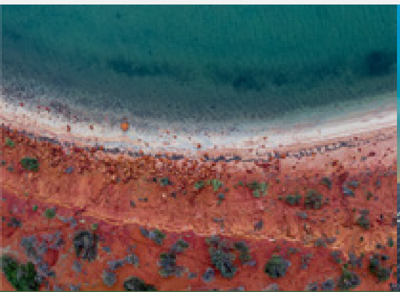
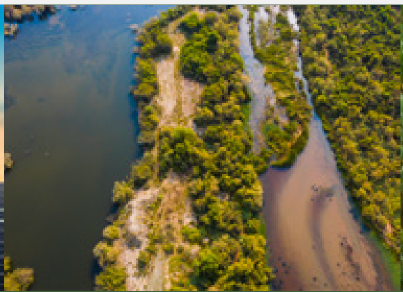
KINGDOM OF SAUDI ARABIA

THE FIRST BIENNIAL TRANSPARENCY REPORT

Submitted to

THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE






2024

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Table 1: Definitions needed to understand NDC

Title	Definition
Circular Carbon Economy (CCE)	A holistic framework, endorsed by G20 leaders in 2020, and adopted by Saudi Arabia to manage carbon emissions through the principles of reduce, reuse, recycle, and remove carbon from the atmosphere. It aligns with the Paris Agreement's goals by promoting innovative technologies such as carbon capture, utilization, and storage (CCUS), as well as advancing renewable energy and low-carbon solutions to support sustainable economic growth.
Mitigation Co-benefits	Refers to the additional positive effects achieved while implementing climate adaptation measures or non-climate-focused policies that also reduce greenhouse gas emissions. For example, improving water management practices not only conserves resources but also reduces energy consumption, thus lowering emissions.
Adaptation with Mitigation Co-benefits	Adaptation measures that simultaneously contribute to emission reductions, aligning with both mitigation and resilience goals under the Paris Agreement. Examples include afforestation projects that enhance carbon sinks while combating desertification, and integrated water management strategies that conserve energy-intensive desalination efforts.
Economic Diversification with Mitigation Co-benefits	A key pillar of Saudi Arabia's NDC and Vision 2030, focusing expanding into diverse and additional sectors like renewable energy, green hydrogen, tourism, and advanced manufacturing. Economic diversification supports low-carbon development while creating jobs and promoting sustainable economic growth.
Energy Efficiency Initiatives	**Saudi Energy Efficiency Center (SEEC):** It oversees the Saudi Energy Efficiency Program (SEEP) and implements initiatives to enhance energy efficiency across industry, buildings, and transportation sectors. **Saudi Energy Efficiency Program (SEEP):** A national initiative launched in 2012 to optimize energy efficiency in key economic sectors. **Energy Efficiency Rating (EER):** A measure of the efficiency of appliances. **Corporate Average Fuel Economy (CAFE):** Standards applied to vehicles to improve fuel efficiency and reduce energy consumption.

Title	Definition
Renewable Energy Initiatives	**National Renewable Energy Program (NREP):** It integrates renewables into the energy mix while fostering local manufacturing and research for economic growth and job creation. **Battery Energy Storage Systems (BESS):** Energy storage solutions introduced alongside renewable energy projects to stabilize and optimize electricity supply.
Carbon Capture, Utilization, and Storage (CCUS)	**Carbon Capture and Storage (CCS):** A technology to capture carbon dioxide from industrial processes and store it underground to reduce emissions. Enhanced Oil Recovery (EOR): A technique using captured CO2 to improve oil extraction efficiency. **Carbon Capture and Utilization (CCU):** The process of capturing carbon dioxide for reuse in producing low-carbon products.
Hydrogen Economy Development	**Green Hydrogen:** Hydrogen produced using renewable energy sources like solar and wind. **Blue Hydrogen:** Hydrogen produced from natural gas with carbon capture to reduce associated emissions.
Natural Gas Utilization	**Natural Gas Expansion:** Increasing natural gas use in electricity generation, water desalination, and industrial sectors to reduce reliance on high-carbon fuels.
Methane Management	**Leak Detection and Repair (LDAR):** A program to detect and repair methane leaks at facilities. **Gas Flaring Intensity:** A metric measuring the volume of gas flared per barrel of oil produced.
Water and Wastewater Management	**National Water Strategy 2030:** A framework to reduce water demand, increase wastewater reuse, and improve overall water resource management. **Reverse Osmosis (RO):** A water purification process used in desalination to produce potable water from saline sources.
Desertification Management and Afforestation	A program under the SGI aiming to combat desertification, enhance vegetation cover, and restore degraded landscapes. Arid Species Resilience Studies: Research to identify plants suitable for arid conditions to support afforestation and desertification control.

Title	Definition
Marine Protection	**Blue Carbon Sinks:** Coastal and marine ecosystems, such as mangroves and seagrasses, that sequester carbon dioxide. Yanbu Seaweed Pilot Project: An initiative to explore seaweed cultivation for ecological and economic benefits.
Urban Planning	**National Spatial Strategy (NSS):** A plan to balance urban and rural development, enhance infrastructure, and mitigate urbanization challenges. Public Transport Projects: Initiatives like the King Abdulaziz Project for Riyadh Public Transport and Haramain High-Speed Rail to reduce emissions and improve urban mobility.
Early Warning Systems (EWS)	**Regional Sandstorm Early Warning Centre (RSEWC):** A facility to monitor and predict sandstorm activity for infrastructure and health protection. **Saudi Dust Detection Index (SDDI):** A metric validated against satellite data to enhance the monitoring of dust storms.
Infrastructure and City Design	**Economic Cities and Zones:** Projects like King Abdullah Economic City and Ras Al-Khair Special Economic Zone to promote sustainable and resilient urban development.
Integrated Coastal Zone Management (ICZM)	**Coastal Aquifer Management:** Strategies to reduce seawater intrusion and protect freshwater resources through hydrogeological assessments. **Jeddah Coastal Information System (CIS):** A technological platform for real-time data on coastal management.
Integrated Water Management Planning (IWMP)	**Zero Liquid Discharge (ZLD):** A desalination process to minimize saline brine discharge while maximizing water production.

Table 2: Acronym list

Acronym	Definition
AI	Aridity Index
AR5	IPCC Fifth Assessment Report
BTR	Biennial Transparency Report
BURs	Biennial Update Reports
CAFE	Corporate Average Fuel Economy
CCE	Circular Carbon Economy
CCERC	Circular Carbon Economy Regional Collaboration
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization, and Storage
CCU	Carbon Capture and Utilization
CH4	Methane
CIS	Coastal Information System
CMS	Carbon Management System
CO2	Carbon Dioxide
CTCN	Climate Technology Centre & Network
DAC	Direct Air Capture
DNA	Designated National Authority
EER	Energy Efficiency Rating
ETF	Enhanced Transparency Framework
EWS	Early Warning System
FGRS	Flaring Gas Recovery System
GCOM	Greenhouse Gas Crediting and Offsetting Mechanism
GEA	General Entertainment Authority

Acronym	Definition
GHGs	Greenhouse Gases
GMP	Global Methane Pledge
GWP	Global Warming Potential
ICT	Information and Communication Technology
ICZM	Integrated Coastal Zone Management Planning
ITMOs	Internationally Transferred Mitigation Outcomes
JPTP	Jeddah Public Transport Program
K.A.CARE	King Abdullah City for Atomic and Renewable Energy
LDAR	Leak Detection and Repair
LPG	Liquefied Petroleum Gas
MAEE	The National Water Efficiency and the Conservation Center
MEWA	Ministry of Environment, Water and Agriculture
MGI	Middle East Green Initiative
MPAs	Marine Protected Areas
MPGs	Modalities, Procedures, and Guidelines
MOMRA	Ministry of Municipal and Rural Affairs
MWAN	National Center for Waste Management
N2O	Nitrous Oxide
NBS	Nature-Based Solutions
NCM	National Center for Meteorology
NDC	Nationally Determined Contribution
NIR	National Inventory Reports
NREP	National Renewable Energy Program
NWC	National Water Company

Acronym	Definition
PA	Paris Agreement
PIF	Public Investment Fund
RO	Reverse Osmosis
SCFD	Standard Cubic Feet per Day
SEEC	Saudi Energy Efficiency Center
SEEP	Saudi Energy Efficiency Program
SGI	Saudi Green Initiative
SIRC	Saudi Investment Recycling Company
SIO	Saudi Irrigation Organization
STP	Sewage Treatment Plants
SWA	Saudi Water Authority
SYR	Synthesis Report
TACCC	Transparency, Accuracy, Consistency, Comparability, and Completeness
UHS	Underground Hydrogen Storage
VRPs	Vision Realization Programs
QA/QC	Quality Assurance and Quality Control
UNFCCC	United Nations Framework Convention on Climate Change
ZLD	Zero Liquid Discharge
ZRF	Zero Routine Flaring by 2030 Initiative

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Chapter 1

Introduction

The Kingdom of Saudi Arabia is characterized by its arid environment, limited water resources, and unique ecosystem which include plateaus, mountains, and approximately 80% of its land covered by desert. Given the absence of perennial rivers, the Kingdom relies on a combination of surface water runoff, groundwater, desalinated seawater—which accounts for approximately 70% of potable water needs—and treated wastewater. Currently, 22.5% of the country's wastewater is being reused to meet its water requirements. These environmental conditions, combined with its sensitive ecosystems, make Saudi Arabia vulnerable to socioeconomic and climate change impacts.

Despite these topographic challenges, the Kingdom has implemented strategies to address sustainability and economic diversification, including **Saudi Vision 2030**, the **Saudi Green Initiative (SGI)**, and the **Middle East Green Initiative (MGI)**. Through these strategic initiatives and frameworks, the Kingdom is advancing sustainable development goals, such as ensuring access to energy for all and tackling poverty, while emphasizing long-term economic diversification and growth. The cornerstone of these strategic objectives is economic diversification. This multifaceted process aims to reduce reliance on primary sectors, fostering a more diverse industrial and service-based economy. Economic Diversification is critical for enhancing the country's resilience to both climate variability and economic uncertainties.

Saudi Vision 2030, launched in 2016, serves as a comprehensive roadmap designed to diversify the economy and improve the quality of life for citizens. Through phased implementation and targeted investments, Vision 2030 focuses on fostering innovation, enhancing economic resilience, and creating an enabling environment for private sector growth. The Vision Realization Programs (VRPs) aim to improve infrastructure, healthcare, education, and tourism while contributing to job creation and improved living standards. Recognizing the essential role of human capital in sustainable development, Saudi Arabia invests heavily in education, research, and workforce development to build a knowledge-based economy. These efforts are designed to enhance technical skills, promote scientific research, and support technological innovation to address climate challenges effectively. The Kingdom is also committed to increasing women's participation in the workforce, with women representing 36.2% of the labor force as of 2024. This inclusive approach aligns with broader goals of social equity and economic empowerment.

SGI and MGI, launched in 2021, are integral to the Kingdom's sustainable strategies under Vision 2030. The initiatives aim to enhance sustainable practices, with emphasis on energy efficiency, afforestation, improved waste management, and increasing terrestrial and marine protected areas. As part of the SGI, Saudi Arabia aims to plant 600 million trees and increase the Kingdom's protected land and marine areas to 30% of its total area by 2030. The MGI complements these efforts by fostering regional cooperation to implement clean energy solutions, advance carbon management strategies, and protection of marine ecosystems.

The Circular Carbon Economy (CCE) approach, endorsed by G20 during Saudi Arabia's G20 Presidency in 2020, focuses on an integrated approach to carbon management through the principles of the 4 Rs, reducing, reusing, recycling, and removing greenhouse gases (GHGs). The CCE Approach is integral to the Kingdom's climate strategy, supporting its ambition of net-zero emissions by 2060 while fostering economic development and energy security. With a focus on technologies like Carbon Capture, Utilization, and Storage (CCUS) are used to transform carbon emissions into resources such as synthetic fuels and chemicals.

Saudi Arabia's updated Nationally Determined Contribution (NDC), submitted in 2021, aims at reducing, avoiding, and removing GHG emissions by 278 million tons of CO_2-equivalent annually by 2030, more than doubling its previous ambitions. These ambitions are aligned with the principles of the Paris Agreement and reflect a dynamic baseline approach that considers the country's national circumstances. Notably, the implementation of this NDC is not contingent on receiving international financial support. Key components of this strategy include expanding renewable energy capacity, advancing hydrogen production and export, enhancing energy efficiency programs, and protecting 30% of the country's land and marine areas by 2030.

The **First Biennial Transparency Report (BTR1)** of Saudi Arabia provides a comprehensive overview of these efforts, detailing the Kingdom's greenhouse gas inventory for 2019, 2020, and 2021.In addition, it covers progress towards the NDC, the impacts of climate change response measures with a focus on economic diversification, adaptation actions, and support provided and received. This report highlights Saudi Arabia's proactive approach to balancing sustainability with economic growth, promoting international collaboration, and advancing global climate action.

Chapter 2

National Inventory Report of Anthropogenic Emissions and Removals

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2.1. Introduction and GHG Inventory Context

2.1.1. Description of the National Focal Point

The Kingdom of Saudi Arabia takes a proactive approach to address climate change issues in the country through a robust and functional institutional arrangement, the Designated National Authority (DNA). The DNA committee is Supervised and Chaired by His Royal Highness, the Minister of Energy, and its committee is represented by a diverse group of representatives from government, semi- government, and private sector entities, ensuring a comprehensive perspective.

As such, the DNA acts as the focal point for preparing the instituted reporting requirements as part of the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement. The responsibilities of the Designated National Authority include:

(i) Preparing and submitting National Communication Reports (NCs) and Biennial Update Reports (BURs) under the UNFCCC, preparing and submitting Biennial Transparency Reports (BTRs) and National Inventory Reports (NIRs) to UNFCCC every two years from 2024 onwards under the Paris Agreement;

(ii) Developing, coordinating and reviewing the Kingdom's NDCs;

(iii) Internally reviewing the NDC every year with the relevant stakeholders and follow up and review of the NDC at the international level every five years;

(iv) Developing the necessary national guidelines for the Enhanced Transparency Framework (ETF);

(v) Serving as the regulatory authority for carbon management, overseeing the issuance of credits and the approval of emission reduction projects and launching the Kingdom's Greenhouse Gas Crediting and Offsetting Mechanism (GCOM);

(vi) The establishment of a comprehensive national Carbon Management System (CMS), a vital tool for MRV efforts;

(vii) The DNA, functioning as the Secretariat of the national committee, coordinates closely with relevant entities to gather and analyze data, and prepare these reports;

(viii) The DNA represents the Kingdom at multiple international forums and is a focal point and active member of many international initiatives;

2.1.2. GHG Inventory Preparation Process

The DNA of Saudi Arabia has established a process for preparing the National Inventory Document (NID), ensuring alignment with the Modalities, Procedures, and Guidelines (MPGs) of the Paris Agreement. The inventory preparation process involves close coordination with various national institutions and stakeholders to ensure accurate data collection, processing, and reporting. The inventory development process included the following major steps:

- Identification of the inventory data input sources.
- Development of questionnaires or forms to collect the required information from the selected ministries and organizations
- Collection of inventory data
- Tabulation of the data collected
- Estimation of greenhouse gas emissions/sinks
- Development of the national inventory report.

Initially, the scope and boundaries of the GHG inventory are defined following the 2006 IPCC Guidelines. The first step is the identification of data requirements and sources. This involves determining the types of data to be collected for each emission source category and sub-sector, as outlined in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. A detailed list of relevant government ministries, semi-governmental organizations, private sector entities, and other stakeholders is prepared to facilitate data collection.

Next, questionnaires and forms are developed to standardize data collection. These tools are tailored to the specific needs of each identified sector and data source. The questionnaires are designed to capture all necessary details required for accurate emission estimations, with clear guidance on data formats, units, and reporting timelines to ensure consistency.

The data collection phase involves distributing the developed questionnaires to the identified ministries and public and private organizations. Follow-ups are conducted to ensure the completeness of submissions and to address any ambiguities or inconsistencies in the responses. Once data is received, it is systematically organized during the tabulation phase. This step ensures that all data is categorized according to emission source categories and sub-sectors, enabling initial checks for completeness and accuracy.

The estimation of greenhouse gas emissions and sinks is achieved using methodologies recommended in the 2006 IPCC Guidelines. This step includes calculating emissions for each source category and sub-sector, as well as estimating the total anthropogenic emissions of greenhouse gases and their removals by sinks. Activity data and emission factors are applied to derive these estimates. The estimated emissions and sinks are aggregated across all sectors to provide a comprehensive overview.

2.1.3. Information Archival System

Archiving all information on the reported data is crucial for maintaining a comprehensive historical record that aids in detailed analysis, research, and strategic decision-making. The DNA of Saudi Arabia employs a centralized, web-based CMS as the repository for all validated input data pertinent to the National Inventory Document (NID). This system maintains a comprehensive database of individual emission sources, which facilitates the estimation of GHG emissions. By implementing this archival system, the DNA ensures secure storage and easy accessibility of data for review and reporting purposes, thereby upholding data integrity and supporting the principles of transparency and consistency, as emphasized in the UNFCCC reporting guidelines. This approach aligns with the guidelines of the IPCC and the ETF under the Paris Agreement.

