**	**1,262**	**65,783**
AUSTRALIA	552,401			414,455		966,856		
CANADA	134,691					134,691		
CINA		109,180				109,180		
COLOMBIA				606,043		606,043		
INDONESIA				1,154,201		1,154,201		
KAZAKISTAN				308,808		308,808		
INDIA		89,618				89,618		
RUSSIA		38,663	62,104	3,869,751		3,970,518		
SOUTH AFRICA			480	2,179,726		2,180,206		
U.S.A.	1,284,237	12,042		163,210		1,459,489		859,583
UK						0		543
TOTAL NON_EU	**1,971,329**	**249,503**	**62,584**	**8,696,194**	**0**	**10,979,610**	**0**	**860,126**
TOTAL	**1,971,329**	**313,819**	**69,169**	**9,785,158**	**308**	**12,139,783**	**1,262**	**925,910**

Source: MASE, several years [b]

Therefore an attempt was made to find out a methodology allowing for a more precise estimation of the carbon content of this fuel. It is possible, using literature data for the coals and detailed statistical records of international trade, to find out the weighted average of carbon content and of the LHV of the fuel imported to Italy each year. The still unresolved problem is how to properly link statistical data, referred to the coal "as it is" without specifying moisture and ash content of the product, to the literature data, referring to sample coals.

The intention is to improve the quality of the collected statistical data including moisture content of coals; currently this obstacle has been overcome with the following procedure:

- using an ample set of experimental data on coals imported in a couple of years on an extensive series of samples, more than 200, analysed by ENEL (the main electricity producing company in Italy) it was possible to correlate "as it is" LHV and carbon content to the average properties of the coals imported in the same period of time and calculated from literature data (EMEP/CORINAIR, 2007);
- for each inventory year, it was possible to calculate the weighted average of LHV and carbon content of imported coals using available literature data;
- using this calculated data and the correlation found out, the estimate of carbon content of the average "as it is" coal reported in the statistics was possible.

Using this methodology and the available statistical data, it was possible to trace back to the year 1990 the average LHV of the imported coal and estimate average carbon EF for each year, see Table A6.4 for detailed data. The results do not show impressive changes yearly; anyway a noticeable difference in the emission factor is highlighted in the table. In Table A6.5 updated coal EFs are reported. National emission factors result in the range given by the lower and upper values for "other bituminous coal" in the IPCC 2006 Guidelines (IPCC, 2006).

With the aim to improve the estimation of the coal CO_2 emission factors an in depth analysis of data reported in the framework of the European emissions trading scheme has been carried out. In consideration that these data referring to emission factors and activity data are validated and the amount of fuel reported accounts for more than 90% of the national coal fuel consumption, the average coal CO_2 emission factors, resulting from ETS data, have been applied from 2005.

With regard the oxidation factors, increasing values have been used from 0.98 in the 1990 to 1.00 in 2005 according to the improvement of combustion efficiency in the nineties.

Table A6.5 – Coal, average carbon emission factors

	t CO_2 / TJ (stechiometric)	t CO_2 / TJ	t CO_2 / t	t CO_2 / toe
Other bituminous coal, IPCC 1996	94.600	92.708	2.427	3.881
Other Bituminous coal, IPCC 2006, av	94.600	94.600	2.441	3.961
lower	89.500			
upper	99.700			
National emission factors				
Steam coal, 1990	96.512	94.582	2.502	3.960
Steam coal, 1995	95.926	94.007	2.519	3.936
Steam coal, 2000	93.312	92.276	2.427	3.863
Steam coal, 2001	95.304	94.457	2.463	3.955
Steam coal, 2002	94.727	94.096	2.457	3.940
Steam coal, 2003	95.385	94.961	2.476	3.976
Steam coal, 2004	95.382	95.170	2.476	3.985
Steam coal, 2005	94.305	94.305	2.399	3.948
Steam coal, 2006	93.741	93.741	2.346	3.925
Steam coal, 2007	94.078	94.078	2.324	3.939
Steam coal, 2008	93.451	93.451	2.287	3.913
Steam coal, 2009	93.847	93.847	2.325	3.929
Steam coal, 2010	93.697	93.697	2.317	3.923
Steam coal, 2011	93.365	93.365	2.318	3.909
Steam coal, 2012	93.667	93.667	2.346	3.922
Steam coal, 2013	93.645	93.645	2.331	3.921
Steam coal, 2014	94.029	94.029	2.339	3.937
Steam coal, 2015	94.619	94.619	2.335	3.962
Steam coal, 2016	95.092	95.092	2.350	3.981
Steam coal, 2017	93.886	93.886	2.361	3.931
Steam coal, 2018	94.340	94.340	2.345	3.950
Steam coal, 2019	95.278	95.278	2.375	3.989
Steam coal, 2020	94.013	94.013	2.356	3.936
Steam coal, 2021	93.078	93.078	2.334	3.897
Steam coal, 2022	93.233	93.233	2.310	3.903

Source: ISPRA elaborations

A6.5 Other fuels

Country specific emission factors have been calculated for other fuels and included in the inventory on account of the analysis of data reported by plants in the framework of the European emissions trading scheme. In consideration that these data referring to emission factors and activity data are validated and the amount of fuels reported accounts for more than 90% of the national fuels consumption, the average CO_2 emission factors have been applied from 2005.

In the following, values of CO_2 emission factors are specified for the different fuels. From 2005, figures result from a weighted average of ETS data; before that period, emission factors derive from literature data or other national data collection.

Oxidation factors have been considered equal to 1 for all the fuels (IPCC, 2006) with exception of residual gases of chemical processes where the oxidation factors resulting from ETS data have been used.

Table A6.6 – Refinery gas, average carbon emission factors

Refinery gas	t CO_2 / TJ (stechiometric)	t CO_2 / TJ	t CO_2 / t	t CO_2 / toe
Refinery gas, 1990-2004	57.600	57.600	2.851	2.412
Refinery gas, 2005	58.320	58.320	2.756	2.442
Refinery gas, 2006	57.369	57.369	2.644	2.402
Refinery gas, 2007	57.110	57.110	2.645	2.391
Refinery gas, 2008	58.137	58.137	2.686	2.434
Refinery gas, 2009	57.477	57.477	2.673	2.406
Refinery gas, 2010	56.750	56.750	2.652	2.376
Refinery gas, 2011	57.291	57.291	2.689	2.399
Refinery gas, 2012	57.269	57.269	2.701	2.398
Refinery gas, 2013	57.447	57.447	2.649	2.405
Refinery gas, 2014	57.095	57.095	2.634	2.390
Refinery gas, 2015	56.865	56.865	2.653	2.381
Refinery gas, 2016	58.210	58.210	2.652	2.437
Refinery gas, 2017	58.110	58.110	2.644	2.433
Refinery gas, 2018	58.307	58.307	2.657	2.441
Refinery gas, 2019	56.465	56.465	2.660	2.364
Refinery gas, 2020	56.146	56.146	2.639	2.351
Refinery gas, 2021	56.014	56.014	2.649	2.345
Refinery gas, 2022	56.531	56.531	2.665	2.367

Source: ISPRA elaborations

Table A6.7 – Coke oven gas, average carbon emission factors

Coke oven gas	**t CO_2 / TJ (stechiometric)**	**t CO_2 / TJ**	**t CO_2 / 10^3 std cubic mt**	**t CO_2 / toe**
Coke oven gas, 1990-2004	42.111	42.111	0.807	1.763
Coke oven gas, 2005	42.128	42.128	0.754	1.764
Coke oven gas, 2006	42.678	42.678	0.743	1.787
Coke oven gas, 2007	42.416	42.416	0.714	1.776
Coke oven gas, 2008	42.250	42.250	0.733	1.769
Coke oven gas, 2009	42.980	42.980	0.748	1.799
Coke oven gas, 2010	42.816	42.816	0.735	1.793
Coke oven gas, 2011	43.328	43.328	0.746	1.814
Coke oven gas, 2012	44.046	44.046	0.773	1.844
Coke oven gas, 2013	42.861	42.861	0.760	1.794
Coke oven gas, 2014	43.767	43.767	0.775	1.832
Coke oven gas, 2015	43.314	43.314	0.751	1.813
Coke oven gas, 2016	43.700	43.700	0.758	1.830
Coke oven gas, 2017	43.877	43.877	0.758	1.837
Coke oven gas, 2018	44.008	44.008	0.763	1.843
Coke oven gas, 2019	44.820	44.820	0.792	1.877
Coke oven gas, 2020	45.854	45.854	0.844	1.920
Coke oven gas, 2021	45.490	45.490	0.830	1.905
Coke oven gas, 2022	44.925	44.925	0.805	1.881

Source: ISPRA elaborations

Table A6.8 – Blast furnace gas, average carbon emission factors

Blast furnace gas	**t CO_2 / TJ (stechiometric)**	**t CO_2 / TJ**	**t CO_2 / 10^3 std cubic mt**	**t CO_2 / toe**
Blast furnace gas, 1990-2004	270.575	270.575	0.954	11.328
Blast furnace gas, 2005	263.653	263.653	0.870	11.039
Blast furnace gas, 2006	255.948	255.948	0.849	10.716
Blast furnace gas, 2007	261.469	261.469	0.835	10.947
Blast furnace gas, 2008	256.133	256.133	0.838	10.724
Blast furnace gas, 2009	259.560	259.560	0.834	10.867
Blast furnace gas, 2010	257.390	257.390	0.863	10.776
Blast furnace gas, 2011	255.351	255.351	0.877	10.691
Blast furnace gas, 2012	252.808	252.808	0.885	10.585

Blast furnace gas	t CO_2 / TJ (stechiometric)	t CO_2 / TJ	t CO_2 / 10^3 std cubic mt	t CO_2 / toe
Blast furnace gas, 2013	251.428	251.428	0.929	10.527
Blast furnace gas, 2014	245.964	245.964	0.958	10.298
Blast furnace gas, 2015	250.072	250.072	0.931	10.470
Blast furnace gas, 2016	247.893	247.893	0.952	10.379
Blast furnace gas, 2017	249.927	249.927	0.877	10.464
Blast furnace gas, 2018	250.282	250.282	0.862	10.479
Blast furnace gas, 2019	249.335	249.335	0.877	10.439
Blast furnace gas, 2020	251.043	251.043	0.883	10.511
Blast furnace gas, 2021	247.920	247.920	0.918	10.380
Blast furnace gas, 2022	250.750	250.750	0.911	10.498

Source: ISPRA elaborations

Table A6.9 – Oxygen furnace gas, average carbon emission factors

Oxygen furnace gas	t CO_2 / TJ (stechiometric)	t CO_2 / TJ	t CO_2 / 10^3 std cubic mt	t CO_2 / toe
Oxygen furnace gas, 1990-2004	195.086	195.086	1.504	8.168
Oxygen furnace gas, 2005	197.579	197.579	1.437	8.272
Oxygen furnace gas, 2006	202.372	202.372	1.390	8.473
Oxygen furnace gas, 2007	195.871	195.871	1.320	8.201
Oxygen furnace gas, 2008	196.465	196.465	1.277	8.226
Oxygen furnace gas, 2009	196.970	196.970	1.253	8.247
Oxygen furnace gas, 2010	197.029	197.029	1.216	8.249
Oxygen furnace gas, 2011	198.482	198.482	1.160	8.310
Oxygen furnace gas, 2012	198.199	198.199	1.226	8.298
Oxygen furnace gas, 2013	185.522	185.522	1.068	7.767
Oxygen furnace gas, 2014	200.970	200.970	1.335	8.414
Oxygen furnace gas, 2015	201.532	201.532	1.351	8.438
Oxygen furnace gas, 2016	203.868	203.868	1.309	8.536
Oxygen furnace gas, 2017	199.257	199.257	1.305	8.343
Oxygen furnace gas, 2018	192.862	192.862	1.353	8.075
Oxygen furnace gas, 2019	194.622	194.622	1.387	8.148
Oxygen furnace gas, 2020	195.877	195.877	1.387	8.148
Oxygen furnace gas, 2021	192.710	192.710	1.397	8.068
Oxygen furnace gas, 2022	191.486	191.486	1.414	8.017

Source: ISPRA elaborations

Table A6.10 – Heavy residual fuels, average carbon emission factors

Heavy residual fuels	t CO_2 / TJ (stechiometric)	t CO_2 / TJ	t CO_2 / t	t CO_2 / toe
Heavy residual fuels, 1999-2006	81.817	81.817	3.213	3.426
Heavy residual fuels, 2007	81.823	81.823	3.214	3.426
Heavy residual fuels, 2008	80.350	80.350	3.156	3.364
Heavy residual fuels, 2009	79.612	79.612	3.125	3.333
Heavy residual fuels, 2010	78.940	78.940	3.104	3.305
Heavy residual fuels, 2011	79.160	79.160	3.091	3.314
Heavy residual fuels, 2012	79.359	79.359	3.098	3.323
Heavy residual fuels, 2013	80.598	80.598	3.139	3.374
Heavy residual fuels, 2014	80.355	80.355	3.129	3.364
Heavy residual fuels, 2015	79.609	79.609	3.100	3.333
Heavy residual fuels, 2016	79.553	79.553	3.098	3.331
Heavy residual fuels, 2017	79.920	79.920	3.112	3.346
Heavy residual fuels, 2018	79.572	79.572	3.099	3.332
Heavy residual fuels, 2019	79.625	79.625	3.101	3.334
Heavy residual fuels, 2020	80.211	80.211	3.124	3.358
Heavy residual fuels, 2021	79.606	79.606	3.100	3.333
Heavy residual fuels, 2022	80.480	80.480	3.134	3.370

Source: ISPRA elaborations

Table A6.11 – Synthesis gas, average carbon emission factors

Synthesis gas	t CO_2 / TJ (stechiometric)	t CO_2 / TJ	t CO_2 / t	t CO_2 / toe
Synthesis gas, 1999-2005	98.103	98.103	0.906	4.107
Synthesis gas, 2006	98.566	98.566	0.982	4.127
Synthesis gas, 2007	98.321	98.321	0.830	4.117
Synthesis gas, 2008	98.860	98.860	0.886	4.139
Synthesis gas, 2009	105.956	105.956	0.956	4.436
Synthesis gas, 2010	110.487	110.487	0.910	4.626
Synthesis gas, 2011	109.188	109.188	0.915	4.571
Synthesis gas, 2012	106.913	106.913	0.881	4.476
Synthesis gas, 2013	100.817	100.817	0.895	4.221
Synthesis gas, 2014	100.596	100.596	0.898	4.212
Synthesis gas, 2015	100.732	100.732	0.930	4.217
Synthesis gas, 2016	103.993	103.993	0.929	4.354
Synthesis gas, 2017	103.043	103.043	0.983	4.314
Synthesis gas, 2018	109.145	109.145	1.009	4.570
Synthesis gas, 2019	104.034	104.034	0.948	4.356
Synthesis gas, 2020	102.912	102.912	0.870	4.309
Synthesis gas, 2021	97.899	97.899	1.196	4.099
Synthesis gas, 2022	99.071	99.071	0.926	4.148

Source: ISPRA elaborations

Table A6.12 – Residual gas of chemical processes, average carbon emission factors

Residual gas of chemical processes	**t CO_2 / TJ (stechiometric)**	**Oxidation factor**	**t CO_2 / TJ**	**t CO_2 / t**	**t CO_2 / toe**
Residuals gas of chem. processes, 1990-2007	51.500	0.995	51.243	2.365	2.145
Residuals gas of chem. processes, 2008	51.308	0.995	51.052	2.505	2.137
Residuals gas of chem. processes, 2009	50.588	0.995	50.342	2.502	2.108
Residuals gas of chem. processes, 2010	50.323	0.996	50.112	2.295	2.098
Residuals gas of chem. processes, 2011	50.568	0.995	50.335	2.516	2.107
Residuals gas of chem. processes, 2012	51.179	0.995	50.947	2.229	2.133
Residuals gas of chem. processes, 2013	47.484	1.000	47.484	2.071	1.988
Residuals gas of chem. processes, 2014	42.912	1.000	42.912	2.273	1.797
Residuals gas of chem. processes, 2015	47.830	1.000	47.830	2.163	2.003
Residuals gas of chem. processes, 2016	47.362	1.000	47.362	2.284	1.983
Residuals gas of chem. processes, 2017	47.525	1.000	47.525	2.256	1.990
Residuals gas of chem. processes, 2018	47.205	1.000	47.205	2.271	1.976
Residuals gas of chem. processes, 2019	52.375	1.000	52.375	2.216	2.193
Residuals gas of chem. processes, 2020	48.229	1.000	48.229	2.189	2.019
Residuals gas of chem. processes, 2021	47.589	1.000	47.589	2.204	1.992
Residuals gas of chem. processes, 2022	48.785	1.000	48.785	2.211	2.043

Source: ISPRA elaborations

Table A6.13 – Petroleum coke for no refinery plants, average carbon emission factors

Petroleum coke	t CO_2 / TJ (stechiometric)	t CO_2 / TJ	t CO_2 / t	t CO_2 / toe
Petroleum coke, 1990-2004	97.500	97.500	3.169	4.082
Petroleum coke, 2005	92.957	92.957	3.097	3.892
Petroleum coke, 2006	93.295	93.295	3.125	3.906
Petroleum coke, 2007	93.427	93.427	3.193	3.912
Petroleum coke, 2008	93.525	93.525	3.203	3.916
Petroleum coke, 2009	94.106	94.106	3.227	3.940
Petroleum coke, 2010	93.679	93.679	3.160	3.922
Petroleum coke, 2011	93.715	93.715	3.219	3.924
Petroleum coke, 2012	93.303	93.303	3.207	3.906
Petroleum coke, 2013	93.178	93.178	3.128	3.901
Petroleum coke, 2014	93.513	93.513	3.122	3.915
Petroleum coke, 2015	93.771	93.771	3.132	3.926
Petroleum coke, 2016	93.459	93.459	3.121	3.913
Petroleum coke, 2017	93.465	93.465	3.129	3.913
Petroleum coke, 2018	93.680	93.680	3.122	3.922
Petroleum coke, 2019	93.498	93.498	3.117	3.915

Petroleum coke, 2020	93.368	93.368	3.126	3.909
Petroleum coke, 2021	93.331	93.331	3.126	3.908
Petroleum coke, 2022	92.968	92.968	3.120	3.892

Source: ISPRA elaborations

Table A6.14 – Petroleum coke for refinery plants, average carbon emission factors

Petroleum coke	t CO_2 / TJ (stechiometric)	t CO_2 / TJ	t CO_2 / t	t CO_2 / toe
Petroleum coke, 2010	100.684	100.684	3.428	4.215
Petroleum coke, 2011	99.331	99.331	3.413	4.159
Petroleum coke, 2012	100.081	100.081	3.435	4.190
Petroleum coke, 2013	99.336	99.336	3.415	4.159
Petroleum coke, 2014	95.879	95.879	3.400	4.014
Petroleum coke, 2015	96.778	96.778	3.432	4.052
Petroleum coke, 2016	101.995	101.995	3.416	4.270
Petroleum coke, 2017	96.734	96.734	3.430	4.050
Petroleum coke, 2018	97.295	97.295	3.422	4.074
Petroleum coke, 2019	96.929	96.929	3.437	4.058
Petroleum coke, 2020	97.082	97.082	3.442	4.065
Petroleum coke, 2021	96.536	96.536	3.423	4.042
Petroleum coke, 2022	96.855	96.855	3.435	4.055

Source: ISPRA elaborations

Table A6.15 –Coke, average carbon emission factors

Coke	**t CO_2 / TJ** (stechiometric)	**t CO_2 / TJ**	**t CO_2 / t**	**t CO_2 / toe**
Coke, 1990-2004	110.368	108.161	3.170	4.528
Coke, 2005	110.916	110.916	3.246	4.644
Coke, 2006	111.049	111.049	3.181	4.649
Coke, 2007	111.814	111.814	3.191	4.681
Coke, 2008	111.649	111.649	3.187	4.675
Coke, 2009	111.303	111.303	3.161	4.660
Coke, 2010	109.079	109.079	3.125	4.567
Coke, 2011	110.380	110.380	3.188	4.621
Coke, 2012	112.969	112.969	3.309	4.730
Coke, 2013	111.113	111.113	3.172	4.652
Coke, 2014	109.195	109.195	3.198	4.572
Coke, 2015	109.728	109.728	3.206	4.594
Coke, 2016	109.533	109.533	3.217	4.586
Coke, 2017	108.755	108.755	3.237	4.553
Coke, 2018	108.864	108.864	3.218	4.558
Coke, 2019	108.590	108.590	3.169	4.546
Coke, 2020	107.468	107.468	3.181	4.499
Coke, 2021	108.466	108.466	3.154	4.541
Coke, 2022	108.216	108.216	3.189	4.531

Source: ISPRA elaborations

Table A6.16 –Coking coal, average carbon emission factors

Coking coal	t CO_2 / TJ (stechiometric)	t CO_2 / TJ	t CO_2 / t	t CO_2 / toe
Coking coal, 1990-2004	94.600	94.600	2.668	3.961
Coking coal, 2005	92.466	92.466	2.971	3.871
Coking coal, 2006	94.058	94.058	2.968	3.938
Coking coal, 2007	94.479	94.479	2.971	3.956
Coking coal, 2008	94.869	94.869	2.961	3.972
Coking coal, 2009	94.718	94.718	2.970	3.966
Coking coal, 2010	94.627	94.627	3.007	3.962
Coking coal, 2011	95.459	95.459	2.999	3.997
Coking coal, 2012	95.380	95.380	3.014	3.993
Coking coal, 2013	94.381	94.381	2.982	3.952
Coking coal, 2014	93.983	93.983	2.991	3.935

Coking coal, 2015	94.457	94.457	2.995	3.955
Coking coal, 2016	94.171	94.171	2.967	3.943
Coking coal, 2017	94.004	94.004	2.967	3.936
Coking coal, 2018	95.361	95.361	2.974	3.993
Coking coal, 2019	94.676	94.676	2.948	3.964
Coking coal, 2020	94.947	94.947	2.966	3.975
Coking coal, 2021	94.757	94.757	2.938	3.967
Coking coal, 2022	94.447	94.447	2.953	3.954

Source: ISPRA elaborations

Table A6.17 –Anthracite, average carbon emission factors

Anthracite	t CO_2 / TJ (stechiometric)	t CO_2 / TJ	t CO_2 / t	t CO_2 / toe
Anthracite, 1990-2004	98.300	98.300	2.625	4.116
Anthracite, 2005	93.035	93.035	2.856	3.895
Anthracite, 2006	95.127	95.127	2.817	3.983
Anthracite, 2007	97.722	97.722	2.796	4.091
Anthracite, 2008	97.183	97.183	2.764	4.069
Anthracite, 2009	98.335	98.335	2.861	4.117
Anthracite, 2010	97.416	97.416	2.844	4.079
Anthracite, 2011	99.465	99.465	2.911	4.164
Anthracite, 2012	98.717	98.717	2.870	4.133
Anthracite, 2013	98.348	98.348	2.886	4.118
Anthracite, 2014	97.960	97.960	2.877	4.101
Anthracite, 2015	101.373	101.373	2.906	4.244
Anthracite, 2016	101.630	101.630	2.924	4.255
Anthracite, 2017	103.107	103.107	3.027	4.317
Anthracite, 2018	100.405	100.405	3.005	4.204
Anthracite, 2019	105.114	105.114	3.033	4.401
Anthracite, 2020	104.757	104.757	2.964	4.386
Anthracite, 2021	104.131	104.131	3.021	4.360
Anthracite, 2022	104.643	104.643	3.044	4.381

Source: ISPRA elaborations

Table A6.18 –Industrial waste (fossil), average carbon emission factors

Industrial waste	t CO_2 / TJ (stechiometric)	t CO_2 / TJ	t CO_2 / t	t CO_2 / toe
Industrial waste, 2005-2012	79.968	79.968	1.924	3.348
Industrial waste, 2013	79.076	79.076	1.853	3.311
Industrial waste, 2014	81.851	81.851	1.931	3.427
Industrial waste, 2015	78.976	78.976	1.988	3.307
Industrial waste, 2016	78.592	78.592	2.019	3.291
Industrial waste, 2017	82.164	82.164	2.090	3.440
Industrial waste, 2018	80.019	80.019	2.034	3.350
Industrial waste, 2019	81.243	81.243	2.093	3.401
Industrial waste, 2020	79.915	79.915	2.070	3.346
Industrial waste, 2021	81.473	81.473	2.027	3.411
Industrial waste, 2022	81.504	81.504	2.054	3.412

Source: ISPRA elaborations

ANNEX 7: AGRICULTURE SECTOR

Additional information used for estimating categories 3A, 3B and 3D from the agriculture sector is reported in this section.

A7.1 Enteric fermentation (3A)

The time series of the parameters used for estimating the Dairy Cattle EF using the Tier 2 approach, are reported in Table A.7.1. Information on the equations used for estimating the different net energy (NE_m, NE_g, etc.) is described in the 2006 IPCC Guidelines (IPCC, 2006).

Table A.7.1 Parameters used for the Tier 2 approach - dairy cattle

	NE_m (MJ/day)	NE_a (MJ/day)	NE_g (MJ/day)	NE_l (MJ/day)	NE_w (MJ/day)	NE_p (MJ/day)	REM	REG	DE (%)	GE (MJ/day)	Y_M (%)
1990	46.95	0.40	0.97	33.52	0.000	4.57	0.514	0.308	65.00	260.66	6.50%
1995	46.95	0.40	0.97	43.38	0.000	4.45	0.514	0.308	65.00	289.83	6.50%
2000	46.95	0.40	0.97	44.31	0.000	4.35	0.514	0.308	65.00	292.33	6.50%
2005	46.95	0.40	0.97	50.84	0.000	4.27	0.519	0.316	66.45	301.97	6.18%
2010	46.95	0.40	0.97	55.54	0.000	4.23	0.522	0.322	67.68	307.49	6.08%
2015	46.95	0.40	0.97	56.89	0.000	4.18	0.522	0.321	67.51	312.24	6.09%
2019	46.95	0.40	0.97	67.67	0.000	4.26	0.525	0.327	68.63	335.36	6.00%
2020	46.95	0.40	0.97	71.74	0.000	4.30	0.525	0.327	68.77	345.77	5.98%
2021	46.95	0.40	0.97	74.94	0.000	4.34	0.525	0.327	68.69	355.27	5.99%
2022	46.95	0.40	0.97	74.98	0.000	4.34	0.525	0.327	68.67	355.52	5.99%

Source: ISPRA elaborations.

For non-dairy cattle, data on nitrogen excreted are derived by the Nitrogen Balance Inter-regional Project that involved Emilia Romagna, Lombardy, Piedmont and Veneto regions, where animal breeding is concentrated and for that they have been assumed representative of the national level.

The project was aimed to develop models to calculate the nitrogen balance for different types of breeding, including cattle. The following information was collected: the movement of the heads and feed at farm level, animal nutrition plans, feed consumption per animal category and bred, management techniques, reproductive phase and the productive results, mortality, age, weight at different growth and fattening phases, number and type of stable places in the herd, the type of simple feed or compound feed used, the estimated nitrogen content, the composition of the feed ration, average levels daily consumption per animal category and stage of breeding cycle (Xiccato et al., 2004).

The survey data related to replacement heifers and other non-dairy cattle are described below.

Replacement heifers

Breeding performance
In Table A.7.2 the national average values of the main characteristics of the replacement heifers breeding are reported. Friesian, Brown and Red-spotted livestock breeds have been considered.
The national value is the average of the result of the survey carried out in Veneto, Emilia Romagna, Lombardy and Piedmont which monitors the feed consumption, the composition of the rations and the numeric movements and weight of livestock in the period between 2002 and 2003. For Veneto, specifically, data from 89 representative farms, for a total of 8,466 heads, were collected (Regione Veneto, 2008; Bittante et al., 2004).

Table A.7.2 Main characteristics of the replacement heifers breeding

Type of feed over the years	Unit of measure	Average value	Sd (2)
Age at weaning	day	85	23
Age at first calving	month	28.5	
Live weight at birth	kg/head	39	

Type of feed over the years	Unit of measure	Average value	Sd (2)
Average live weight at weaning	kg/head	101	19
Average live weight at first calving	kg/head	540	
Feed ration distribution			
Traditional	%	25	
Unifeed	%	38	
Mixed	%	37	
Intake of dry matter from weaning at first calving	kg/head/period	6473	1459
Daily dry matter intake	kg/d	8.24	1.89
Average crude protein ration (Nx6,25)	kg/kg	0.121	0.018
Nitrogen balance			
N consumed from birth to weaning	kg/head/period	5.3	2.7
N consumed from weaning to calving	kg/head/period	123.9	29.7
N retention in products from birth to calving	kg/head/period	14.41	
N excreted from birth to calving	kg/head/period	114.8	29.6
N annually excreted	kg/head/year	48.3 (1)	12.5

(1) the value was divided by the average weight and used to calculate the annual average nitrogen excretion for females from breeding between 1 and 2 years and more than 2 years (reported in CRPA, 2006[a]); (2) Standard deviation.

Feed consumption and composition of rations

Average value of dry matter intake from weaning at first calving is 6473 kg/head/period (8.24 kg of dry matter intake per day).

Animals receive rations based, even in summer, on hay fodder, corn silage and fibrous products with minimal additions of feed concentrates.

The protein content of these rations is on average 12% of dry matter intake. The use of fresh grass is generally avoided, the best fodder is normally reserved for dairy cows and the inferior fodder for the replacement heifers.