2.1.4. QA/QC Plan and Implementation

The Designated National Authority (DNA) has developed a Quality Assurance and Quality Control (QA/QC) plan for the NID, aligning with the MPGs of the Paris Agreement. This plan upholds the principles of Transparency, Accuracy, Consistency, Completeness, and Comparability (TACCC).

National entities contribute data, each implementing their own QA/QC procedures prior to submission, thereby enhancing accuracy and reliability. An evaluation team conducts objective assessments of the data, providing an additional layer of quality assurance. Subsequently, the DNA team approves and securely archives the data, following standard data handling protocols.

Data sourced from scientific literature, international organization reports, and other credible references undergo the same rigorous QA/QC. For each source category, the QA/QC process involves multiple stages and stakeholders, including national entities implementing their own QA/QC procedures, an independent evaluation team conducting objective assessments, and the inventory preparation team evaluating data sourced from scientific literature and other credible references.

2.1.5. Completeness Assessment

The DNA conducts a thorough assessment to ensure that all relevant greenhouse gas sources and sinks are accounted for in the NID.

2.1.6. GHG Inventory Approval Process

The Secretariat of the Designated National Authority prepares the National Greenhouse Gas Inventory as described above in section 2.1.2 “Inventory Preparation process” while coordinating with the relevant national stakeholders for the collection of data and addressing any subsequent gaps, as needed. The collected data then undergoes rigorous and objective assessments to ensure consistency, accuracy and completeness of the inventory prior to approval.

2.1.7. Metrics

The preparation of this Report follows paragraph 37 of the MPG, using 100-year time-horizon global warming potential (GWP) values from the IPCC Fifth Assessment Report (AR5), which requires each Party to use the 100-year time-horizon GWP values (i.e., 28 and 265 for methane and nitrous oxide, respectively) from the IPCC assessment report adopted by the CMA for the reporting of aggregate emissions and removals of GHGs.

2.1.8. Planned Improvement

As part of the continuous improvement process for the national greenhouse gas inventory, the Kingdom of Saudi Arabia recognizes the need to enhance the accuracy and specificity of emission estimates. Due to the current unavailability of country- specific information, the Tier 1 approach has been employed for this submission. To address this issue, a team will be formed, comprising representatives from all main stakeholders, to develop a comprehensive plan for collecting and validating the required country-specific data. This plan will be developed through a participatory approach, ensuring the inclusion of all relevant expertise and perspectives. Once finalized, the plan will be communicated demonstrating the Kingdom's commitment to transparency and the ongoing refinement of its greenhouse gas inventory. The implementation of this plan is expected to enable the adoption of higher-tier methodologies for the selected categories, as appropriate.

2.1.9. Recalculation

No recalculation was performed in preparing the 2019 GHG emissions inventory. This decision was made after an assessment, which confirmed that there were no significant changes.

2.1.10. Methodology

Tier 1 methodology was adopted for estimating greenhouse gases from source categories due to the unavailability of country-specific emission factors. In addition, the emission factors were adopted from the 2006 IPCC Guidelines, as well as the calculation methodologies.

2.1.11. Activity Data

The activity data was obtained from national and international sources and databases, corporate reports, and scientific literature. The inputs were carefully reviewed and analyzed for utilization in the calculations of greenhouse gas emissions.

The basic information sources prepared during the development of the previous reports for the Kingdom of Saudi Arabia were updated to select relevant organizations and obtain necessary data pertinent to direct greenhouse gas emission sources in the Kingdom. The custom-made questionnaires were prepared and mailed to each of the targeted organizations/companies. The data from these organizations/companies were carefully reviewed and analyzed for utilization in the calculations of greenhouse gas emissions.

2.1.12. Time-Series Consistency

The GHG emissions estimation methodology from source categories consistently used the same or almost similar methods and emission factors for each reported year. The activity data was also obtained from the same sources in most cases.

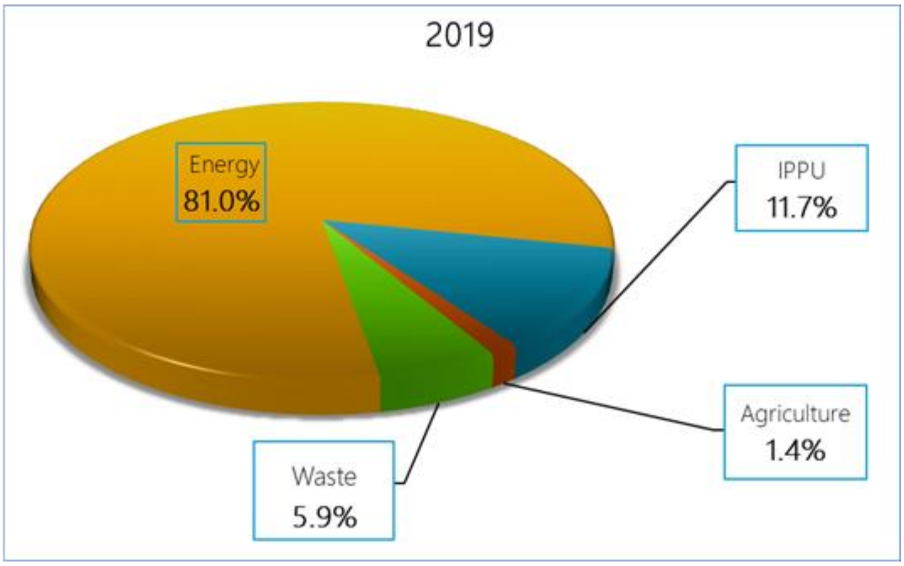
2.2. Total Emissions and Key Category Analysis

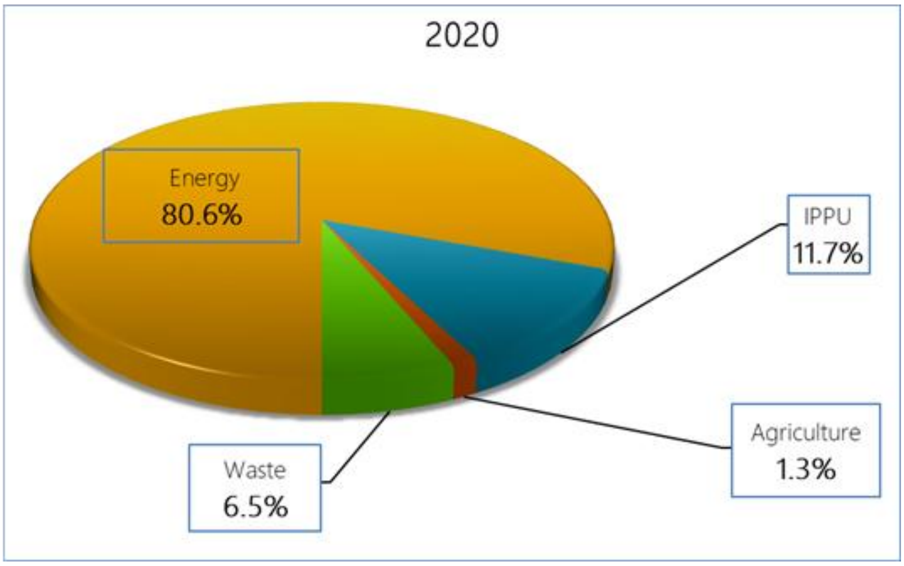
2.2.1. Total Emissions

The national GHG emissions include direct greenhouse gases, namely carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Emissions were calculated for energy, industrial processes, and product use (IPPU), agriculture, land-use, land-use change and forestry (LULUCF), and waste sectors of the Kingdom. The sector emissions are presented for each gas separately (Table 1). In 2019, the energy sector accounted for 81.0% of total GHG emissions, followed by IPPU (11.7%), waste (5.9%), and agriculture (1.4%). In 2020, the shares of these sectors were 80.6%, 11.7%, 6.5%, and 1.3%, respectively. In 2021, the shares of these sectors were 80.8%, 11.7%, 6.2%, and 1.3%, respectively (Figure 1).

Table 1. National Greenhouse Gas Emissions (in Gg) for 2019, 2020, and 2021.

Year	Gas	Energy	IPPU	Agriculture	LULUCF	Waste
2019	CO_2 (Gg)	533,207	75,164	1,785	(7,519)	-
	CH_4 (Gg)	290	128	125		1,375
	N_2O (Gg)	9	-	16		4
	Total (Gg of CO_2eq)	**543,691**	**78,745**	**9,406**	**(7,519)**	**39,668**
2020	CO_2 (Gg)	546,383	77,342	817	(7,509)	-
	CH_4 (Gg)	289	128	144		1,553
	N_2O (Gg)	8		14		5
	Total (Gg of CO_2eq)	**556,626**	**80,926**	**8,661**	**(7,509)**	**44,693**
2021	CO_2 (Gg)	568,685	80,583	954	(7,509)	-
	CH_4 (Gg)	307	132	144		1,532
	N_2O (Gg)	9		16		5
	Total (Gg of CO_2eq)	**579,622**	**84,270**	**9,205**	**(7,509)**	**44,110**





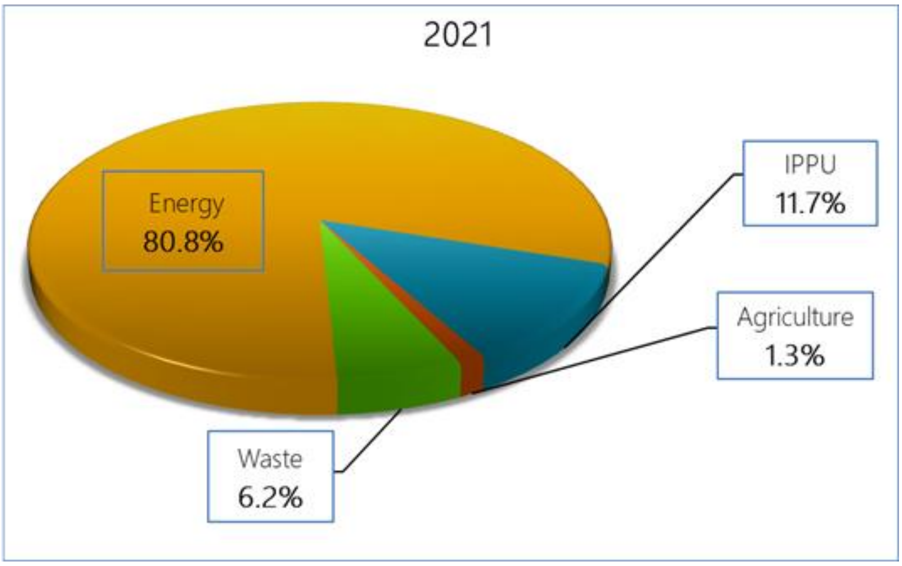


Figure 1. Shares of Total Emissions of GHGs (CO_2, CH_4, & N_2O) in CO_2eq for the Sectors of Saudi Arabia (without LULUCF).

2.2.2. Key Category Analysis

This report presents the greenhouse gas emissions inventory for the years 2019, 2020, and 2021, with 2019 as the base year. The analysis was performed using a threshold no less than 85 percent. Using Approach 1, a key category analysis based on level assessment was conducted for 2019 and 2021 (Table 2 and Table 3). In 2019 and 2021, based on level assessment, the key categories were Energy Industries - Gaseous Fuels, Energy Industries - Liquid Fuels, Road Transportation - Liquid Fuels, Manufacturing Industries and Construction - Gaseous Fuels, Petrochemical and Carbon Black Production, Cement Production, Manufacturing Industries and Construction - Liquid Fuels, and Wastewater Treatment and Discharge (not in the same order).

Table 2. Key Categories for 2019 based on Level Assessment.

Code	IPCC Category	Greenhouse Gas	Cumulative Share
1.A.1	Energy Industries - Gaseous Fuels	CO_2	0.23
1.A.1	Energy Industries - Liquid Fuels	CO_2	0.43
1.A.3.b	Road Transportation - Liquid Fuels	CO_2	0.63
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CO_2	0.71
2.B.8	Petrochemical and Carbon Black Production	CO_2	0.75
2.A.1	Cement Production	CO_2	0.79
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CO_2	0.82
4.D	Wastewater Treatment and Discharge	CH_4	0.85

Table 3. Key Categories for 2021 based on Level Assessment.

Code	IPCC Category	Greenhouse Gas	Cumulative Share
1.A.1	Energy Industries - Gaseous Fuels	CO_2	0.24
1.A.1	Energy Industries - Liquid Fuels	CO_2	0.46
1.A.3.b	Road Transportation - Liquid Fuels	CO_2	0.63
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CO_2	0.71
2.B.8	Cement Production	CO_2	0.75
2.A.1	Petrochemical and Carbon Black Production	CO_2	0.79
1.A.2	Wastewater Treatment and Discharge	CH_4	0.82
4.D	Manufacturing Industries and Construction - Liquid Fuels	CO_2	0.86

Additionally, a trend assessment key category analysis was performed for 2019 to 2021 (Table 4). Based on trend assessment, the key categories were Road Transportation - Liquid Fuels, Energy Industries - Liquid Fuels, Cement Production, Wastewater Treatment and Discharge, Energy Industries - Gaseous Fuels, Lime Production, Manufacturing Industries and Construction - Gaseous Fuels, Ammonia Production, Petrochemical and Carbon Black Production, Non-Energy Products from Fuels and Solvent Use, and Solid Waste Disposal.

Table 4. Key Categories for 2021 based on Trend Assessment.

Code	IPCC Category	Greenhouse Gas	Cumulative Share
1.A.3.b	Road Transportation - Liquid Fuels	CO_2	0.29
1.A.1	Energy Industries - Liquid Fuels	CO_2	0.56
2.A.1	Cement Production	CO_2	0.62
4.D	Wastewater Treatment and Discharge	CH_4	0.67
1.A.1	Energy Industries - Gaseous Fuels	CO_2	0.71
2.A.2	Lime Production	CO_2	0.74
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CO_2	0.77
2.B.1	Ammonia Production	CO_2	0.79
2.B.8	Petrochemical and Carbon Black Production	CO_2	0.81
2.D	Non-Energy Products from Fuels and Solvent Use	CO_2	0.83
4.A	Solid Waste Disposal	CH_4	0.85

2.3. Energy

2.3.1. Fuel Combustion (CRT category 1.A)

2.3.1.1. International Aviation and International Water-borne Navigation

Greenhouse gas emissions from international aviation and international water-borne navigation are important considerations in the context of the UNFCCC and the Paris Agreement. According to the MPGs (i.e., paragraph 53), Parties should report greenhouse gas emissions from international aviation and water-borne navigation. These emissions should be reported separately from national totals. Greenhouse gas emissions from international aviation and international water-borne navigation for the years 2019, 2020, and 2021 are presented in Table 5. The emissions significantly dropped from 2019 to 2020 due to the COVID-19 pandemic.

Table 5. Greenhouse Gas Emissions of CO_2, CH_4, and N_2O (in Gg) from International Aviation and International Water borne Navigation.

2019	**CO_2**	**CH_4**	**N_2O**
International Aviation	8,604.4	0.1	0.2
International Water-Borne Navigation	10,500.3	0.9	0.3
2020	**CO_2**	**CH_4**	**N_2O**
International Aviation	3,144.7	0.03	0.1
International Water-Borne Navigation	8,571.0	0.8	0.2
2021	**CO_2**	**CH_4**	**N_2O**
International Aviation	3,666.6	0.03	0.1
International Water-Borne Navigation	9,293.3	0.8	0.2

2.3.1.2. Energy Industries (CRT category 1.A.1)

The energy industries category (1.A.1) encompasses emissions from three primary sources: electricity generation, combined heat and power generation (CHP), and petroleum refining. These subcategories represent critical processes within the energy sector that contribute significantly to national greenhouse gas inventories. Electricity generation refers to the production of electrical energy through combustion-based power plants, including fossil fuels. CHP systems simultaneously produce heat and electricity from a single fuel source, improving overall efficiency while reducing emissions compared to standalone electricity generation. Petroleum refining involves the processing of crude oil into various petroleum products, contributing to emissions through combustion processes and other operational activities.

The emissions of CO_2, CH_4, and N_2O from sub-categories under the Energy Industries Category were estimated and summarized (Table 6). In 2019, the total CO_2, CH_4, and N_2O emissions from this category were 295,298.0 Gg, 8.3 Gg, and 1.4 Gg, respectively. In 2020, the total CO_2, CH_4, and N_2O emissions from this category were 325,161.16 Gg, 9.2 Gg, and 1.5 Gg, respectively. In 2021, the total CO_2, CH_4, and N_2O emissions from this category were 332,129.0 Gg, 9.5 Gg, and 1.6 Gg, respectively.

In 2019, electricity generation in the energy industries category accounted for 53.3% of total GHG emissions, followed by CHP (38.2%) and petroleum refining (8.5%). In 2020, the shares of these sub-categories were 62.1%, 30.5%, and 7.4%, respectively. In 2021, the shares were 61.8%, 30.6%, and 7.6%, respectively (Figure 2).