Digestibility

The feed ration is rich in fiber (as described above) and therefore less digestible than the ration of fattening animals. Methane conversion factors were estimated with the formula proposed by Ellis (Ellis et al, 2007) based on daily DMI and forages proportion (FP) in the diet (see section below CH_4 conversion factors for non-dairy cattle category).

Other cattle

Breeding performance

A revision of the feeding plan, diets and slaughtering categories were made on the bases of an up-dated literature and research results. The review also takes in account the development that beef cattle breeding has undergone since the early 2000s, when alongside the breeding of animals of specialised breeds (mainly imported calves), the practice of using dairy females fertilised with beef bull semen to obtain cross-breeds for slaughter was widely introduced. Based on the information gathered by CRPA in the bibliography and field experiences, the dry matter intake values were updated. In addition, the Ym values in use were recalculated with the Ellis formula based on the updated results of the composition of the diets.

In Italy there are different types of beef cattle breeding, which can be traced back to 3 main cases (CRPA, 2011[b]):

- farms oriented to the fattening phase only, widespread in particular in regions of the Po Valley. This production model mainly uses calves over 6 months old, whose final growing-fattening phase is carried out in confinement farms ("ristallo"). This type of breeding in the northern Italian plain guarantees the largest physical flow of product to the beef supply chain in Italy;
- farms with suckler cows that wean calves that are then fattened. Placed mainly in the regions of Central-Southern Italy and in Piedmont. Cows are from specialized breeds for the production of meat, mostly of national origin (Marchigiana, Chianina, Piemontese), French breeds like Limousine and double purpose breeds;

- extensive breeding with national rustic breeds, followed in particular in southern Italy and islands, generally located in the internal hilly and mountainous areas; these farms are now marginal in terms of meat quantity, but provide niche products.

The concentration of other cattle is in the northern area of Italy, and more specifically in Piedmont (21%) Veneto (19%), and Lombardy (14%) more than half of the beef cattle of the national herd (ISMEA, 2022). Today less than 10% of the animals in the meat supply chain belong to local meat breeds, and 26% of the herd is made up of crossbreeds. Meat supply is mainly represented by cattle between 1 and 2 years of age (57%), "late-career" cattle over two years of age account for about 20% of the national supply, and cattle slaughtered before one year of age are the 23% (ISMEA, 2022).

Feed consumption and composition of rations

Since the beginning of the sixties, the intensive farming under confinement, the most prevalent in the Po valley, has been closely linked to the development of the cultivation of maize, as the main energy source, and the availability of flour from imported soybean, as a protein source (Regione Veneto, 2008). In the same years, in agricultural areas in Northern Italy a substantial abandonment of the cattle from traditional meat, based on a wide use of permanent and/or temporary fodder was recorded. This process has developed as a result of the development of the product ensiling technique obtained by chopping of the whole plant, harvested in the milky-wax ripeness phase of kernels (corn silage). The use of corn silage increases by about 50% the amount of energy per hectare, reducing, consequently, the cost of the unit forage (Regione Veneto, 2008). The use of corn silage and concentrated feed, suitably integrated, in diets for cattle, increases the speed of growth of animals, improving the energy efficiency of the ration, reducing the duration of the production cycle and raising the yields of slaughter and the qualitative level of carcasses and meat (Regione Veneto, 2008).

A recent manual on ruminant feeding in Italy (Cevolani D. *et al*, 2021; 2022) provides useful information on the diet of beef cattle.

Table A.7.3 Examples of rationing for growth/fattening beef cattle with corn silage and without (dry feeding)

Ration feed	Growing kg/head/day	Fattening kg/head/day	Growing kg/head/day	Fattening kg/head/day
Corn silage	7	9	0	0
Straw	0.5	0.5	1	1
Corn flour	3.5	5	5	6.2
Soibean meal	1	0.8	0.8	0.8
Sugar beet pulp, dehydrated	1	0.7	1.5	1.5
Sunflouwer meal	0.5	0.5	0.5	0.5
Oils/fats	0.2	0.3	0.2	0.3
Supplement	0.2	0.2	0.2	0.2
Forages total	7.5	9.5	1	1
Concentrate total	6.4	7.5	8.2	9.5
DMI intake	13.9	17	9.2	10.5
% Forages	53.96	55.88	10.87	9.52
% Concentrate	46.04	44.12	89.13	90.48

Source: Cevolani D. et al, 2022.

Table A.7.4 Examples of rationing for suckler cow and beef cattle

Ration feed	Gestation kg/head/day	Lactation kg/head/day	Growing kg/head/day	Fattening kg/head/day
Pastures	25	25	0	0
Hay	3.5	3.5	1.5	1.0
Straw	2.5	1.5	0.5	0.5
Concentrate	1.0	5.0	4.0	7.0
Corn silage	0	0	6.0	8.0
Forages total	31	30	8	9.5
Concentrate total	1	5	4	7
DMI intake	32	35	12	16.5

Ration feed	Gestation kg/head/day	Lactation kg/head/day	Growing kg/head/day	Fattening kg/head/day
% Forages	96.88	85.71	66.67	57.58
% Concentrate	3.13	14.29	33.33	42.42

Source: Cevolani D. et al, 2021.

Those data are in line with the survey conducted on 135 farms in Veneto, Lombardy and Piedmont on the average type of the feed composition and crude protein content of rations for Charolais cattle (Cozzi, 2007 – see Table A.7.5). Despite some differences between farms located in different regions it is observed that in all cases the corn silage, the corn mash and cereals are the main constituents of rations. The use of dried beet pulp, in particular in the Veneto region, was significant. In Veneto and Lombardy, the long-fiber forages are represented almost exclusively by straw, while in Piedmont these are partially or totally replaced by permanent pasture hay. The supplement of protein is generally based on soybean flour. The protein content is in all cases around 14% of dry matter, a content slightly lower than that found by Xiccato et al., (Xiccato et al., 2005) on 40 farms in Veneto (14.4% + 0.9%) and slightly higher than that found by Mazzenga et al., (Mazzenga et al., 2007) on 406 farms in the Po valley (13% + 1.1%).

Table A.7.5 Feed and chemical composition of total mixed rations for Charolais cattle in different regions – data of feed ration in dry matter

Ration feed	Veneto	Lombardy	Piedmont
Farms, n.	101	23	11
Feed ration, kg			
Silage corn	2.99	3.46	2.12
Mash corn	0.52	0.91	1.76
Cereals, flour and grains	0.86	0.58	0.67
Dried beet pulp	0.39	0.21	0.18
Fodder long fiber	0.61	0.61	0.87
Protein supplements, vitamins and minerals	2.00	2.26	2.09
Molasses and vegetable fats	0.09	0.09	0.17
Chemical composition:			
Dry matter %	55.2	52.6	62.3
Crude protein %	14.0	13.9	14.0
Total forages	4.50	5.19	4.92
Total concentrates	2.95	2.93	2.93
Total feed	7.45	8.11	7.86
% of concentrates	40	36	37
% of forages	60	64	63

Source: Cozzi, 2007.

Taking in consideration also values of DMI reported by Grossi (Grossi et al, 2022) and by the Association of Piemontese breeders (ANABORAPI, 2022), and also some direct experience on field, value of DMI reference consumption is evaluated by CRPA (see section CH_4 conversion factors for non-dairy cattle category).

In general, dry matter consumption is reported in the bibliography by weight classes, but within weight classes females are rarely distinguished from males.

Digestibility

As mentioned above, the rations consist mainly of silage and cereals and for fattening animals the ration has been assumed more digestible.

This assumption is supported by a recent survey on dry matter (DM) total tract apparent digestibility in beef cattle (Pacchioli et al, 2023), carried-out on Charolais male in growing and finishing periods feed with wheat silage and corn mash as fodder bases. DM total tract apparent digestibility value were 77.64% and 74.12% at growing and fattening, respectively.

CH_4 conversion factors for non-dairy cattle category

Considering information provided by CRPA and reported in Feed consumption and composition of rations section in terms of typical diets used in Italy and dry matter consumption of beef cattle types grown, the following parameters are adopted by CRPA for non-dairy cattle subcategories.
For cattle less than one year, DMI is estimated at 4.9 kg/head/day;
Males from 1 to 2 years: DMI is considered at 2.0% by weight for breeding males and 1.7% for slaughter,
Females 1 to 2 years: DMI is considered at 3.0% by weight for breeding females and 2.0% for slaughter,
Males > 2 years: DMI is considered at 2.0% by weight for all,
Females > 2 years: DMI is considered at 2.5 % by weight for breeding females and at 1.7% for slaughter, for other cows, DMI is considered to be 2.0 % by weight.
The country specific Ym, for the different subcategories, have been calculating (see Table A.7.6) with the formula proposed by Ellis (Ellis et al, 2007) based on daily DMI and forages proportion (FP) in the diet, considering the national weight and DMI values and assuming percentages of forages between 30% and 65%, (see previous section). Cattle < 1 year (reported in Table A.7.6) in Italy is baby beef: the average weight is 236 kg and daily consumption is in average 7.5 kg (5 kg of concentrates and 2.5 kg of silage and dry forage); dry matter intake is about 5 kg (equal to 2.1% live weight) and the percentage of forages is only about 30%.

Table A.7.6 Estimation of Ym values by non-dairy cattle subcategories

Livestock categories		Average live weight	Dry matter intake (DMI)	DMI (DMI= weight *DMI %)	DMI	forages on dry matter	CH_4 - Ellis et al 2007 formula	Methane conversion factors - Ym
			% with respect to weight	kg/head/day	MJ/day	%	MJ/day	%
< 1 year	others	236	2.1	4.85 (1)	89.4	30%	3.7	4.16%
1-2 years Male	breeding animal	557	2	11.14	205.5	65%	9.7	4.72%
	slaughter animal	557	1.7	9.47	174.7	55%	8.1	4.62%
1-2 years Female	breeding animal	405	3	12.15	224.2	65%	10.4	4.63%
	slaughter animal	444	2	8.88	163.8	55%	7.7	4.68%
> 2 years	Male	700	2	14.00	258.3	55%	11.2	4.32%
> 2 years Female	breeding heifers	540	2.5	13.50	249.1	65%	11.3	4.54%
	heifers for slaughter	540	1.7	9.18	169.4	55%	7.9	4.65%
	other cows	557	2	11.14	205.5	55%	9.2	4.48%

(1) for this subcategory the previous value (CRPA, 1997[a]) very similar to the current one (4.96) has not been changed.

A7.2 Manure management (3B)

In this section the country-specific methodology for estimating the amount of manure sent to the bio-digesters and the amount of methane produced, to be subtracted from the total amount of methane deriving from manure management, is explained.

The inventory of methane emissions from manure management is based on a country specific methodology which also takes into account the share of manure sent to bio-digesters annually to recover power and heat.
In Italy the number of bio-digesters has been increasing for the last years in a significant way. Anaerobic digestion of animal manure allows for the recovery of energy and heat and also for reducing methane emissions to air.

1) The anaerobic bio-digesters in Italy and relevant assumptions

The information available concerning heat and power production from biogas at anaerobic digesters fed with animal manure and agriculture residues (energy crops, agro-industrial by-products) is supplied by TERNA and CRPA.

TERNA, the Italian electricity transmission grid operator, reports annually the production of energy from traditional sources and from renewable. As for energy from biogas production in anaerobic digesters TERNA accounts for the number of digesters connected to the national grid and reports the power capacity, the energy production, combined heat and energy production and provides the figures separately for two categories:

- Bio-digesters receiving animal manure
- Bio-digesters receiving agriculture residues

The information is collected electronically and submitted by bio-digesters operators. TERNA's data about installed power, energy production, biogas used for energy production are then available for the inventory purposes (see data from renewable sources in sections "power plants" and "production" at https://www.terna.it/it/sistema-elettrico/statistiche/pubblicazioni-statistiche).

CRPA is the Research Centre on Animal Production, among other activities it has been studying the implementation of anaerobic digestion in the agricultural sector of our country and it has been carrying out surveys to build a picture of the anaerobic digestion plants in the livestock and agro-industrial sector in Italy. In the surveys total number of Italian anaerobic systems is considered, so the plants not connected to the national energy grid are included too. CRPA archive includes also information about the feed (plants working with animal manure, energy crops and agro-industrial by-products). Information about technologies and changes in technologies along the inventory time series is then also available for the inventory purposes.

Comparing the number of plants using manure in the CRPA surveys and those to TERNA, there is evidence that many operators using manure together with crops as a feed to digesters report their information to TERNA under the most general category agriculture residues.

Based on official data by TERNA and on information collected by CRPA (CRPA, 2013; CRPA, 2011[a]; ENAMA, 2011; CRPA, 2008[a]) the inventory team provides with the following picture concerning bio-digesters in Italy:

- As for technology, up to 2005 anaerobic digestion of animal manure was implemented at about less than 100 plants. In the '90s typical reactor was a coverage storage structure where manure was stored and anaerobic digestion could occur, the output of the process being biogas mainly burned to recover heat for the livestock facility. In the following years, due to an increasing interest into anaerobic digestion and thanks to incentives to the sector, the implementation of multiple substrates (biomass) co-digestion at the same digester can be observed. As a consequence, the type of process reactor has been changing too, with CSTR (completely stirred tank reactor) reactors becoming the largest share out of the total number of digesters.
- The number of installations has been significantly increasing for the last years (following table), thus affecting also the amount of CH_4 emissions released actually to the atmosphere, that's why the GHG emissions inventory shall take into account also this practice.

In Table A.7.7 a summary of the information provided by TERNA and the estimated data for biogas production is supplied.

Table A.7.7 Anaerobic digesters in Italy

N° of plants and productions	*Anaerobic digesters*		*Energy production*			*Biogas production*
	Total	Animal manure	Total	Animal manure	Agricultural residues	Total
	n.	n.	GWh	GWh	GWh	Mm^3
1990	-	-	-	-	-	-
1995	5	4	10.7	8.1	2.6	Not available
2000	10	5	8.8	4.9	3.9	Not available
2005	24	14	142	26	117	Not available
2010	176	95	611.2	221	390.2	839

N° of plants and productions	Anaerobic digesters		Energy production			Biogas production
	Total	Animal manure	Total	Animal manure	Agricultural residues	Total
	n.	n.	GWh	GWh	GWh	Mm^3
2015	1,466	493	6,557	1,067	5,490	3,194
2019	1,699	636	6,820	1,255	5,565	3,599
2020	1,734	656	6,892	1,294	5,599	3,710
2021	1,793	688	6,942	1,297	5,645	3,869
2022	1,850	719	6,739	1,277	5,462	3,883

Source: TERNA and estimated data for biogas production.

Official information about biogas used and energy production at bio-digesters, provided by TERNA, and information about feed of the bio-digesters, provided by CRPA, allow for estimating the amount of slurry and manure fed annually to the Italian bio-digesters.
The biogas average yield and the chemical characteristics of substrates fed to digesters are described in Table A.7.8 supplied by CRPA (CRPA, 2012).

Table A.7.8 Average yields and average chemical characteristics of some substrates used for biogas production

Tabella 8 - Rese medie e caratteristiche chimiche medie di alcuni substrati utilizzabili per la produzione di biogas

Matrice	Solidi volatili (kg/t)	Biogas (m^3/kg SV)	CH_4 (%)	NTK (% ST)	Matrice	Solidi volatili (kg/t)	Biogas (m^3/kg SV)	CH_4 (%)	NTK (% ST)
Liquami zootecnici									
Liquame suino	30	0,50	67	8	Liquame bovino	82	0,35	55	4,7
Solido separato bovino	200	0,4	55	2,5	Letame bovino	210	0,40	55	2,7
Prodotti vegetali									
Insilato di sorgo zuccherino	282	0,6	53	1,8	Insilato di grano	289	0,60	53	1,7
Insilato di erba	248	0,56	52	2,7	Insilato di mais	310	0,65	53	1,4
Scarti agro-industriali animali									
Siero di latte	55	0,75	60	2,3	Sangue bovino	101	0,65	65	11,4
Contenuti ruminali bovini	176	0,75	53	2,6	Fanghi di macelli suini	160	0,35	60	3
Fango di flottazione avicolo	85	0,35	60	14,7	Fanghi di macelli bovini	122	0,35	60	4,8
Scarti agro-industriali vegetali									
Scarti di lavorazione del mais dolce	154	0,48	55	2,2	Buccette e semi di pomodori	291	0,35	55	3,1
Scarti di leguminose	169	0,6	60	4,9	Scarti di lavorazione della patata	230	0,60	53	1,5

Dati CRPA

As for the types of feed treated in bio-digesters there has been a significant shift from single substrate feed to multiple substrates feed during the last years (CRPA, 2013; CRPA, 2011[a]); the share of bio-digesters treating animal manure only has been decreasing while the share of plants operating co-digestion of multiple substrates feed has been increasing.

Table A.7.9 Bio-digesters (%) by type of feed sent to anaerobic digesters over the years

Type of feed over the years	2007	2010	2011	2012
animal manure only (%)	56	36	29	18
animal manure+energy crops+ agricultural residues (%)	38	55	58	62
energy crops only (%)	6	9	13	20

Source: CRPA.

Because of multiple substrates fed to bio-digesters, the following average characteristics of the feed, as supplied by CRPA, are considered for the Italian bio-digesters to calculate the total amount of feed from animal manure anaerobic digestion (CRPA, 2018).

Table A.7.10 Type of feed sent to anaerobic digesters

Type of feed	Units	animal manure	energy crops	agro-industrial by-products
Animal manure only	% in the feed	100	0	0
Animal manure + energy crops + agro-industrial by-products	% in the feed	28	52	20
Animal manure + energy crops	% in the feed	38	62	0
Animal manure + agro-industrial by-products	% in the feed	69	0	31
Energy crops + agro-industrial by-products	% in the feed	0	81	19

Source: CRPA.

On the basis of the information reported above and in consideration of the typical feed of the bio-digesters the average parameters for animal manure, energy crops and agro-industrial by-products are those reported in Table A.7.11. The biogas methane content is generally reported to range from 50% to 65%, for the inventory purposes and according to CRPA methane content is assumed to be 55% (CRPA/AIEL, 2008; CRPA, 2008[b]). As regards the average volatile solids content, values for animal manure and agro-industrial by-products have been changed based on the recent study of CRPA (CRPA, 2018).

Table A.7.11 Average parameters by the type of feed sent to anaerobic digesters

Parameters	Units	animal manure	energy crops	agro-industrial by-products
Average biogas producing potential	m^3 biogas/kg VS	0.4	0.6	0.6
Average CH_4 content	%	55	55	55
Average volatile solids content	VS kg/t feed	139	280	237

Source: CRPA.

On the basis of all this information total biogas generated from the amount of slurry and manure fed to bio-digesters can be estimated assuring that for the inventory purposes it does not include biogas generated based on other carbon sources than animal manure.

2) Losses from bio-digesters

Based on the information collected about the Italian bio-digesters, losses of biogas/methane can be characterized as:

- Biogas losses from anaerobic digestion unit (biogas escaping from the digester)
- Biogas losses from digestate storage
- Biogas losses from the combustion unit in the power&heat production step

As for point 1) according to the available literature on Italian bio-digesters (Fabbri *et al.*, 2011) and to the NIR of other EU Country (UBA, 2014) and to the 2023 EMEP/EEA Guidebook (EMEP/EEA, 2023) (see chapter 5.B.2 Biological treatment of waste – anaerobic digestion at biogas facilities, paragraph 2.3), where manure is processed in bio-digesters with similar technology implemented, the average losses of biogas is reported to be about 1% of the total biogas produced.
As for point 2) according to the IPCC Guidelines this contribution to the emission is equal to zero when covered storage units are in place. Based on our information, digestate covered storage units are in places at the Italian bio-digesters.
As for point 3) emissions resulting from power&heat production step are not to be allocated under agriculture for the purposes of the GHG emissions inventory and are already estimated and allocated in the energy sector.

3) Methodology and parameters

Based on the information supplied by TERNA and CRPA, a country specific methodology to estimate the *amount of animal manure treated in the bio-digesters* has been developed for the years 2007, 2010, 2011 and 2012 onwards. The amount of animal manure sent to anaerobic digesters is used to estimate both the equivalent number of heads and their related *CH_4 emissions to be subtracted* from the total CH_4 emissions from manure management and *CH_4 emissions from losses of the digesters*.
N_2O emissions from manure management have been revised too because the emission factors (EFs) for animal manure sent to digesters are different from EFs for the other manure management systems (liquid system and solid storage).
In addition, for the reporting purposes the CH_4 producing potentials (Bo), the percentages of nitrogen allocation (by climate region and manure management systems) and methane conversion factors (MCF) have been revised for the relevant animal categories.

Amount of animal manure treated in bio-digesters
Official data about power capacity of digesters (TERNA) have been disaggregated based on the *distribution of digesters' installed power by type of feed* (CRPA).
On the basis of the operating hours, calculated from TERNA data on total energy production divided by the total installed power at digesters, the *energy production by type of feed* has been calculated for the relevant years.
TERNA data are used also to calculate the average energy efficiency and the lower heating value (LHV) that applied to energy productions allow for deriving the *amount of biogas used to produce energy per type of feed*.
Taking into account the percentage of biogas losses at digesters, equal to 1%, and the percentage of biogas flared at digesters, equal to 4%, it is possible to estimate the *biogas produced per type of feed* from biogas used. In 2017 submission, in response to the UNFCCC review process, the percentage of biogas flared has been estimated.
From biogas produced per type of feed it is possible to estimate the *total amount of feed* using the maximum biogas producing capacity (m^3 biogas/kg VS – volatile solid) and the VS content in the feed (kg VS/t feed).
In order to estimate the *amount of animal manure sent to digesters*, multiple substrates in the feed have to be considered taking in account the shares of different substrates in the feeds.

CH_4 emissions to be subtracted
In order to take into account the practice of manure management in anaerobic bio-digesters, the equivalent, in terms of MMS (liquid and solid), CH_4 emissions should be calculated on the basis of the amount of manure treated in these plants considering the equivalent number of heads and then subtracted from the total CH_4 emissions from manure management. This is because the country specific methodology calculates the average EFs by livestock on the basis of national and international literature which refer to the "conventional" MMS of liquid and solid manure.
Manure sent to digesters has been distributed according to the type of manure (liquid/slurry and solid) and the animal category using the distribution of the national inventory.
Based on the coefficients of the national inventory related to annual production of manure per head and animal category and type of manure, it is possible to estimate *the number of head equivalent* per animal category and type of manure.
Finally, *CH_4 emissions from manure* sent to digesters are calculated multiplying these equivalent heads by EFs of the inventory expressed in kg CH_4/head per year.

CH_4 emissions from losses of bio-digesters
Losses from digesters are equal to 1% of biogas produced. Considering that CH_4 content is equal to 55% of biogas the resulting amount of CH_4 is calculated and added to the total CH_4 emissions from manure management and distributed by animal category.

N_2O emissions

On the basis of CRPA data on measurements of nitrogen quantities in livestock manure (downstream of releases to housing and storage) per animal category and type of manure, the nitrogen quantities in livestock manure sent to anaerobic digestion were estimated. The coefficients, expressed as g N/kg manure, were calculated gross of losses and then the losses to housing were deducted. The resulting coefficients were then multiplied by the quantities of manure sent for anaerobic digestion.
Consequently, the amount of nitrogen stored in the other storage system has been estimated subtracting these N amounts from the relevant animal categories and their type of manure.
Emission factor of the 2006 IPCC Guidelines has been used to estimate the N_2O emissions from manure stored in digesters. The value is zero as reported in the 2006 IPCC Guidelines (IPCC, 2006).

MCF for anaerobic digester

The methane conversion factor has been calculated according to Formula 1 in Table 10.17 in the 2006 IPCC Guidelines:

MCF = [{CH_4 prod - CH_4 used - CH_4 flared + (MCFstorage /100 * Bo * VSstorage * 0.67)}/ (Bo* VSstorage * 0.67)] *100
Where:
CH_4 prod = methane production in digester, (kg CH_4).
Note: When a gas tight coverage of the storage for digested manure is used, the gas production of the storage should be included.
CH_4 used = amount of methane gas used for energy, (kg CH_4)
CH_4 flared = amount of methane flared, (kg CH_4)
MCFstorage = MCF for CH_4 emitted during storage of digested manure (%)
VSstorage = amount of VS excreted that goes to storage prior to digestion (kg VS)
Note: When a gas tight storage is included: MCFstorage = 0; otherwise MCFstorage = MCF value for liquid storage.
The equation (CH_4 prod - CH_4 used - CH_4 flared) is equal to CH_4 emissions from losses of bio-digesters that is equal to 1% of biogas produced (as reported above): 1475 Mmc (millions of cubic meters of biogas produced from manure in 2022) * 0.01 * 0.55 (methane content is assumed to be 55%) = 8.11 Mmc CH_4.
The amount of volatile solids (VS) has been calculated multiplying the amount of animal manure by different type of feed treated in bio-digesters to the average VS content by different type of feed (these values can be obtained from the values shown in Table A.7.11): 2316 kt (animal manure only) * 139 kg VS/t feed + 1017 kt (animal manure from the co-digestion of multiple substrates such as "animal manure + energy crops + agro-industrial by-products")* 232 kg VS/t feed + 4754 kt (animal manure from the co-digestion of multiple substrates such as “animal manure + energy crops”) * 226 kg VS/t feed + 8358 kt (animal manure from the co-digestion of multiple substrates such as “animal manure + agro-industrial by-products”) * 169 kg VS/t feed = 3050 kt VS. CH_4 producing capacity (Bo) is equal to 0.22 mc CH_4/kg VS. MCF = [8.11 Mmc CH_4 / (3050 kt VS * 0.22 mc CH_4/kg VS)] *100 = 1.21%. In addition, digestate covered storage units are in places at the Italian bio-digesters so according to the Guidelines $MCF_{storage}$ is equal to 0.
The figure 0.22 mc CH_4/kg VS used in the calculation is an average of the values related to pigs slurry, cattle slurry and solid manure, cattle separate solid manure. These values represent the maximum methanigenous potential and have been measured in the laboratory trying to simulate in a controlled environment what happens in an anaerobic digester (as reported in CRPA, 2012). This value is different respect to the values in CRT table3.B(a)s1 that have been estimated with the equation 10.23 of the 2006 IPCC Guidelines. However, the measured and estimated data should be comparable.
More information on the estimate of weighted average values of MCF and Bo for animal manure digested in anaerobic digesters has been provided above, reporting a numerical example of how the MCF value is calculated including information on the data sources for the different parameters used.
The biogas flared at bio-digesters has been assumed equal to 4% of the total biogas produced (CRPA, 2016).

In the CRT table 3B(a), the nitrogen allocation and MCF supplied by climate region and manure management systems are reported.
The average CH_4 producing potential reported in Table 3B(a) of the CRT has been revised accordingly using the average MCF for all manure management systems and the 2006 IPCC Guidelines' Equation 10.23.

4) Time series of total manure sent to anaerobic digestion

The amount of animal manure treated in the bio-digesters has been developed for the years 2007, 2010, 2011 and 2012 onwards, as described in the previous paragraphs. In order to develop the complete time series, the following assumptions have been considered taking in account the information provided by TERNA:

- For the years 1990 no changes in the estimation occurred because digesters were not in place;
- For the years 1991-2000 the amount of animal manure treated in the bio-digesters has been estimated based on the energy production from anaerobic digestion of animal manure;
- For the years 2001-2006 the amount of animal manure treated in the bio-digesters has been estimated based on the biogas from animal manure used for energy production;
- For the years 2008 and 2009 the amount of animal manure treated in the bio-digesters has been estimated based on the total biogas used for energy production.

In Table A.7.12-14 all data, parameters and equations used to estimate CH_4 emission from manure management for cattle and buffalo are reported. These data are: the average monthly temperature; storage temperatures and timescale for emptying manure storages; the amount of manure generated by each subcategory of cattle and buffalo (m^3/head day^{-1}); the *methane emission rates* (g CH_4/m^3 day^{-1}) calculated on the basis of the equations 5.1 and 5.2 reported in the paragraph 5.3.2; the specific conversion factors (g CH_4/kg VS); the content of VS in manure (g VS/head day^{-1}) produced by different subcategories of cattle (dairy and non-dairy cattle) and buffalo (cow buffaloes and other buffaloes); the slurry and solid manure EFs (kg CH_4/head $year^{-1}$) calculated with Equations 5.3 and 5.4 respectively; the total (slurry and solid manure) amount of VS handled in slurry/liquid and solid manure management systems for the entire reporting period; the total (slurry and solid manure) CH_4 emission factors.