There are two sources of uncertainty in estimating greenhouse gas emissions from the Energy Industry category. These are from the activity data source and emission factors. The activity data mainly includes the data provided by government agencies. Therefore, the uncertainty of activity data is assumed to be low. The uncertainty in the CO_2 emission factor is expected to be low. The combined uncertainty in CH_4 and N_2O emissions from this could be very high, mainly due to the uncertainty associated with the emission factor.

Table 6. Emissions of GHGs from the Energy Industry.

Year	GHG	1.A.1.a.i - Electricity Generation	1.A.1.a.ii - Combined Heat and Power Generation	1.A.1.b - Petroleum Refining	Total
2019	CO_2 (Gg)	157,441.38	112,692.06	25,164.55	295,298.0
	CH_4 (Gg)	4.90	2.93	0.45	8.3
	N_2O (Gg)	0.87	0.46	0.05	1.4
	Total (Gg of CO_2eq)	**157,809**	**112,896**	**25,189**	**295,895**
2020	CO_2 (Gg)	201,872.22	99,296.34	23,993.04	325,161.6
	CH_4 (Gg)	6.02	2.74	0.45	9.2
	N_2O (Gg)	1.04	0.45	0.05	1.5
	Total (Gg of CO_2eq)	**202,317**	**99,492**	**24,019**	**325,827**
2021	CO_2 (Gg)	205,122.02	101,609.18	25,397.81	332,129.0
	CH_4 (Gg)	6.17	2.81	0.47	9.5
	N_2O (Gg)	1.07	0.46	0.05	1.6
	Total (Gg of CO_2eq)	**205,579**	**101,811**	**25,424**	**332,814**

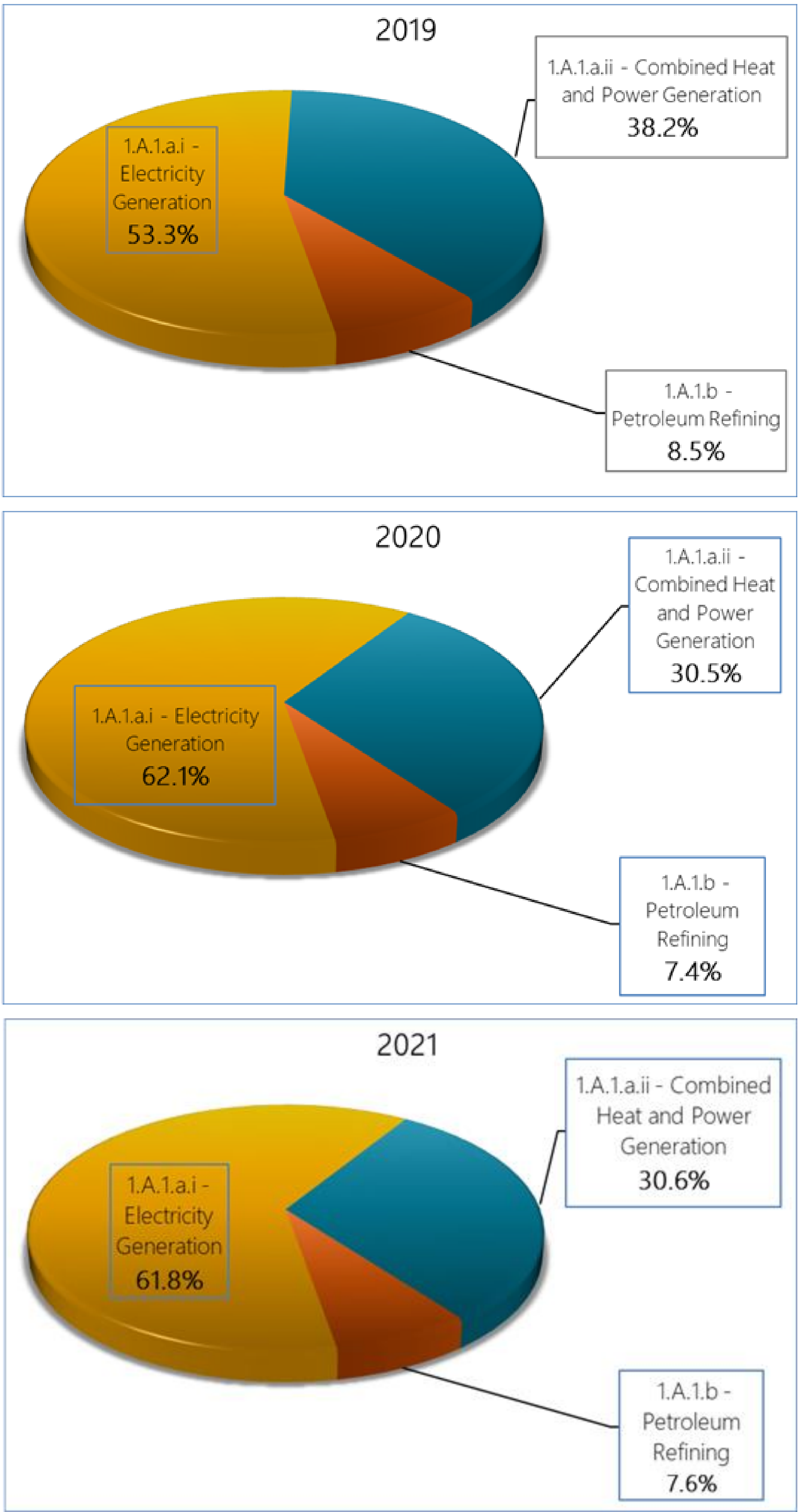


Figure 2. Shares of Total Emissions of GHGs (CO_2, CH_4, and N_2O) in CO_2eq for the Energy Industry.

2.3.1.3. Manufacturing Industries and Construction (CRT category 1.A.2)

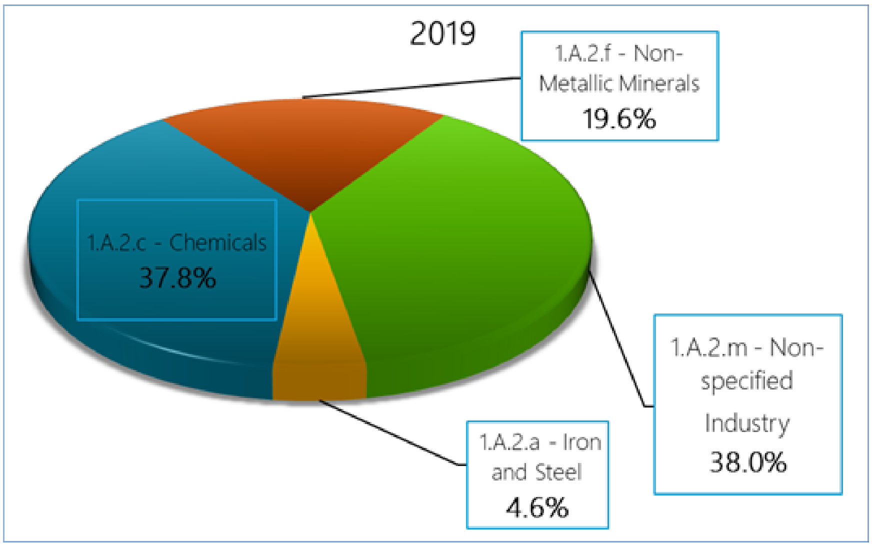
The Manufacturing Industries and Construction category consists of activities related to the iron and steel industry, chemicals, non-metallic minerals, and non-specified industries. The emissions of CO_2, CH_4, and N_2O from various sub-categories under the Manufacturing Industries and Construction Category were estimated and summarized (Table 7).

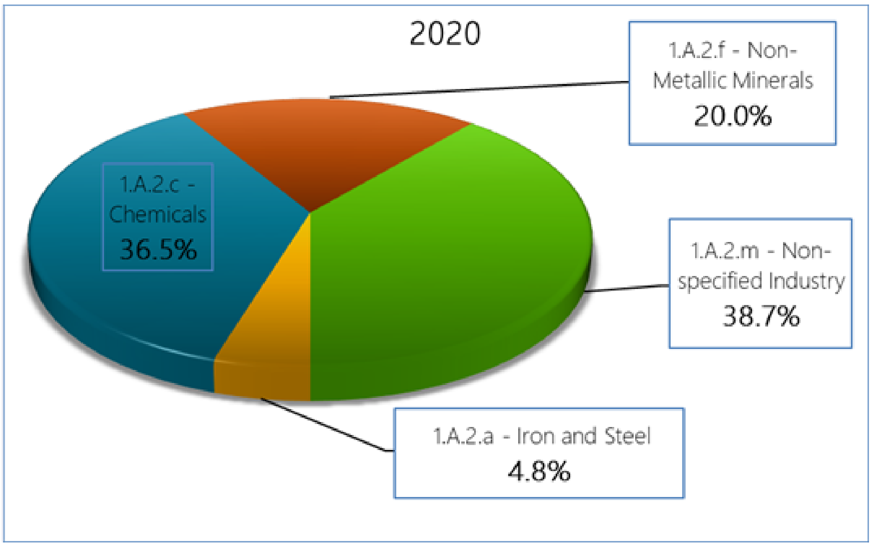
Table 7. Emissions of GHGs from the Manufacturing Industry and Construction.

Year	GHG	1.A.2.a - Iron and Steel	1.A.2.c - Chemicals	1.A.2.f – Non - Metallic Minerals	1.A.2.m - Non-Specified Industry	Total
2019	CO_2 (Gg)	3,662.72	29,930.63	15,435.31	30,022.34	79,051.0
	CH_4 (Gg)	0.07	0.53	0.56	0.72	1.9
	N_2O (Gg)	0.01	0.05	0.11	0.11	0.3
	Total (Gg of CO_2eq)	**3,666**	**29,960**	**15,480**	**30,071**	**79,177**
2020	CO_2 (Gg)	3,962.72	30,013.01	16,420.73	31,838.82	82,235.3
	CH_4 (Gg)	0.07	0.53	0.61	0.76	2.0
	N_2O (Gg)	0.01	0.05	0.12	0.11	0.3
	Total (Gg of CO_2eq)	**3,967**	**30,042**	**16,469**	**31,890**	**82,368**
2021	CO_2 (Gg)	4,540.06	30,095.38	17,240.63	32,028.79	83,904.9
	CH_4 (Gg)	0.08	0.54	0.63	0.77	2.0
	N_2O (Gg)	0.01	0.05	0.12	0.11	0.3
	Total (Gg of CO_2eq)	**4,544**	**30,125**	**17,291**	**32,080**	**84,040**

In 2019, the total CO_2, CH_4, and N_2O emissions from this category were 79,051.0 Gg, 1.9 Gg, and 0.3 Gg, respectively. In 2020, the total CO_2, CH_4, and N_2O emissions from this category were 82,235.3 Gg, 2.0 Gg, and 0.3 Gg, respectively. In 2021, the total CO_2, CH_4, and N_2O emissions from this category were 83,904.9 Gg, 2.0 Gg, and 0.3 Gg, respectively.

In 2019, the non-specified industry sub-category accounted for 38.0% of total GHG emissions, followed by chemicals (37.8%), non-metallic minerals (19.6%), and iron and steel (4.6%). In 2020, the shares of these sub-categories were 38.7%, 36.5%, 20.0%, and 4.8%, respectively. In 2021, the shares were 38.2%, 35.8%, 20.6%, and 5.4%, respectively (Figure 3).





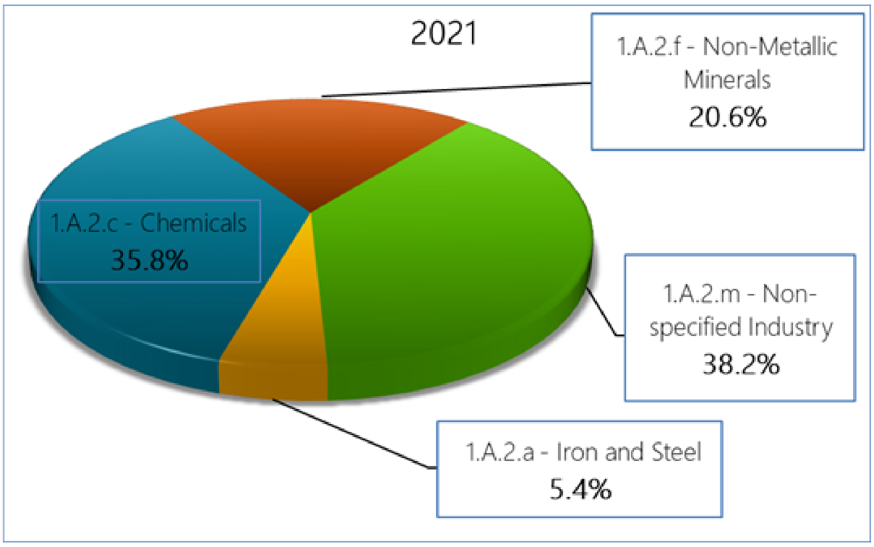


Figure 3. Shares of Total Emissions of GHGs (CO_2, CH_4, and N_2O) in CO_2eq for the Manufacturing Industry and Construction.

There are two sources of uncertainty in estimating greenhouse gas emissions from the Manufacturing Industries and Construction category. These are from the activity data source(s) and emission factors. The activity data mainly includes the data provided by government agencies. Therefore, the uncertainty of activity data is assumed to be low. The uncertainty in the CO_2 emission factor is expected to be low. Thus, the combined uncertainty in CO_2 emissions from this category is expected to be low. The combined uncertainty in CH_4 and N_2O emissions could be high.

2.3.1.4. Transportation (CRT category 1.A.3)

The transport category includes emissions resulting from the combustion of fuels used across various modes of transportation. Road transportation encompasses emissions from vehicles operating on roads, such as passenger cars, buses, motorcycles, and freight vehicles fueled by gasoline and diesel. Civil aviation accounts for emissions from domestic and international flights, including takeoff, cruising, and landing operations of aircraft. The emission from international aviation should not be added to the national GHG emissions inventory. Railways cover emissions from fuel combustion in freight and passenger trains, excluding electric trains, which fall under the energy sector. Water-borne navigation includes emissions from ships, boats, and other vessels used for the movement of passengers and goods in domestic and international waters. The emission from international maritime navigation should not be added to the national GHG emissions inventory.

The activity data for the transportation category comes from various reliable sources. Data on road transportation, as well as international civil aviation and maritime transport, was obtained from the United Nations Data Bank (UNDB). Railway fuel consumption, maritime fuel usage, and domestic civil aviation data were collected from relevant national agencies.

The emissions of CO_2, CH_4, and N_2O from various sub-categories under the transportation category were estimated and summarized (Table 8). In 2019, the total CO_2, CH_4, and N_2O emissions from transportation category were 140,005.0 Gg, 37.1 Gg, and 6.8 Gg, respectively. In 2020, the total CO_2, CH_4, and N_2O emissions were 120,150.5 Gg, 32.4 Gg, and 5.9 Gg, respectively. In 2021, the total CO_2, CH_4, and N_2O emissions were estimated to be 132,670.2 Gg, 34.3 Gg, and 6.5 Gg, respectively.

In 2019, the road transportation sub-category accounted for 94.9% of total GHG emissions, followed by water-borne navigation (3.0%), civil aviation (2.0%), and railways (0.1%). In 2020, the shares of these sub-categories were 95.7%, 2.9%, 1.3%, and 0.1%, respectively. In 2021, the shares were 95.1%, 2.8%, 1.9%, and 0.2%, respectively (Figure 4).

The fuel consumption data was adopted from national and international sources, which are reliable because energy balance data are primarily based on well-established and institutionalized accounting methodologies. The overall uncertainty in CO_2 emission estimates from the Transportation category is expected to be low to moderate. The overall uncertainties of CH_4 and N_2O are expected to be high.

Table 8. Emissions of GHGs from Transportation.

Year	GHG	1.A.3.a - Civil Aviation	1.A.3.b - Road Transportation	1.A.3.c - Railways	1.A.3.d - Water-borne Navigation	Total
2019	CO_2 (Gg)	2,871.88	132,752.69	112.16	4,268.25	140,005.0
	CH_4 (Gg)	0.03	36.68	0.01	0.39	37.1
	N_2O (Gg)	0.09	6.53	0.04	0.11	6.8
	Total (Gg of CO_2eq)	**2,895**	**135,511**	**124**	**4,308**	**142,839**
2020	CO_2 (Gg)	1,546.84	114,962.62	158.20	3,482.87	120,150.5
	CH_4 (Gg)	0.02	32.01	0.01	0.32	32.4
	N_2O (Gg)	0.05	5.66	0.06	0.09	5.9
	Total (Gg of CO2eq)	**1,559**	**117,357**	**175**	**3,516**	**122,607**
2021	CO_2 (Gg)	2,502.09	126,178.40	213.37	3,776.33	132,670.2
	CH_4 (Gg)	0.03	33.95	0.01	0.34	34.3
	N_2O (Gg)	0.07	6.22	0.08	0.10	6.5
	Total (Gg of CO_2eq)	**2,523**	**128,779**	**236**	**3,812**	**135,349**

2.3.1.5. Other Sectors (CRT category 1.A.4)

The residential and agriculture categories contribute to GHG emissions through energy consumption in households and agricultural activities. The residential sector includes emissions from fuel combustion for heating, cooking, and water heating, covering fossil fuels (e.g., LPG and kerosene). On the other hand, the agriculture category encompasses emissions from fuel (e.g., diesel) use in activities including irrigation, operation of field machinery, and greenhouse operations. The data on residential activities was collected from both the UNDB and relevant national agencies.