Table A.7.12 Data, parameters and equations used to estimate CH_4 emission from manure management for cattle and buffalo (solid manure)

CATTLE and BUFFALO

number of heads	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Calves	300,000	458,936	408,000	500,049	507,452	492,126	461,877	463,597	450,312	419,500
Male cattle	1,994,704	1,829,546	1,564,000	1,372,963	1,116,364	959,551	1,048,733	1,047,980	1,022,680	984,884
Female cattle	2,503,044	2,242,966	2,428,000	2,065,176	2,090,412	2,183,502	2,468,778	2,481,914	2,448,951	2,125,147
Other non dairy cattle	312,649	657,856	588,000	471,733	372,089	319,685	352,442	361,142	338,983	472,077
Dairy cattle	2,641,755	2,079,783	2,065,000	1,842,004	1,746,140	1,826,484	1,643,117	1,638,382	1,609,948	1,631,128
Cow buffalo	61,800	93,528	116,000	137,242	244,599	230,323	232,605	232,887	234,424	233,712
Other buffaloes	32,700	54,876	76,000	67,851	120,487	144,135	169,681	174,140	174,984	182,341

solid manure

solid manure (m3/head/day)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022	average m3/heads day-1 1990-2000	average m3/heads day-1 2001-2010	average m3/heads day-1 from 2011
Calves	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000	0.000	0.000
Male cattle	0.0177	0.0187	0.0181	0.0188	0.0175	0.0154	0.0153	0.0153	0.0153	0.0155	0.018	0.018	0.016
Female cattle	0.0207	0.0207	0.0211	0.0214	0.0197	0.0179	0.0173	0.0172	0.0174	0.0169	0.021	0.021	0.018
Other non dairy cattle	0.0356	0.0356	0.0356	0.0356	0.0326	0.0287	0.0280	0.0280	0.0280	0.0280	0.036	0.035	0.029
Dairy cattle	0.0504	0.0504	0.0504	0.0504	0.0432	0.0366	0.0352	0.0352	0.0352	0.0352	0.050	0.049	0.037
Cow buffalo	0.0598	0.0583	0.0568	0.0553	0.0466	0.0357	0.0335	0.0335	0.0335	0.0335	0.058	0.053	0.036
Other buffaloes	0.0187	0.0182	0.0178	0.0174	0.0165	0.0154	0.0152	0.0152	0.0152	0.0152	0.018	0.017	0.015

CH_4 EF solid manure - model 1990-2000	temperature	temp storage	storage time (days)	FE CH4 (g/m3 day) - methane emission rate	Calves m3/head	Male cattle m3/head	Female cattle m3/head	Other non dairy cattle m3/head	Dairy cattle m3/head	Cow buffalo m3/head	Other buffaloes m3/head	Calves g CH_4/head	Male cattle g CH_4/head	Female cattle g CH_4/head	Other non dairy cattle g CH_4/head	Dairy cattle g CH_4/head	Cow buffalo g CH_4/head	Other buffaloes g CH_4/head
January	5.1	11.3	75.0	0.3	0.0	41.6	48.7	82.8	117.1	135.6	42.4	0.0	12.9	15.1	25.7	36.3	42.1	13.2
February	6.3	12.7	105.0	0.4	0.0	52.6	61.6	104.7	148.1	171.4	53.6	0.0	18.9	22.1	37.6	53.1	61.5	19.2
March	9.2	17.0	15.0	0.5	0.0	8.3	9.7	16.6	23.4	27.1	8.5	0.0	4.6	5.4	9.1	12.9	14.9	4.7
April	12.3	23.4	45.0	1.0	0.0	24.2	28.3	48.1	68.0	78.7	24.6	0.0	25.1	29.4	49.9	70.6	81.8	25.6
May	17.1	37.9	75.0	4.4	0.0	41.6	48.7	82.8	117.1	135.6	42.4	0.0	184.3	215.7	366.5	518.6	600.3	187.7
June	20.8	55.4	105.0	25.6	0.0	56.4	66.0	112.2	158.7	183.7	57.4	0.0	1,444.3	1,690.3	2,872.2	4,063.9	4,703.9	1,471.0
July	23.6	73.2	15.0	100.0	0.0	8.3	9.7	16.6	23.4	27.1	8.5	0.0	832.6	974.4	1,655.7	2,342.7	2,711.7	848.0
August	23.3	71.5	45.0	100.0	0.0	25.0	29.2	49.7	70.3	81.3	25.4	0.0	2,497.8	2,923.3	4,967.2	7,028.1	8,135.0	2,544.0
September	19.6	48.8	75.0	13.2	0.0	40.3	47.2	80.1	113.4	131.2	41.0	0.0	530.8	621.2	1,055.5	1,493.4	1,728.6	540.6
October	14.6	29.4	105.0	1.9	0.0	58.3	68.2	115.9	164.0	189.8	59.4	0.0	110.3	129.0	219.3	310.2	359.1	112.3
November	8.7	16.3	15.0	0.5	0.0	8.1	9.4	16.0	22.7	26.2	8.2	0.0	4.1	4.8	8.2	11.6	13.4	4.2
December	6.1	12.4	45.0	0.3	0.0	25.0	29.2	49.7	70.3	81.3	25.4	0.0	8.7	10.1	17.2	24.4	28.2	8.8
Total	13.9	27.4		1.6	0.0	389.7	456.1	775.0	1096.5	1269.2	396.9	0.0	5,674.2	6,640.9	11,284.1	15,965.8	18,480.3	5,779.2

CH_4 EF solid manure - model 2001-2010	temperature	temp storage	storage time (days)	FE CH4 (g/m3 day) - methane emission rate	Calves m3/head	Male cattle m3/head	Female cattle m3/head	Other non dairy cattle m3/head	Dairy cattle m3/head	Cow buffalo m3/head	Other buffaloes m3/head	Calves g CH_4/head	Male cattle g CH_4/head	Female cattle g CH_4/head	Other non dairy cattle g CH_4/head	Dairy cattle g CH_4/head	Cow buffalo g CH_4/head	Other buffaloes g CH_4/head
January	4.7	10.9	75.0	0.3	0.0	42.3	49.1	81.0	112.9	123.9	40.0	0.0	12.5	14.6	24.0	33.5	36.8	11.9
February	5.4	11.6	105.0	0.3	0.0	53.4	62.1	102.4	142.8	156.7	50.6	0.0	17.1	19.8	32.7	45.6	50.0	16.1
March	9.3	17.2	15.0	0.6	0.0	8.5	9.8	16.2	22.6	24.8	8.0	0.0	4.7	5.5	9.1	12.6	13.9	4.5
April	12.7	24.4	45.0	1.2	0.0	24.5	28.5	47.0	65.6	71.9	23.2	0.0	28.3	32.8	54.2	75.5	82.9	26.7
May	17.6	40.1	75.0	5.5	0.0	42.3	49.1	81.0	112.9	123.9	40.0	0.0	234.3	272.2	449.3	626.2	687.2	221.8
June	21.5	59.3	105.0	37.7	0.0	57.2	66.5	109.8	153.0	167.9	54.2	0.0	2,158.6	2,507.6	4,138.6	5,768.1	6,329.8	2,043.3
July	24.2	78.2	15.0	100.0	0.0	8.5	9.8	16.2	22.6	24.8	8.0	0.0	845.1	981.7	1,620.3	2,258.2	2,478.1	799.9
August	23.9	75.9	45.0	100.0	0.0	25.4	29.5	48.6	67.7	74.3	24.0	0.0	2,535.3	2,945.2	4,860.8	6,774.7	7,434.3	2,399.8
September	19.8	50.1	75.0	15.1	0.0	40.9	47.5	78.4	109.3	119.9	38.7	0.0	616.7	716.4	1,182.3	1,647.8	1,808.3	583.7
October	15.0	30.6	105.0	2.1	0.0	59.2	68.7	113.4	158.1	173.5	56.0	0.0	126.1	146.5	241.7	336.9	369.7	119.4
November	9.1	16.9	15.0	0.5	0.0	8.2	9.5	15.7	21.9	24.0	7.7	0.0	4.5	5.2	8.6	11.9	13.1	4.2
December	5.3	11.4	45.0	0.3	0.0	25.4	29.5	48.6	67.7	74.3	24.0	0.0	8.0	9.3	15.3	21.3	23.4	7.5
Total	14.0	27.9	0.0	1.6	0.0	395.6	459.5	758.4	1057.0	1159.9	374.4	0.0	6,591.1	7,656.7	12,636.8	17,612.4	19,327.4	6,238.9
								VS production (g VS/head day-1)					1,945.1	2,259.5	3,729.2	5,197.5	5,703.6	1,841.1
								Specific conversion factor (gCH4/KgVS head day-1)					9.28	9.28	9.28	9.28	9.28	9.28

CH_4 EF solid manure - model from 2011	temperature	temp storage	storage time (days)	FE CH4 (g/m3 day) - methane emission rate	Calves m3/head	Male cattle m3/head	Female cattle m3/head	Other non dairy cattle m3/head	Dairy cattle m3/head	Cow buffalo m3/head	Other buffaloes m3/head	Calves g CH_4/head	Male cattle g CH_4/head	Female cattle g CH_4/head	Other non dairy cattle g CH_4/head	Dairy cattle g CH_4/head	Cow buffalo g CH_4/head	Other buffaloes g CH_4/head
January	4.7	10.8	75.0	0.3	0.0	36.5	41.6	67.3	85.8	84.3	36.0	0.0	10.8	12.3	19.8	25.3	24.9	10.6
February	6.0	12.3	105.0	0.3	0.0	46.1	52.6	85.1	108.4	106.6	45.6	0.0	15.8	18.1	29.2	37.2	36.6	15.6
March	9.7	18.0	15.0	0.6	0.0	7.3	8.3	13.5	17.2	16.9	7.2	0.0	4.4	5.1	8.2	10.4	10.2	4.4
April	13.4	26.0	45.0	1.4	0.0	21.2	24.2	39.1	49.8	48.9	20.9	0.0	28.6	32.6	52.8	67.3	66.1	28.3
May	17.9	41.3	75.0	6.2	0.0	36.5	41.6	67.3	85.8	84.3	36.0	0.0	226.6	258.5	417.9	532.8	523.7	223.9
June	22.1	62.9	105.0	54.1	0.0	49.4	56.4	91.1	116.2	114.2	48.8	0.0	2,670.5	3,046.4	4,926.1	6,280.4	6,172.0	2,639.0
July	24.4	79.5	15.0	100.0	0.0	7.3	8.3	13.5	17.2	16.9	7.2	0.0	729.3	832.0	1,345.3	1,715.1	1,685.5	720.7
August	24.3	79.2	45.0	100.0	0.0	21.9	25.0	40.4	51.5	50.6	21.6	0.0	2,187.9	2,495.9	4,035.9	5,145.4	5,056.6	2,162.1
September	19.9	50.4	75.0	15.5	0.0	35.3	40.3	65.1	83.0	81.6	34.9	0.0	546.8	623.8	1,008.6	1,285.9	1,263.7	540.4
October	15.0	30.8	105.0	2.2	0.0	51.1	58.2	94.2	120.1	118.0	50.4	0.0	111.5	127.2	205.6	262.1	257.6	110.2
November	9.8	18.0	15.0	0.6	0.0	7.1	8.1	13.0	16.6	16.3	7.0	0.0	4.3	4.9	7.9	10.1	9.9	4.2
December	5.5	11.7	45.0	0.3	0.0	21.9	25.0	40.4	51.5	50.6	21.6	0.0	7.1	8.0	13.0	16.6	16.3	7.0
To																		

VS production (g VS/head/day)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Calves	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Male cattle	1,896.0	2,001.1	1,932.3	2,012.2	1,867.8	1,650.2	1,633.1	1,635.3	1,637.2	1,660.2
Female cattle	2,210.8	2,216.4	2,254.2	2,289.8	2,109.9	1,911.2	1,851.2	1,841.9	1,857.5	1,805.6
Other non dairy cattle	3,810.9	3,810.9	3,810.9	3,810.9	3,484.2	3,075.9	2,994.3	2,994.3	2,994.3	2,994.3
Dairy cattle	5,392.0	5,392.0	5,392.0	5,392.0	4,618.6	3,912.3	3,771.0	3,771.0	3,771.0	3,771.0
Cow buffalo	6,403.9	6,241.2	6,078.4	5,915.7	4,984.8	3,821.3	3,588.6	3,588.6	3,588.6	3,588.6
Other buffaloes	1,998.6	1,951.7	1,904.9	1,858.1	1,767.0	1,653.1	1,630.3	1,630.3	1,630.3	1,630.3

CH_4 EF (kg CH_4/head/year)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Calves	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Male cattle	5.61	5.93	5.72	6.82	6.33	6.43	6.37	6.37	6.38	6.47
Female cattle	6.55	6.56	6.67	7.76	7.15	7.45	7.22	7.18	7.24	7.04
Other non dairy cattle	11.28	11.28	11.28	12.91	11.81	11.99	11.67	11.67	11.67	11.67
Dairy cattle	15.97	15.97	15.97	18.27	15.65	15.25	14.70	14.70	14.70	14.70
Cow buffalo	18.96	18.48	18.00	20.05	16.89	14.90	13.99	13.99	13.99	13.99
Other buffaloes	5.92	5.78	5.64	6.30	5.99	6.44	6.36	6.36	6.36	6.36

Table A.7.13 Data, parameters and equations used to estimate CH_4 emission from manure management for cattle and buffalo (slurry manure)

slurry manure

slurry (m3/head/day)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022	average m3/heads day-1 1990-2000	average m3/heads day-1 2001-2010	average m3/heads day-1 from 2011
Calves	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
Male cattle	0.018	0.019	0.019	0.019	0.020	0.019	0.020	0.020	0.020	0.020	0.018	0.019	0.020
Female cattle	0.011	0.011	0.011	0.011	0.011	0.010	0.010	0.010	0.010	0.010	0.011	0.011	0.010
Other non dairy cattle	0.015	0.015	0.015	0.015	0.014	0.012	0.012	0.012	0.012	0.012	0.015	0.015	0.012
Dairy cattle	0.021	0.021	0.021	0.021	0.030	0.030	0.030	0.030	0.030	0.030	0.021	0.024	0.030
Cow buffalo	0.016	0.017	0.018	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.017	0.019	0.019
Other buffaloes	0.011	0.012	0.012	0.012	0.011	0.010	0.010	0.010	0.010	0.010	0.012	0.012	0.010

CH_4 EF slurry manure - model 1990-2000	temperature	storage time (days)	FE CH4 (g/m3 day) - methane emission rate	Calves m3/head	Male cattle m3/head	Female cattle m3/head	Other non dairy cattle m3/head	Dairy cattle m3/head	Cow buffalo m3/head	Other buffaloes m3/head	Calves g CH_4/head	Male cattle g CH_4/head	Female cattle g CH_4/head	Other non dairy cattle g CH_4/head	Dairy cattle g CH_4/head	Cow buffalo g CH_4/head	Other buffaloes g CH_4/head
January	5.1	75.0	3.7	55.0	43.0	25.4	35.5	49.9	38.6	27.0	201.1	157.1	93.0	129.7	182.4	141.2	98.9
February	6.3	105.0	4.2	69.6	54.3	32.2	44.9	63.1	48.8	34.2	293.5	229.3	135.7	189.3	266.1	206.1	144.3
March	9.2	15.0	5.9	11.0	8.6	5.1	7.1	10.0	7.7	5.4	65.3	51.0	30.2	42.1	59.2	45.9	32.1
April	12.3	45.0	8.6	31.9	24.9	14.8	20.6	29.0	22.4	15.7	276.2	215.7	127.7	178.2	250.4	194.0	135.8
May	17.1	75.0	15.3	55.0	43.0	25.4	35.5	49.9	38.6	27.0	842.1	657.8	389.3	543.2	763.6	591.3	414.0
June	20.8	105.0	24.0	74.5	58.2	34.5	48.1	67.6	52.3	36.6	1790.3	1398.4	827.7	1154.8	1623.3	1257.2	880.1
July	23.6	15.0	33.4	11.0	8.6	5.1	7.1	10.0	7.7	5.4	367.5	287.1	169.9	237.1	333.2	258.1	180.7
August	23.3	45.0	32.5	33.0	25.8	15.3	21.3	29.9	23.2	16.2	1071.1	836.6	495.2	690.9	971.2	752.1	526.5
September	19.6	75.0	20.7	53.2	41.6	24.6	34.3	48.3	37.4	26.2	1099.4	858.8	508.3	709.2	996.9	772.0	540.4
October	14.6	105.0	11.3	77.0	60.1	35.6	49.7	69.8	54.1	37.9	872.6	681.6	403.5	562.9	791.2	612.8	429.0
November	8.7	15.0	5.6	10.6	8.3	4.9	6.9	9.7	7.5	5.2	60.0	46.9	27.7	38.7	54.4	42.1	29.5
December	6.1	45.0	4.1	33.0	25.8	15.3	21.3	29.9	23.2	16.2	134.9	105.4	62.4	87.0	122.3	94.7	66.3
Total	13.9		10.5	514.9	402.2	238.1	332.1	466.9	361.6	253.1	7074.1	5525.6	3270.6	4563.1	6414.3	4967.6	3477.5
							VS production (g VS/head day-1)				1123.733	877.749	519.545	724.863	1018.921	789.118	552.404
							Specific conversion factor (gCH4/KgVS head day-1)				17.25	17.25	17.25	17.25	17.25	17.25	17.25

CH_4 EF slurry manure - model 2001-2010	temperature	storage time (days)	FE CH4 (g/m3 day) - methane emission rate	Calves m3/head	Male cattle m3/head	Female cattle m3/head	Other non dairy cattle m3/head	Dairy cattle m3/head	Cow buffalo m3/head	Other buffaloes m3/head	Calves g CH_4/head	Male cattle g CH_4/head	Female cattle g CH_4/head	Other non dairy cattle g CH_4/head	Dairy cattle g CH_4/head	Cow buffalo g CH_4/head	Other buffaloes g CH_4/head
January	4.7	75.0	3.5	55.0	44.5	25.8	34.6	56.0	43.3	27.7	191.9	155.3	90.2	120.8	195.4	151.2	96.6
February	5.4	105.0	3.8	69.6	56.3	32.7	43.8	70.8	54.8	35.0	262.1	212.1	123.1	165.0	266.8	206.5	131.9
March	9.3	15.0	6.0	11.0	8.9	5.2	6.9	11.2	8.7	5.5	66.2	53.5	31.1	41.7	67.4	52.1	33.3
April	12.7	45.0	9.1	31.9	25.8	15.0	20.1	32.5	25.2	16.1	290.7	235.3	136.6	183.1	296.0	229.1	146.4
May	17.6	75.0	16.4	55.0	44.5	25.8	34.6	56.0	43.3	27.7	901.7	729.7	423.7	567.8	918.1	710.4	453.9
June	21.5	105.0	26.0	74.5	60.3	35.0	46.9	75.9	58.7	37.5	1939.2	1569.2	911.1	1221.1	1974.4	1527.8	976.2
July	24.2	15.0	36.1	11.0	8.9	5.2	6.9	11.2	8.7	5.5	396.9	321.2	186.5	249.9	404.1	312.7	199.8
August	23.9	45.0	34.8	33.0	26.7	15.5	20.8	33.6	26.0	16.6	1149.8	930.4	540.3	724.1	1170.7	905.9	578.8
September	19.8	75.0	21.3	53.2	43.1	25.0	33.5	54.2	41.9	26.8	1135.5	918.9	533.6	715.1	1156.1	894.7	571.6
October	15.0	105.0	11.9	77.0	62.3	36.2	48.5	78.4	60.7	38.8	914.7	740.2	429.8	576.0	931.3	720.7	460.5
November	9.1	15.0	5.9	10.6	8.6	5.0	6.7	10.8	8.4	5.4	62.9	50.9	29.5	39.6	64.0	49.5	31.7
December	5.3	45.0	3.7	33.0	26.7	15.5	20.8	33.6	26.0	16.6	122.3	99.0	57.5	77.0	124.6	96.4	61.6
Total	14.0	0.0	10.7	514.9	416.7	241.9	324.3	524.3	405.7	259.2	7433.8	6015.6	3492.9	4681.3	7568.8	5857.0	3742.1
							VS production (g VS/head day-1)				1123.7	909.3	528.0	707.6	1144.1	885.4	565.7
							Specific conversion factor (gCH4/KgVS head day-1)				18.12	18.12	18.12	18.12	18.12	18.12	18.12

CH_4 EF slurry manure - model from 2011	temperature	storage time (days)	FE CH4 (g/m3 day) - methane emission rate	Calves m3/head	Male cattle m3/head	Female cattle m3/head	Other non dairy cattle m3/head	Dairy cattle m3/head	Cow buffalo m3/head	Other buffaloes m3/head	Calves g CH_4/head	Male cattle g CH_4/head	Female cattle g CH_4/head	Other non dairy cattle g CH_4/head	Dairy cattle g CH_4/head	Cow buffalo g CH_4/head	Other buffaloes g CH_4/head
January	4.7	75.0	3.5	55.0	45.8	22.9	28.1	70.7	43.8	24.4	190.5	158.6	79.2	97.4	244.7	151.7	84.4
February	6.0	105.0	4.0	77.0	64.1	32.0	39.3	98.9	61.3	34.1	311.7	259.5	129.6	159.3	400.4	248.1	138.0
March	9.7	15.0	6.4	11.0	9.2	4.6	5.6	14.1	8.8	4.9	69.9	58.2	29.1	35.7	89.7	55.6	30.9
April	13.4	45.0	9.8	33.0	27.5	13.7	16.9	42.4	26.3	14.6	323.8	269.6	134.7	165.5	416.0	257.8	143.4
May	17.9	75.0	16.9	55.0	45.8	22.9	28.1	70.7	43.8	24.4	932.0	775.8	387.6	476.2	1197.2	741.9	412.7
June	22.1	105.0	27.9	77.0	64.1	32.0	39.3	98.9	61.3	34.1	2148.6	1788.5	893.5	1097.9	2760.1	1710.4	951.3
July	24.4	15.0	36.8	11.0	9.2	4.6	5.6	14.1	8.8	4.9	405.0	337.1	168.4	207.0	520.3	322.4	179.3
August	24.3	45.0	36.6	33.0	27.5	13.7	16.9	42.4	26.3	14.6	1208.9	1006.3	502.7	617.7	1552.9	962.3	535.2
September	19.9	75.0	21.5	55.0	45.8	22.9	28.1	70.7	43.8	24.4	1180.9	983.0	491.1	603.4	1517.0	940.1	522.9
October	15.0	105.0	12.0	77.0	64.1	32.0	39.3	98.9	61.3	34.1	923.3	768.5	384.0	471.8	1186.0	735.0	408.8
November	9.8	15.0	6.4	11.0	9.2	4.6	5.6	14.1	8.8	4.9	70.0	58.2	29.1	35.8	89.9	55.7	31.0
December	5.5	45.0	3.8	33.0	27.5	13.7	16.9	42.4	26.3	14.6	125.6	104.5	52.2	64.2	161.3	100.0	55.6
Total	14.4	0.0	10.7	528.0	439.5	219.6	269.8	678.3	420.3	233.8	7890.1	6567.7	3281.2	4031.9	10135.5	6280.9	3493.5
							VS production (g VS/head day-1)				1123.7	935.383	467.320	574.227	1443.522	894.547	497.553
							Specific conversion factor (gCH4/KgVS head day-1)				19.24	19.24	19.24	19.24	19.24	19.24	19.24

VS production (g VS/head/day)	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2019**	**2020**	**2021**	**2022**
Calves	1,123.7	1,123.7	1,123.7	1,123.7	1,123.7	1,123.7	1,123.7	1,123.7	1,123.7	1,123.7
Male cattle	868.4	916.6	885.1	921.7	929.9	925.2	939.8	941.1	942.2	955.4
Female cattle	518.9	516.9	520.8	536.7	508.7	464.1	458.4	458.0	460.5	460.5
Other non dairy cattle	724.9	724.9	724.9	724.9	656.0	569.9	552.7	552.7	552.7	552.7
Dairy cattle	1,018.9	1,018.9	1,018.9	1,018.9	1,427.1	1,444.4	1,447.8	1,447.8	1,447.8	1,447.8
Cow buffalo	737.9	789.1	840.4	891.6	892.9	894.6	895.0	895.0	895.0	895.0
Other buffaloes	540.5	552.4	564.3	576.2	540.2	495.3	486.3	486.3	486.3	486.3

CH_4 EF (kg CH_4/head/year)	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2019**	**2020**	**2021**	**2022**
Calves	7.07	7.07	7.07	7.43	7.43	7.89	7.89	7.89	7.89	7.89
Male cattle	5.47	5.77	5.57	6.10	6.15	6.50	6.60	6.61	6.62	6.71
Female cattle	3.27	3.25	3.28	3.55	3.37	3.26	3.22	3.22	3.23	3.23
Other non dairy cattle	4.56	4.56	4.56	4.80	4.34	4.00	3.88	3.88	3.88	3.88
Dairy cattle	6.41	6.41	6.41	6.74	9.44	10.14	10.17	10.17	10.17	10.17
Cow buffalo	4.65	4.97	5.29	5.90	5.91	6.28	6.28	6.28	6.28	6.28
Other buffaloes	3.40	3.48	3.55	3.81	3.57	3.48	3.41	3.41	3.41	3.41

Table A.7.14 Data, parameters and equations used to estimate CH_4 emission from manure management for cattle and buffalo (total manure)

Total SV (kg dm/head/day)	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2019**	**2020**	**2021**	**2022**
Calves	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12
Male cattle	2.76	2.92	2.82	2.93	2.80	2.58	2.57	2.58	2.58	2.62
Female cattle	2.73	2.73	2.77	2.83	2.62	2.38	2.31	2.30	2.32	2.27
Other non dairy cattle	4.54	4.54	4.54	4.54	4.14	3.65	3.55	3.55	3.55	3.55
Dairy cattle	6.41	6.41	6.41	6.41	6.05	5.36	5.22	5.22	5.22	5.22
Cow buffalo	7.14	7.03	6.92	6.81	5.88	4.72	4.48	4.48	4.48	4.48
Other buffaloes	2.54	2.50	2.47	2.43	2.31	2.15	2.12	2.12	2.12	2.12
Total average SV (kg dm/head/day)	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2019**	**2020**	**2021**	**2022**
Cattle	4.00	3.89	3.90	3.90	3.65	3.31	3.14	3.13	3.14	3.20
Dairy cattle	6.41	6.41	6.41	6.41	6.05	5.36	5.22	5.22	5.22	5.22
Non dairy cattle	2.76	2.88	2.86	2.85	2.62	2.37	2.35	2.34	2.35	2.38
Buffalo	5.55	5.36	5.16	5.36	4.70	3.73	3.49	3.47	3.47	3.45
Total CH_4 EF (kg CH4/head/year)	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2019**	**2020**	**2021**	**2022**
Calves	7.07	7.07	7.07	7.43	7.43	7.89	7.89	7.89	7.89	7.89
Male cattle	11.08	11.70	11.29	12.92	12.48	12.93	12.97	12.98	13.00	13.18
Female cattle	9.81	9.82	9.95	11.31	10.51	10.71	10.43	10.40	10.47	10.27
Other non dairy cattle	15.85	15.85	15.85	17.71	16.15	15.99	15.55	15.55	15.55	15.55
Dairy cattle	22.38	22.38	22.38	25.01	25.09	25.39	24.87	24.87	24.87	24.87
Cow buffalo	23.61	23.45	23.29	25.94	22.80	21.18	20.27	20.27	20.27	20.27
Other buffaloes	9.32	9.26	9.19	10.11	9.56	9.92	9.77	9.77	9.77	9.77
CH_4 emissions (t)	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2019**	**2020**	**2021**	**2022**
Calves	2,122	3,247	2,886	3,717	3,772	3,883	3,644	3,658	3,553	3,310
Male cattle	22,103	21,398	17,663	17,733	13,933	12,406	13,597	13,606	13,293	12,981
Female cattle	24,562	22,018	24,166	23,356	21,980	23,383	25,761	25,802	25,652	21,830
Other non dairy cattle	4,955	10,425	9,318	8,354	6,008	5,113	5,482	5,617	5,272	7,342
Dairy cattle	59,123	46,546	46,215	46,072	43,813	46,379	40,858	40,740	40,033	40,560
Cow buffalo	1,459	2,193	2,701	3,561	5,577	4,878	4,716	4,721	4,752	4,738
Other buffaloes	305	508	699	686	1,152	1,430	1,658	1,701	1,710	1,781
Total	114,628	106,334	103,649	103,479	96,235	97,471	95,715	95,846	94,265	92,542
Total CH_4 IEF (kg CH4/head/year)	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2019**	**2020**	**2021**	**2022**
EF non dairy cattle (kg/head)	**10.52**	**11.00**	**10.83**	**12.05**	**11.18**	**11.32**	**11.19**	**11.18**	**11.21**	**11.36**
EF dairy cattle (kg/head)	**22.38**	**22.38**	**22.38**	**25.01**	**25.09**	**25.39**	**24.87**	**24.87**	**24.87**	**24.87**
EF buffalo (kg/head)	**18.66**	**18.20**	**17.71**	**20.70**	**18.43**	**16.85**	**15.84**	**15.78**	**15.78**	**15.67**
Bo (m3 CH_4/kg VS)	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2019**	**2020**	**2021**	**2022**
Calves	0.283	0.283	0.291	0.295	0.299	0.345	0.356	0.377	0.383	0.379
Male cattle	0.180	0.180	0.185	0.196	0.201	0.247	0.256	0.271	0.275	0.272
Female cattle	0.162	0.162	0.166	0.178	0.181	0.222	0.229	0.243	0.246	0.245
Other non dairy cattle	0.157	0.157	0.162	0.174	0.176	0.216	0.222	0.235	0.239	0.237
Dairy cattle	0.192	0.192	0.198	0.218	0.186	0.219	0.222	0.236	0.240	0.241
Cow buffalo	0.178	0.174	0.169	0.182	0.178	0.180	0.176	0.176	0.176	0.175

A7.3 Agricultural soils (3D)

Sewage sludge applied to soils

In Table A.7.15 parameters used for estimating direct and indirect N_2O emissions from sewage sludge applied to soils are presented.

Table A.7.15 Time series of sewage sludge activity data

Year	Total amount sewage sludge for agriculture (t dry matter)	N content (%)	N sewage sludge (t)
1990	98,164	5.2	5,071
1995	157,512	5.2	8,137
2000	217,424	5.0	10,954
2005	215,742	4.1	8,874
2010	248,215	4.0	10,040
2015	222,225	3.7	8,303
2019	171,343	4.0	6,791
2020	180,415	3.9	7,078
2021	171,710	3.9	6,745
2022	179,184	3.9	6,950

Source: ISPRA elaborations from MASE (MASE, several years).

Bedding material in the estimates for the category animal manure applied to soils

A description of the types of agricultural residues considered in the estimates of the animal manure applied to soils (3Da2a), crop residues (3Da4) and field burning of agricultural residues (3F) categories is reported.

First of all, the agricultural residues are distinguished between removable and fixed. The last term is used to differentiate them from removable residues (such as straw and cereal stalks and residues of woody crops), "fixed" (no- removable) residues refer to residues which remain on the ground after harvest. The fixed residues include the remaining cereal stalks and the residues of other crops (such as beans, tubers, forages, grass, vegetables, etc.). The distinction between fixed and removable residues is required in the UNECE/LRTAP Convention.

From the cultivation of the crop (e.g. wheat), the product (grain), the removable residue (straw and wheat stalks) and the fixed residue (portion of the wheat stalks that remains on the ground after harvest) are obtained. As regards the removable residues, it is assumed that a portion (10% of residues) is burnt (first is removed from the field and then burned in the open air) and the corresponding emissions are reported in the waste sector (5C open burning of agricultural waste). Another portion (90% of residues) is used for various purposes (feed, bedding, construction, etc.). As regards the fixed residues, it is assumed that a portion (10% of residues) is burnt (the combustion of the residues takes place in the field) and the corresponding emissions are reported in the agriculture sector in 3F field burning of agricultural residues category. Another portion (90% of residues) is returned to soils and the corresponding emissions are reported in crop residues category (3Da4).

Considering the example of wheat, the total amount of durum wheat residues is thus distributed (2022 data):
72% are the removable residues used for various purposes (feed, bedding, construction, etc.),
18% are the fixed residues returned to soils,
8% are the removable residues burnt (removed from the field and then burned in the open air),
2% are the fixed residues burnt (the combustion of the residues takes place in the field).
As regard the estimate of the amount of straw used as bedding and the nitrogen content (see Table A.7.16), the following data are used: the number of dairy cattle, non-dairy cattle and buffalo (excluding pigs for which assumes only the liquid storage); the average weight of the subcategories of cattle and buffalo categories; the types of housings in each subcategory; the amount of straw per day (per tons of

live weight, per type of housing for cattle and buffalo subcategories); the nitrogen content in straw. Data on the amount of straw per day (per tons of live weight, per type of housing, for cattle and buffalo) are contained in the Ministerial Decree of 25 February 2016 on the use of zootechnical effluents, combined with the manure production coefficients used in the estimation of methane emissions from storage. As recommended during the 2019 UNFCCC review, data on the quantity of bedding material used in solid manure management system are provided for 2022: 1.47 kg dm (straw)/head/day for dairy cattle and fattening cattle; 1.49 kg dm (straw)/head/day for replacement cows; 2.37 kg dm (straw)/head/day for other non-dairy cattle; 2.52 kg dm (straw)/head/day for buffalo. Data for 2021 are: 1.47 kg dm (straw)/head/day for dairy cattle; 1.53 kg dm (straw)/head/day for fattening cattle; 1.61 kg dm (straw)/head/day for replacement cows; 2.30 kg dm (straw)/head/day for other non-dairy cattle; 2.45 kg dm (straw)/head/day for buffalo. The amount of nitrogen estimated from bedding materials was added to the nitrogen input from manure applied to soils (3Da2a category) to estimate N_2O emissions.

Table A.7.16 Time series of estimated annual straw consumption (dry matter) and N content

Year	Dairy cattle – straw consumed	Non-dairy cattle – straw consumed	Buffalo – straw consumed	Total straw consumed	N in organic bedding material (straw consumed)
			tons		
1990	1,828,772	2,690,058	90,119	4,608,949	23,567
1995	1,439,743	2,807,134	138,572	4,385,448	22,231
2000	1,429,510	2,665,661	175,378	4,270,548	21,623
2005	1,275,139	2,324,638	183,317	3,783,094	19,093
2010	1,034,808	2,126,664	326,327	3,487,799	17,510
2015	994,450	2,066,608	334,438	3,395,496	17,006
2019	878,785	2,317,306	359,099	3,555,191	17,969
2020	876,253	2,326,975	363,300	3,566,528	18,042
2021	861,046	2,285,123	365,427	3,511,596	17,683
2022	872,373	2,178,739	371,300	3,422,412	17,348

Crop residues (FCR)

In Tables A.7.17-22, the cultivated surface, crops production, residues production and parameters used for emission calculation of nitrogen input from crop residues (FCR) for each type of crop are shown, respectively.

As recommended during the 2019 UNFCCC review, to enhance transparency on the total amount of crop residues generated and shares of the crop residue amounts used for different purposes (such as bedding material (3.D.a.2.a), left on fields (3.D.a.4), burnt on-site (3.F) and off-site (1.A, 5.C.2)), a flow-chart is reported in Figure A.7.1.

Table A.7.17 Cultivated surfaces for the estimation of crop residues

Cultivated surfaces (ha)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Wheat	2,759,926	2,482,119	2,321,893	2,122,896	1,830,475	1,882,516	1,754,636	1,711,219	1,726,608	1,776,729
Rice	214,124	239,259	220,348	224,015	247,653	227,329	220,027	227,319	227,038	218,421
Barley	469,344	381,482	343,701	319,944	272,213	242,895	261,411	263,430	251,762	267,963
Maize, stalks	767,780	942,475	1,063,555	1,113,166	926,776	727,366	628,801	602,856	588,597	563,704
Maize, cobs	767,780	942,475	1,063,555	1,113,166	926,776	727,366	628,801	602,856	588,597	563,704
Rye	8,105	7,108	3,479	2,654	4,513	4,113	3,910	3,580	3,382	3,663
Oats	156,628	134,647	140,748	174,799	130,024	108,956	103,789	103,459	99,490	104,111
Sorghum	23,676	34,417	33,900	31,578	40,311	45,374	46,799	52,912	37,542	36,049
Triticum	4,215	3,716	5,882	6,766	21,658	36,955	32,962	46,951	43,797	39,992
Potatoes	120,481	89,350	81,894	69,912	62,400	50,416	46,806	47,346	46,699	47,034
Sweet potatoes	526	597	1,268	1,431	457	354	385	371	372	504
Sugar beet	274,000	283,993	249,154	253,043	62,266	38,124	29,967	27,265	27,905	25,791
Sunflower	111,797	230,402	216,852	129,874	100,475	114,449	118,518	122,767	116,985	110,818
Cabbage	26,296	22,345	24,778	27,556	27,196	25,213	23,981	21,486	21,641	21,705
Artichoke	48,172	51,273	50,283	50,127	50,321	41,299	39,419	38,163	38,452	38,166
Asparagus	6,046	6,520	5,516	6,442	6,359	6,397	7,158	7,400	7,446	7,461
Salad	48,725	49,288	51,219	50,010	47,371	40,647	42,443	40,915	39,857	33,173
Spinach	7,573	7,959	6,992	7,367	6,406	6,461	6,287	6,141	6,084	5,570
Tomato	136,379	114,917	136,265	138,759	119,977	107,178	99,020	99,783	102,056	97,611
Cauliflower	19,405	23,991	24,827	18,150	17,867	15,624	15,670	15,508	15,128	14,728
Pumpkin and zucchini	13,253	13,490	14,621	16,736	17,354	18,614	19,084	20,151	19,950	19,048
Cucumber	4,373	3,814	2,048	2,331	2,219	2,071	2,055	2,097	2,012	1,980
Eggplant	10,574	10,334	12,355	12,169	10,816	10,148	9,546	9,508	9,571	9,596
Pepper and chili	14,864	13,099	14,489	13,787	11,881	11,521	10,284	10,007	9,670	9,393
Onion	17,453	15,725	14,562	12,281	12,603	11,877	14,064	12,816	12,514	12,633
Garlic	4,707	4,070	3,677	3,163	2,966	3,044	3,411	3,287	3,590	3,729
Bean,freshseed	29,096	23,943	23,448	23,146	19,027	17,059	18,253	17,915	18,378	15,748
Bean,dryseed	23,002	14,462	11,046	8,755	7,001	5,870	5,587	5,541	5,265	3,489
Broadbean,freshseed	16,564	14,180	11,998	9,484	8,487	7,914	7,624	7,372	7,310	14,424
Broadbean,dryseed	104,045	63,257	47,841	48,507	52,108	42,157	60,007	61,982	57,207	50,058
Pea,freshseed	28,192	21,582	11,403	11,636	8,691	14,940	16,197	16,154	15,730	16,428
Pea,dryseed	10,127	6,625	4,498	11,134	11,692	11,181	22,926	20,766	17,771	16,033
Chickpea	4,624	3,023	3,996	5,256	6,813	11,167	20,999	18,579	17,617	14,068

Cultivated surfaces (ha)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Lentil	1,048	1,038	1,016	1,786	2,458	3,099	5,861	5,612	5,710	4,925
Vetch	5,768	6,532	6,800	7,142	7,560	7,795	7,827	7,827	7,827	7,827
Lupin	3,303	3,070	3,300	2,500	3,401	3,358	3,337	3,337	3,337	3,337
Soyabean	521,169	195,191	256,647	152,331	159,511	308,979	273,332	256,134	285,464	342,532
Alfalfa	987,000	823,834	810,866	779,430	745,128	667,325	719,073	715,642	694,481	684,187
Clovergrass	224,087	125,009	114,844	103,677	102,691	119,942	127,087	127,270	124,308	143,941
Waxy Corn	97,435	271,532	285,148	270,739	282,407	339,787	367,322	378,943	375,493	368,816
Grass Barley	11,291	35,913	44,745	43,834	40,055	51,045	52,760	52,760	52,760	52,760
Waxy Barley	3,615	9,967	11,807	11,549	21,813	8,230	13,553	12,914	17,184	17,568
Ryegrass	20,719	52,000	57,520	57,324	61,213	76,636	94,490	87,218	88,354	92,156
Other grasses	84,925	224,471	171,828	141,733	129,913	137,752	266,063	280,281	303,299	273,765
Gramineae	8,906	33,615	77,386	74,394	120,408	125,229	84,505	87,033	101,360	101,753
Leguminosae	13,772	33,118	78,001	59,569	57,128	65,635	81,716	84,526	91,919	97,587
Other mixtures	140,222	349,350	282,921	261,488	269,885	307,785	279,284	288,789	280,823	299,798
Sainfoin (*Lupinella*)	21,521	39,677	39,257	20,082	18,930	14,460	14,729	14,674	14,262	15,283
Sulla	51,469	112,049	106,194	89,865	89,032	90,017	94,040	99,233	95,720	97,864
Polyphytic meadows	109,860	224,444	213,389	177,689	204,313	144,946	312,528	330,586	345,079	392,552
Total	**8,557,961**	**8,796,747**	**8,783,759**	**8,295,171**	**7,388,997**	**7,088,614**	**7,118,334**	**7,080,682**	**7,073,402**	**7,160,175**

Table A.7.18 Crop production for the estimation of crop residues

Crops production (t)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Wheat	8,108,500	7,946,081	7,427,660	7,717,129	6,849,858	7,394,495	6,576,584	6,553,861	7,118,272	6,449,773
Rice	1,290,700	1,320,851	1,245,555	1,444,818	1,574,320	1,505,804	1,505,099	1,530,921	1,496,545	1,236,962
Barley	1,702,500	1,387,069	1,261,560	1,214,054	944,257	955,131	1,072,447	1,090,630	1,059,803	1,124,283
Maize, stalks	5,863,900	8,454,198	10,139,639	10,427,930	8,495,946	7,073,897	6,258,747	6,771,089	6,060,232	4,681,925
Maize, cobs	5,863,900	8,454,198	10,139,639	10,427,930	8,495,946	7,073,897	6,258,747	6,771,089	6,060,232	4,681,925
Rye	20,800	19,780	10,292	7,876	13,926	13,183	12,509	11,475	10,886	11,409
Oats	298,400	301,322	317,926	429,153	288,880	261,366	238,107	242,709	233,452	242,282
Sorghum	114,200	214,802	215,200	184,915	275,572	294,218	312,384	361,694	223,459	191,161
Triticum	10,480	13,210	0	0	0	0	0	0	0	0
Potatoes	2,308,700	2,080,896	2,053,043	1,755,686	1,558,030	1,355,409	1,338,432	1,434,651	1,362,127	1,332,981
Sweet potatoes	11,300	14,273	14,496	20,251	8,681	7,547	5,534	6,179	5,894	7,998
Sugar beet	11,768,400	13,188,317	11,569,182	14,155,683	3,549,871	2,183,878	1,779,127	1,831,092	1,510,710	1,110,283
Sunflower	403,500	533,581	460,714	289,365	212,900	248,007	292,836	297,948	280,583	264,312
Cabbage	491,600	450,687	482,147	478,972	502,955	467,412	457,819	420,638	413,500	403,898
Artichoke	487,000	517,229	512,946	469,975	480,112	401,335	378,819	367,079	376,277	378,110
Asparagus	28,382	33,479	30,492	43,496	43,973	44,055	49,913	47,039	45,715	51,549
Salad	901,700	906,200	968,833	1,010,470	990,572	846,754	956,528	933,656	904,711	791,038
Spinach	87,300	106,500	92,959	99,367	90,608	92,385	99,518	99,870	100,769	96,867
Tomato	5,469,068	5,172,611	7,487,358	7,187,014	6,026,766	6,410,249	5,777,614	6,247,909	6,644,793	6,136,383
Cauliflower	375,800	470,800	518,030	430,669	427,407	385,972	368,154	365,355	359,728	352,065
Pumpkin and zucchini	338,800	356,000	412,779	488,054	509,512	533,495	569,123	600,431	601,663	558,942
Cucumber	90,278	83,032	54,010	72,572	59,598	55,599	58,120	58,366	60,826	59,822
Eggplant	270,900	301,600	357,031	338,803	303,046	300,182	300,616	304,687	306,444	307,434
Pepper and chili	343,200	325,100	365,624	362,994	296,074	282,896	249,637	247,624	244,052	232,677
Onion	486,200	471,965	437,359	358,926	380,855	378,300	477,905	457,972	415,588	396,974
Garlic	41,200	34,939	31,639	29,598	26,501	27,123	29,270	27,966	32,765	33,092
Bean,freshseed	234,400	200,700	218,379	218,757	185,752	148,713	154,391	162,215	169,902	147,397
Bean,dryseed	35,900	23,647	20,274	18,908	13,181	12,215	11,645	13,201	12,424	7,697
Broadbean,freshseed	90,100	85,512	72,948	53,796	50,837	46,527	47,850	46,641	40,271	78,673
Broadbean,dryseed	114,600	98,730	71,762	86,920	104,241	79,772	118,785	119,810	104,445	89,243
Pea,freshseed	168,100	129,600	72,078	71,411	52,092	74,702	79,649	80,412	81,569	74,981
Pea,dryseed	34,400	19,756	12,107	34,464	30,872	26,240	69,991	61,019	50,083	45,117

Crops production (t)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Chickpea	4,200	3,358	4,140	6,113	9,143	16,761	35,525	33,170	30,439	24,790
Lentil	800	865	758	1,234	1,697	2,484	5,285	4,895	5,008	4,216
Vetch	4,700	6,134	6,800	8,000	8,555	9,050	9,101	9,101	9,101	9,101
Lupin	4,200	5,144	4,800	3,500	4,810	4,748	4,721	4,721	4,721	4,721
Soyabean	1,750,500	732,448	908,290	553,002	552,454	1,116,982	1,001,154	965,439	886,566	905,699
Alfalfa	30,094,610	27,858,100	25,662,700	25,924,100	21,928,700	17,255,600	20,931,600	21,312,007	18,418,557	15,549,612
Clovergrass	6,304,100	2,899,100	2,397,800	2,203,300	1,982,500	2,107,700	2,190,000	2,125,454	2,025,131	2,216,320
Waxy Corn	5,445,099	14,033,200	13,517,200	14,334,200	14,088,600	16,668,600	18,691,400	20,653,520	20,124,845	17,646,955
Grass Barley	187,415	518,100	790,900	816,800	677,800	729,200	767,300	767,300	767,300	767,300
Waxy Barley	84,982	285,300	351,200	334,800	979,100	224,600	357,200	369,902	485,733	470,191
Ryegrass	734,816	1,800,000	1,855,400	1,717,500	1,696,600	2,223,200	2,116,700	2,029,998	2,106,172	2,031,427
Other grasses	2,236,744	5,060,400	3,649,400	3,057,900	2,306,900	2,390,000	4,483,800	4,944,599	5,212,511	4,504,561
Gramineae	202,038	557,800	1,471,600	1,191,900	1,261,800	1,277,500	700,700	779,826	1,101,699	971,157
Leguminosae	160,962	387,700	1,365,400	1,059,700	785,700	550,500	860,400	1,032,338	1,086,378	1,045,464
Other mixtures	3,112,241	7,869,200	5,840,000	5,422,300	3,198,800	3,569,200	4,231,300	4,455,097	3,717,484	3,389,316
Sainfoin (*Lupinella*)	412,452	793,800	751,000	334,400	281,900	208,200	207,300	202,579	180,392	167,815
Sulla	705,718	1,876,900	1,723,400	1,262,200	1,214,300	1,140,500	1,165,300	1,213,939	1,101,977	1,109,208
Polyphytic meadows	2,828,675	5,346,900	4,561,400	3,838,900	4,048,700	2,563,500	3,256,600	3,743,313	3,751,221	3,957,644

Table A.7.19 Parameters used for emission of nitrogen input from crop residues (FCR)

Crops	Residues/Crop product mass ratio [1]	Residues/Crop surface (t/ha) [2]	Dry matter of residues (%) [3]	Reincorporated fraction [4]	Protein in dry matter [5]	N content of aboveground residues [5]	Ratio of belowground residues to above-ground biomass (RBG-BIO) [6]	N content of belowground residues (NBG) [6]	Dry matter fraction of harvested product (DRY) [6]	Slope [6]	Intercept [6]
Wheat	0.1725		85	0.91	0.03	0.0048	0.24	0.009	0.89		
Rice	0.1675		75	0.6	0.045	0.0072	0.16	0.014	0.89		
Barley	0.2		85	0.91	0.04	0.0064	0.22	0.014	0.89		
Maize, stalks	0.13		40	1	0.045	0.0072	0.22	0.007	0.87		
Maize, cobs	0.02		50	1	0.035	0.0056	0.22	0.007	0.87		
Rye	0.175		85	0.91	0.04	0.0064	0.24	0.011	0.88		
Oats	0.175		85	0.91	0.04	0.0064	0.25	0.008	0.89		
Sorghum		0.625	85	0.91	0.045	0.0072	0.24	0.006	0.89		
Triticum	0.2		85	0.91	0.04	0.0064	0.25	0.008	0.88		
Potatoes	0.4		40	0.9	0.09	0.0144	0.2	0.014	0.22		
Sweet potatoes	0.4		40	0.9	0.09	0.0144	0.2	0.014	0.22		
Sugar beet	0.07		20	0.9	0.125	0.02	0.2	0.014	0.16		
Sunflower	0.4		60	0.9	0.025	0.004	0.24	0.006	0.94		
Cabbage	2.5		15	0.9	0.175	0.028	0.2	0.014	0.07		
Artichoke	2.5		15	0.9	0.135	0.0216	0.2	0.014	0.08		
Asparagus		2.8	8	0.9	0.09375	0.015	0.2	0.014	0.08		
Salad		3.4	4.5	0.9	0.09375	0.015	0.2	0.014	0.06		
Spinach		3.4	8	0.9	0.09375	0.015	0.2	0.014	0.08		
Tomato	0.3		15	0.9	0.08	0.0128	0.2	0.014	0.06		
Cauliflower		3.8	8	0.9	0.09375	0.015	0.2	0.014	0.08		
Pumpkin and zucchini		9.5	4.5	0.9	0.09375	0.015	0.2	0.014	0.08		
Cucumber		8.5	4.5	0.9	0.09375	0.015	0.2	0.014	0.04		
Eggplant		9.5	8	0.9	0.09375	0.015	0.2	0.014	0.08		
Pepper and chili		9.5	8	0.9	0.09375	0.015	0.2	0.014	0.07		
Onion		0.7	8	0.9	0.09375	0.015	0.2	0.014	0.09		
Garlic		0.7	30	0.9	0.09375	0.015	0.2	0.014	0.09		
Bean,freshseed		17.7	20	0.9	0.125	0.02	0.19	0.008	0.91		

Crops	Residues/Crop product mass ratio [(1)]	Residues/Crop surface (t/ha) [(2)]	Dry matter of residues (%) [(3)]	Reincorporated fraction [(4)]	Protein in dry matter [(5)]	N content of aboveground residues [(5)]	Ratio of belowground residues to above-ground biomass (RBG-BIO) [(6)]	N content of belowground residues (NBG) [(6)]	Dry matter fraction of harvested product (DRY) [(6)]	Slope [(6)]	Intercept [(6)]
Bean,dryseed		0.6699	85	0.9	0.1	0.016	0.19	0.01	0.9		
Broadbean,freshseed		17.7	20	0.9	0.125	0.02	0.19	0.008	0.91		
Broadbean,dryseed		0.6699	85	0.9	0.1	0.016	0.19	0.008	0.91		
Pea,freshseed		17.7	20	0.9	0.125	0.02	0.19	0.008	0.91		
Pea,dryseed		0.6699	85	0.9	0.1	0.016	0.19	0.008	0.91		
Chickpea		0.6699	85	0.9	0.1	0.016	0.19	0.008	0.91		
Lentil		0.6699	85	0.9	0.1	0.016	0.19	0.008	0.91		
Tare		0.6699	85	0.9	0.1	0.016	0.19	0.008	0.91		
Lupin		0.6699	85	0.9	0.1	0.016	0.19	0.008	0.91		
Soyabean		2.6	47.5	0.9	0.075	0.012	0.19	0.008	0.91		
Alfalfa			90	0.2	0.16875	0.027	0.4	0.019	0.9		
Clovergrass			90	0.2	0.16875	0.027	0.4	0.022	0.9		
Other temporary forages				0.2		0.018	0.6	0.013	0.9	0.3	0
Perennial grasses				0.2		0.015	0.8	0.012	0.9	0.3	0

(1) CESTAAT, 1988 and ENEA, 1994; (2) CRPA/CNR, 1992 and ENEA, 1994; (3) IPCC, 1997; CRPA/CNR, 1992; CESTAAT, 1988; Borgioli, 1981; CREA expert judgment; (4) Values are the complement of the fraction of fixed residues burned (CRPA, 1997 [b]). Values also include the non-combusted portion of burned grain residues, which have a combustion coefficient C of 90%, except for rice, which is 80%; (5) Nitrogen in dry matter is equal to raw protein in residues (dry matter fraction) (CESTAAT, 1988; Borgioli, 1981) dividing by factor 6.25 (100 g of protein/16 g of nitrogen); (6) Table 11.2 of the 2006 IPCC Guidelines.

Table A.7.20 Aboveground residues production for the estimation of crop residues

t dry matter	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Wheat	1,188,909	1,165,094	1,089,081	1,131,524	1,004,360	1,084,218	964,292	960,960	1,043,717	945,698
Rice	162,144	165,932	156,473	181,505	197,774	189,167	189,078	192,322	188,003	155,393
Barley	289,425	235,802	214,465	206,389	160,524	162,372	182,316	185,407	180,166	191,128
Maize, stalks	304,923	439,618	527,261	542,252	441,789	367,843	325,455	352,097	315,132	243,460
Maize, cobs	58,639	84,542	101,396	104,279	84,959	70,739	62,587	67,711	60,602	46,819
Rye	3,094	2,942	1,531	1,172	2,072	1,961	1,861	1,707	1,619	1,697
Oats	44,387	44,822	47,292	63,837	42,971	38,878	35,418	36,103	34,726	36,039
Sorghum	14,798	21,511	21,188	19,736	25,194	28,359	29,249	33,070	23,464	22,531
Triticum	1,782	2,246	0	0	0	0	0	0	0	0
Potatoes	369,392	332,943	328,487	280,910	249,285	216,865	214,149	229,544	217,940	213,277
Sweet potatoes	1,808	2,284	2,319	3,240	1,389	1,208	885	989	943	1,280
Sugar beet	164,758	184,636	161,969	198,180	49,698	30,574	24,908	25,635	21,150	15,544
Sunflower	96,840	128,059	110,571	69,448	51,096	59,522	70,281	71,507	67,340	63,435
Cabbage	184,350	169,008	180,805	179,615	188,608	175,280	171,682	157,739	155,063	151,462
Artichoke	182,625	193,961	192,355	176,241	180,042	150,501	142,057	137,655	141,104	141,791
Asparagus	16,929	18,256	15,444	18,038	17,805	17,913	20,042	20,721	20,848	20,892
Salad	165,665	167,579	174,144	170,035	161,060	138,199	144,305	139,112	135,514	112,790
Spinach	25,748	27,061	23,774	25,049	21,781	21,966	21,377	20,879	20,685	18,938
Tomato	246,108	232,767	336,931	323,416	271,204	288,461	259,993	281,156	299,016	276,137
Cauliflower	73,739	91,166	94,343	68,970	67,895	59,371	59,546	58,930	57,486	55,966
Pumpkin and zucchini	125,904	128,155	138,898	158,987	164,863	176,831	181,298	191,430	189,521	180,960
Cucumber	37,171	32,419	17,405	19,813	18,865	17,600	17,469	17,825	17,098	16,828
Eggplant	100,453	98,173	117,371	115,602	102,751	96,404	90,686	90,330	90,926	91,157
Pepper and chili	141,208	124,441	137,648	130,975	112,871	109,454	97,700	95,065	91,869	89,234
Onion	12,217	11,008	10,193	8,597	8,822	8,314	9,845	8,971	8,760	8,843
Garlic	3,295	2,849	2,574	2,214	2,076	2,131	2,388	2,301	2,513	2,610
Bean,freshseed	103,000	84,758	83,004	81,936	67,354	60,388	64,617	63,420	65,057	55,748
Bean,dryseed	13,098	8,235	6,290	4,985	3,986	3,342	3,181	3,155	2,998	1,987
Broadbean,freshseed	58,637	50,197	42,473	33,573	30,044	28,016	26,989	26,097	25,877	51,061
Broadbean,dry seed	59,245	36,019	27,241	27,621	29,671	24,005	34,169	35,293	32,575	28,504
Pea,freshseed	99,800	76,400	40,366	41,193	30,766	52,887	57,336	57,186	55,683	58,154

t dry matter	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Pea,dryseed	5,766	3,772	2,561	6,340	6,658	6,367	13,054	11,824	10,119	9,129
Chickpea	2,633	1,721	2,275	2,993	3,879	6,359	11,957	10,579	10,031	8,011
Lentil	597	591	579	1,017	1,400	1,765	3,337	3,196	3,251	2,804
Vetch	3,284	3,719	3,872	4,067	4,305	4,439	4,457	4,457	4,457	4,457
Lupin	1,881	1,748	1,879	1,424	1,937	1,912	1,900	1,900	1,900	1,900
Soyabean	643,644	241,061	316,959	188,129	196,996	381,589	337,565	316,325	352,548	423,027
Alfalfa	1,963,673	1,817,741	1,674,491	1,691,548	1,430,848	1,125,928	1,365,787	1,390,608	1,201,811	1,014,612
Clovergrass	567,369	260,919	215,802	198,297	178,425	189,693	197,100	191,291	182,262	199,469
Other temporary forages	2,507,313	6,404,657	6,098,715	6,052,511	5,338,221	6,207,568	7,223,184	7,834,582	7,749,260	6,782,716
Total	**10,046,247**	**13,098,813**	**12,720,426**	**12,535,653**	**10,954,243**	**11,608,386**	**12,663,500**	**13,329,081**	**13,083,035**	**11,745,488**

Table A.7.21 Estimate of nitrogen from crop residues of perennial grasses (1)

	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Surface (ha)	855,117	931,388	893,737	828,835	879,405	924,270	856,000	832,254	791,733	744,229
Production (t)	15,213,383	16,945,600	15,841,500	13,853,700	14,478,400	11,766,500	9,499,900	9,445,691	9,085,736	8,114,003
Crop (kg dm/ha) (2)	16,012	16,375	15,953	15,043	14,817	11,458	9,988	10,215	10,328	9,812
AG_{DM} (t/ha) (3)	4.80	4.91	4.79	4.51	4.45	3.44	3.00	3.06	3.10	2.94
R_{AG} (kg dm/ kg dm) (4)	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
R_{BG} (kg dm/ kg dm) (5)	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
F_{CR} of perennial grasses (t N) (6)	**36,640**	**40,812**	**38,153**	**33,365**	**34,870**	**28,338**	**22,880**	**22,749**	**21,882**	**19,542**