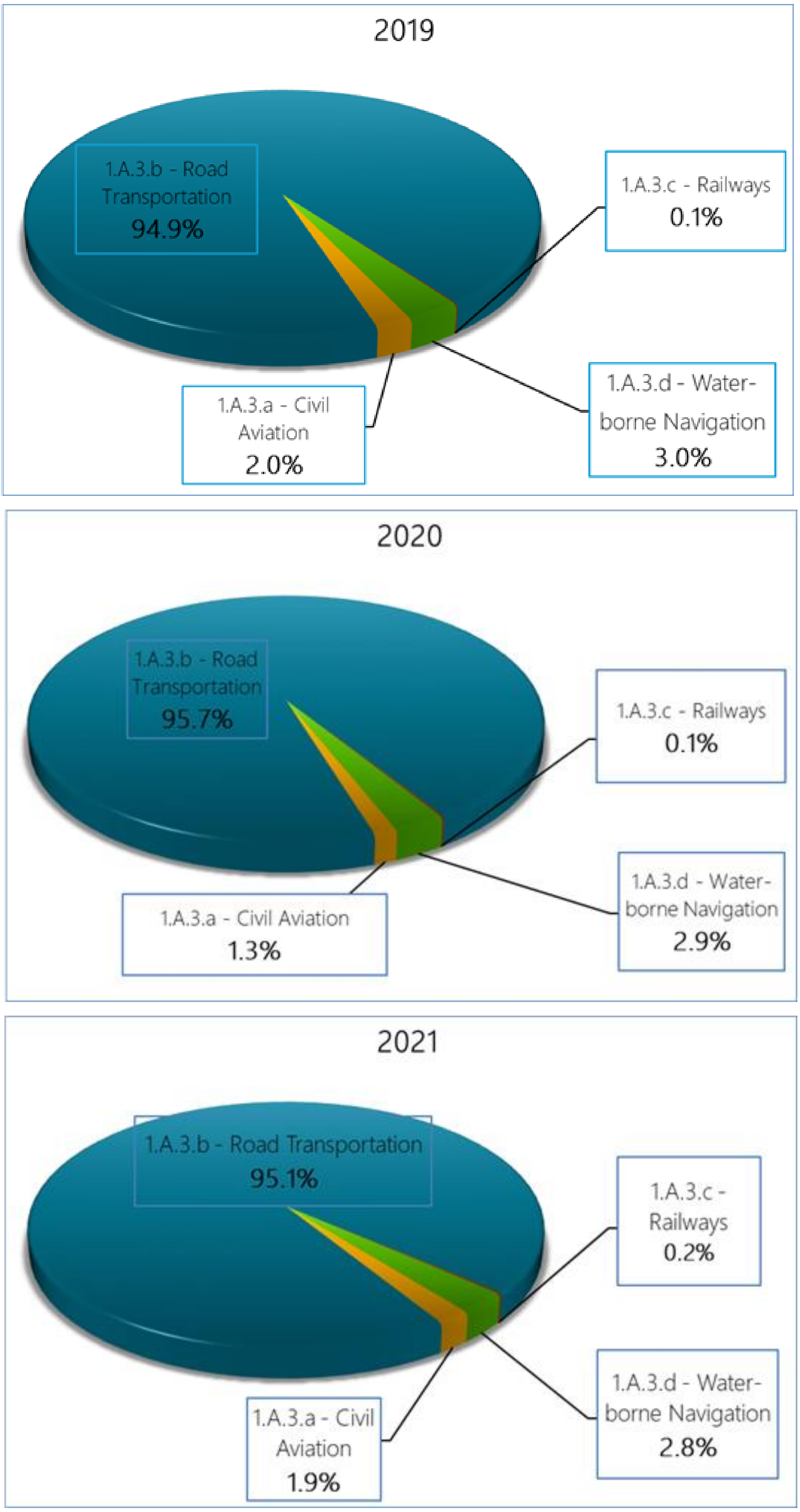


Figure 4. Shares of Total Emissions of GHGs (CO_2, CH_4, and N_2O) in CO_2eq for the Transportation.

The emissions of CO_2, CH_4, and N_2O from various sub-categories under the Other Sectors Category were estimated and summarized (Table 9).

Table 9. Emissions of GHGs from the Other Sectors.

Year	GHG	1.A.4.b - Residential	1.A.4.c - Agriculture /Forestry /Fishing/Fish Farms	Total
2019	CO_2 (Gg)	4,866.5	4,065.7	8,932.1
	CH_4 (Gg)	0.48	0.55	1.03
	N_2O (Gg)	0.02	0.03	0.05
	Total (Gg of CO_2eq)	**4,885**	**4,090**	**8,975**
2020	CO_2 (Gg)	4,764.13	4,836.03	9,600.16
	CH_4 (Gg)	0.46	0.65	1.11
	N_2O (Gg)	0.02	0.04	0.06
	Total (Gg of CO_2eq)	**4,781**	**4,865**	**9,646**
2021	CO_2 (Gg)	5,073.81	4,986.00	10,059.81
	CH_4 (Gg)	0.46	0.67	1.13
	N_2O (Gg)	0.01	0.04	0.05
	Total (Gg of CO_2eq)	**5,090**	**5,016**	**10,106**

In 2019, the total CO_2, CH_4, and N_2O emissions from this category were 8,932.1 Gg, 1.0 Gg, and 0.1 Gg, respectively. In 2020, the total CO_2, CH_4, and N_2O emissions from this category were 9,600.2 Gg, 1.1 Gg, and 0.1 Gg, respectively. In 2021, the total CO_2, CH_4, and N_2O emissions from this category were 10,059.8 Gg, 1.1 Gg, and 0.1 Gg, respectively. In 2019, the residential sub-category accounted for 54.4% of total GHG emissions, followed by agriculture/forestry/fishing/fish firms (45.6%). In 2020, the shares of these sub-categories were 49.6% and 50.4%, respectively. In 2021, the shares were 50.4% and 49.6%, respectively (Figure 5).

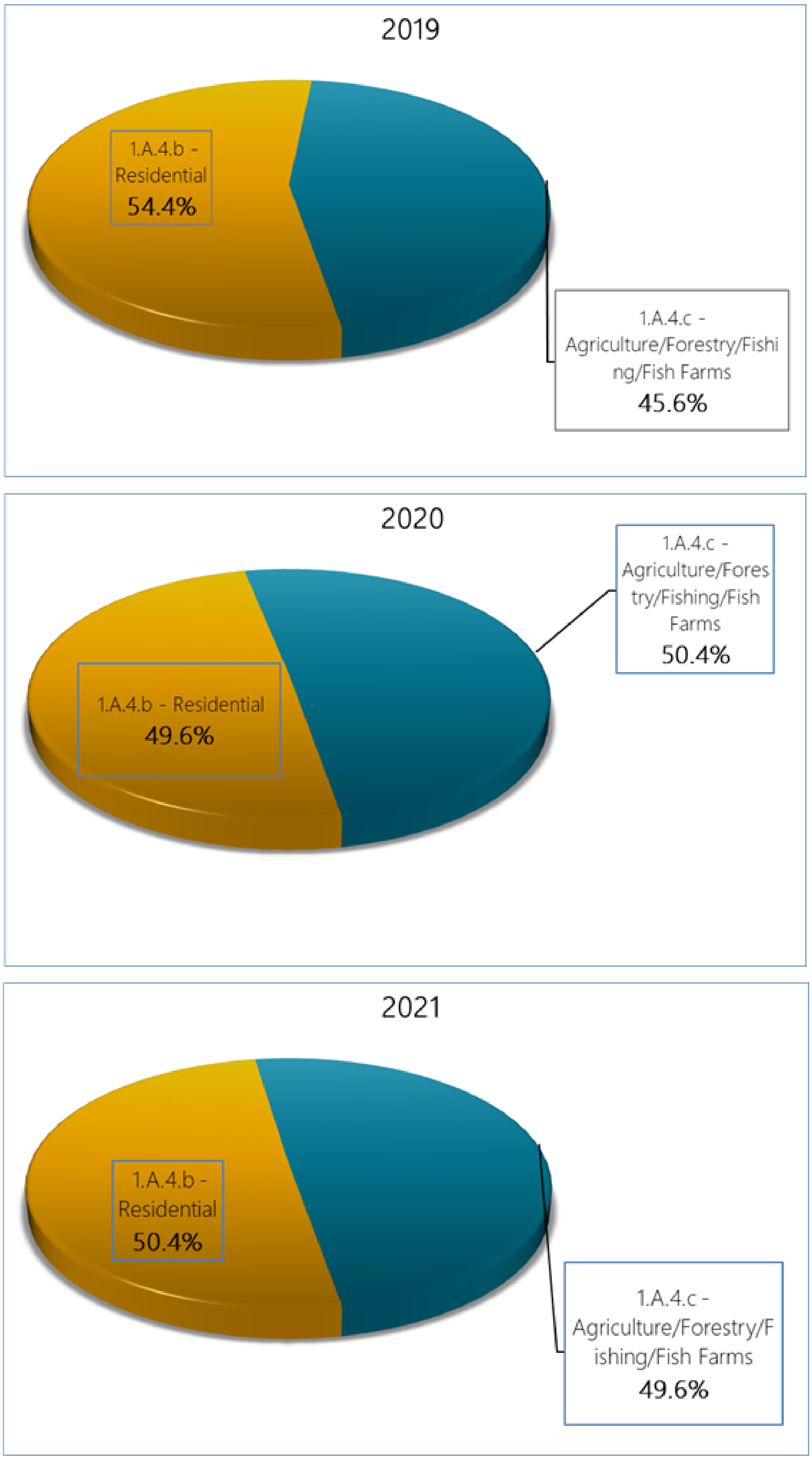


Figure 5. Shares of Total Emissions of GHGs (CO_2, CH_4, and N_2O) in CO_2eq for the Other Sectors.

The fuel consumption data for the other sectors category was adopted from national and international sources, which are reliable because energy balance data are primarily based on well-established and institutionalized accounting methodologies. The overall uncertainty in CO_2 emission estimates from the Other Sectors category is expected to be low to moderate. The overall uncertainties of CH_4 and N_2O are expected to be high.

2.3.2. Fugitive emissions from energy production (CRT category 1.B)

2.3.2.1. Oil and Natural Gas (CRT category 1.B.2)

Fugitive emissions from oil and natural gas operations contribute to GHG emissions, primarily in the form of CO_2, CH_4, and, to a lesser extent, N_2O. Emissions from oil-related activities, such as exploration, production, refining, storage, and transportation, arise from leaks, venting, and flaring processes. These activities release CO_2 and CH_4. Similarly, emissions from natural gas operations occur during production, processing, storage, and distribution, with methane being the predominant emission due to leaks in pipelines, compressor stations, and associated equipment. While nitrous oxide emissions are less common, they may occur in specific scenarios such as flaring or combustion processes. Although Saudi Arabia is the largest global oil producer, it has a small number of extremely large and productive reservoirs. The Kingdom's average crude oil upstream GHG emissions intensity is among the lowest in the World (Masnadi et al., 2018). Saudi Arabia's upstream methane intensity reached 0.06% and 0.05% in 2020 and 2021, respectively (Saudi Aramco, 2022). The Kingdom has been maintaining a master gas collection network throughout its oil and gas fields and its gas flaring status is below 1%. Methane intensity is the methane emissions from upstream operations per volume of marketed natural gas. The activity data was collected from relevant national organizations.

The fugitive emissions of CO_2, CH_4, and N_2O from sub-categories under the Oil and Gas Category were estimated and summarized (Table 10). In 2019, the total CO_2, CH_4, and N_2O emissions from this category were 9,920.9 Gg, 242.1 Gg, and

0.4 Gg, respectively. In 2020, the total CO_2, CH_4, and N_2O emissions from this category were 9,235.1 Gg, 244.4 Gg, and 0.4 Gg, respectively. In 2021, the total CO_2, CH_4, and N_2O emissions from this category were 9,921.6 Gg, 260.1 Gg, and 0.4 Gg, respectively.

In 2019, the oil sub-category accounted for 99.9% of total fugitive GHG emissions, followed by natural gas (0.1%). In 2020, the shares of these sub-categories were 96.5% and 3.5%, respectively. In 2021, the shares were 97.0% and 3.0%, respectively (Figure 6).

The uncertainty assessment for Fugitive Emissions from the Oil and Gas Industry category is challenging due to the reliance on throughput-based information and the high variability in emission factors. Therefore, the overall uncertainties of CO_2, CH_4, and N_2O are expected to be very high.

Table 10. Fugitive Emissions of GHGs from the Oil and Natural Gas.

Year	GHG	1.B.2.a - Oil	1.B.2.b - Natural Gas	Total
2019	CO_2 (Gg)	9,908.88	12.03	9,920.91
	CH_4 (Gg)	241.77	0.28	242.05
	N_2O (Gg)	0.41	0.00	0.41
	Total (Gg of CO_2eq)	**16,786**	**20**	**16,806**
2020	CO_2 (Gg)	9,221.29	13.78	9,235.07
	CH_4 (Gg)	224.40	19.99	244.38
	N_2O (Gg)	0.38	0.00	0.38
	Total (Gg of CO_2eq)	**15,605**	**573**	**16,178**
2021	CO_2 (Gg)	9,908.84	12.71	9,921.55
	CH_4 (Gg)	241.68	18.37	260.05
	N_2O (Gg)	0.41	0.00	0.41
	Total (Gg of CO_2eq)	**16,785**	**527**	**17,312**

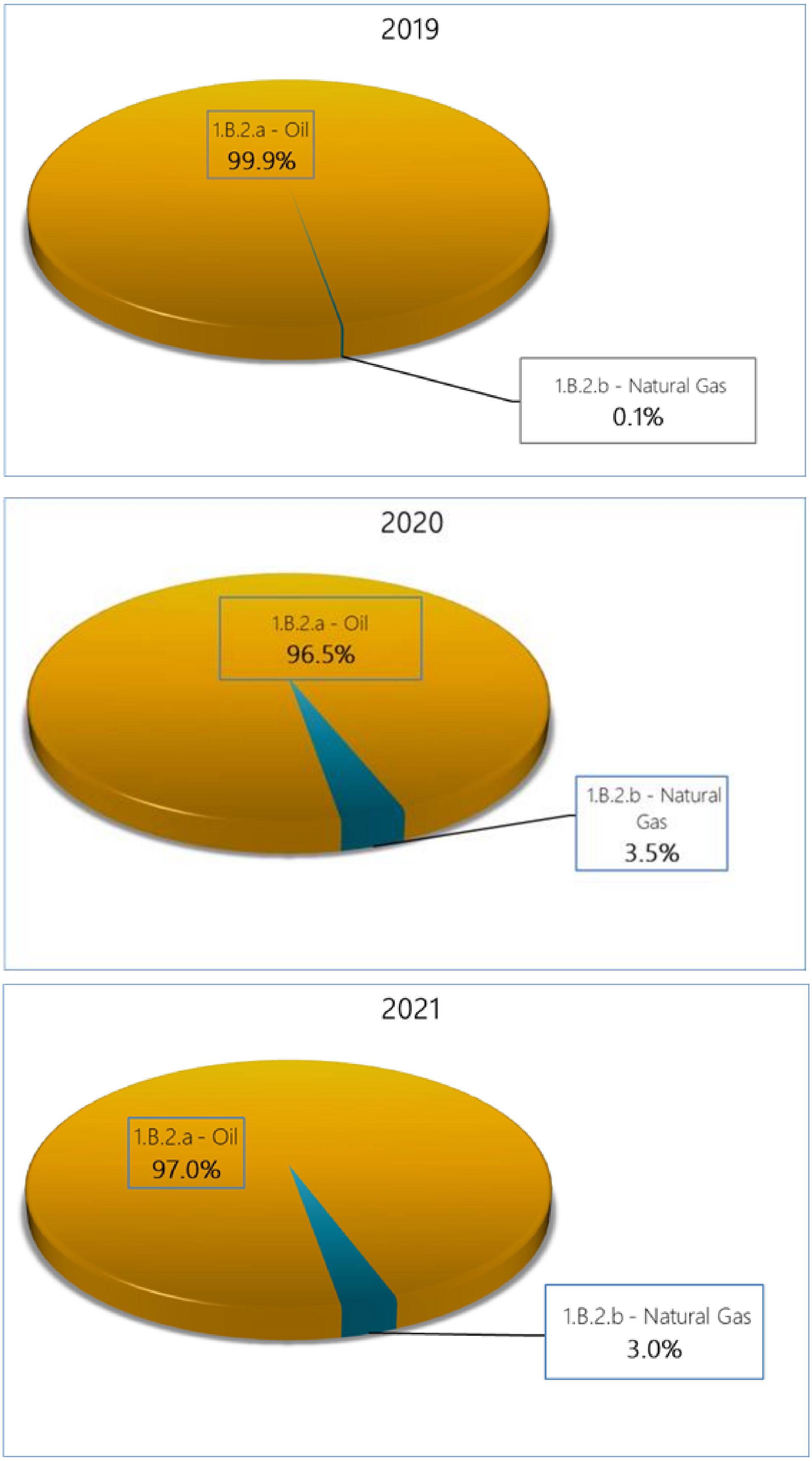


Figure 6. Shares of Total Fugitive Emissions of GHGs (CO_2, CH_4, and N_2O) in CO_2eq for the Oil and Natural Gas.