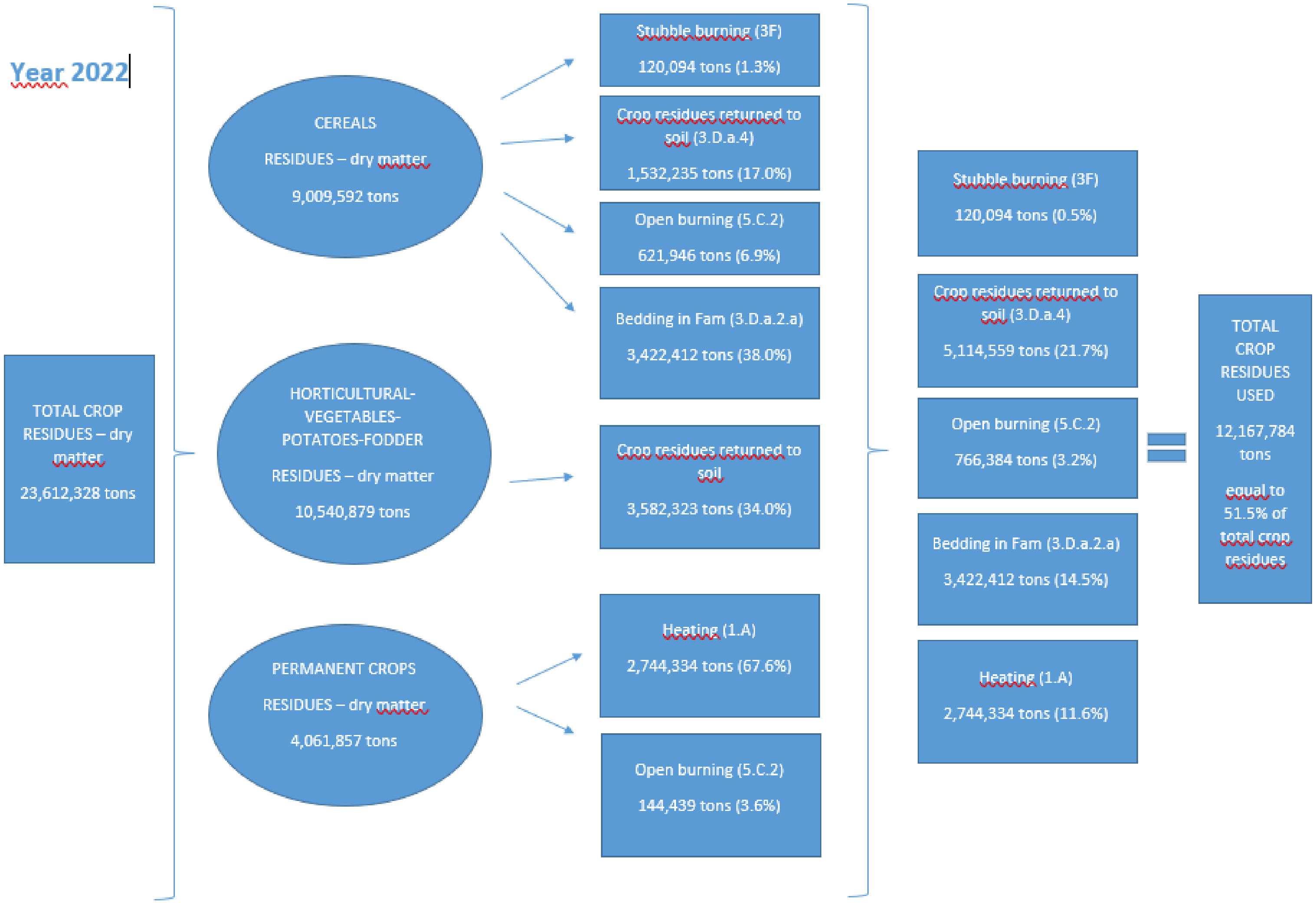
*(1) According to the equations 11.6 and 11.7 of the 2006 IPCC Guidelines; (2) Harvested annual dry matter yield - kg harvested fresh yield / ha * DRY (dry matter fraction); (3) Above-ground residue dry matter calculated as (Crop/1000)*slope+intercept; (4) Ratio of above-ground residues dry matter to harvested yield, calculated as AG_{DM}*1000/Crop; (5) Ratio of below-ground residues to harvested yield, calculated as R_{BG-BIO}*[(AG_{DM}*1000+Crop)/Crop]; (6) Calculated according to equation 11.6 assuming $Frac_{Renew}$=1/5, Area burnt=0, $Frac_{Remove}$=0.8.*

Table A.7.22 Total nitrogen content in the aboveground and belowground crop residues

Total nitrogen (t N)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Wheat	23,349	22,881	21,388	22,222	19,725	21,293	18,938	18,872	20,498	18,573
Rice	3,637	3,722	3,419	4,228	4,892	4,755	4,759	4,842	4,735	3,917
Barley	7,244	5,902	5,368	5,166	4,018	4,064	4,563	4,641	4,509	4,784
Maize, stalks	10,521	15,169	18,193	18,711	15,244	12,693	11,230	12,149	10,874	8,401
Maize, cobs	8,275	11,931	14,309	14,716	11,989	9,983	8,832	9,555	8,552	6,607
Rye	75	71	37	28	50	47	45	41	39	41
Oats	878	887	936	1,263	850	769	701	714	687	713

Total nitrogen (t N)	1990	1995	2000	2005	2010	2015	2019	2020	2021	2022
Sorghum	265	447	445	395	555	604	634	728	474	425
Triticum	32	41	0	0	0	0	0	0	0	0
Potatoes	7,244	6,529	6,442	5,509	4,888	4,253	4,199	4,501	4,274	4,182
Sweet potatoes	35	45	45	64	27	24	17	19	18	25
Sugar beet	8,699	9,749	8,552	10,464	2,624	1,614	1,315	1,354	1,117	821
Sunflower	1,034	1,368	1,181	742	546	636	751	764	719	677
Cabbage	5,258	4,821	5,157	5,123	5,380	4,999	4,897	4,499	4,423	4,320
Artichoke	4,171	4,430	4,393	4,025	4,112	3,437	3,244	3,144	3,222	3,238
Asparagus	282	305	259	304	300	302	338	348	350	352
Salad	2,852	2,884	3,001	2,941	2,792	2,395	2,513	2,424	2,361	1,971
Spinach	439	465	408	431	375	379	371	363	360	330
Tomato	4,443	4,202	6,083	5,839	4,896	5,208	4,694	5,076	5,398	4,985
Cauliflower	1,286	1,591	1,654	1,221	1,202	1,054	1,053	1,042	1,018	991
Pumpkin and zucchini	2,128	2,169	2,357	2,701	2,801	3,002	3,083	3,255	3,224	3,075
Cucumber	616	538	290	331	314	293	291	297	286	281
Eggplant	1,698	1,668	1,993	1,960	1,743	1,639	1,546	1,541	1,551	1,555
Pepper and chili	2,369	2,092	2,315	2,206	1,898	1,840	1,641	1,598	1,545	1,500
Onion	322	298	276	231	240	231	281	262	248	244
Garlic	64	55	50	44	41	42	46	45	49	51
Bean,freshseed	2,335	1,932	1,922	1,902	1,572	1,384	1,475	1,462	1,505	1,292
Bean,dryseed	275	175	137	114	88	75	72	74	70	46
Broadbean,freshseed	1,269	1,098	930	730	657	611	593	574	561	1,106
Broadbean,dryseed	1,102	710	533	560	617	492	708	728	663	577
Pea,freshseed	2,181	1,671	888	903	673	1,136	1,229	1,227	1,200	1,239
Pea,dryseed	139	87	58	149	149	138	305	273	230	208
Chickpea	48	32	42	56	74	124	239	214	202	162
Lentil	11	11	10	18	25	32	60	58	59	50
Vetch	59	68	71	76	80	83	84	84	84	84
Lupin	36	35	37	28	37	37	37	37	37	37
Soyabean	10,351	3,983	5,161	3,083	3,191	6,246	5,544	5,233	5,570	6,464
Alfalfa	76,990	71,268	65,652	66,320	56,099	44,144	53,548	54,521	47,119	39,780
Clovergrass	24,699	11,359	9,395	8,633	7,767	8,258	8,580	8,328	7,934	8,684
Other temporary forages	107,212	265,491	248,641	240,532	205,788	230,420	268,402	291,795	286,107	253,321
Perennial grasses	36,640	40,812	38,153	33,365	34,870	28,338	22,880	22,749	21,882	19,542
Total	**360,563**	**502,989**	**480,180**	**467,328**	**403,187**	**407,073**	**443,737**	**469,430**	**453,752**	**404,650**

Figure A.7.1. Flow-chart on the amount of crop residues generated and shares of the crop residue amounts used for different purposes



Note: part of the 26,612,328 tons of total crop residues is used to feed the anaerobic digesters, but at the moment it is not possible to quantify their size; the quantity of stubble burning and open burning refer to the amount of dry residues burnt.

ANNEX 8: ADDITIONAL INFORMATION OF THE ANNUAL INVENTORY SUBMISSION

A8.1 Annual inventory submission

This appendix shows Tables 10s1 and 10s6 from the Common Reporting Tables, submitted in 2024, in which time series of emission estimates are reported in CO_2 eq.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	(kt CO_2 eq)									
Total (net emissions)[(2)]	517418.77	503655.82	505003.27	511023.31	492133.06	511901.55	505222.06	521360.30	536733.23	533212.87
1. Energy	426167.39	426236.97	425937.28	421030.17	416098.53	438670.25	435501.05	441352.76	454038.19	458558.43
A. Fuel combustion (sectoral approach)	411964.23	412218.23	411847.24	406886.82	402304.36	425294.44	422436.58	428152.95	440872.41	446443.91
1. Energy industries	137620.14	131981.14	131190.71	125341.92	127784.65	140603.23	135258.00	137630.61	138882.21	133460.93
2. Manufacturing industries and construction	92150.78	89471.25	89483.42	88035.34	89822.04	90203.86	89332.30	93414.46	96853.35	101831.99
3. Transport	102189.86	104815.71	109984.56	111651.85	111516.32	114215.03	115950.38	117888.29	122306.96	123872.35
4. Other sectors	78867.80	84651.13	79798.43	80285.18	71597.77	78713.19	80616.85	77889.32	81703.44	86078.73
5. Other	1135.66	1299.00	1390.11	1572.53	1583.59	1559.13	1279.05	1330.27	1126.45	1199.91
B. Fugitive emissions from fuels	14203.15	14018.74	14090.05	14143.35	13794.16	13375.81	13064.47	13199.81	13165.78	12114.53
1. Solid fuels	148.33	131.11	145.54	97.32	91.19	83.17	78.12	78.65	74.33	71.29
2. Oil and natural gas and other emissions from energy production	14054.83	13887.63	13944.51	14046.03	13702.98	13292.63	12986.35	13121.16	13091.44	12043.23
C. CO_2 transport and storage	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2. Industrial Processes	37945.93	37505.53	37093.07	34253.80	32982.20	36298.88	33492.29	34119.66	35208.36	35998.40
A. Mineral industry	20720.45	20682.33	21476.60	19076.44	18591.19	20239.69	18575.37	18844.17	19106.28	19903.26
B. Chemical industry	9626.06	9905.71	9427.94	8911.37	8282.03	9370.71	8327.04	8526.13	8592.25	8430.52
C. Metal industry	6232.18	5596.08	4750.25	4730.71	4367.57	4293.36	3693.37	3477.33	3271.99	2717.81
D. Non-energy products from fuels and solvent use	369.53	340.32	333.21	306.27	308.73	322.92	313.77	318.82	317.87	319.30
E. Electronic industry	NO	NO	NO	NO	NO	222.95	218.76	240.76	300.19	284.82
F. Product uses as ODS substitutes	NO	NO	123.94	227.11	395.38	621.94	874.23	1180.71	2154.41	3063.62
G. Other product manufacture and use	997.71	981.08	981.13	1001.91	1037.29	1227.32	1489.74	1531.74	1465.37	1279.07
H. Other	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3. Agriculture	37952.78	38814.31	38284.80	38698.14	38318.04	38311.92	38341.81	38835.42	38159.71	38630.57
A. Enteric fermentation	17092.76	17376.75	16796.79	16604.07	16685.19	16696.92	16907.02	16808.96	16703.03	16933.60
B. Manure management	7941.80	7964.75	7637.78	7583.28	7417.14	7568.52	7576.88	7550.69	7602.12	7679.90
C. Rice cultivation	2101.64	2005.86	2082.82	2183.95	2239.56	2227.63	2194.49	2178.83	2058.12	2016.08
D. Agricultural soils	10287.79	10869.27	11150.17	11624.56	11310.45	11232.91	11155.11	11695.04	11205.53	11386.75
E. Prescribed burning of savannas	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
F. Field burning of agricultural residues	18.93	20.47	19.98	19.13	19.23	18.46	19.50	17.84	20.16	19.71
G. Liming	1.36	1.36	1.37	1.38	1.38	1.39	1.38	1.39	1.37	2.01
H. Urea application	464.84	519.31	536.33	621.90	588.39	512.05	439.22	525.41	526.32	550.90
I. Other carbon-containing fertilizers	43.68	56.54	59.56	59.88	56.70	54.03	48.20	57.27	43.05	41.62
J. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
4. Land use, land-use change and forestry[(2)]	-3643.15	-18642.64	-16483.71	-3660.97	-16678.24	-23387.66	-24862.99	-16402.28	-13829.38	-23122.28
A. Forest land	-17344.49	-29377.72	-27973.72	-17560.43	-27931.68	-31019.12	-30764.56	-23164.05	-21644.95	-27089.43

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	(kt CO_2 eq)									
B. Cropland	2082.36	539.90	1017.92	511.53	328.65	1385.94	2097.13	1547.17	1242.63	770.47
C. Grassland	4904.97	1407.55	1378.47	4642.54	1893.82	-1940.81	-2347.78	-1044.12	657.64	-2847.34
D. Wetlands	NE,NO	4.98	4.98	4.98	4.98	4.98	8.16	8.16	8.16	8.16
E. Settlements	7089.06	8862.82	8863.76	8863.82	8864.74	8866.97	6925.58	6925.82	6925.89	6926.41
F. Other land	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
G. Harvested wood products	-387.80	-94.49	209.02	-140.92	142.18	-706.26	-799.58	-690.80	-1031.74	-901.01
H. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5. Waste	18995.82	19741.65	20171.82	20702.16	21412.54	22008.17	22749.91	23454.73	23156.37	23147.74
A. Solid waste disposal	13670.94	14370.76	14855.65	15505.31	16219.11	16937.94	17695.93	18332.85	18033.73	18087.65
B. Biological treatment of solid waste	23.31	28.30	33.29	38.28	56.22	53.90	44.71	114.14	138.13	183.17
C. Incineration and open burning of waste	598.36	639.35	631.76	588.87	592.45	546.83	547.54	572.16	568.39	490.97
D. Waste water treatment and discharge	4703.21	4703.24	4651.12	4569.70	4544.77	4469.50	4461.73	4435.59	4416.11	4385.95
E. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
6. Other *(as specified in summary 1.A)*	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Memo items:										
International bunkers	8636.79	8658.01	8457.94	8865.86	8989.99	9822.01	9090.98	9259.83	10376.50	10523.86
Aviation	4317.33	5164.15	5106.96	5264.45	5438.99	5845.16	6200.25	6273.71	6821.79	7538.87
Navigation	4319.46	3493.86	3350.98	3601.41	3551.00	3976.86	2890.73	2986.12	3554.71	2984.98
Multilateral operations	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
CO_2 emissions from biomass	14177.23	16543.74	15524.59	15895.45	16386.59	16973.83	16991.53	18313.70	18535.21	20111.63
CO_2 captured	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA
Long-term storage of C in waste disposal sites	7058.15	8451.21	8687.54	9312.79	9100.43	9806.65	9655.64	9703.71	9742.87	10165.67
Indirect N_2O	2720.25	2782.29	2835.39	2724.91	2591.16	2539.37	2457.36	2373.47	2251.18	2121.31
Indirect CO_2 (3)	1311.23	1320.38	1349.69	1312.29	1269.46	1210.53	1168.11	1164.97	1105.74	1104.18
Total CO_2 equivalent emissions without LULUCF	521061.92	522298.46	521486.98	514684.28	508811.30	535289.21	530085.05	537762.58	550562.61	556335.15
Total CO_2 equivalent emissions with LULUCF	517418.77	503655.82	505003.27	511023.31	492133.06	511901.55	505222.06	521360.30	536733.23	533212.87
Total CO_2 equivalent emissions, including indirect CO2, without LULUCF	522373.15	523618.85	522836.66	515996.57	510080.77	536499.75	531253.16	538927.56	551668.35	557439.33
Total CO_2 equivalent emissions, including indirect CO2, with LULUCF	518730.00	504976.20	506352.95	512335.60	493402.52	513112.09	506390.17	522525.28	537838.97	534317.05

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	(kt CO_2 eq)									
Total (net emissions)(2)	540025.83	532183.14	534226.52	561610.90	560810.72	560872.01	549676.15	566572.40	535435.16	477081.71
1. Energy	460484.13	459194.56	466070.04	483866.11	487639.44	488344.07	482620.10	476711.67	467769.65	418468.01
A. Fuel combustion (sectoral approach)	448393.66	447763.60	454788.02	472145.55	476935.58	477728.34	472687.51	466947.08	458024.30	409262.10
1. Energy industries	144873.56	143396.70	154420.64	159524.21	161375.89	159889.74	162147.17	159116.31	156039.48	134060.77
2. Manufacturing industries and construction	96245.30	91622.94	89478.54	95663.42	94527.82	92299.33	89145.16	91277.83	86801.22	64570.13
3. Transport	123953.70	125713.73	128109.86	128248.15	129937.10	128358.11	129589.67	129627.25	122798.14	117263.37
4. Other sectors	82444.24	86651.20	82443.14	87989.74	89895.19	95866.85	90727.86	85940.75	91571.47	92434.06
5. Other	876.86	379.03	335.84	720.03	1199.59	1314.31	1077.66	984.93	813.98	933.77
B. Fugitive emissions from fuels	12090.46	11430.96	11282.02	11720.56	10703.86	10615.74	9932.59	9764.59	9745.35	9205.90
1. Solid fuels	108.73	121.46	120.06	150.43	94.83	100.84	73.77	127.39	108.12	66.46
2. Oil and natural gas and other emissions from energy production	11981.74	11309.50	11161.96	11570.13	10609.02	10514.90	9858.82	9637.20	9637.24	9139.44
C. CO_2 transport and storage	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2. Industrial Processes	38240.20	40586.48	41404.42	43457.62	46505.90	47132.13	43607.01	43661.65	41095.54	35735.18
A. Mineral industry	20749.02	21531.35	21554.56	22429.73	23186.82	23304.75	23361.75	23781.94	21498.18	17249.99
B. Chemical industry	9048.01	9329.07	9098.25	9205.72	10283.10	9686.78	5342.57	4651.96	3666.14	2908.08
C. Metal industry	2755.28	3027.44	2784.86	2481.05	2416.50	2769.71	2663.02	2632.48	2646.75	1905.98
D. Non-energy products from fuels and solvent use	332.02	298.14	308.17	297.65	290.80	303.55	287.70	296.68	280.98	228.98
E. Electronic industry	374.50	311.14	337.08	351.30	324.73	302.58	224.62	179.53	189.13	155.34
F. Product uses as ODS substitutes	3714.00	4907.65	6212.23	7574.69	8843.93	9636.15	10553.20	11067.48	11722.68	12245.20
G. Other product manufacture and use	1267.37	1181.68	1109.27	1117.48	1160.02	1128.61	1174.14	1051.57	1091.68	1041.60
H. Other	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3. Agriculture	37430.21	37039.70	36517.20	36359.99	35652.41	35028.38	34364.92	35041.13	34153.90	33443.79
A. Enteric fermentation	16509.39	15844.10	15353.45	15421.08	14544.52	14484.22	14076.55	14593.30	14497.71	14523.83
B. Manure management	7452.33	7829.86	7606.09	7605.17	7401.73	7395.90	7336.74	7496.92	7415.86	7375.43
C. Rice cultivation	1855.18	1897.03	1999.25	2066.29	2167.38	2078.33	2068.26	2099.47	2066.88	2186.34
D. Agricultural soils	11023.94	10863.64	10929.93	10635.73	10890.42	10489.58	10277.57	10245.51	9606.26	8925.47
E. Prescribed burning of savannas	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
F. Field burning of agricultural residues	18.48	16.60	17.99	15.74	18.53	16.61	15.40	14.74	15.71	12.42
G. Liming	1.85	2.12	6.32	6.24	10.20	14.36	11.78	15.66	18.46	17.40

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	(kt CO_2 eq)									
H. Urea application	525.37	539.23	560.22	564.97	576.04	506.92	539.36	536.96	498.22	371.58
I. Other carbon-containing fertilizers	43.67	47.13	43.95	44.77	43.59	42.47	39.27	38.58	34.78	31.33
J. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
4. Land use, land-use change and forestry(2)	-20223.03	-30167.78	-34463.59	-26622.79	-32878.02	-33685.03	-34357.01	-11872.50	-30007.70	-33133.27
A. Forest land	-26285.42	-32075.51	-35569.63	-29487.84	-33867.61	-34942.87	-34530.67	-18760.77	-31301.72	-33221.18
B. Cropland	988.57	-1171.94	-578.94	-237.38	-558.63	-410.45	-1005.89	-987.26	-370.56	-458.10
C. Grassland	-1416.66	-3643.74	-4922.95	-3417.57	-4836.89	-5593.73	-5879.81	835.66	-5407.86	-6019.20
D. Wetlands	8.16	8.16	8.16	8.16	8.16	8.16	8.16	8.16	8.16	129.57
E. Settlements	6927.98	6930.36	6933.01	6935.23	6937.78	7748.65	7758.43	7762.17	7803.73	6745.97
F. Other land	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
G. Harvested wood products	-453.55	-223.02	-341.14	-431.28	-568.73	-502.68	-715.11	-738.36	-747.35	-318.22
H. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5. Waste	24094.32	25530.19	24698.45	24549.97	23890.99	24052.46	23441.13	23030.45	22423.77	22568.01
A. Solid waste disposal	19263.51	20659.32	19845.23	19642.68	18975.38	19042.68	18400.86	18036.28	17509.14	17637.32
B. Biological treatment of solid waste	232.37	301.35	370.33	407.69	401.80	455.64	484.36	497.18	485.32	494.74
C. Incineration and open burning of waste	287.20	305.98	256.66	279.17	276.58	314.06	325.85	294.17	289.84	328.39
D. Waste water treatment and discharge	4311.23	4263.53	4226.23	4220.44	4237.22	4240.09	4230.06	4202.82	4139.47	4107.56
E. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
6. Other *(as specified in summary 1.A)*	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Memo items:										
International bunkers	11910.96	12487.98	12151.18	14187.71	14631.07	15263.13	16519.78	17452.42	17624.56	15300.77
Aviation	8020.99	7924.62	6864.77	7978.25	8017.19	8547.64	9276.25	9840.75	9447.18	8332.51
Navigation	3889.97	4563.36	5286.41	6209.46	6613.88	6715.49	7243.53	7611.67	8177.38	6968.26
Multilateral operations	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
CO_2 emissions from biomass	19182.31	18820.12	13721.14	20267.20	16411.39	23618.21	26958.13	34588.46	41524.16	43007.03
CO_2 captured	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA
Long-term storage of C in waste disposal sites	10249.61	9542.73	8470.02	8039.55	8016.06	8131.58	7203.64	7050.40	7064.69	6684.88
Indirect N_2O	2023.51	1966.43	1884.75	1874.83	1817.25	1731.56	1655.24	1587.03	1416.70	1295.30
Indirect CO_2 (3)	1072.93	1060.94	1054.64	1046.87	1038.96	1041.44	1054.02	1035.09	985.95	926.54
Total CO_2 equivalent emissions without land use, land-use change and forestry	560248.85	562350.93	568690.11	588233.69	593688.74	594557.05	584033.16	578444.90	565442.86	510214.98

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	(kt CO_2 eq)									
Total CO_2 equivalent emissions with land use, land-use change and forestry	540025.83	532183.14	534226.52	561610.90	560810.72	560872.01	549676.15	566572.40	535435.16	477081.71
Total CO_2 equivalent emissions, including indirect CO2, without land use, land-use change and forestry	561321.78	563411.87	569744.75	589280.56	594727.70	595598.49	585087.18	579479.99	566428.80	511141.52
Total CO_2 equivalent emissions, including indirect CO2, with land use, land-use change and forestry	541098.75	533244.08	535281.16	562657.77	561849.68	561913.45	550730.17	567607.49	536421.10	478008.26

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	2010	2011	2012	2013	2014	2015	2019	2020	2021	2022	Change from base to latest reported year
	(kt CO_2 eq)										
Total (net emissions)[(2)]	481827.58	475599.45	465268.11	413236.98	391043.23	399928.98	378004.78	350846.92	385754.95	391113.49	-24.41
1. Energy	429915.51	417076.00	400273.01	367874.04	347663.84	359980.92	336404.40	300064.25	332164.19	337877.45	-20.72
A. Fuel combustion (sectoral approach)	420239.26	407233.49	390629.40	358290.38	338562.69	351303.83	329439.91	293870.90	326508.42	332826.10	-19.21
1. Energy industries	137466.73	133361.16	128307.11	109131.01	100492.53	106052.49	91,693.02	81,634.49	86,427.87	94,871.17	-31.06
2. Manufacturing industries and construction	70047.62	70899.32	66492.07	56756.91	52573.39	55569.10	49,957.88	45,839.27	54,560.65	54,727.97	-40.61
3. Transport	115902.44	114905.92	107525.36	104429.78	109286.84	106715.62	106,346.56	86,561.03	102,926.18	109,774.38	7.42
4. Other sectors	96134.11	87524.65	87944.29	87350.86	75613.09	82490.07	80,976.76	79,195.62	82,270.05	72,929.46	-7.53
5. Other	688.35	542.43	360.58	621.81	596.84	476.54	465.69	640.49	323.67	523.12	-53.94
B. Fugitive emissions from fuels	9676.26	9842.51	9643.61	9583.66	9101.14	8677.10	6964.49	6193.35	5655.77	5051.35	-64.44
1. Solid fuels	96.67	102.67	89.57	65.39	63.92	58.93	36.01	28.78	27.90	29.73	-79.96
2. Oil and natural gas and other emissions from energy production	9579.59	9739.84	9554.04	9518.27	9037.22	8618.16	6,928.48	6,164.57	5,627.87	5,021.62	-64.27
C. CO_2 transport and storage	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	0.00
2. Industrial Processes	36590.78	36346.48	33226.21	31758.76	30995.96	29093.66	27329.77	24289.62	25300.24	23619.92	-37.75
A. Mineral industry	17341.49	16713.25	13775.44	12281.06	11685.33	11291.17	11,005.66	9,862.18	11,145.65	10,175.54	-50.89
B. Chemical industry	3088.68	2913.55	2724.16	2919.58	2742.21	2747.29	2,207.26	1,843.99	1,752.54	1,434.46	-85.10
C. Metal industry	2002.95	2202.24	2023.29	1736.01	1679.84	1615.04	1,649.86	1,477.57	1,783.80	1,627.67	-73.88
D. Non-energy products from fuels and solvent use	267.12	263.86	229.87	239.53	276.77	280.89	307.78	272.81	309.38	286.78	-22.39
E. Electronic industry	206.47	241.01	217.87	232.86	259.57	246.06	235.29	207.35	223.19	228.98	100.00
F. Product uses as ODS substitutes	12791.38	13116.73	13310.67	13471.29	13562.10	12061.77	11,076.65	9,958.03	9,398.09	9,072.82	100.00
G. Other product manufacture and use	892.69	895.84	944.91	878.43	790.14	851.43	847.27	667.70	687.58	793.66	-20.45
H. Other	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.00
3. Agriculture	32633.74	33122.03	33552.05	32847.79	32421.80	32455.30	32313.70	33533.90	32862.17	30763.81	-18.94
A. Enteric fermentation	14099.82	14098.48	14152.38	14309.83	14164.29	14271.91	14,583.55	14,770.86	14,695.40	14,486.54	-15.25
B. Manure management	7166.59	7426.14	7215.35	7109.02	6941.59	6884.57	6,681.50	6,684.51	6,553.95	6,513.46	-17.99
C. Rice cultivation	2254.87	2212.51	2137.82	2067.42	1936.59	1943.42	1,720.68	1,696.22	1,677.37	1,547.03	-26.39
D. Agricultural soils	8719.67	8970.34	9442.70	8869.11	8924.86	8885.76	8,887.97	9,868.49	9,463.23	7,971.79	-22.51
E. Prescribed burning of savannas	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	0.00
F. Field burning of agricultural residues	11.73	10.76	11.69	11.10	10.85	11.34	10.41	10.43	10.95	10.15	-46.37
G. Liming	18.31	25.42	15.88	14.12	11.97	13.50	16.24	9.98	25.59	4.22	211.60

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	2010	2011	2012	2013	2014	2015	2019	2020	2021	2022	Change from base to latest reported year
	(kt CO_2 eq)										
H. Urea application	335.10	350.76	550.91	450.42	411.00	424.93	396.45	471.95	413.50	218.28	-53.04
I. Other carbon-containing fertilizers	27.65	27.63	25.33	16.77	20.66	19.87	16.88	21.47	22.17	12.34	-71.75
J. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	0.00
4. Land use, land-use change and forestry(2)	-39683.63	-32656.70	-23610.94	-39657.03	-40234.93	-41935.30	-37702.44	-27499.13	-24787.09	-21199.29	481.89
A. Forest land	-36413.10	-33067.71	-28200.60	-38612.36	-39501.08	-40277.63	-35,391.18	-29,842.52	-28,439.94	-26,051.17	50.20
B. Cropland	375.23	1807.95	2885.62	2423.60	2260.83	1741.79	673.78	3,706.69	2,220.25	2,277.58	9.38
C. Grassland	-8300.36	-6318.66	-3302.98	-8545.87	-8000.85	-8326.08	-7,095.20	-6,294.44	-3,037.87	-1,960.46	-139.97
D. Wetlands	129.57	129.57	129.57	129.57	129.57	129.57	31.61	31.61	NO,NE	NO,NE	0.00
E. Settlements	4658.78	4665.74	4670.85	4679.64	4688.60	4708.51	5,532.72	5,538.43	4,812.59	4,815.97	-32.06
F. Other land	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	0.00
G. Harvested wood products	-141.65	120.09	201.82	265.26	186.42	88.54	-1,469.13	-657.36	-360.58	-299.67	-22.73
H. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	0.00
5. Waste	22371.17	21711.65	21827.78	20413.42	20196.56	20334.39	19659.35	20458.28	20215.44	20051.60	5.56
A. Solid waste disposal	17428.84	16815.25	16915.13	15546.42	15483.75	15717.72	15,060.37	15,967.13	15,682.75	15,564.59	13.85
B. Biological treatment of solid waste	577.33	588.36	587.48	614.89	665.53	598.76	582.38	560.37	558.50	528.84	2168.71
C. Incineration and open burning of waste	255.20	254.76	281.36	299.46	187.23	175.21	168.03	161.62	188.43	182.30	-69.53
D. Waste water treatment and discharge	4109.80	4053.29	4043.82	3952.65	3860.05	3842.70	3,848.57	3,769.16	3,785.76	3,775.87	-19.72
E. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	0.00
6. Other *(as specified in summary 1.A)*	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	0.00
Memo items:											
International bunkers	17087.64	15942.97	15815.77	14968.82	14178.87	14649.02	17941.84	8049.96	10685.77	13446.88	55.69
Aviation	8877.33	9278.06	8990.98	8934.82	9088.21	9638.58	12,487.80	3,817.04	4,999.79	9,177.69	112.58
Navigation	8210.30	6664.91	6824.79	6033.99	5090.65	5010.45	5,454.03	4,232.92	5,685.98	4,269.19	-1.16
Multilateral operations	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	0.00
CO_2 emissions from biomass	42587.99	36933.16	42902.09	46205.50	43159.80	45618.16	45,751.53	45,013.73	48,181.61	44,558.43	214.30
CO_2 captured	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA	0.00
Long-term storage of C in waste disposal sites	6620.25	5772.69	5050.28	4839.50	4438.06	4009.23	2,854.33	2,628.05	2,583.69	2,307.86	-67.30
Indirect N_2O	1260.26	1211.82	1154.46	1047.58	1029.95	977.61	864.08	766.86	802.01	822.24	-69.77
Indirect CO_2 (3)	859.67	880.46	826.67	806.81	742.83	692.44	786.20	704.78	739.66	728.11	-44.47
Total CO_2 equivalent emissions without land use, land-use change and forestry	521511.21	508256.15	488879.05	452894.01	431278.16	441864.28	415707.22	378346.05	410542.04	412312.78	-20.87

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	2010	2011	2012	2013	2014	2015	2019	2020	2021	2022	Change from base to latest reported year
	(kt CO_2 eq)										
Total CO_2 equivalent emissions with land use, land-use change and forestry	481827.58	475599.45	465268.11	413236.98	391043.23	399928.98	378004.78	350846.92	385754.95	391113.49	-24.41
Total CO_2 equivalent emissions, including indirect CO2, without land use, land-use change and forestry	522370.88	509136.62	489705.73	453700.82	432020.99	442556.72	416493.42	379050.83	411281.70	413040.89	-20.93
Total CO_2 equivalent emissions, including indirect CO2, with land use, land-use change and forestry	482687.25	476479.92	466094.78	414043.79	391786.06	400621.42	378790.98	351551.70	386494.61	391841.60	-24.46

GREENHOUSE GAS EMISSIONS	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	(kt CO_2 eq)									
CO_2 emissions without net CO_2 from LULUCF	438208.03	437741.83	437936.51	430267.77	424506.71	448595.81	442842.92	448570.96	460824.37	465507.84
CO_2 emissions with net CO_2 from LULUCF	432936.73	417927.31	420215.99	424804.79	406467.24	424242.48	417159.90	431012.01	445670.36	441487.04
CH_4 emissions without CH_4 from LULUCF	54970.87	55974.65	55743.29	56081.10	56511.49	57026.36	57649.37	58206.84	57738.49	57753.62
CH_4 emissions with CH_4 from LULUCF	55691.01	56302.18	56107.95	56810.84	56946.33	57195.90	57836.65	58624.07	58275.08	58019.58
N_2O emissions without N_2O from LULUCF	24475.15	25503.87	25222.67	25772.44	25238.66	26415.52	26625.96	27516.01	27678.19	28236.84
N_2O emissions with N_2O from LULUCF	25383.16	26348.22	26094.82	26844.72	26165.06	27211.65	27258.71	28255.45	28466.22	28869.40
HFCs	372.00	376.47	503.58	602.28	773.72	1099.50	976.81	1389.48	2346.73	3099.23
PFCs	2614.99	2257.62	1635.01	1502.75	1278.23	1350.88	1119.28	1163.24	1209.13	1210.12
Unspecified mix of HFCs and PFCs	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA	24.43	24.43	24.43	24.43	24.43
SF_6	420.89	444.02	445.91	457.93	502.49	700.13	784.51	837.53	707.45	476.39
NF_3	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	76.57	61.78	54.09	33.83	26.69
Total (without LULUCF)	521061.92	522298.46	521486.98	514684.28	508811.30	535289.21	530085.05	537762.58	550562.61	556335.15
Total (with LULUCF)	517418.77	503655.82	505003.27	511023.31	492133.06	511901.55	505222.06	521360.30	536733.23	533212.87
Total (without LULUCF, with indirect)	522373.15	523618.85	522836.66	515996.57	510080.77	536499.75	531253.16	538927.56	551668.35	557439.33
Total (with LULUCF, with indirect)	518730.00	504976.20	506352.95	512335.60	493402.52	513112.09	506390.17	522525.28	537838.97	534317.05

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	(kt CO_2 eq)									
1. Energy	426167.39	426236.97	425937.28	421030.17	416098.53	438670.25	435501.05	441352.76	454038.19	458558.43
2. Industrial processes and product use	37945.93	37505.53	37093.07	34253.80	32982.20	36298.88	33492.29	34119.66	35208.36	35998.40
3. Agriculture	37952.78	38814.31	38284.80	38698.14	38318.04	38311.92	38341.81	38835.42	38159.71	38630.57
4. Land use, land-use change and forestry(5)	-3643.15	-18642.64	-16483.71	-3660.97	-16678.24	-23387.66	-24862.99	-16402.28	-13829.38	-23122.28
5. Waste	18995.82	19741.65	20171.82	20702.16	21412.54	22008.17	22749.91	23454.73	23156.37	23147.74
6. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total (including LULUCF)(5)	517418.77	503655.82	505003.27	511023.31	492133.06	511901.55	505222.06	521360.30	536733.23	533212.87

GREENHOUSE GAS EMISSIONS	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	(kt CO_2 eq)									
CO_2 emissions without net CO_2 from LULUCF	469598.27	469679.26	477107.22	495093.78	500687.24	501365.57	496074.79	489794.14	478127.96	424061.78
CO_2 emissions with net CO_2 from LULUCF	448286.43	438624.04	441942.25	467493.57	467031.50	466925.47	461014.05	476240.42	447186.97	389966.56
CH_4 emissions without CH_4 from LULUCF	57698.41	58188.78	56347.44	56652.68	54284.24	54805.60	53239.87	53990.73	53505.94	53279.74
CH_4 emissions with CH_4 from LULUCF	58098.40	58456.59	56493.13	56979.54	54480.03	54973.22	53373.81	54766.24	53789.02	53617.64
N_2O emissions without N_2O from LULUCF	27182.90	27254.50	26818.17	26547.41	27419.53	26337.36	21751.95	21358.46	19966.33	18989.74
N_2O emissions with N_2O from LULUCF	27871.74	27874.13	27373.86	27197.96	28001.45	26924.80	22321.75	22264.16	20616.54	19613.79
HFCs	3747.33	4942.89	6241.46	7609.70	8873.63	9666.13	10583.65	11096.84	11741.79	12254.76
PFCs	1363.28	1370.91	1361.50	1712.93	1770.46	1759.44	1749.68	1703.21	1547.39	1099.48
Unspecified mix of HFCs and PFCs	24.43	24.43	24.43	24.43	24.43	24.43	24.43	24.43	24.43	24.43
SF_6	620.97	877.38	761.83	564.94	600.36	565.14	586.59	465.53	510.23	487.09
NF_3	13.26	12.79	28.06	27.84	28.86	33.38	22.20	11.57	18.79	17.97
Total (without LULUCF)	560248.85	562350.93	568690.11	588233.69	593688.74	594557.05	584033.16	578444.90	565442.86	510214.98
Total (with LULUCF)	540025.83	532183.14	534226.52	561610.90	560810.72	560872.01	549676.15	566572.40	535435.16	477081.71
Total (without LULUCF, with indirect)	561321.78	563411.87	569744.75	589280.56	594727.70	595598.49	585087.18	579479.99	566428.80	511141.52
Total (with LULUCF, with indirect)	541098.75	533244.08	535281.16	562657.77	561849.68	561913.45	550730.17	567607.49	536421.10	478008.26

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	(kt CO_2 eq)									
1. Energy	460484.13	459194.56	466070.04	483866.11	487639.44	488344.07	482620.10	476711.67	467769.65	418468.01
2. Industrial processes and product use	38240.20	40586.48	41404.42	43457.62	46505.90	47132.13	43607.01	43661.65	41095.54	35735.18
3. Agriculture	37430.21	37039.70	36517.20	36359.99	35652.41	35028.38	34364.92	35041.13	34153.90	33443.79
4. Land use, land-use change and forestry(5)	-20223.03	-30167.78	-34463.59	-26622.79	-32878.02	-33685.03	-34357.01	-11872.50	-30007.70	-33133.27
5. Waste	24094.32	25530.19	24698.45	24549.97	23890.99	24052.46	23441.13	23030.45	22423.77	22568.01
6. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total (including LULUCF)(5)	540025.83	532183.14	534226.52	561610.90	560810.72	560872.01	549676.15	566572.40	535435.16	477081.71

GREENHOUSE GAS EMISSIONS	2010	2011	2012	2013	2014	2015	2019	2020	2021	2022	Change from base to latest reported year
	(kt CO_2 eq)										(%)
CO_2 emissions without net CO_2 from LULUCF	435700.92	423897.87	403444.46	369461.68	349390.64	361246.35	339641.02	302613.86	335919.66	340904.20	-22.20
CO_2 emissions with net CO_2 from LULUCF	395418.92	390466.44	378526.92	329397.56	308656.45	318828.26	301380.14	274409.02	310024.44	318796.21	-26.36
CH_4 emissions without CH_4 from LULUCF	52874.49	51546.91	52101.95	50508.47	49370.91	49370.21	46685.43	47402.06	47035.59	45714.16	-16.84
CH_4 emissions with CH_4 from LULUCF	53070.63	51864.39	52774.02	50596.04	49524.57	49518.17	46786.85	47587.60	47524.70	46072.36	-17.27
N_2O emissions without N_2O from LULUCF	18304.76	17669.77	18147.86	17413.12	17098.01	17101.12	16897.24	17569.75	17457.43	15737.91	-35.70
N_2O emissions with N_2O from LULUCF	18706.98	18127.01	18782.38	17732.63	17443.61	17435.94	17354.27	18089.91	18076.45	16288.40	-35.83
HFCs	12804.87	13132.26	13322.49	13485.40	13579.18	12081.54	11089.47	9971.44	9411.13	9085.41	2342.32
PFCs	1376.64	1503.76	1357.00	1543.53	1419.94	1528.73	915.40	498.66	395.32	439.10	-83.21
Unspecified mix of HFCs and PFCs	24.43	24.43	24.43	24.43	24.43	24.43	23.15	22.37	25.33	22.13	100.00
SF_6	404.94	453.38	455.94	431.69	366.88	483.50	437.57	251.69	282.35	390.31	-7.26
NF_3	20.17	27.78	24.93	25.70	28.17	28.42	17.94	16.24	15.23	19.56	100.00
Total (without LULUCF)	521511.21	508256.15	488879.05	452894.01	431278.16	441864.28	415707.22	378346.05	410542.04	412312.78	-20.87
Total (with LULUCF)	481827.58	475599.45	465268.11	413236.98	391043.23	399928.98	378004.78	350846.92	385754.95	391113.49	-24.41
Total (without LULUCF, with indirect)	522370.88	509136.62	489705.73	453700.82	432020.99	442556.72	416493.42	379050.83	411281.70	413040.89	-20.93
Total (with LULUCF, with indirect)	482687.25	476479.92	466094.78	414043.79	391786.06	400621.42	378790.98	351551.70	386494.61	391841.60	-24.46

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	2010	2011	2012	2013	2014	2015	2019	2020	2021	2022	Change from base to latest reported year
	CO_2 equivalent (kt)										
1. Energy	429915.51	417076.00	400273.01	367874.04	347663.84	359980.92	336404.40	300064.25	332164.19	337877.45	-20.72
2. Industrial processes and product use	36590.78	36346.48	33226.21	31758.76	30995.96	29093.66	27329.77	24289.62	25300.24	23619.92	-37.75
3. Agriculture	32633.74	33122.03	33552.05	32847.79	32421.80	32455.30	32313.70	33533.90	32862.17	30763.81	-18.94
4. Land use, land-use change and forestry(5)	-39683.63	-32656.70	-23610.94	-39657.03	-40234.93	-41935.30	-37702.44	-27499.13	-24787.09	-21199.29	481.89
5. Waste	22371.17	21711.65	21827.78	20413.42	20196.56	20334.39	19659.35	20458.28	20215.44	20051.60	5.56
6. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	0.00
Total (including LULUCF)(5)	481827.58	475599.45	465268.11	413236.98	391043.23	399928.98	378004.78	350846.92	385754.95	391113.49	-24.41

ANNEX 9: THE NATIONAL REGISTRY

The Consolidated System of European Registries, in short CSEUR, was developed together with the new EU registry on the basis the following modalities:

1. Each Party retains its organization designated as its registry administrator to maintain the national registry of that Party and remains responsible for all the obligations of Parties that are to be fulfilled through registries;
2. Each Kyoto unit issued by the Parties in such a consolidated system is issued by one of the constituent Parties and continues to carry the Party of origin identifier in its unique serial number;
3. Each Party retains its own set of national accounts as required by paragraph 21 of the Annex to Decision 15/CMP.1. Each account within a national registry keeps a unique account number comprising the identifier of the Party and a unique number within the Party where the account is maintained;
4. Kyoto transactions continue to be forwarded to and checked by the UNFCCC Independent Transaction Log (ITL), which remains responsible for verifying the accuracy and validity of those transactions;
5. The transaction log and registries continue to reconcile their data with each other in order to ensure data consistency and facilitate the automated checks of the ITL;
6. The requirements of paragraphs 44 to 48 of the Annex to Decision 13/CMP.1 concerning making non-confidential information accessible to the public is fulfilled by each Party through a publically available web page hosted by the Union registry;
7. All registries reside on a consolidated IT platform sharing the same infrastructure technologies. The chosen architecture implements modalities to ensure that the consolidated national registries are uniquely identifiable, protected and distinguishable from each other, notably:
    - With regards to the data exchange, each national registry connects to the ITL directly and establishes a secure communication link through a consolidated communication channel (VPN tunnel);
    - The ITL remains responsible for authenticating the national registries and takes the full and final record of all transactions involving Kyoto units and other administrative processes such that those actions cannot be disputed or repudiated;
    - With regards to the data storage, the consolidated platform continues to guarantee that data is kept confidential and protected against unauthorized manipulation;
    - The data storage architecture also ensures that the data pertaining to a national registry are distinguishable and uniquely identifiable from the data pertaining to other consolidated national registries;
    - In addition, each consolidated national registry keeps a distinct user access entry point (URL) and a distinct set of authorisation and configuration rules.

Following the successful implementation of the CSEUR, the 28 national registries concerned were re-certified in June 2012 and switched over to their new national registry on 20 June 2012. Croatia was migrated and consolidated as of 1 March 2013. During the go-live process, all relevant transaction and holdings data were migrated to the Union registry platform and the individual connections to and from the ITL were re-established for each Party.

A complete description of the consolidated registry has been provided in the common readiness documentation and specific readiness documentation for the national registry of the EU and all consolidating national registries. This description includes:

- Readiness questionnaire;
- Application logging;
- Change management procedure;
- Disaster recovery;
- Manual Intervention;
- Operational Plan;
- Roles and responsibilities;
- Security Plan;
- Time Validation Plan;
- Version change Management.

The documents above have been annexed to the National Inventory Report submission for year 2013.

A new central service desk has been set up to support the registry administrators of the consolidated system. The new service desk acts as 2nd level of support to the local support provided by the Parties. It also plays a key communication role with the ITL Service Desk with regards notably to connectivity or reconciliation issues.

Since 2006 ISPRA acts as national administrator and an operational unit has been set up including:

- 1 chief of the unit;
- 4 employees in charge of Registry functions and operations, implementing Competent Authority's provisions, preparing documents and reports, providing support to users through a dedicated helpdesk;
- 1 employee assisting with legal and security issues;
- 1 employee for the design of a BMS application facilitating the administrative tasks;
- 1 employee dedicated to paper documentation archiving and minor secretarial tasks.

Economic resources for the administration of the Registry are supplied to ISPRA by account holders paying a fee. The amount of such fees has been regulated by Ministerial Decree 6 December 2021.

Supplementary information with regards to the national registry and in accordance with the guidelines set down in Decision 15 CMP.1 (Annex II.E Paragraph 32) is reported below:

(a) *The name and contact information of the registry administrator designated by the Party to maintain the national registry*

The Italian Registry is administrated by ISPRA (national Institute for Environmental Protection and Research).

The contact person is: Mr Riccardo Liburdi

address: Via Vitaliano Brancati 48 – 00144 Rome – Italy

telephone: +39 0650072544

e-mail: riccardo.liburdi@isprambiente.it

No change of name or contact occurred during the reported period.

(b) *The names of the other Parties with which the Party cooperates by maintaining their national registries in a consolidated system*

Italy maintains its national registry in a consolidated manner with all the Parties that are also EU Member States and with the European Union, sharing the same platform hosted and facilitated by the European Commission.

No change of regarding cooperation arrangement occurred during the reported period.

(c) ***A description of the database structure and capacity of the national registry***

The complete description of the consolidated registry was provided in the common readiness documentation and specific readiness documentation for the national registry of EU and all consolidating national registries.

During certification, the consolidated registry was notably subject to connectivity testing, connectivity reliability testing, distinctness testing and interoperability testing to demonstrate capacity and conformance to the Data Exchange Standard (DES). All tests were executed successfully and lead to successful certification on 1 June 2012.

There has been 3 new EUCR releases (versions 13.6.1, 13.7.1 and 13.8.2) after version 13.5.2 (the production version at the time of the last submission).

No changes were applied to the database, whose model is provided in Annex A.

No change was required to the application backup plan or to the disaster recovery plan.

No change to the capacity of the national registry occurred during the reported period.

(d) ***A description of how the national registry conforms to the technical standards for data exchange between registry systems for the purpose of ensuring the accurate, transparent and efficient exchange of data between national registries, the clean development mechanism registry and the transaction log (decision 19/CP.7, paragraph 1)***

The overall change to a Consolidated System of EU Registries triggered changes to the registry software and required new conformance testing. The complete description of the consolidated registry was provided in the common readiness documentation and specific readiness documentation for the national registry of EU and all consolidating national registries.

During certification, the consolidated registry was notably subject to connectivity testing, connectivity reliability testing, distinctness testing and interoperability testing to demonstrate capacity and conformance to the Data Exchange Standard (DES). All tests were executed successfully and lead to successful certification on 1 June 2012.

The changes that have been introduced with versions 13.6.1, 13.7.1 and 13.8.2 compared with version 13.5.2 of the national registry are presented in Annex B.

It is to be noted that each release of the registry is subject to both regression testing and tests related to new functionality. These tests also include thorough testing against the DES and are carried out prior to the relevant major release of the version to Production (see Annex B).

No other change in the registry's conformance to the technical standards occurred for the reported period.

(e) ***A description of the procedures employed in the national registry to minimize discrepancies in the issuance, transfer, acquisition, cancellation and retirement of ERUs, CERs, tCERs, lCERs, AAUs and/or RMUs, and replacement of tCERS and lCERs, and of the steps taken to terminate transactions where a discrepancy is notified and to correct problems in the event of a failure to terminate the transactions***

The overall change to a Consolidated System of EU Registries also triggered changes to discrepancies procedures, as reflected in the updated *manual intervention document* and the *operational plan*. The complete description of the consolidated registry was provided in the common readiness documentation and specific readiness documentation for the national registry of EU and all consolidating national registries.

Detailed information for year 2022 according to paragraphs 12 to 17 is provided below:

- paragraph 12 *List of discrepant transactions*: no discrepant transactions occurred in 2022;
- paragraph 13 and 14 *List of CDM notifications*: no CDM notifications occurred in 2022;
- paragraph 15 *List of non-replacements*: no non-replacements occurred in 2022;
- paragraph 16 *List of invalid units*: no invalid units exist as of 31 December 2022;
- paragraph 17 *Actions and changes to address discrepancies*: since no discrepant transactions occurred in 2022, there's been no need for actions to correct or changes to prevent discrepancies in the reported period.

Therefore, no change of discrepancies procedures occurred during the reported period.

Considering the information above, reports R2, R3, R4 and R5 have not been included in the submission.

(f) ***An overview of security measures employed in the national registry to prevent unauthorized manipulations and to prevent operator error and of how these measures are kept up to date***

The overall change to a Consolidated System of EU Registries also triggered changes to security, as reflected in the updated *security plan*. The complete description of the consolidated registry was provided in the common readiness documentation and specific readiness documentation for the national registry of EU and all consolidating national registries.

No changes regarding security were introduced.

(g) ***A list of the information publicly accessible by means of the user interface to the national registry***

Non-confidential information required by Decision 13/CMP.1 annex II.E paragraphs 44-48, is publicly accessible via the Union Registry website at:

https://unionregistry.ec.europa.eu/euregistry/IT/public/reports/publicReports.xhtml

and it is also available on the informative website at :

https://ariet.isprambiente.it/ArietWeb/customPage/reportistica

Information is updated on a monthly basis and is provided with the following exceptions:

- paragraph 45(d)(e): account number, representative identifier name and contact information is deemed as confidential according to Annex III and VIII (Table III-I and VIII-I) of Commission Delegated Regulation (EU) No 2019/1122;
- paragraph 46: no Article 6 (Joint Implementation) project is reported as conversion to an ERU under an Article 6 project did not occur in the specified period;
- paragraph 47(a)(d)(f): holding and transaction information is provided on an account type level, due to more detailed information being declared confidential by article 80 of Commission Delegated Regulation (EU) No 2019/1122.

No change to list of publicly available information occurred during the reported period.

(h) ***The Internet address of the interface to its national registry***

The registry is available at https://unionregistry.ec.europa.eu/euregistry/IT/index.xhtml and the URL has not changed since last submission.

(i) ***A description of measures taken to safeguard, maintain and recover data in order to ensure the integrity of data storage and the recovery of registry services in the event of a disaster***

The overall change to a Consolidated System of EU Registries also triggered changes to data integrity measures, as reflected in the updated *disaster recovery plan*. The complete description of the consolidated registry was provided in the common readiness documentation and specific readiness documentation for the national registry of EU and all consolidating national registries.

No change of data integrity measures occurred during the reported period.

(j) ***The results of any test procedures that might be available or developed with the aim of testing the performance, procedures and security measures of the national registry undertaken pursuant to the provisions of decision 19/CP.7 relating to the technical standards for data exchange between registry systems***

The consolidated EU system of registries successfully completed a full certification procedure in June 2012. Notably, this procedure includes connectivity testing, connectivity reliability testing, distinctness testing and interoperability testing to demonstrate capacity and conformance to the Data Exchange Standard (DES). This included a full Annex H test. All tests were executed successfully and led to successful certification on 1 June 2012.

No change occurred during the reported period.

Previous Review Recommendations

The SIAR Report for Italy from last year reported no recommendations.

ANNEX 10: OVERVIEW OF THE CURRENT SUBMISSION IMPROVEMENTS

A10.1 Results of the UNFCCC review process

During the last UNFCCC review process, in 2022, some issues were raised which have been considered to improve the current submission. Responses to the main recommendations, received in the review report, are described in the following table.

Category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation
Comparison with international data – refinery feedstocks (E.4, 2021) Accuracy	Not resolved. .... The ERT considers that the recommendation has not yet been fully addressed, as the difference between national and international data remains significant, for example by 230.8 per cent for 2020 when data in the CRF tables are compared with those in the IEA data. Italy has no access to further IEA information about the data, but can confirm what is reported in the NIR and that the data of the different fuels are taken from the same joint questionnaire. In addition to production, import and export, refinery feedstocks also include 'backflow', which has not yet been characterized in the Party's submission and requires further investigation to properly characterize it.	E.1	In our opinion, it is only an allocation issue. In order to improve transparency and comparability Italy could split backflows and feedstock and report this information in the NIR
2.D.3 Other (non-energy products from fuels and solvent use) – CO2 (I.5, 2021) (I.10, 2019) Convention reporting adherence	Addressing. The Party continued to report total national emissions including indirect CO2 in the CRF tables (e.g. CRF table summary 2 and CRF table 10) in the row intended for total national emissions excluding indirect CO2, while reporting "NA" for the national emission totals including indirect CO2 rather than providing numerical values to reflect the reporting of indirect CO2 emissions from solvents. Italy explained in its NIR (section 2.5, p.61) that the indirect CO2 emissions are reported in the relevant categories of solvent use. During the review, Italy provided an Excel spreadsheet which shows GHG national total emissions with and without indirect CO2. The ERT considers that, if Italy reports those emissions in CRF table 6, this issue will be resolved.	I.2	Indirect CO2 emissions from solvent use have been reported separately from this year's submission. The national totals include these emissions
4.A Forest land – CO2 (L.4, 2021) (L.3, 2019) (L.2, 2018) (L.5, 2016) (L.5, 2015) (56, 2014) Transparency	Addressing. In previous review reports, the ERTs noted that fully resolving this recommendation will require data from the third NFI to validate the For-est Model. The Party reported in its NIR (p.267 and 598–599) and confirmed during the review that the complete set of data from the third NFI will be available in late 2022 and therefore the For-est Model validation against the latest NFI data is due to be implemented for the next submission.	L.4	The recommendation has been addressed in the 2023 submission.
4.G HWP – AD (L.19, 2021) Transparency	Not resolved. The Party has not provided the full series of HWP AD in CRF table 4.Gs2. ... The ERT considers that the recommendation has not yet been addressed because CRF table 4.Gs2 should include AD from the first year for which they were available.	L.5	The recommendation has been addressed in the 2023 submission.
4.G HWP – CO2 (L.12, 2021) (L.16, 2019) Transparency	Not resolved. The Party has not documented in the HWP section of its NIR (section 6.12, pp.296–297) the methodology used for estimating CO2 emissions from HWP in SWDS. During the review, the Party clarified that it applies the default half-lives of 35 years for sawnwood, 25 years for wood panels and 2 years for paper provided in the 2019 Refinement to the 2006 IPCC Guidelines, table 12.3,	L.6	The recommendation has been addressed in the 2023 submission; in particular the CO_2 emissions reported in the CRF table 4Gs.1 are estimated with the same methodology used to estimate annual change in total long-term carbon storage in HWP waste reported as a memo item in CRF table 5.