2.4. Industrial Processes & Product Use (IPPU)

2.4.1. Mineral Industry (CRT category 2.A)

The mineral industry category is a significant source of GHG emissions due to the chemical and thermal processes involved in various production activities. Cement production releases CO_2 during the calcination of limestone in clinker production. Similarly, lime production generates CO_2 emissions through the calcination of carbonate minerals such as limestone and dolomite. Glass production contributes to emissions from the decomposition of carbonates used in the process. Additionally, other process uses of carbonates in industrial applications release CO_2 during the decomposition of carbonate compounds. The production data was collected from relevant national and international sources, including the General Authority of Statistics (GASTAT) of Saudi Arabia and the United States Geological Survey (USGS).

The emissions of CO_2 from sub-categories under the Mineral Industry Category were estimated and are summarized (Table 11). In 2019, 2020, and 2021, the total CO_2 emissions from this category were 26,711.9 Gg, 27,275.6 Gg, and 30,024.8 Gg, respectively. In 2019, the cement production sub-category accounted for 88.7% of total CO_2 emissions, followed by lime production (8.9%), other process uses of carbonates (1.6%), and glass production (0.8%). In 2020, the shares of these sub-categories were 94.0%, 3.5%, 1.6%, and 0.8%, respectively. In 2021, the shares were 94.5%, 3.3%, 1.5%, and 0.7%, respectively (Figure 7).

The uncertainty of input data, especially the cement production data used in estimating emissions from the Mineral Industry category, is low. The combined uncertainty in CO_2 emissions, including emission factors, is expected to be moderate.

Table 11. Emissions of GHGs from the Mineral Industry.

Year	GHG	2.A.1 - Cement Production	2.A.2 - Lime production	2.A.3 - Glass Production	2.A.4 - Other Process Uses of Carbonates	Total
2019	CO_2 (Gg)	23,684.30	2,370.24	218.80	438.59	26,711.9
	CH_4 (Gg)					-
	N_2O (Gg)					-
	Total (Gg of CO_2eq)	**23,684**	**2,370**	**219**	**439**	**26,712**
2020	CO_2 (Gg)	25,651.22	964.22	219.40	440.79	27,275.6
	CH_4 (Gg)					-
	N_2O (Gg)					-
	Total (Gg of CO_2eq)	**25,651**	**964**	**219**	**441**	**27,276**
2021	CO_2 (Gg)	28,372.78	988.86	220.20	442.99	30,024.8
	CH_4 (Gg)					-
	N_2O (Gg)					-
	Total (Gg of CO_2eq)	**28,373**	**989**	**220**	**443**	**30,025**

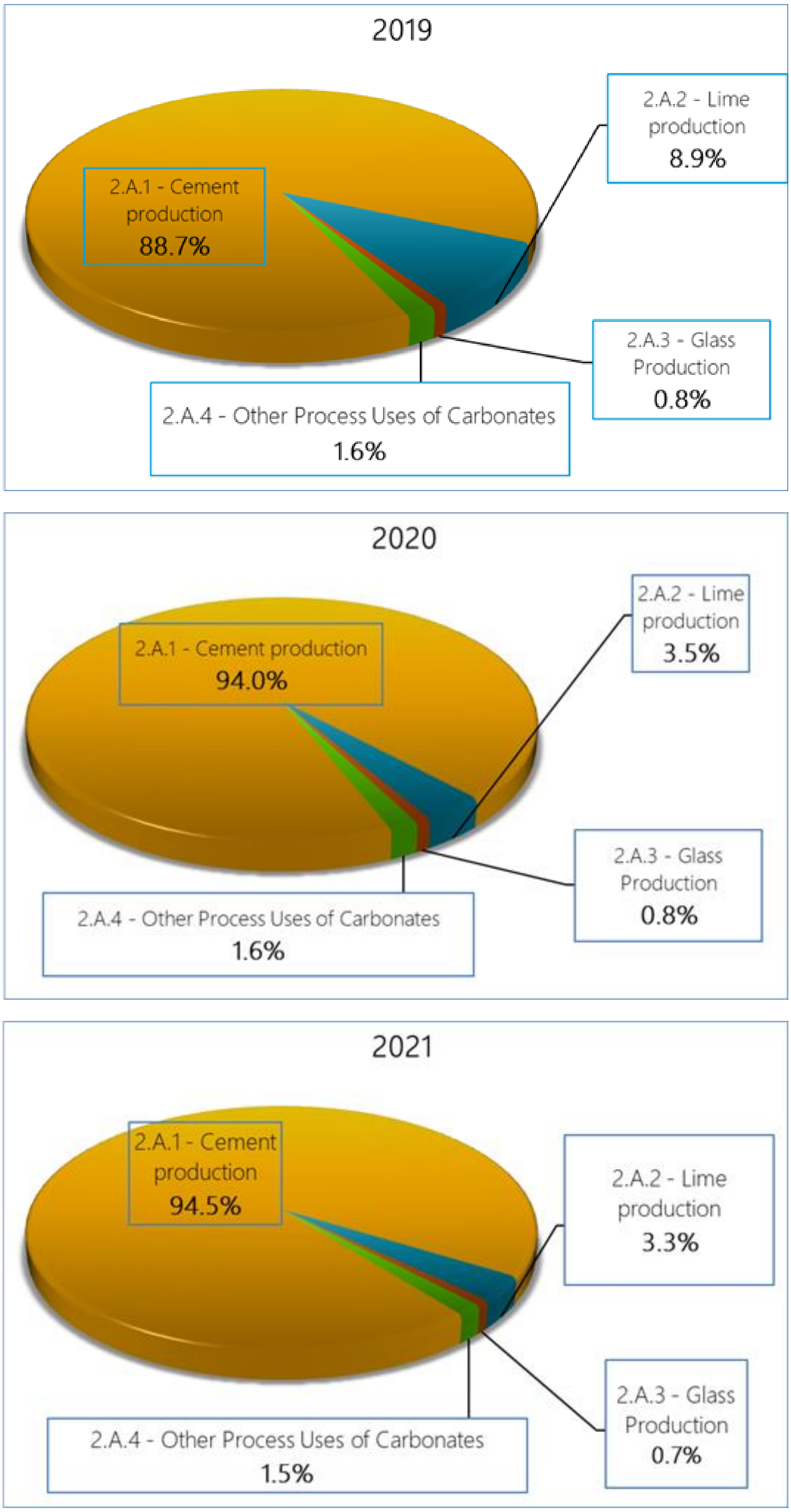


Figure 7. Shares of Total Emissions of CO_2 for the Mineral Industry.

2.4.2. Chemical Industry (CRT category 2.B)

The chemical industry is a significant source of GHG emissions due to the diverse processes involved in transforming raw materials into chemical products. Ammonia production generates substantial CO_2 emissions as a byproduct of natural gas or hydrocarbon reforming. Similarly, titanium dioxide production releases CO_2 during the chemical transformation processes. Soda ash production contributes to emissions through the decomposition of raw materials like limestone, releasing CO_2. The petrochemical production results in the release of CO_2 and CH_4. The production data was obtained from relevant national and international organizations, including the Gulf Petrochemicals and Chemicals Association (GPCA).

The emissions of CO_2 and CH_4 from sub-categories under the Chemical Industry Category were estimated and summarized (Table 12). In 2019, the total CO_2 and CH_4 emissions from this category were 34,174.6 Gg and 127.9 Gg, respectively. In 2020, the total CO_2 and CH_4 emissions from this category were 34,795.9 Gg and 128.0 Gg, respectively. In 2021, the total CO_2 and CH_4 emissions from this category were 34,342.3 Gg and 131.7 Gg, respectively.

In 2019, the petrochemical and carbon black production sub-category accounted for 78.0% of total GHG emissions, followed by ammonia production (21.4%) and titanium dioxide production (0.6%). In 2020, the shares of these sub-categories were 76.9%, 22.5%, and 0.6%, respectively. In 2021, the shares were 79.6%, 19.8%, and 0.6%, respectively (Figure 8).

The production data was adopted from national and international sources, which are reliable because the data are primarily based on well-established and institutionalized accounting methodologies. The overall uncertainty in CO_2 and CH_4 emission estimates from the Chemical Industry category is expected to be moderate.

Table 12. Emissions of GHGs from the Chemical Industry.

Year	GHG	2.B.1 - Ammonia Production	2.B.6 – Titanium Dioxide Production	2.B.8 - Petrochemical and Carbon Black Production	Total
2019	CO_2 (Gg)	8,064.53	230.70	25,879.35	34,174.6
	CH_4 (Gg)			127.89	127.9
	N_2O (Gg)				-
	Total (Gg of CO_2eq)	**8,065**	**231**	**29,460**	**37,756**
2020	CO_2 (Gg)	8,629.45	235.33	25,931.13	34,795.9
	CH_4 (Gg)			128.00	128.0
	N_2O (Gg)				-
	Total (Gg of CO_2eq)	**8,629**	**235**	**29,515**	**38,380**
2021	CO_2 (Gg)	7,529.45	239.96	26,572.91	34,342.3
	CH_4 (Gg)			131.69	131.7
	N_2O (Gg)				-
	Total (Gg of CO_2eq)	**7,529**	**240**	**30,260**	**38,030**

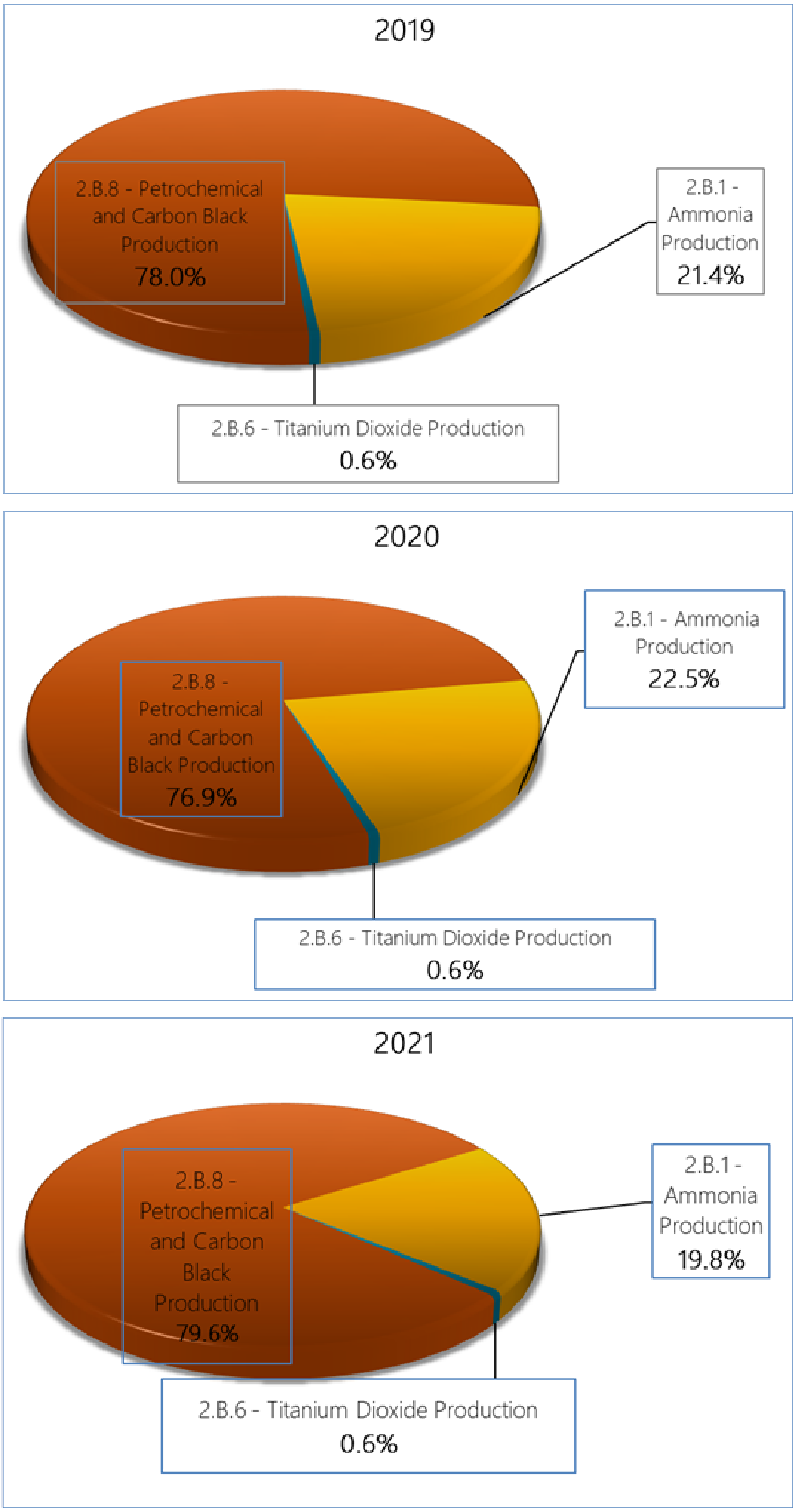


Figure 8. Shares of Total GHG Emissions (CO_2 and CH_4) in CO_2 eq for the Chemical Industry.

2.4.3. Metal Industry

The metal industry generates significant greenhouse gas emissions through process-related activities involved in the production of metals. In iron and steel production, process emissions primarily arise from the reduction of iron ore using carbon-based materials like coke, which release carbon dioxide (CO_2) as a byproduct of the chemical reactions. Aluminum production contributes to emissions during the electrolytic reduction process in smelting, including the release of CO_2 from anode consumption. In zinc production, process emissions result from the chemical reactions involved in the smelting and refining stages, releasing CO_2. The production data was obtained from relevant national and international organizations, including the World Steel Association and the USGS.

The emissions of CO_2 from sub-categories under the Metal Industry Category were estimated and are summarized (Table 13). In 2019, 2020, and 2021, the total CO_2 emissions from this category were 14,159.2 Gg, 13,341.1 Gg, and 15,032.1 Gg, respectively. In 2019, the iron and steel production sub-category accounted for 89.9% of total GHG emissions, followed by aluminum production (8.8%) and zinc production (1.3%). In 2020, the shares of these sub-categories were 89.1%, 9.5%, and 1.4%, respectively. In 2021, the shares were 90.1%, 8.6%, and 1.3%, respectively (Figure 9).

The production data was adopted from national and international sources, which are reliable because the data are primarily based on well-established and institutionalized accounting methodologies. The overall uncertainty in CO_2 and CH_4 emission estimates from the Metal Industry category is expected to be moderate.

Table 13. Emissions of GHGs from the Metal Industry.