Category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation
	which are equivalent to those provided in table 2.8.2 of the Kyoto Protocol Supplement, and that the methodology for estimating CO2 emissions from HWP in SWDS is described in the NIR (section 7.2.6, p.314). However, when comparing the current and previous submissions, the ERT noted that the Party has updated the methodology for estimating annual change in total long-term carbon storage in HWP waste reported as a memo item in CRF table 5, whereas the methodology for estimating CO2 net emissions from HWP in SWDS reported in CRF table 4.Gs1 has not been changed and is therefore not the same as that described in section 7.2.6 of the NIR. In addition, Italy has not provided an explanation for reporting "NO" for gains in HWP in SWDS together with positive annual stock change in CRF table 4.Gs1.		
4.G HWP – CO2 (L.20, 2021) Accuracy	Addressing. The Party reported in its NIR (p.314) that CO2 emissions from HWP in SWDS are under investigation. During the review, the Party clarified that the HWP sheet in the first-order decay model from the 2006 IPCC Guidelines was implemented to estimate the long-term storage of carbon in waste disposal sites and the annual change in total long-term carbon storage in HWP waste. The information has been reported in section 7.2.6 of the NIR. The ERT considers that the recommendation has not yet been fully addressed, as the information regarding HWP in SWDS reported in CRF table 4.Gs1 is not consistent with CRF table 5 (see ID# L.6 above).	L.7	The recommendation has been addressed in the 2023 submission; the CO_2 emissions reported in the CRF table 4Gs.1 are estimated with the same methodology used to estimate annual change in total long-term carbon storage in HWP waste reported as a memo item in CRF table 5.
4.G HWP – CO2 (L.21, 2021) Transparency	Not resolved. The Party has not included any additional information in NIR section 6.12.2 concerning the methodology for estimating emissions from HWP (pp.296–297). During the review, the Party clarified that the relevant information is provided in NIR section 9.4.5 (pp.358–359), stating that all wood originating from deforestation is assigned to fuelwood and that there are no HWP originating from deforestation. However, the ERT could not identify any documentation or references which justify this assumption.	L.8	Relevant information is provided in the NIR, section 6.13.
1.B.2.a Oil – liquid fuels – CH4	During the review, the ERT noted a significant inter-annual change between 2015 and 2016 of –60.13 per cent for CH4 emissions from oil production (CRF table 1.B.2.a) due to recalculation of the emissions. ... The ERT welcomes the Party's detailed explanation and recommends that the Party include in its NIR information provided during the review that explains why updating CH4 EFs for oil production would not reflect the actual state of emissions prior to 2016.	E.4	Additional information has been included in the NIR.
1.B.2.a Oil – natural gas liquids – CH4 1.A(a) - – natural gas	During the review, the ERT noted that for 2020, IEA has reported natural gas liquid consumption of about 412 TJ, while the CRF tables 1.A(b) and 1.A(d) report no apparent consumption for this fuel, leading to a 100 per cent difference between the two data sets. ... The ERT recommends that the Party investigate production and use of natural gas liquids in Italy and if the activity does occur, report activity data and emissions, both for fugitive as well as for combustion emissions, with respect to refinery operations.	E.5	Natural gas liquid has been made explicit among fuels reported in the reference approach since 2020. In previous years it was included in the crude oil. As concern this category we verified that the amount of natural gas liquid is already included in the activity data so that no changes are due.

Category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation
4.B.1 Cropland remaining cropland – 4.C.1 Grassland remaining grassland – CO2	The ERT noted that the description provided in the NIR regarding the estimation of CSCs in mineral soils for cropland remaining cropland (pp.270–273) and grassland remaining grassland (grazing land) (pp.276–278) is not transparent enough to check if the applied approach is consistent with the 2006 IPCC Guidelines (vol, 4, chap.5). .... The ERT recommends that the Party include in the NIR more transparent information regarding the estimation of CSCs in mineral soils for cropland remaining cropland and grassland remaining grassland (grazing land), such as trends in land areas under different management practices since 1970.	L.9	The recommendation has been addressed in the 2023 submission; additional information has been included in the NIR to transparently describe the methodology used for CSC estimation.
4.C.2 Land converted to grassland – CO2	The Party reported in its NIR (p.280) that it applies a tier 1 methodology to estimate CSCs in land converted to grassland, assuming that carbon stocks in biomass immediately after the conversion are equal to 0 t C ha-1. However, the ERT noted that losses in the biomass carbon pool were reported in CRF table 4.C for land converted to grassland as "NO". .... The ERT recommends that the Party provide transparent information on BBEFORE values for each type of land conversion, as well as justification for the parameter values used to estimate CSCs in biomass for annual crops converted to natural grazing land and woody crops converted to other wooded land.	L.10	The recommendation has been addressed in the 2023 submission; additional information has been included in the NIR to transparently describe the methodology used for CSC estimation.
5.A Solid waste disposal on land – CH4	The Party reported in its NIR (section 7.2.2, p.306) and CRF table 5.A a DOCf value of 0.5 (50 per cent), which is the default value in the 2006 IPCC Guidelines (vol.5, chap.3, p.3.13) despite the fact that the Party indicates that it applies tier 2 method for the category. .... The ERT recommends that the Party plan and begin research in order to verify that the parameters presented in the short term national studies are still relevant to the national conditions of Italy in order to improve the estimates by using a higher tier methodology (tier 2 or 3) that use separate country-specific DOCf values defined for specific waste types. .. The ERT notes that it is good practice to use disaggregated DOCf values specific to waste types only when waste composition data are based on representative sampling and analysis over a longer period.	W.6	Italy has planned a survey on the characterization of waste also from the point of view of degradable organic carbon through discussions with the staff of the national waste center managed by ISPRA. The goal is to evaluate data and studies with useful information and to verify the accuracy and consistency of DOCf values.
5.C.2 Open burning of waste – CO2	The Party reported in its NIR (p.321) the fraction of the population burning waste (Pfrac) of 9–9.4 and the fraction of the waste amount that is burned relative to the total amount of waste treated (Bfrac) of 0.4 to calculate emissions of CO2 from open burning of waste. ... The ERT recommends that the Party update the fraction of the population burning waste (Pfrac) and the fraction of the waste amount that is burned relative to the total amount of waste treated (Bfrac) using the survey or research data available, or expert judgment.	W.7	Italy does not agree with the recommendation. The 2006 IPCC Guidelines report as default value Bfrac=0.6. In recent years the most important fires (industrial warehouses) involved 1800 Mg in Corteolona in 2018 and 8400 Mg in Pomezia in 2017 which means negligible quantities even considering an order of magnitude higher. For example, if they were 100,000 Mg of open burning waste annually, they would be equivalent, from 1990 to 2018, to approximately 0.4% to 0.3% (instead of the 60% represented by the default). More 2006GL stated that "For countries that have well functioning waste collection systems in place, it is good practice to investigate whether any fossil carbon is open-burned. In a developed

Category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation
			country, Pfrac can be assumed to be the rural population for a rough estimate. In a region where urban population exceeds 80 percent of total population, one can assume no open burning of waste occurs." and Pfrac (Istat,2017 "Forme, livelli e dinamiche dell'urbanizzazione in Italia") is less than 10% (9-9.4%) which means that rural population is more than 90% and open burning of urban waste can be considered negligible.
5.D.1 Domestic wastewater – CH4	The ERT compared the indigenous sewage sludge gas production reported by the Party to Eurostat (2,137 TJ in 2019) with the amounts of CH4 for energy recovery reported in CRF table 5.D (21.56 kt in 2019, which is approximately 1,087 TJ) and found a difference of about 50 per cent. ... The ERT recommends that the Party reconsider its assumption of a 50 per cent share of CH4 in biogas and provide the value and its documentation in the NIR. The ERT also recommends that Italy investigate possible reasons for the remaining difference between the amount reported to Eurostat (2,137 TJ in 2019) and the amount it estimated on the basis of the volume of biogas provided by Terna (1,415 TJ in 2019), which may include other uses of biogas (e.g. blending with natural gas, own use in wastewater treatment plants) in addition to the use of biogas for the production of electricity and heat, or consider estimating CH4 recovery for energy on the basis of total indigenous biogas production.	W.8	Both the biogas produced and that used for energy purposes are provided via the same questionnaire (TERNA/GSE) which feeds the Italian energy balance and also Eurostat. These data do not necessarily have to coincide. For sludge biogas in 2019 TERNA/GSE correctly reports biogas produced equal to 2,136.6 TJ and energy recovery equal to 1,414.4 TJ. The balance sheet obviously reports all the energy uses and final consumption of biogas in Italy. Again in 2019, out of 84,288.2 TJ of total biogas produced (regardless of whether from landfill, sludge or agriculture), 82,768.1 TJ are used in the transformation sector (which includes 1,712.9 TJ for blending with motor gasoline/diesel) while 1,520.1 TJ are made up of final consumption divided between industry 682.9 TJ and 836.2 TJ commercial heating.
5.D.2 Industrial wastewater - CH4	The Party reported in table 7.36 of its NIR (p.328) the wastewater generation (m3/t) from several industries and associated COD (g/l) values used in the estimates. ....The ERT recommends that the Party conduct an investigation into COD values and wastewater production for the most significant industries and to report data in the next submission.	W.10	Additional info has been included in the NIR

A10.2 Results of the ESD technical review process

During the last ESD technical review process, no issues were raised in the review report and no revised estimates or technical corrections were deemed necessary. Anyway, issues identified during the review have been taken into account as much as possible to improve the current submission.

ANNEX 11: REPORTING UNDER EU REGULATION 2018/1999

A11.1 Consistency with ETS data

Reporting on consistency of reported emissions with data from the EU emissions trading system. Year 2024					
	Total emissions (CO2 -eq)				
Category[1]		Greenhouse gas inventory emissions [kt CO_2eq][3]	Verified emissions under Directive 2003/87/EC [kt CO2eq][3]	Ratio in % (Verified emissions/ inventory emissions)[3]	Comment[2]
Greenhouse gas emissions (total emissions without LULUCF for GHG inventory and without emissions from 1A3a Civil aviation, total emissions from installations under Article 3h of Directive 2003/87/EC)	Total GHG	409,828	136,287.68	33.25%	
CO2 emissions (total CO2 emissions without LULUCF for GHG inventory and without emissions from 1A3a Civil aviation, total emissions from installations under Article 3h of Directive 2003/87/EC)	Total CO_2	338,420	136,251.75	40.26%	

CO_2 emissions					
Category[1]		Greenhouse gas inventory emissions [kt CO_2eq][3]	Verified emissions under Directive 2003/87/EC [kt CO_2eq][3]	Ratio in % (Verified emissions/ inventory emissions)[3]	Comment[2]
1.A Fuel combustion activities, total	CO_2	322,611.19	NA	NA	
1.A Fuel combustion activities, stationary combustion [4]	CO_2	325,100.22	122,180.69	37.58%	
1.A.1 Energy industries	CO_2	94,409.57	92,827.80	98.32%	
1.A.1.a Public electricity and heat production	CO_2	71,387.70	69,806.04	97.78%	
1.A.1.b Petroleum refining	CO_2	19,035.46	19,035.46	100.00%	
1.A.1.c Manufacture of solid fuels and other energy industries	CO_2	3,986.41	3,986.30	100.00%	
Iron and steel total (1.A.1.c, 1.A.2, 1.B, 2.C.1) [5]	CO_2	14,136.10	12,517.00	88.55%	
1.A.2. Manufacturing industries and construction	CO_2	53,700.72	28,038.32	52.21%	
1.A.2.a Iron and steel	CO_2	8,757.82	7,138.83	81.51%	
1.A.2.b Non-ferrous metals	CO_2	1,132.86	456.79	40.32%	
1.A.2.c Chemicals	CO_2	10,080.19	4,624.42	45.88%	
1.A.2.d Pulp, paper and print	CO_2	4,535.39	3,498.73	77.14%	
1.A.2.e Food processing, beverages and tobacco	CO_2	3,377.49	1,645.32	48.71%	

CO_2 emissions					
Category[1]		Greenhouse gas inventory emissions [kt CO_2eq][3]	Verified emissions under Directive 2003/87/EC [kt CO_2eq][3]	Ratio in % (Verified emissions/ inventory emissions)[3]	Comment[2]
1.A.2.f Non-metallic minerals	CO_2	11,388.72	8,850.21	77.71%	
1.A.2.g Other	CO_2	14,428.25	1,824.03	12.64%	
1.A.3. Transport	CO_2	108,654.21	825.99	0.76%	
1.A.3.e Other transportation (pipeline transport)	CO_2	981.78	825.99	84.13%	
1.A.4 Other sectors	CO_2	68,335.72	488.58	0.71%	
1.A.4.a Commercial / Institutional	CO_2	19,314.76	488.58	2.53%	
1.A.4.c Agriculture/ Forestry / Fisheries	CO_2	7,245.72	-	0.00%	
1.B Fugitive emissions from Fuels	CO_2	1,799.43		87.42%	
1.C CO2 Transport and storage	CO_2				
1.C.1 Transport of CO2	CO_2				
1.C.2 Injection and storage	CO_2				
1.C:3 Other 2.A Mineral products	CO_2				
2.A Mineral products	CO_2	10,175.54	9,647.51	94.8%	
2.A.1 Cement Production	CO_2	7,093.35	7,082.43	99.85%	
2.A.2. Lime production	CO_2	1,814.80	1,592.92	87.77%	
2.A.3. Glass production	CO_2	623.40	592.88	95.10%	
2.A.4. Other process uses of carbonates	CO_2	644.00	379.29	58.90%	
2.B Chemical industry	CO_2	1,093.86	1,261.53	115.33%	Includes emissions from urea production
2.B.1. Ammonia production	CO_2	246.79	417.93	169.35%	Includes emissions from urea production
2.B.3. Adipic acid production (CO2)	CO_2	1.92	1.92	100.00%	
2.B.4. Caprolactam, glyoxal and glyoxylic acid production	CO_2				
2.B.5. Carbide production	CO_2	3.47	-	0.00%	
2.B.6 Titanium dioxide production	CO_2				
2.B.7 Soda ash production	CO_2	260.54	260.54	100.00%	
2.B.8 Petrochemical and carbon black production	CO_2	581.14	581.14	100.00%	
2.C Metal production	CO_2	1,588.98	1,588.98	100.00%	
2.C.1. Iron and steel production	CO_2	1,391.87	1,391.87	100.00%	
2.C.2 Ferroalloys production	CO_2				
2.C.3 Aluminium production	CO_2				
2.C.4 Magnesium production	CO_2				
2.C.5 Lead production	CO_2				
2.C.6 Zinc production	CO_2	197.10	197.10	100.00%	
2.C.7 Other metal production	CO_2				

N_2O emissions					
Category[1]	Gas	Greenhouse gas inventory emissions [kt CO_2eq][3]	Verified emissions under Directive 2003/87/EC [kt CO_2eq][3]	Ratio in % (Verified emissions/ inventory emissions)[3]	Comment[2]
2.B.2. Nitric acid production	N_2O	21.28	21.28	100.00%	
2.B.3. Adipic acid production	N_2O	14.64	14.64	100.00%	
2.B.4. Caprolactam, glyoxal and glyoxylic acid production	N_2O				

PFC emissions					
Category[1]	Gas	Greenhouse gas inventory emissions [kt CO2eq][3]	Verified emissions under Directive 2003/87/EC [kt CO_2eq][3]	Ratio in % (Verified emissions/ inventory emissions)[3]	Comment[2]
2.C.3 Aluminium production	PFC				

[1] The allocation of verified emissions to disaggregated inventory categories at four digit level must be reported where such allocation of verified emissions is possible and emissions occur. The following notation keys should be used: NO = not occurring IE = included elsewhere C = confidential negligible = small amount of verified emissions may occur in respective CRF category, but amount is < 5% of the category

[2] The column comment should be used to give a brief summary of the checks performed and if a Member State wants to provide additional explanations with regard to the allocation reported. Member States should add a short explanation when using IE or other notation keys to ensure transparency.

[3] Data to be reported up to one decimal point for kt and % values

[4] 1.A Fuel combustion, stationary combustion should include the sum total of the relevant rows below for 1.A (without double counting) plus the addition of other stationary combustion emissions not explicitly included in any of the rows below.

[5] To be filled on the basis of combined CRF categories pertaining to 'Iron and Steel' , to be determined individually by each Member State; e.g. (1.A.2.a+ 2.C.1 + 1.A.1.c and other relevant CRF categories that include emissions from iron and steel (e.g. 1A1a, 1B1))

Notation: x = reporting year

A11.2 Consistency with energy statistics

Reporting on consistency with energy statistics. Year 2024

FUEL TYPES			Apparent consumption reported in GHG inventory (TJ) (3)	Apparent consumption using data reported pursuant to Regulation (EC) No 1099/2008 (TJ) (3)	Absolute difference (1) (TJ) (3)	Relative difference (2) % (3)	Explanations for differences
Liquid fossil	Primary fuels	Crude oil	2,756,970.9	2,756,970.9	0.0	0.0%	
		Orimulsion					
		Natural gas liquids	413.6	413.6	0.0	0.0%	
	Secondary fuels	Gasoline	-311,207.5	-311,488.0	280.4	-0.1%	
		Jet kerosene	-61,374.4	-62,197.0	822.7	-1.3%	
		Other kerosene	-4,226.8	-4,214.6	-12.2	0.3%	
		Shale oil					
		Gas/diesel oil	-156,340.7	-154,468.4	-1,872.2	1.2%	
		Residual fuel oil	-138,643.8	-136,303.0	-2,340.9	1.7%	
		Liquefied petroleum gases (LPG)	100,478.4	100,358.8	119.6	0.1%	
		Ethane					
		Naptha	-9,123.6	-9,477.9	354.4	-3.9%	
		Bitumen	-44,683.1	-44,758.5	75.5	-0.2%	
		Lubricants	-10,008.9	-10,458.8	449.9	-4.5%	
		Petroleum coke	46,314.7	46,314.7	0.0	0.0%	
		Refinery feedstocks	124,020.5	124,020.5	0.0	0.0%	
		Other oil	25,847.6	25,739.8	107.8	0.4%	
	Other liquid fossil						
	Liquid fossil total		2,318,436.9	2,320,452.1	-2,015.1	-0.1%	
Solid fossil	Primary fuels	Anthracite	2,112.7	2,112.7	0.0	0.0%	
		Coking coal	57,193.6	57,193.6	0.0	0.0%	
		Other bituminous coal	252,314.5	252,314.5	0.0	0.0%	
		Sub-bituminous coal					
		Lignite	3.2	3.2	0.0	0.0%	
		Oil shale and tar sand					
	Secondary fuels	BKB and patent fuel					
		Coke oven/gas coke	-912.9	-912.9	0.0	0.0%	
		Coal tar	-494.6	-494.6	0.0	0.0%	
	Other solid fossil						
	Solid fossil totals		310,216.5	310,216.5	0.0	0.0%	
Gaseous fossil		Natural gas (dry)	2,349,239.2	2,348,959.8	279.4	0.0%	
Other gaseous fossil							
Gaseous fossil totals			2,349,239.2	2,348,959.8	279.4	0.0%	

	Waste (non-biomass fraction)		48,546.8	47,272.9	1,274.0	2.6%	
Other fossil fuels							
Peat							
Total			5,026,439.5	5,026,901.3	-461.8	0.0%	

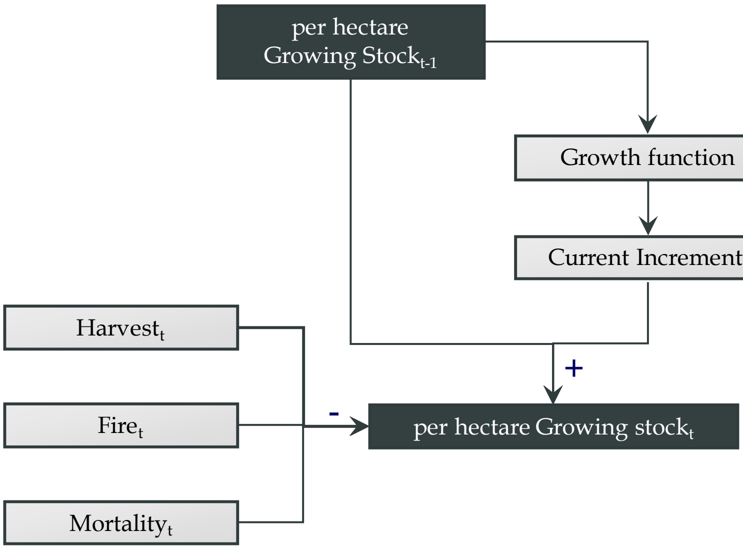
(1) Apparent consumption reported in GHG inventory minus apparent consumption using data reported pursuant to Regulation (EC) No 1099/2008
(2) Absolute difference divided by apparent consumption reported in GHG inventory

(3) Data to be reported up to one decimal point for kt and % values

ANNEX 12: FOR-EST MODEL

For-est is a book keeping model (Figure A12.1) that calculates annually the C stock of the aboveground biomass pool, as derived from the growing stock, by adding the annual net increment and subtracting annual losses associated with formal and informal[57] harvest (industrial roundwood and fuelwood), forest fires and other mortality, which includes all other disturbances[58] (i.e. drought, grazing, wind).

Figure A12.1 *For-est* model flow-chart



The model is applied to each of the 26[59] forest inventory typology, at regional/provincial scale (NUTS2 - 19 regions[60] and 2 provinces), using as model input data for the forest area and initial growing stock of the first NFI (NFI1985) and forest area of the second and third NFIs (NFI2005, NFI2015). An independent verification (Tabacchi et al., 2010) of the model results versus measured data was carried out in the year 2008 by comparison of the growing stock calculated by the model vs the data collected in the second national forest inventory[61], showing that the difference between the measured and modeled biomass C stocks is around -7%; which means that the model has underestimated by almost 0.3% net C stocks per year across the period 1985-2008.

Consistently, the time series of growing stock values in each forest inventory typology in each region/province is estimated applying the following steps:

1. deriving the initial growing stock volume for the year 1985 from the NFI data (MAF/ISAFA, 1988);

[57] "Informal harvest" includes all harvest not captured by the official system of statistics either because occurring outside the chain of data collection, e.g. domestic fuelwood collection, or because may have occurred outside the planned harvest, e.g. small areas for which no harvesting plan is required and illegal harvest.
[58] Although natural mortality does not explicitly include losses caused by exceptional occurrences of those other disturbances, such exceptional losses are included in the national GHG inventory through the subsequent salvage logging of those lost biomass stocks.
[59] 4 different management system of practices (High stands, Coppices, Plantations, Protective) are combined with 22 forest types to classify 26 forest inventory typologies:

Stands*: 1. norway spruce, 2. silver fir, 3. larches, 4. mountain pines, 5. mediterranean pines, 6. other conifers, 7. European beech, 8. turkey oak, 9. other oaks, 10. other broadleaves.*

Coppices: *11. European beech, 12. sweet chestnut, 13. hornbeams, 14. other oaks, 15. turkey oak, 16. evergreen oaks, 17. other broadleaves, 18. conifers.*

Plantations: *19. eucalyptuses coppices, 20. other broadleaves coppices, 21. poplar stands, 22. other broadleaves stands, 23. conifers stands, 24. others.*

Protective Forests: *25. rupicolous forest, 26. riparian forests*

[60] Abruzzo, Alto Adige/Sud Tirolo, Basilicata, Calabria, Campania, Emilia Romagna, Friuli Venezia Giulia, Lazio, Liguria, Lombardia, Marche, Molise, Piemonte, Puglia, Sardegna, Sicilia, Toscana, Trentino, Umbria, Valle d'Aosta, Veneto.
[61] https://www.sian.it/inventarioforestale/jsp/risultati_introa.jsp?menu=3

2. for each year, the current increment per hectare [m^3 $ha^{-1}yr^{-1}$] is computed with the forest inventory typology specific derivative Richards function, for each forest inventory typology using as independent variable x the per hectare growing stock.
3. for each year, the following losses are calculated:
    a. harvest, statistical data collected from ISTAT on industrial roundwood production (all assigned to "*stands*" forests), fuelwood (all assigned to "*coppices*" forests) and wood outside forest (all assigned to "*plantations*" forests). Aiming at considering the informal[62] harvest, the time series has been recalculated, applying a correction factor, on regional basis, to the commercial harvested wood statistical data (Table A12.2). The correction factor[63], was inferred from the outcome of a 2005 NFI survey[64] (Table A12.1), carrying out a regional assessment of the harvested biomass. In each region/province, harvested quantities are assigned to each forest inventory typology in proportion of its total annual increment. The correction factors, at regional level, are reported in table A12.3.

Table A12.1 NFI survey - harvested volume

Region	Harvested volume	S.E.	Harvested volume	S.E.
	m^3	*%*	*m^3ha^{-1}*	*%*
Piemonte	1,360,223	31	1.6	30.9
Valle d'Aosta	-	-	-	-
Lombardia	1,039,728	52.7	1.7	52.7
Alto Adige (Bolzano)	862,811	62.4	2.6	62.4
Trentino	1,348,355	40.7	3.6	40.6
Veneto	475,573	40	1.2	39.9
Friuli - Venezia Giulia	462,541	67.3	1.4	67.3
Liguria	372,380	61.9	1.1	61.9
Emilia Romagna	362,005	62.2	0.6	62.2
Toscana	1,745,382	28.1	1.7	28
Umbria	1,294,494	43.6	3.5	43.6
Marche	418,031	74.9	1.4	74.9
Lazio	1,576,155	54.5	2.9	54.5
Abruzzo	388,752	51.8	1	51.7
Molise	200,825	54.5	1.5	54.4
Campania	915,244	59.6	2.4	59.6
Puglia	255,981	60.5	1.8	60.5
Basilicata	7,820	71.4	0	71.4
Calabria	624,762	53	1.3	53
Sicilia	23,477	58	0.1	57.9
Sardegna	62,323	53.3	0.1	53.2
Italia	**13,796,864**	**12.9**	**1.6**	**12.9**

[62] Data on biomass removed in commercial harvest have been judged underestimated, particularly fuelwood consumption (APAT - ARPA Lombardia, 2007, UNECE – FAO, Timber Committee, 2008, Corona et al., 2007).
[63] A correction factor for each Italian region (21) has been pointed out. The mean value is 1.57, obtained as ratio of data from official statistics and NFI survey data. The variance is equal to 0.82.
[64] NFI survey on harvested volume: http://www.sian.it/inventarioforestale/caricaDocumento?idAlle=442

Table A12.2 ISTAT data: harvested volume

Region	Harvested volume
	m^3
Piemonte	363,846
Valle d'Aosta	16,279
Lombardia	1,060,701
Alto Adige (Bolzano)	589,191
Trentino	484,906
Veneto	270,880
Friuli - Venezia Giulia	180,544
Liguria	96,515
Emilia Romagna	485,777
Toscana	1,477,135
Umbria	471,070
Marche	192,068
Lazio	875,408
Abruzzo	203,632
Molise	159,104
Campania	518,376
Puglia	101,776
Basilicata	299,019
Calabria	753,042
Sicilia	59,850
Sardegna	139,751
Italia	**8,798,869**

Table A12.3 Correction factors

Region	Correction factor
Piemonte	3.74
Valle d'Aosta	1.00
Lombardia	1.00
Alto Adige (Bolzano)	1.46
Trentino	2.78
Veneto	1.76
Friuli - Venezia Giulia	2.56
Liguria	3.86
Emilia Romagna	1.00
Toscana	1.18
Umbria	2.75
Marche	2.18
Lazio	1.80
Abruzzo	1.91
Molise	1.26
Campania	1.77
Puglia	2.52
Basilicata	1.00
Calabria	1.00
Sicilia	1.00
Sardegna	1.00
Italia	**1.57**

b. fires, burnt area from Forest service statistics, assigned to forest inventory typologies proportionally to their area. The growing stock loss caused by forest fires is estimated based on the average growing stock per hectare. The methodology used for emission estimates due to forest fires is described in Annex 13.

c. mortality, an average constant ratio of mortality to total growing stock (Federici et al, 2008) estimated by expert judgement for evergreen (1.16%) and deciduous (1.17%) forests;

4. for protective forest (i.e., rupicolous and riparian forests) only, an average constant ratio of 3% (expert judgement - Federici et al., 2008) of C stock losses associated with drain and grazing. Starting from 1986, for each year, the final growing stock per hectare [m^3 ha^{-1}] is computed adding to the final growing stock volume of the previous year the increment calculated for the current year and subtracting the losses occurred in the year as due to harvest, fires and mortality.

The procedure can be summarized as follows:

$$v_i = \frac{V_{i-1} + I_i - H_i - F_i - M_i - D_i}{A_i}$$

where:

$I_i = f(v_{i-1}) \cdot A_{i-1}$;

v_i is the volume per hectare of growing stock for the current year;

V_{i-1} is the total previous year growing stock volume;

I_i is the total current increment of growing stock for the current year;
H_i is the total amount of harvested growing stock for the current year;
F_i is the total amount of burned growing stock for the current year;
M_i is the annual rate of mortality;
D is the annual rate of drain and grazing for the protective forest;
A_i is the total area referred to a specific forest typology for the current year;
v_{i-1} is the previous year growing stock volume per hectare;
A_{i-1} is the total area referred to a specific forest typology for the previous year;
f is the Richard function reported above.

The annual current increment is estimated thought the use of a non-linear function, the Richards function, that has the growing stock as its independent variable. The Richards' 4 parameters allow the needed flexibility to represent the various potential growth rates, including the initial, nearly constant, rate. To calculate the 4 parameters for each forest inventory typology the Richards function has been fitted through the data of growing stock [m^3 ha^{-1}] and increment [m^3 $ha^{-1}yr^{-1}$] obtained from the collection of Italian yield tables.

$$y = a \cdot \left[1 \pm e^{(\beta - kt)}\right]^{-\frac{1}{\nu}}$$ (*Richards function*)

The per hectare growing stock (i.e. the biomass density of the stand) is the independent variable *x*, while the dependent variable *y* is the increment computed with the Richards function - first derivative.

$$\frac{dy}{dt} = \frac{k}{v} \cdot y \cdot \left[1 - \left(\frac{y}{a}\right)^{v}\right] + y_0$$ (*Richards function - first derivative*)

where the general constrain for the parameters are the following:

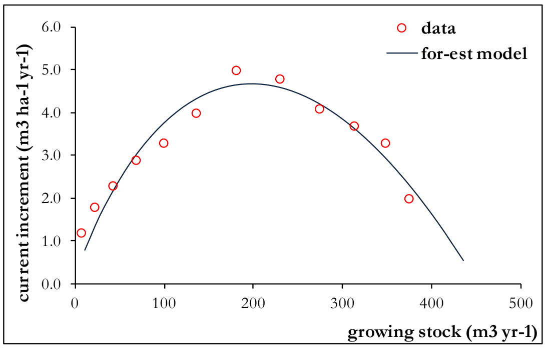
$a,k>0$ $-1 \leq v \leq \infty$ and $v \neq 0$

The constant y_0 is the growing stock volume at 1-year age.