Year	GHG	2.C.1 - Iron and Steel Production	2.C.3 - Aluminum production	2.C.6 - Zinc Production	Total
2019	CO_2 (Gg)	12,728.46	1,240.90	189.79	14,159.2
	CH_4 (Gg)				-
	N_2O (Gg)				-
	Total (Gg of CO_2eq)	**12,728**	**1,241**	**190**	**14,159**
2020	CO_2 (Gg)	11,881.50	1,273.61	186.00	13,341.1
	CH_4 (Gg)				-
	N_2O (Gg)				-
	Total (Gg of CO_2eq)	**11,882**	**1,274**	**186**	**13,341**
2021	CO_2 (Gg)	13,548.70	1,288.09	195.30	15,032.1
	CH_4 (Gg)				-
	N_2O (Gg)				-
	Total (Gg of CO_2eq)	**13,549**	**1,288**	**195**	**15,032**

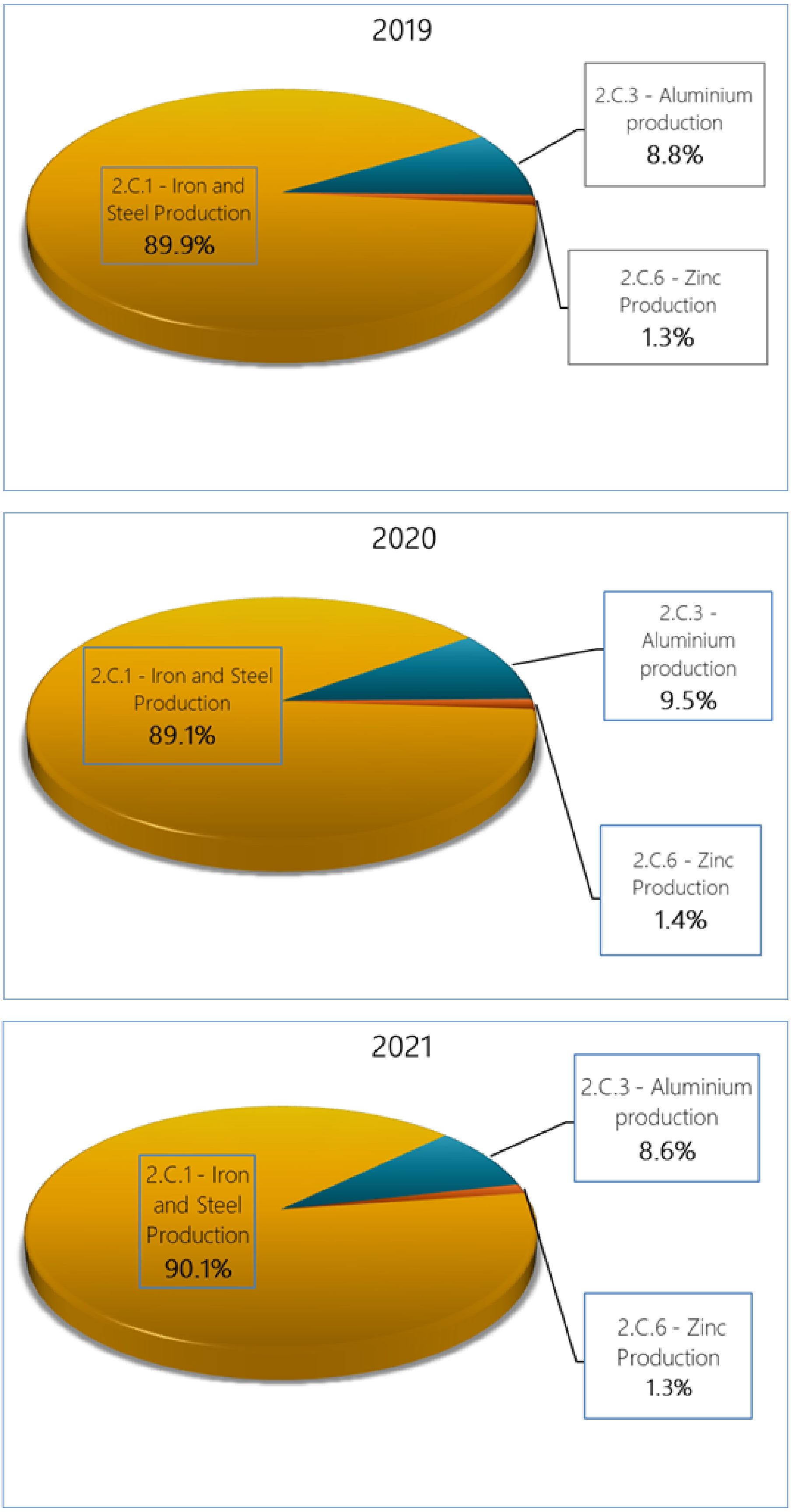


Figure 9. Shares of Total CO_2 Emissions for the Metal Industry.

2.4.4. Non-Energy Products from Fuels and Solvent Use (CRT category 2.D)

The Lubricant Use category focuses on GHG emissions resulting from the use of lubricants in various industrial and mechanical applications. These emissions primarily arise from the incomplete oxidation of lubricants during their use, leading to the release of CO_2 into the atmosphere. Lubricants, which are derived from petroleum-based products, undergo chemical transformations during operations such as friction reduction, cooling, and sealing in machinery and engines. The activity data was collected from the UN Data Bank.

The CO_2 emissions from the Non-Energy Products from Fuels and Solvent Use Category were estimated and summarized (Table 14). In 2019, 2020, and 2021, the total CO_2 emissions from this category were 118.5 Gg, 1,929.8 Gg, and 1,183.3 Gg, respectively.

The lubricant data was obtained from an international source, which is reliable because the data is primarily based on well-established and institutionalized accounting methodologies. The overall uncertainty in CO_2 emission estimates from the Lubricant Use category is expected to be moderate to high.

Table 14. Emissions of GHGs from the Lubricant Use.

Source Category	GHG	2019	2020	2021
2.D.1 - Lubricant Use	CO_2 (Gg)	118.51	1,929.76	1,183.33
	CH_4 (Gg)			
	N_2O (Gg)			
	Total (Gg of CO_2eq)	**119**	**1,930**	**1,183**

2.5. Agriculture

The source categories under the agriculture sector include enteric fermentation, manure management, crop burning, urea application, and direct and indirect nitrous oxide emissions. Enteric fermentation is a significant source of methane emissions resulting from livestock digestive processes, with emissions varying across different animal types. Methane emissions from manure management arise during the anaerobic decomposition of organic material in livestock manure, with emission levels varying by animal type and manure handling practices. The burning in the cropland category accounts for GHG emissions resulting from the intentional burning of crop residues in agricultural fields. While carbon dioxide emissions from this activity are not considered due to their biogenic nature, methane and nitrous oxide (N_2O) are released during the combustion process. The liming and urea application category represents sources of carbon dioxide emissions. Direct N_2O emissions from managed soils arise from activities such as the application of synthetic and organic fertilizers, manure deposition by grazing animals, and crop residue management, which enhance microbial processes like nitrification and denitrification, releasing N_2O directly from the soil. Indirect N_2O emissions from managed soils occur when nitrogen is transferred to other environmental media through volatilization, leaching, or runoff. Volatilized ammonia and nitrogen oxides or leached nitrates can contribute to N_2O emissions elsewhere. Similarly, indirect N_2O emissions from manure management result from nitrogen losses through volatilization or as nitrates through leaching and runoff, which subsequently produce N_2O emissions in other locations.

The emissions of CO_2, CH_4, and N_2O from source categories under the agriculture sector were estimated and summarized (Table 15).

In 2019, 2020, and 2021, the total CO_2 emissions from this sector were 1,785 Gg, 817 Gg, and 954 Gg, respectively. For the same years, the total CH_4 emissions were 125 Gg, 144 Gg, and 144 Gg, respectively. The total N_2O emissions were 16 Gg, 14 Gg, and 16 Gg, respectively. In 2019, Direct and Indirect (DI) N_2O emissions accounted for 39.4% of total GHG emissions, followed by enteric fermentation (33.4%), liming (15.0%), manure management (6.0%), urea application (3.5%), and crop burning (2.7%). In 2020, the shares of these categories were 39.8%, 43.0%, 6.7%, 7.4%, 2.7%, and 0.4%, respectively. In 2021, the shares were 42.0%, 40.3%, 6.5%, 7.1%, 3.9%, and 0.4%, respectively (Figure 10).

The activity data were obtained from relevant national and international sources, including GASTAT, FAO, and UN Data Bank. The input data was adopted from reliable national and international sources. The overall uncertainty in CH_4 and N_2O emission estimates from the source categories is expected to be high, and the overall uncertainty in CO_2 emission estimates could be moderate to high.

Table 15. Emissions of GHGs from the Agriculture Sector.

Year	GHG	3.A.1 - Enteric Fermentation (EF)	3.A.2 - Manure Management (MM)	3.C.1 - Burning	3.C.2 - Liming	3.C.3 - Urea application (UA)	3.C.4-6 Direct and Indirect (DI) N_2O	Total
2019	CO_2 (Gg)				1,447.8	336.8		1,784.6
	CH_4 (Gg)	115.0	9.3	0.9				125.170
	N_2O (Gg)		1.2	0.9			14.3	16.397
	Total (Gg of CO_2eq)	**3,219**	**574**	**259**	**1,448**	**337**	**3,798**	**9,634**
2020	CO_2 (Gg)				579.6	237.6		817.2
	CH_4 (Gg)	133.1	10.4	0.9				144.4
	N_2O (Gg)		1.3	0.0			13.02	14.3
	Total (Gg of CO_2eq)	**3,725**	**637**	**31**	**580**	**238**	**3,450**	**8,661**
2021	CO_2 (Gg)				597.0	357.3		954.4
	CH_4 (Gg)	132.5	10.6	0.9				144.0
	N_2O (Gg)		1.3	0.0			14.6	15.9
	Total (Gg of CO_2eq)	**3,710**	**651**	**32**	**597**	**357**	**3,865**	**9,213**

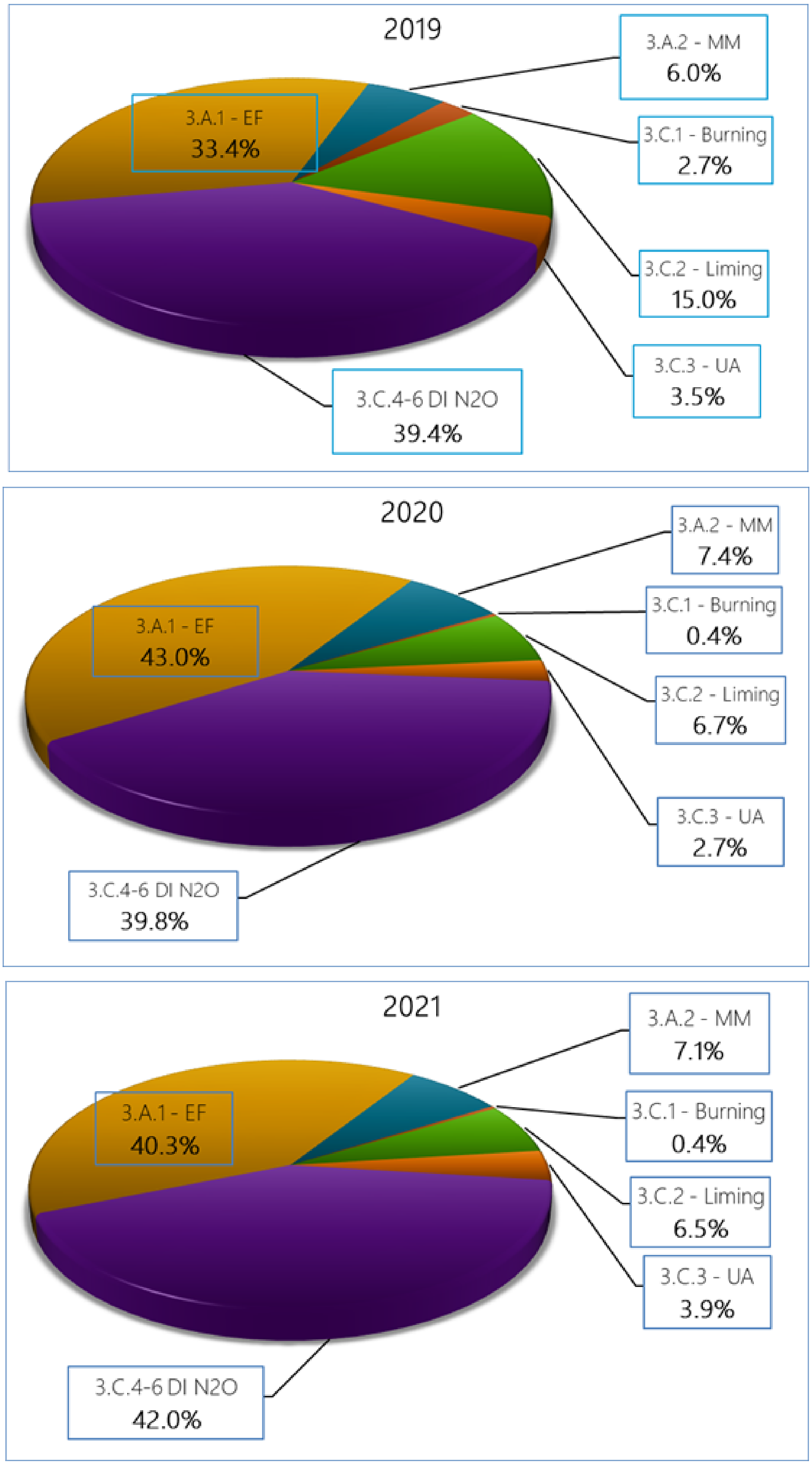


Figure 10. Shares of Total Emissions of GHGs (CH_4 and N_2O) in CO_2eq for the Agriculture Sector.

The input data was adopted from an international source, which is reliable because the data is primarily based on well-established and institutionalized accounting methodologies. The overall uncertainty in CH_4 emission estimates from the Enteric Fermentation category is expected to be moderate to high.

2.6. Land Use, Land Use Change and Forestry

The estimations of emissions from LULUCF focus on two activities: forest land remaining forest and land converted to forest land. This category accounts for forests' role as carbon sinks. The activity data was obtained from relevant national and international sources. In 2019, the forest land remaining forest and land converted to forest land converted approximately 2,429 Gg and 5,091 Gg of CO_2, respectively. In 2020, the contributions were approximately 3,240 Gg and 4,269 Gg of CO_2, respectively. In 2021, the contributions were approximately 3,240 Gg and 4,269 Gg of CO_2, respectively (Table 16).

In 2019, the land converted to forest land accounted for 67.7% of total GHG sinks, followed by forest land remaining forest land (32.3%). In 2020, the same shares were 56.9% and 43.1%, respectively. In 2021, the shares were 56.9% and 43.1%, respectively (Figure 11).

The input data provided by national and international sources are considered reliable and accurate because they are primarily based on well-established and institutionalized accounting methodologies. However, the overall uncertainty associated with the emission estimates could be high.

Table 16. Emissions of GHGs from the LULUCF Sector.

Year	GHG	3.B.1.a - Forest land Remaining Forest land	3.B.1.b - Land Converted to Forest land	Total
2019	CO_2 (Gg)	(2,428.6)	(5,090.7)	(7,519.3)
	CH_4 (Gg)			-
	N_2O (Gg)			-
	Total (Gg of CO_2eq)	**(2,429)**	**(5,091)**	**(7,519)**
2020	CO_2 (Gg)	(3,239.9)	(4,269.2)	(7,509.2)
	CH_4 (Gg)			-
	N_2O (Gg)			-
	Total (Gg of CO_2eq)	**(3,240)**	**(4,269)**	**(7,509)**
2021	CO_2 (Gg)	(3,239.9)	(4,269.2)	(7,509.2)
	CH_4 (Gg)			-
	N_2O (Gg)			-
	Total (Gg of CO_2eq)	**(3,240)**	**(4,269)**	**(7,509)**

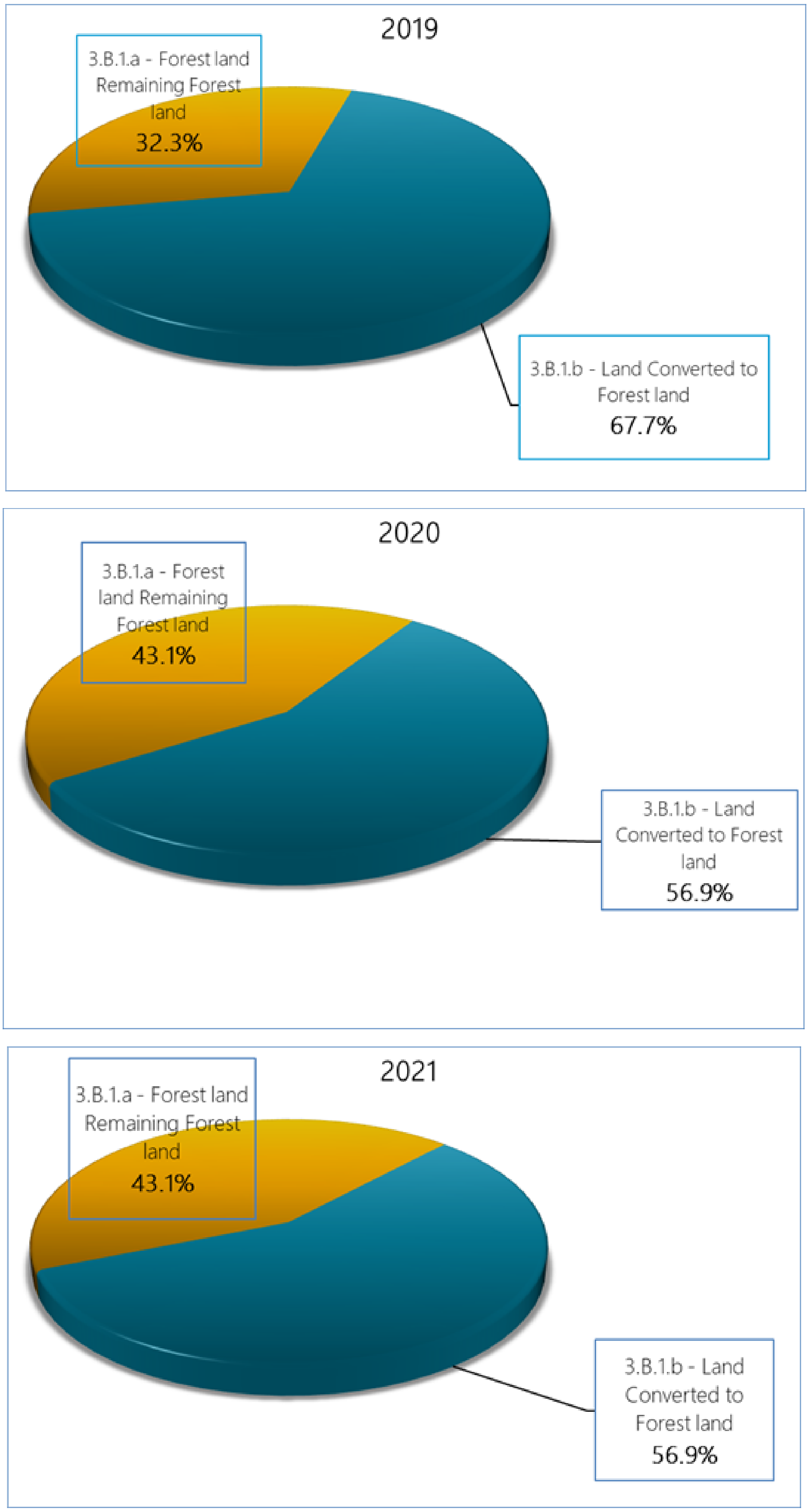


Figure 11. Shares of Total Emissions of GHGs (CO_2) for the LULUCF Sector.

2.7. Waste

The Waste Sector includes categories such as solid waste disposal, biological treatment of solid waste, and wastewater treatment and discharge. The solid waste disposal category encompasses greenhouse gas emissions from managed waste disposal sites, unmanaged waste disposal sites, and uncategorized waste disposal sites. The biological treatment of solid waste category includes composting, anaerobic digestion of organic waste, and mechanical-biological treatment. The wastewater treatment and discharge consist of both domestic and industrial sub-categories. The activity data was obtained from relevant national and international organizations.

The emissions of CH_4 and N_2O from categories under the Waste Sector were estimated and summarized (Table 17). In 2019, the total CH_4 and N_2O emissions from this sector were 1,374.7 Gg and 4.4 Gg, respectively. In 2020, the total CH_4 and N_2O emissions were 1,552.5 Gg and 4.6 Gg, respectively. In 2021, the total CH_4 and N_2O emissions were 1,531.8 Gg and 4.6 Gg, respectively.

In 2019, the industrial wastewater treatment and discharge category accounted for 47.3% of total GHG emissions, followed by uncategorized waste disposal sites (43.0%), domestic wastewater treatment and discharge (9.4%), and composting (0.2%). In 2020, the shares of these categories were 49.8%, 40.1%, 10.0%, and 0.2%, respectively. In 2021, the shares were 50.6%, 39.1%, 10.1%, and 0.2%, respectively (Figure 12).

The input data provided by national and international sources are considered reliable and accurate because they are primarily based on well-established and institutionalized accounting methodologies. However, the overall uncertainty associated with the emission estimates could be high.

Table 17. Emissions of GHGs from the Waste Sector.

Year	GHG	4.A.3 - Uncategorized Waste Disposal Sites	4.B.1 - Composting	4.D.1 - Domestic Wastewater Treatment and Discharge	4.D.2 - Industrial Wastewater Treatment and Discharge	Total
2019	CO_2 (Gg)					-
	CH_4 (Gg)	609.5	1.8	92.8	670.6	1,374.7
	N_2O (Gg)		0.1	4.3	-	4.4
	Total (Gg of CO_2eq)	**17,066**	**79**	**3,746**	**18,777**	**39,668**
2020	CO_2 (Gg)					-
	CH_4 (Gg)	639.6	1.9	116.5	794.5	1,552.5
	N_2O (Gg)		0.1	4.5	-	4.6
	Total (Gg of CO_2eq)	**17,909**	**83**	**4,454**	**22,247**	**44,693**
2021	CO_2 (Gg)					-
	CH_4 (Gg)	616.4	1.9	116.3	797.2	1,531.8
	N_2O (Gg)		0.1	4.5	-	4.6
	Total (Gg of CO_2eq)	**17,258**	**83**	**4,448**	**22,321**	**44,110**

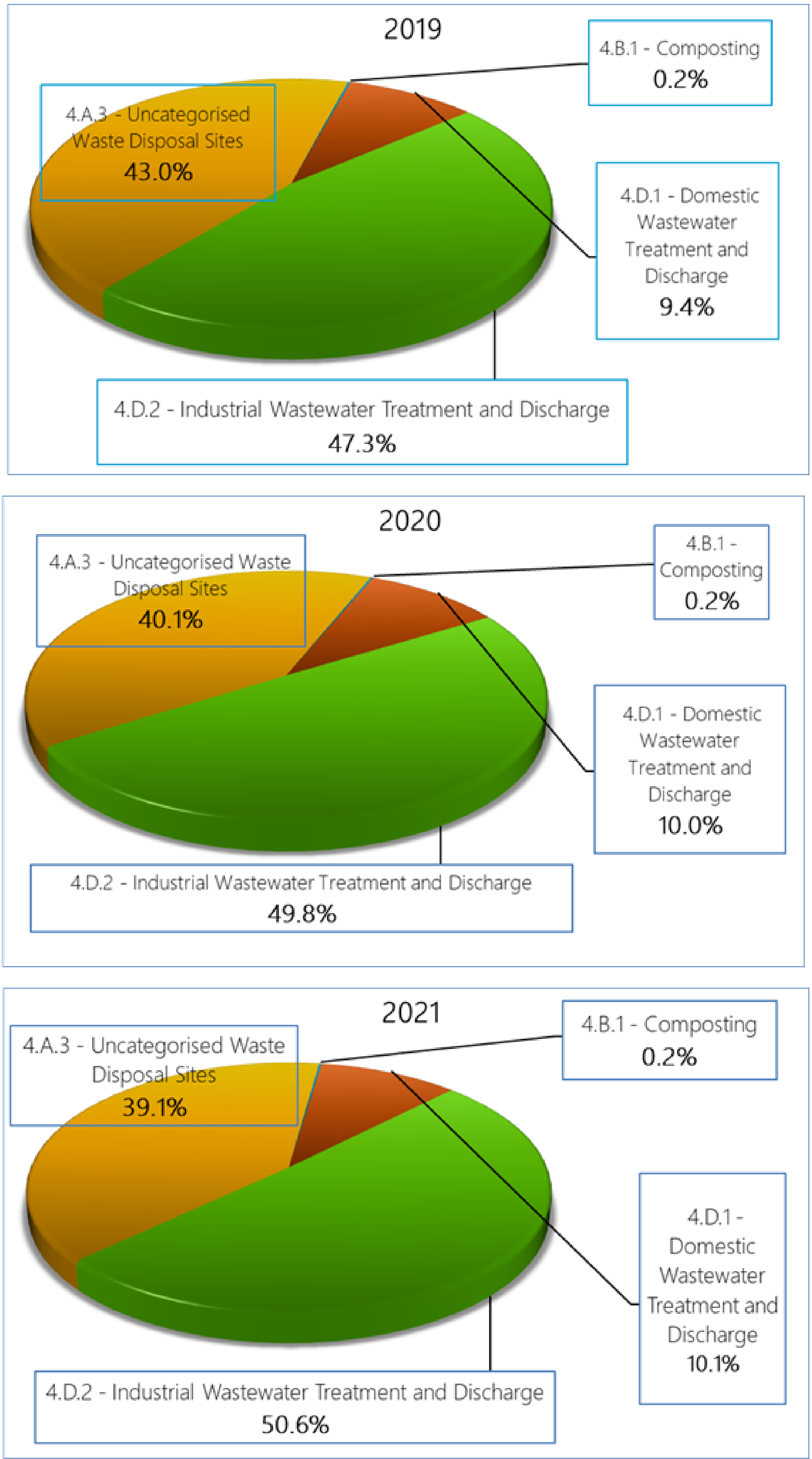


Figure 12. Shares of Total Emissions of GHGs (CH_4 and N_2O) in CO_2eq for the Waste Sector.

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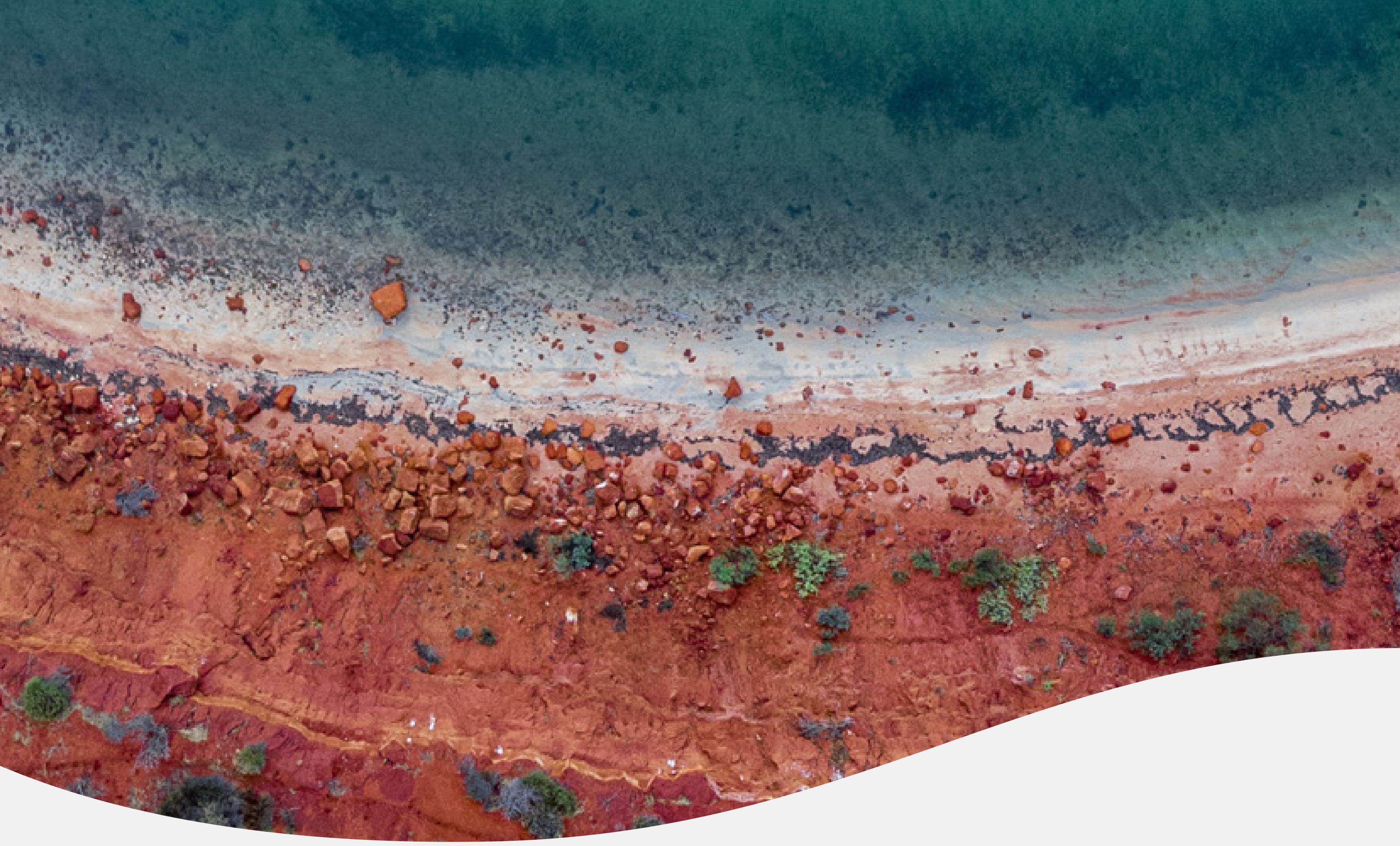

Chapter 3

Tracking Progress on Nationally Determined Contribution (NDC)

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3.1. National Circumstances and Institutional Arrangements

3.1.1. Government Structure

The Kingdom of Saudi Arabia has established institutional arrangements to effectively track and report updates on its NDC under the Paris Agreement. These arrangements are coordinated through the Designated National Authority (DNA), which ensures collaboration among relevant stakeholders and alignment with international reporting requirements.

The DNA is the entity that facilitates the Kingdom of Saudi Arabia's fulfilment of reporting requirements under UNFCCC and Paris Agreement (PA). This includes:

- **Monitoring NDC Progress**: Tracking and evaluating the implementation of initiatives and policies contributing towards NDC.
- **Review and Update**: Periodically reviewing and updating the NDC in collaboration with national stakeholders.
- **National Reporting**: Preparing reports in coordination with national stakeholders, such as the National Communications (NCs), Biennial Update Reports (BURs), and the Biennial Transparency Reports (BTRs).

In its role as the regulatory authority for carbon management, the DNA is also responsible for overseeing the issuance of credits and the approval of emission reduction projects, thus launching the Kingdom's GCOM in 2022.

The DNA is a committee that consists of more than 20 members from various governmental and private sector organizations. This structure ensures the alignment of sectoral initiatives with the Kingdom's NDC objectives and facilitates comprehensive tracking of progress. The DNA committee is supervised and chaired by HRH, the Minister of Energy, and consists of members from the following entities: (Figure 1).

Figure 1. The Designated National Authority Committee Members

The DNA is also an active member and a focal point of numerous international key initiatives on climate change such as Climate Technology Centre & Network (CTCN), Global Methane Pledge (GMP), and Zero Routine Flaring by 2030 Initiative (ZRF), demonstrating the Kingdom's commitment to address climate issues and challenges.

By integrating efforts across sectors and institutions, the DNA supports the Kingdom’s efforts to achieving its NDC, contributing to both national and global objectives.

3.1.2. Population Profile

The total population of Saudi Arabia in 2023 was reported at 32.18 million (General Authority for Statistics, 2023). The average age of the population is 29 years. The census indicates that approximately 2.3 million Saudi citizens fall within the 5–9-year age group, while the 75–79-year age group has the smallest population, totaling 110,571 individuals. Notably, 63% of the Kingdom’s population is under the age of 30, reflecting a predominantly young demographic profile (Saudi Census, 2022).

3.1.3. Geographic Profile

The Kingdom of Saudi Arabia, located in Southwest Asia, occupies an area of over 2.25 million square kilometers, comprising nearly 80% of the Arabian Peninsula. The Kingdom is bordered by the Arabian Gulf to the east, and the Red Sea to the west. Saudi Arabia shares its borders with Bahrain, Qatar, and the United Arab Emirates to the east, and with Jordan, Iraq, and Kuwait to the north, with Oman and Yemen to the south. (NC4, Kingdom of Saudi Arabia, 2022)

The Kingdom’s topography is diverse, consisting of vast deserts, coastal plains, and mountain ranges. The Asir Mountains in the southwest rise to around 3,000 meters, while the northern region is marked by lava fields and volcanic plateaus. This geological diversity contributes significantly to the Kingdom's unique natural landscape.

3.1.4. Economic Profile

In recent years, the Kingdom of Saudi Arabia has undergone substantial socio-economic transformation, driven by Vision 2030, launched in April 2016. The Kingdom is actively diversifying its economy through initiatives aimed at enhancing domestic production, developing new economic sectors, and supporting national industries. Additionally, the SGI, launched in 2021, enhances sustainable practices and leverages investments to drive economic growth.

Sustainability and economic diversification are central to realizing Vision 2030. The private sector is a critical component, programs, such as the “Shareek” (Partner) Program, encourage large private companies to increase local investment by 2030 through incentives like tax exemptions and favorable loans.

The Public Investment Fund (PIF) also plays a key role in supporting private sector growth, with investments that have created over 365,000 jobs and grown assets to nearly SAR 1.5 trillion. Sources of income from other sectors (i.e. tourism, entertainment, etc.) to government revenue has grown significantly, with an average increase of 38% from 2016 to 2021, compared to 19% from 1970 to 2014 (Ministry of Economy & Planning, 2022).

Tourism is an example of a sector identified as a priority sector within Vision 2030. The National Tourism Strategy aims to expand this sector by creating an estimated one million jobs and increasing its contribution to GDP from 3.8% to a projected 10% by 2030 (Ministry of Economy & Planning, 2022). Significant investments in tourism have improved Saudi Arabia's ranking, advancing to 33rd on the World Economic Forum's Travel and Tourism Development Index from 2019 to 2021 (Ministry of Economy & Planning, 2022).

While challenges remain, Saudi Arabia is making progress towards achieving its Vision 2030 objectives, committed to sustainable development, environmental management, and economic growth. The Kingdom aims to maintain its position as a global leader in ensuring a reliable energy supply.

3.1.5. Climate Profile

Saudi Arabia has an arid climate with high temperatures and low precipitation. Annual rainfall varies, ranging from 50–100 millimeters in most areas, with the southwestern mountains receiving up to 300 millimeters. Summer temperatures in inland regions range from 27°C to 43°C, while coastal areas are milder. Winter temperatures range from 8°C to 20°C in the interior and 19°C to 29°C along the Red Sea coast. (National Centre for Meteorology, 2024).

The absence of perennial rivers or permanent freshwater bodies further characterizes Saudi Arabia's arid environment. The climate is marked by high evaporation rates and significant temperature variations between the interior and coastal regions. This climatic and topographical variability plays a key role in shaping the Kingdom's natural ecosystems and resource management challenges.

3.1.6. Sector Details

The key Sectors in the Kingdom of Saudi Arabia are as covered in the National Inventory Report including Energy, IPPU, Waste management, Agriculture and Forestry.

3.1.7. The Impact of National Circumstances on GHG Emissions and Removals

National circumstances assume a pivotal role in shaping greenhouse gas (GHG) emissions and removals over time, and in Saudi Arabia, several factors influence these dynamics, including geographical, economic, technological, and policy-driven elements.

Saudi Arabia's vast desert landscape and arid climate present significant challenges for GHG removals, as limited natural vegetation reduces the capacity for carbon sequestration through natural processes.