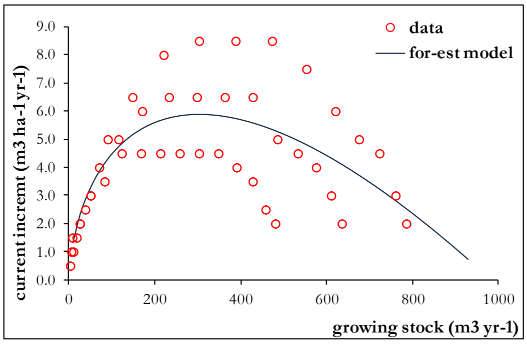
The Richards function, first derivative, has been fitted against data taken from all quality classes of each yield table (figure A13.2), to calculate a set of variables' values for each forest inventory typology.

The curves have been derived from a collection of around 100 Italian yield tables.

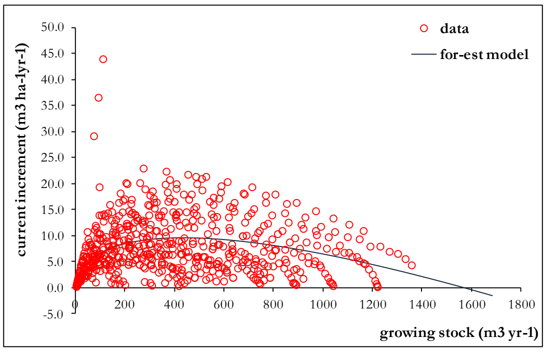
Figure A12.2: *For-est* model fitting



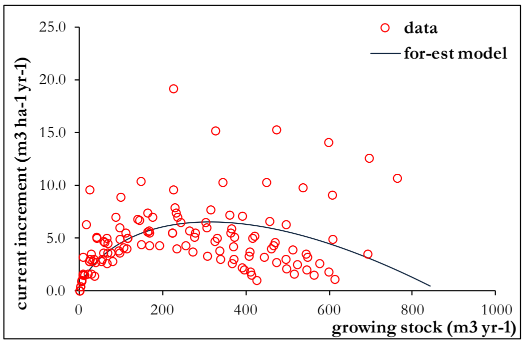
A12.2a Trentino, *larches*



A12.2b Lombardia, *norway spruce*



A12.2c Piemonte, *other conifers*



A12.2d Campania, *European beech*

The per hectare growing stock and associated gain and losses are converted into aboveground biomass stock applying the following equation:

$$\text{Aboveground tree biomass (d.m.)} = GS \cdot BEF \cdot WBD \cdot A$$

where:

GS = volume of growing stock (MAF/ISAFA, 1988) [m^3 ha^{-1}] of specific forest inventory typology;

BEF = Biomass Expansion Factors which expands growing stock volume to volume of aboveground woody biomass (ISAFA, 2004);

WBD = Wood Basic Density for conversions from fresh volume to dry weight (d.m.) [t m^{-3}] (Giordano, 1980);

A = forest area of specific forest inventory typology [ha].

The BEFs and WBDs have been estimated for each forest inventory typology and are reported in following Table A12.4.

Table A12.4 Biomass Expansion Factors and Wood Basic Densities

	Inventory typology	BEF aboveground biomass / growing stock	WBD Dry weigth t/ fresh volume
Stands	norway spruce	1.29	0.38
	silver fir	1.34	0.38
	larches	1.22	0.56
	mountain pines	1.33	0.47
	mediterranean pines	1.53	0.53
	other conifers	1.37	0.43
	european beech	1.36	0.61
	turkey oak	1.45	0.69
	other oaks	1.42	0.67
	other broadleaves	1.47	0.53
Coppices	european beech	1.36	0.61
	sweet chestnut	1.33	0.49
	hornbeams	1.28	0.66
	other oaks	1.39	0.65
	turkey oak	1.23	0.69
	evergreen oaks	1.45	0.72
	other broadleaves	1.53	0.53
	conifers	1.38	0.43
Plantations	eucalyptuses coppices	1.33	0.54
	other broadleaves coppices	1.45	0.53
	poplars stands	1.24	0.29
	other broadleaves stands	1.53	0.53
	conifers stands	1.41	0.43
	others	1.46	0.48
Protective	rupicolous forest	1.44	0.52
	riparian forest	1.39	0.41

Applying a Root/Shoot ratio (R) to the aboveground volume and the same WBDs the belowground biomass is derived for each forest inventory typology. The Rs have been estimated for each forest inventory typology and are reported in Table A12.2. Data on root to shoot ratios have been taken from the following European projects: CANIF[65] (*CArbon and NItrogen cycling in Forest ecosystems*), CARBODATA[66] (*Carbon Balance Estimates and Resource Management - Support with Data from Project Networks Implemented at European Continental Scale*), CARBOINVENT[67] (*Multi-source inventory methods for quantifying carbon stocks and stock changes in European forests*) and COST[68] Action E21- Contribution of forests and forestry to mitigate greenhouse effects.

$$\text{Belowground tree biomass (d.m.)} = \text{Abovegroundtree biomass} \cdot R$$

where:

R = Root/Shoot ratio dimensionless of each specific forest inventory typology.

[65] CANIF-*CArbon and NItrogen cycling in Forest ecosystems* http://www.bgc-jena.mpg.de/bgc-processes/research/Schulze_Euro_CANIF.html; Scarascia Mugnozza G., Bauer G., Persson H., Matteucci G., Masci A.(2000). Tree biomass, growth and nutrient pools. In: Schulze E.-D. (edit.) Carbon and Nitrogen Cycling in European forest Ecosystems, Ecological Studies 142, Springer Verlag, Heidelberg. Pp. 49-62. ISBN 3-540-67239-7

[66] CARBODATA - Carbon Balance Estimates and Resource Management - Support with Data from Project Networks Implemented at European Continental Scale: http://afoludata.jrc.it/carbodat/proj_desc.html

[67] CARBOINVENT - Multi-source inventory methods for quantifying carbon stocks and stock changes in European forests; http://www.joanneum.at/carboinvent/

[68] COST Action E21 - Contribution of forests and forestry to mitigate greenhouse effects: http://www.cost.eu/domains_actions/fps/Actions/E21;http://www.afs-journal.org/index.php?option=com_article&access=standard&Itemid=129&url=/articles/forest/pdf/2005/08/F62800f.pdf

Table A12.5 Root/Shoot ratio and Wood Basic Densities

	Inventory typology	R *Root/shoot ratio*
Stands	norway spruce	0.29
	silver fir	0.28
	Larches	0.29
	mountain pines	0.36
	mediterranean pines	0.33
	other conifers	0.29
	european beech	0.20
	turkey oak	0.24
	other oaks	0.20
	other broadleaves	0.24
Coppices	european beech	0.20
	sweet chestnut	0.28
	Hornbeams	0.26
	other oaks	0.20
	turkey oak	0.24
	evergreen oaks	1.00
	other broadleaves	0.24
	Conifers	0.29
Plantations	eucalyptuses coppices	0.43
	other broadleaves coppices	0.24
	poplars stands	0.21
	other broadleaves stands	0.24
	conifers stands	0.29
	others	0.28
Protective	rupicolous forest	0.42
	riparian forest	0.23

The biomass stocks and stock changes are converted to carbon units applying the IPCC default carbon fraction (CF) value of 0.47 t C (t d.m.)$^{-1}$.

The dead wood mass has been estimated using coefficients calculated from Italian national forest inventory (NFI) survey, in 2008 and 2009, which specifically intended to investigate the carbon storage of forests. Samples of dead-wood were collected across the country from the plots of the national forest inventory network, and their basic densities measured to calculate conversion factors for estimating the dry weight of dead-wood (Di Cosmo et al., 2013). The values used, aggregated at regional level, may be found on the NFI website: http://www.sian.it/inventarioforestale/jsp/dati_carquant_tab.jsp.

The definition of the deadwood pool, coherent with the definition adopted by the NFI, is related to "*All non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, stumps larger than or equal to 10 cm in diameter and standing trees with DBH > 4,5 cm*". Additional explanation on the data and parameters used for deadwood are included in the paper Di Cosmo et al., 2013, and in the NFI website (http://www.sian.it/inventarioforestale/jsp/necromassa.jsp).

In Table A12.6 dead wood coefficients are reported.

Table A12.6 Dead-wood expansion factor

	Inventory typology	dead wood (dry matter) *t ha⁻¹*
stands	norway spruce	6.360
	silver fir	7.770
	Larches	3.830
	mountain pines	4.385
	mediterranean pines	2.670
	other conifers	4.290
	european beech	3.350
	turkey oak	1.770
	other oaks	1.690
	other broadleaves	3.990
coppices	european beech	3.350
	sweet chestnut	12.990
	hornbeams	2.730
	other oaks	1.690
	turkey oak	1.770
	evergreen oaks	1.370
	other broadleaves	2.690
	Conifers	4.290
plantations	eucalyptuses coppices	0.670
	other broadleaves coppices	0.670
	poplars stands	0.480
	other broadleaves stands	0.670
	conifers stands	3.040
protective	rupicolous forest	2.730
	riparian forest	4.790

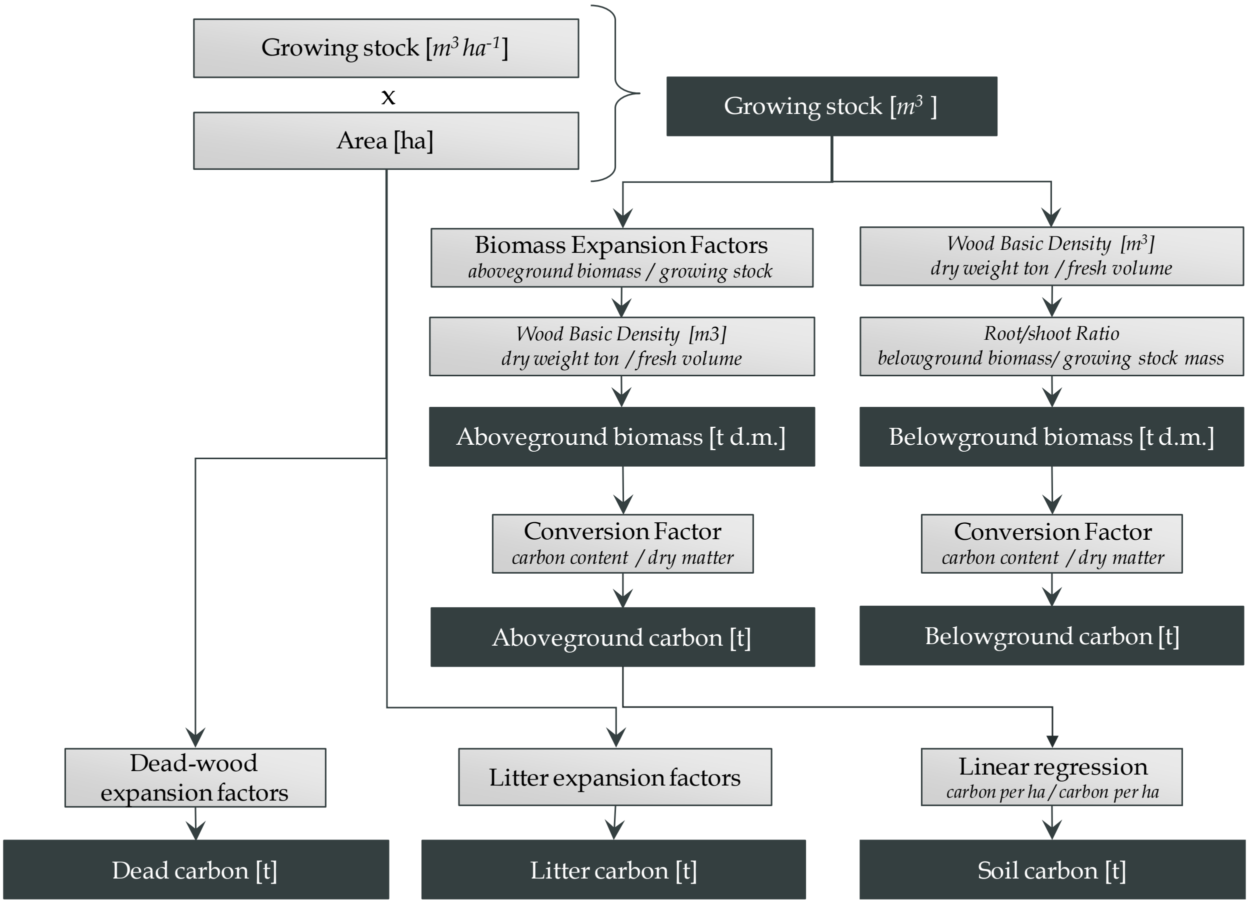
Carbon amount contained in litter pool has been estimated using the values of litter carbon content, per hectare, assessed by the Italian national forest inventory. The values used, aggregated at regional level, may be found on the NFI website: http://www.sian.it/inventarioforestale/jsp/dati_carquant_tab.jsp. The average value of litter organic carbon content, for Italy, is equal to 2.67 t C ha^{-1}.

A comparison between carbon in the aboveground, deadwood and litter pools, estimated with the described methodology, and the II NFI data (INFC2005) is reported in Table A12.7.

Table A12.7 Comparison between estimated and INFC2005 carbon stocks

	INFC2005 *t C*	For-est model *t C*	*differences* *t C*	*%*
aboveground	456,857,390	425,240,589	-31,616,801	**-6.92**
deadwood	15,987,541	15,869,766	-117,775	**-0.74**
litter	28,170,660	28,138,039	-32,621	**-0.12**

Figure A12.3: *For-est* model complete flow-chart



ANNEX 13: FOR-FIRES MODEL

For-fires is a bookkeeping model that calculates the non-CO_2 emissions from fires affecting forest and other wooded land categories. The model is based on the approach developed by Bovio (2007); to this aim, the template used by Carabinieri Force[69], for each forest event, was modified in 2007 to collect the data needed to implement this approach.

A13.1 Method description

For-fires model is based on the on the equation 2.27 of the 2006 IPCC Guidelines (vol.4, ch. 2):

$$L_{fire} = A \times M_B \times C_f \times G_{ef} \times 10^{-3}$$

where

L_{fire} amount of greenhouse gas emissions released from fire;

A burned area (hectares);

M_B mass of fuel available for combustion (t ha^{-1});

C_f combustion factor (dimensionless);

G_{ef} emission factors (g kg^{-1} dry matter burnt).

The key driver for fires emissions release is the assessment of the burned and oxidized biomass in each fire event. The combustion factor (C_f) term is the most critical to be estimated as it represents the fraction of pre-disturbance biomass that is combusted during the fire event. Its estimation has been carried out based on the abovementioned approach, which assess forest fire damage in Italy, considering two main elements: the burned forest typology, and the fire intensity (assessed through the scorch height).

The approach groups the forest typologies into 9 forest vegetation classes considering the possible effect that a fire event can have on them because of specific forest characteristics and their distribution over the country (Table A13.1).

[69] the Armed Forces and Police Authority where the State Forestry Service is embedded, following the legislative decree 19/08/2016, n. 177

Table A13.1: Bovio (2007) forest vegetation classes and forest typologies: correspondence matrix

Forest vegetation class	forest typology
A	european beech stands sweet chestnut stands hornbeam stands riparian forests other broadleaves
B	turkey oak stands other oak stands evergreen oak stands cork oaks
C	Larches norway spruce silver fir mountain pines above 500 m a.s.l. black pine above 500 m a.s.l.
D	mountain pines below 500 m asl black pine below 500 m asl mediterranean pines other conifers
E	european beech coppices sweet chestnut coppices
F	turkey oak coppices other oak coppices evergreen oak coppices hornbeam coppices
G	shrublands (including mediterranean maquis)
H	other broadleaves with a mean height lower than 3.5m (temporary unstocked broadleaves forests)
I	other conifers with a mean height than3.5m (temporary unstocked conifer forests)

Bovio (2007) assumed that, in each forest vegetation class, the damage level depends on the fire intensity, which, in turn, can be estimated as a function of scorch height. In Table A13.2, the damage level as a function of scorch height (and fire intensity), for each forest vegetation class, is shown.

Table A13.2: Damage level of forest typologies as a function of fire intensity and forest vegetation class

Forest vegetation class	Scorch height (m)				
	<1	1-2.5	2.5-3.5	3.5-4.5	>4.5
A	0.10	0.15	0.30	0.60	0.90*
B	0.08	0.20	0.30	0.80	0.90
C	0.10	0.25	0.50	0.80	0.90
D	0.08	0.30	0.55	0.85	0.95
E	0.05	0.15	0.40	0.65	0.90*
F	0.05	0.20	0.35	0.60	0.95
G	0.10	0.30	0.60	0.80	0.95
H	0.30	0.70	0.80	0.90	1.00
I	0.25	0.40	0.70	0.90*	1.00*

** values not included in Bovio (2007); they have been assumed based on the damage levels assigned to the other forest vegetation classes for the corresponding scorch height categories*

A13.2 Activity data

The activity data needed to estimate the annual loss of biomass (burned) caused by forest fires are:

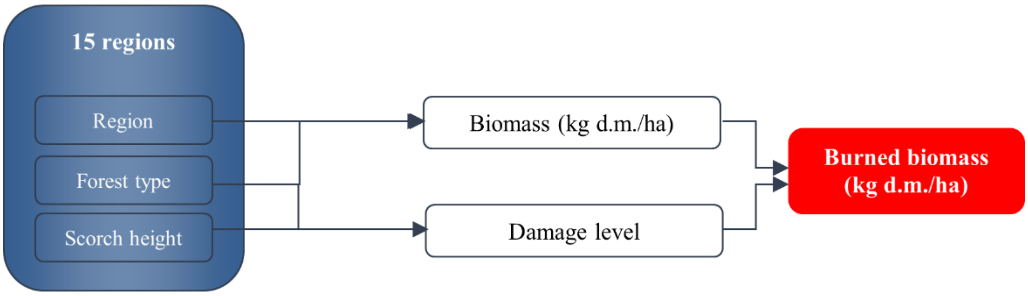
- *year;*
- *burned area [ha];*
- *forest typology (27 NFI typologies)* to assess the available combustion fuel and the combustion factor;
- *mean scorch height [m]* to assess the combustion factor.

A detailed database, annually provided by Carabinieri Force, has been used; the database collects data, from 2008 onward, related to any fire event occurred in 15 administrative Italian regions[70] (the 5 autonomous regions are not included), reporting, for each fire event, the following information:

- *year;*
- *administrative region name;*
- *burned area [ha];*
- *forest typology (27 classes in line with the NFI nomenclature);*
- *scorch height [m];*
- *fire's type (crown, surface or ground fire).*

The database was checked to select only the observations with known scorch height (and corresponding damage level), and the assignation of the fire event to a forest category that does exist in the corresponding region according to the NFI[71]. For these observations, the burned biomass per hectare is estimated according to the logical pathway summarised in Figure A13.1.

Figure A13.1: Logical pathway to estimate the burned biomass on hectare basis caused by forest fires



Data and information on fire occurrences in the 5 remaining autonomous regions are collected at regional level, with different level of disaggregation and details (e.g., in Sardinia region, the amount of biomass burned is reported instead of the scorch height).

For the period 1990-2007, national statistics on areas affected by fire per region and aggregated forest types are available for (ISTAT, several years [a]). The aggregated forest types are high forest (conifers, broadleaves, mixed) and coppice (simple, compound and degraded).

Therefore, the data used in the estimation process may be subdivided into the following groups with similar characteristics:

a. time series from 2008 onward for the 15 Regions: data related to burned area, divided into different forest types, scorch height and fire's type;
b. time series from 2008 onward for the 5 autonomous regions/provinces: data related to burned area;
c. time series from 1990 to 2007 for the 20 Italian regions: data related to burned area.

A13.3 Methodological issues

Based on three different datasets identified in the previous section A13.2, different approaches and assumptions have been followed to estimate non-CO_2 emissions from fires.

a. Time series from 2008 onward for the 15 Regions

The estimation of non-CO_2 emissions from fires in the 15 regions has been carried out based on the approach developed by Bovio (Bovio, 2007). The burnt biomass has been assessed, for each fire event,

[71] It is possible that some forest categories have been erroneously assigned to a specific administrative region because of problems in the forest identification on the field (e.g. due to the important damage caused by the fire event).

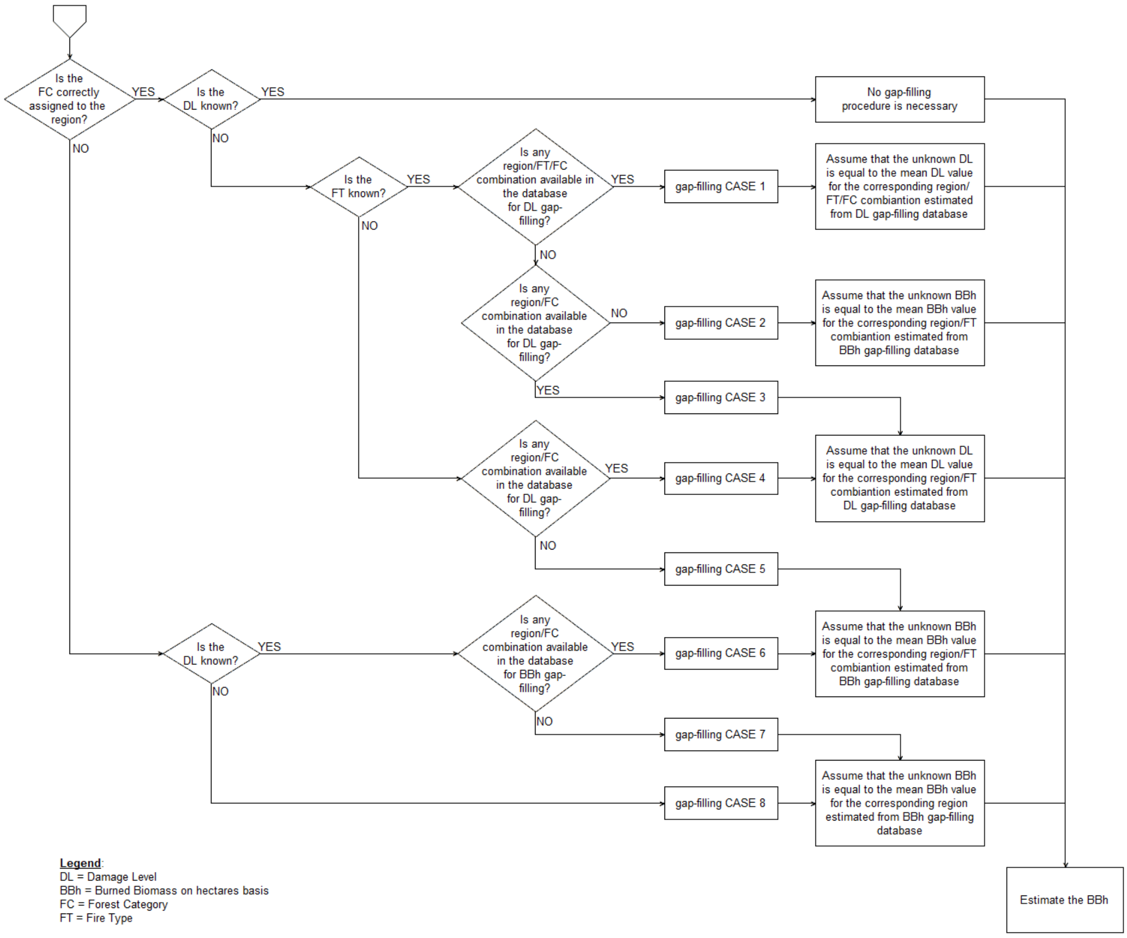
based on the damage level (assessed through the scorch height) and the forest typologies affected by fire. These two elements allow an assessment of the fraction of biomass burnt in a fire event.

In case of some data missing, record by record, a gap filling procedure has been specifically applied according to the causes of the missing or unreliable data. The main causes are:

1. Scorch height data missing (unknown damage level)
2. No volume is associated with the record – this is due to the probable misclassification of the forest type by the surveyors, which have attributed a forest type that is not present in the region, thus no data from NFI can be attributed (unknown damage level)
3. Scorch height and volume missing: In case information on both issues is missing (unknown damage level)

For these fire events, the gap-filling procedure follows a logical framework shown in Figure A13.2.

Figure A13.2: Workflow of gap-filling procedure



In summary, it is not possible to directly calculate the burnt biomass if:

- the damage level (which is derived from the flame height) is missing;
- the forest category burned by a fire event is not correctly assigned to a specific region.

When these issues occur singularly or simultaneously, damage level or burnt biomass per hectare are assigned on the basis of the corresponding mean values estimated from the full dataset for the period 2008-2016 considering the region/forest category/fire type parameters (or their combination), when available. This choice, i.e., use of 2008-2016 data to deduce average values, estimation is due to the fact that:

- the year 2017 was not included in the dataset since the 2017 was not representative, since it was characterized by an extremely dry summer period, in which the overall surface covered by fires was anomalous compared to the past (on average +263% over the period 1990-2016) and in which the damage caused by the fires themselves was significantly more important than in the previous period (2008-2016);
- a possible annual extension of this period from 2008 to the last reported year constantly affects the gap-filling procedure causing annually recalculations of the relative GHG emissions along the whole time-series.

Finally, it has to be noted that the average values, instead of the maximum average ones, have been applied to implement the gap-filling procedure, addressing the 2019 UNFCCC review process's recommendation. Finally, the total burned biomass is estimated multiplying the burned (lost) biomass per hectare by the burned area of the corresponding fire event.

b. Time series from 2008 onward for the 5 autonomous regions/provinces

The emissions from fires have been estimated based on the average values assessed for the 15 regions from 2008 on. The burnt biomass per hectare for fires has been estimated by applying the above-described gap filling procedure. The implementation consists in the following:

A. clustering the 15 regions (those considered in the full dataset 2008-2016) into three groups with similar climatic conditions and forest types (Northern, Central and Southern Italy);
B. estimating, for each cluster, the burnt biomass per hectare as the mean of burnt volume per hectare of the related regions;
C. classifying the 5 autonomous regions based on the clusters identified at step A;
D. assigning to each of the 5 autonomous regions the burnt biomass per hectare of the corresponding cluster estimated at step B.

Finally, the total burned biomass is estimated multiplying the estimated burned (lost) biomass per hectare by the total annual burned area for each year of the time-series (1990-2019), a datum that is available from ISTAT (several years [a]).

c.Time series from 1990 to 2007 for the 20 Italian regions

The emissions from fires for the period 1990-2007 for the 20 Italian regions have been estimated based on the average values computed among 2008 and 2016, considering the fire's type and each region. The average values, instead of the maximum average values adopted in the previous submissions, have implemented to address the 2019 UNFCCC review process's recommendation. The selected value of released carbon is then multiplied by the burned area of the region in each year from 1990 to 2007.

CH_4, N_2O, CO and NO_x have been estimated following the IPCC 2006 methodology (eq. 2.27, vol. 4, ch. 2), multiplying the burned biomass, estimated as described above, by the 2006 IPCC Table 2.5 (IPCC, 2006) emission factors related to extra tropical forest category, as shown in Table A13.3; in the same table emission ratios for NMVOC, NH_3 and SO_2 also reported (as described in the EMEP/EEA Guidebook 2023, chapter 11.B, Table 3-3 (EMEP/EEA, 2023)

Table A13.3: CO, CH_4, NMVOC, NO_x, NH_3, N_2O, SO_2 emission factors

Pollutant/GHG	*emission factor / emission ratio*	*unit*	*reference*
CO	107	*g X/kg dry matter burned*	IPCC 2006 (Table 2.5)
CH_4	4.7	*g X/kg dry matter burned*	IPCC 2006 (Table 2.5)
NMVOC	21	*g X/kg C emitted as CO_2*	EMEP/EEA 2023 (Table 3-3)
NO_X	3.0	*g X/kg dry matter burned*	IPCC 2006 (Table 2.5)
NH_3	1.8	*g X/kg C emitted as CO_2*	EMEP/EEA 2023 (Table 3-3)
N_2O	0.26	*g X/kg dry matter burned*	IPCC 2006 (Table 2.5)
SO_2	1.6	*g X/kg C emitted as CO_2*	EMEP/EEA 2023 (Table 3-3)

PM10, PM2.5, dioxin, and polycyclic aromatic hydrocarbon (PAH) emissions have been also estimated, by multiplying the burnt biomass (dry matter) by the emission factors reported in Table A13.4. For black carbon, emissions have been estimated considering a percentage, i.e., 9%, of the PM2.5 emissions, in line with the EMEP/EEA Guidebook 2023, chapter 5.C.2, Table 3-5 (for temperate forest).

Table A13.4: PM10, PM2.5, dioxin, and polycyclic aromatic hydrocarbon (PAH) emission factors

pollutant	*emission factor*	*unit*	*reference*
PM10	11	*g X/kg dry matter burned*	EMEP/EEA 2023 (Table 3-5)
PM2.5	9	*g X/kg dry matter burned*	EMEP/EEA 2023 (Table 3-5)
Dioxin	10	*ng C/kg C*	EMEP/EEA 2023 (Table 3-1)
PAH	14.75	*g/t*	EMEP/EEA 2023 (Table 3-2)