Despite these challenges, Saudi Arabia is making notable progress in addressing GHG emissions and enhancing removals through strategic initiatives and policies. Under Vision 2030, the Kingdom is actively pursuing energy diversification, renewable energy development, and the implementation of energy efficiency standards. Investments in advanced technologies, such as CCUS, and the promotion of sustainable urban planning further reflect the Kingdom's efforts to reduce emissions.

3.2. Saudi Arabia’s Nationally Determined Contribution

3.2.1. Introduction

The Kingdom of Saudi Arabia is implementing actions, projects, and plans that aim to reduce, avoid, and remove GHG emissions by 278 million tons of CO_2eq annually by 2030, with the year 2019 designated as the base year. This NDC represents an increase of more than two-fold compared to the previously outlined 130 million tons of CO_2eq annually in the Kingdom’s Intended Nationally Determined Contribution (INDC).

In pursuit of its sustainable development objectives, initiatives are being undertaken by the Kingdom to promote economic diversification, yielding the following co-benefits:

- Avoidance, reduction, and removal of greenhouse gas emissions
- Climate adaptation
- Management of the impacts of response measures

Two scenarios have been outlined in the Kingdom’s NDC for determining dynamic baselines for the period 2020–2030

Scenario 1: Economic diversification with a robust contribution from hydrocarbon and its derivatives export revenues. Export revenues channeled into investments in high value-added sectors such as financial services, medical services, tourism, education, renewable energy and energy efficiency technologies to enhance economic growth. Ambitions outlined in the Kingdom’s NDC are set under this scenario.

Scenario 2: Accelerated domestic industrialization based on sustainable utilization of hydrocarbons. A heavy industrial base built to use domestic energy resources as feedstock or energy source abated with best suitable technologies. Increasing contributions of petrochemical, cement, mining and metal production industries to the national economy. In this case, the NDC will be adjusted to account for this scenario.

The primary contrast between the two baseline scenarios lies in how hydrocarbons are allocated between domestic consumption and export. While exported hydrocarbons have no impact on Saudi Arabia's greenhouse gas (GHG) emissions, domestic consumption leads to an increase in GHG emissions. Consequently, when conducting ex-ante estimations, the baseline is established by considering various combinations of these scenarios with different weights.

Saudi Arabia's NDC covers multiple sectors including Energy, Water Resources, Agriculture and Forestry, Waste Management, Transportation, Urban Planning, Industrial, and Health and Education.

3.2.2. Enablers for Achieving NDC Goals

The Kingdom's strategy for achieving its NDC includes several enabling approaches, such as:

- **Circular Carbon Economy (CCE) Approach:** This approach emphasizes a "4Rs" model—Reduce, Reuse, Recycle, and Remove—to effectively manage and minimize carbon emissions while sustaining economic growth.
- **Finance:** The implementation of the Kingdom's NDC is not contingent on receiving international financial support.
- **Technology:** Large-scale technological innovation and deployment are essential to meeting the NDC. Saudi Arabia prioritizes key technologies like Carbon Capture, Utilization and Storage (CCUS), Direct Air Capture

(DAC), and clean hydrogen for emissions abatement and removal, as well as water-saving, low-energy intensive desalination and early warning systems for climate adaptation. The Kingdom promotes international cooperation and technology transfer through platforms like Mission Innovation, the Clean Energy Ministerial, and the Global Methane Initiative.

- **Market mechanisms and approaches:** Saudi Arabia views voluntary cooperation within market mechanisms and approaches as tools to incentivize emission reduction and removal projects. Domestically, the Kingdom operationalized its market mechanism, the GCOM in October 2023, regulated by the DNA to further mobilize finance and cooperation across sectors, enabling companies to meet their climate goals through transparent, high-quality credits and certificates that encompass GHG and Non-GHG metrics. Internationally, the Kingdom is considering exploring voluntary market approaches, like the use of Internationally Transferred Mitigation Outcomes "ITMOs" under Article 6 of the Paris Agreement to achieve its national climate goals and contribute to global efforts, utilizing a learning-by-doing approach following the finalization of the rulebook in COP29.
- **Capacity Building**: Ongoing efforts for economic diversification and development of emerging sectors require an increase in human capacity and enabling a strong and capable workforce. Given the Kingdom's young population, developing technical and institutional capacities is essential for implementing, monitoring, and enhancing climate action across all sectors.

3.3. Progress towards Achieving the NDC

In line with paragraphs (65-77) of Modalities, Procedures, and Guidelines (18/CMA.1) of the Enhanced Transparency Framework this section provides a description of the Kingdom's actions, projects, and plans towards its Nationally Determined Contribution.

3.3.1. Economic Diversification with Mitigation Co-Benefits

The Kingdom of Saudi Arabia's Updated NDC to the UNFCCC underscores the Kingdom's commitment to diversifying its economy in a manner that contributes positively to global climate action. Core initiatives include enhancing energy efficiency, accelerating renewable energy expansion, managing methane emissions, increasing natural gas utilization, and deploying carbon capture, utilization, and storage (CCUS) technologies. To realize these ambitious goals, Saudi Arabia has laid out a multifaceted strategy across critical sectors such as industry, transportation, and buildings.

3.3.1.1 Energy Efficiency

The Saudi Energy Efficiency Center (SEEC), established in 2010, oversees the Saudi Energy Efficiency Program (SEEP), a nationwide initiative launched in 2012 to significantly enhance energy efficiency across key sectors, including industry, buildings, and transportation, which together account for over 90% of Saudi Arabia's energy use. Aiming to optimize and rationalize energy consumption, SEEP's efforts have yielded substantial results, achieving a 16% increase in energy savings and a 12% reduction in carbon emissions (equivalent to 57 million tons of CO_2) in 2022 compared to 2021. This progress underscores energy efficiency as a core component of the Kingdom's Nationally Determined Contribution (NDC) goals (Kingdom of Saudi Arabia, 2021; SEEC, 2023).

3.3.1.1.1. Building Sector

The building sector in Saudi Arabia accounts for 29% of the Kingdom's primary energy consumption, with 70% attributed to cooling (SEEP, 2017). Initiatives by

SEEC have achieved significant energy savings, including 3,700 GWh from government building rehabilitation and street lighting projects. Efforts include the establishment of 27 energy efficiency standards, including eight mandatory labeling requirements for products such as insulation, air conditioners, and lighting. Notable results include a 57% rise in Energy Efficiency Rating (EER) for split AC units (2012–2019) and reductions of 22% for refrigerators, 60% for washing machines, and 80% for lighting. Additional regulations and guidelines optimize energy use in buildings (SEEP, 2019; SEEC, 2020).

3.3.1.1.2. Land Transportation Sector

Since implementing the fuel economy standard in 2016, Saudi Arabia's fuel economy rate has improved by around 24%, with land transport consuming approximately 20% of the Kingdom's primary energy.

Initiatives including the Saudi CAFE for light-duty vehicles (LDVs), first introduced in 2016 and revised in early 2021, have driven progress contributing to a 16% improvement in the fuel economy of the new vehicle fleet. By 2019, the average fuel economy of new vehicles had improved to 14.5 kilometers per liter, up from 10.6-11.5 kilometers per liter in the 2013-2016 period (Sheldon and Dua, 2021). A third phase of the CAFE standards set for 2024 targets providing financial benefits, and financial incentives for fuel-efficient vehicle licenses are being rolled out in phases, with the first phase beginning in October 2023 (Belaïd and Massié, 2023).

3.3.1.1.3. Industrial Sector

Saudi Arabia's industrial sector, consuming about 44% of the nation's primary energy is being tackled with multiphase approach. The first phase, running from 2011 to 2019, focused on energy conservation in key manufacturing industries, including iron, cement, clinker, and petrochemicals, achieving energy intensity reductions of 2%, 2.8%, 4.2%, and 2.9%, respectively. The second phase, spanning from 2020 to 2025, encompasses additional industries and subsectors to improve the utilization efficiency of feedstock for key raw materials, such as hydrocarbon cracking, ammonia, methanol, propane dehydrogenation, isobutylene, and benzene-toluene-xylene. To support these efforts, the 2023 energy management program, was developed introducing a digital platform and SEEC50001 Ready tool to help establishments align with energy efficiency standards (Belaïd and Massié, 2023).

3.3.1.1.4. Utilities Sector

In the Utilities sector, SEEC targets improving energy production efficiency. Since January 2022, SEEC has been collecting data from over 125 energy production, transmission, and distribution stations to track performance. Annual performance reports are published to monitor efficiency, and since January 2023, a sector-wide initiative has been conducting site visits to 25 stations to assess operational efficiency, share best practices, and promote continuous improvement in energy efficiency across companies.

3.3.1.1.5. Other

Other noteworthy initiatives include Aramco’s Energy Management Program, which reduced cumulative emissions reduction of 31.43 million metric tons of CO_2 equivalent, commissioning combined cycle steam turbine generators and optimizing gas processing operations in 2023. Forty Aramco organizations received ISO 50001 certification while Aramco's AI-driven Energy Demand Forecasting Solution, with up to 99% accuracy, contributes to a 23% reduction in corporate energy intensity (Aramco, 2023). The Saudi Electricity Company has installed over 10 million smart meters, enhancing energy efficiency and load forecasting (Saudi Electricity Company, 2022). The Ministry of Energy aims to save one million barrels of oil equivalent per day by transitioning from liquid fuels to gas by 2030 (Ministry of Energy, 2024). Additionally, SABIC’s AI-driven Asset Healthcare Program minimizes shutdowns, while its Cell Line Conversion Project cut energy intensity by 34%, with a vent gas-recovery initiative targeting an additional 14% reduction (SABIC, 2023).

Table 1. Description of Indicators Selected to Track Progress for Energy Efficiency Initiatives

Indicator(s) selected to track progress	Description
Energy Efficiency Initiatives	
Information for the reference point(s), level(s), baseline(s), base year(s) or starting point(s), as appropriate	The Saudi Energy Efficiency Center (SEEC) is the implementing agency of the Saudi Energy Efficiency Program (SEEP), a nationwide initiative launched in 2012 to enhance energy efficiency across key sectors, including industry, buildings, and transportation.
Updates in accordance with any recalculation of the GHG inventory, as appropriate	N/A
Relation to NDC	This indicator contributes to the NDC goal of reduction of Greenhouse Gas Emissions by 278 million tons CO_2e by 2030 . It also supports diversification by targeting the sectors that account for 90% of energy demand (buildings, transportation, and industry) and by reducing energy waste, and creating jobs.”

3.3.1.2. Renewable Energy

Saudi Arabia has made significant strides in expanding the utilization of renewable energy as part of its broader energy strategy. The goal is to have 45-50% of electricity generation capacity come from renewable energy by 2030 (Saudi Green Initiative, 2024). As part of its ongoing efforts, Saudi Arabia has tendered 44 GW of renewable energy projects. Looking ahead to 2030, the Kingdom aims to achieve 130 GW of renewable capacity, driven by demand growth, with an additional 20 GW tendered annually to sustain momentum. The Kingdom has achieved multiple record-breaking lowest Levelized Cost of

Electricity (LCOE) in both solar and wind projects. In the solar sector, the Sakaka project, connected in 2020, achieved an LCOE of 2.34¢/kWh at 300MW, followed by the upcoming Al-Shuaiba project in 2024 at an unprecedented 1.04¢/kWh, and the Sadawi project, set to be connected in 2027, at 1.29¢/kWh. Similarly, in the wind sector, the Dumat Al-Jandal project, connected in 2022, delivered an LCOE of 1.99¢/kWh, while the future Al-Ghat project, planned for connection in 2026, is set to achieve 1.56¢/kWh (Ministry of Energy, FII Institute, 2024).

Table 2. Description of Indicators Selected to Track Progress for Renewable Energy Initiatives

Indicator(s) selected to track progress	Description
Renewable Energy Initiatives	
Information for the reference point(s), level(s), baseline(s), base year(s) or starting point(s), as appropriate	Initiated in 2021. The Saudi Green Initiative aims to achieve ambitious goals for electricity generation capacity from renewable energy sources, including 45-50% of the Kingdom's electricity mix from renewables by 2030.
Updates in accordance with any recalculation of the GHG inventory, as appropriate	N/A
Relation to NDC	The indicator directly contributes to the goals of reducing greenhouse gas emissions and enhancing economic diversification through the deployment of renewable energy.

3.3.1.3. Carbon Capture Utilization & Storage

To support its emissions reduction goals, Saudi Arabia is developing and deploying cutting-edge CCUS technologies. The focus is on cost-effective CO_2 capture from hard-to-abate sectors such as power plants, with an emphasis on reducing capture costs while advancing the Kingdom's economic diversification, particularly through low-carbon products like blue hydrogen (Kingdom of Saudi Arabia, 2021). Saudi Arabia has made significant progress in carbon capture and utilization (CCU) technologies, highlighted by its CCU plant, the largest of its kind globally. This plant captures 500,000 metric tons of CO_2 annually from ethylene glycol production and it has been successful in converting CO_2 into valuable feedstock for processes such as urea, methanol, and liquefied CO_2, which are used in agriculture, chemicals, and the food industry (Sabic, 2024).

The Kingdom has also planned for two large-scale CCUS Hubs projects in two of its major industrial cities; Jubail and Yanbu, both offering abundant opportunities for supporting a circular carbon economy (Kingdom of Saudi Arabia, 2021). These hubs are expected to capture a significant amount of CO_2 and helping to reduce a projected over 44 million tons of CO_2 annually by 2035 (Aramco, 2023; Ministry of Energy, 2024; Sabic, 2022).

Explorations of various CCUS technologies and geological formations suitable for CO_2 storage are also active. An evaluation of geological CO_2 storage capacities in Saudi Arabia's sedimentary basins has identified the Eastern Arabian Basin and the Interior Homocline-Central Arch as the most suitable for CO_2 storage, with an estimated total effective storage capacity of approximately 432 gigatons in deep saline aquifers (Ye et al., 2023).

Saudi Aramco's Carbon Capturing & Injection Project at the Hawyiah NGL Recovery Plant exemplifies the practical application of CCS, capturing 750 kilotons of CO_2 annually for enhanced oil recovery (Ahmari & Mufti, 2022). Most recently, Aramco, Linde, and SLB have signed a shareholders' agreement to develop a Carbon Capture and Storage (CCS) hub in Jubail, Saudi Arabia, aiming to capture and store up to 9 million metric tons of CO_2 annually by 2027 (Aramco, 2024).

Table 3. Description of Indicators Selected to Track Progress for Carbon Capture, Utilization, and Storage

Indicator(s) selected to track progress	Description
Carbon Capture, Utilization, and Storage	
Information for the reference point(s), level(s), baseline(s), base year(s) or starting point(s), as appropriate	Saudi Arabia's ambitious initiatives in carbon capture, storage, and utilization (CCUS) emerged in 2015.
Updates in accordance with any recalculation of the GHG inventory, as appropriate	N/A
Relation to NDC	The indicator reflects Saudi Arabia’s efforts towards to CCE approach, incorporating emissions reduction, reuse, recycling, and removal strategies.

3.3.1.4. Hydrogen

Saudi Arabia's strategic location and policies support the development of a hydrogen-based economy, with underground hydrogen storage (UHS) being explored as a solution to manage seasonal supply and demand fluctuations, utilizing geological formations like salt caverns and saline aquifers for storage (Alanazi et al., 2024). Saudi Arabia holds a competitive advantage in hydrogen-based economies due to its capacity to produce hydrogen at reduced costs, as such enabling exports of carbon-neutral products including ammonia, steel, and cement, simultaneously advancing its position in international hydrogen markets while reducing emissions in domestic carbon-heavy industries (Hassan et al., 2024).

As such Saudi Arabia is advancing its hydrogen economy through both blue and green hydrogen initiatives.

3.3.1.4.1. Blue Hydrogen

Blue hydrogen is important part of Saudi Arabia's hydrogen ambitions. This hydrogen production method is closely linked with carbon capture technologies, capturing CO_2 emissions during the extraction process and supporting the country's emissions reduction goals (Kingdom of Saudi Arabia, 2021). The Kingdom's availability of natural gas reserves, particularly in its eastern regions, allows for feasible blue hydrogen production and exportation (Aziz et al., 2024). The country is also prioritizing pilots, research, and demonstrations to advance the technology, lower costs, and implement it in industries such as aviation, shipping, petrochemicals, and steel (Aramco, 2024; Ocean Conservancy, 2023).

3.3.1.4.2. Green Hydrogen

In addition to blue hydrogen, green hydrogen plays a significant role in Saudi Arabia's broader energy strategy. The integration of green hydrogen into Saudi Arabia's energy mix is crucial for its energy plans. The Kingdom has several large-scale projects already underway. For example, the NEOM Green Hydrogen project aims to produce 600 metric tons of hydrogen per day using 4 GW of solar and wind energy, primarily for ammonia production and export (Anandaiah, 2023). This could save the planet up to 5 million tonnes of CO_2 every year.

Saudi Arabia is developing the necessary infrastructure to support both green and blue hydrogen. While existing pipeline networks offer potential for hydrogen transportation, the financial viability of vessel-based long-distance transport has become an increasingly important aspect of Saudi Arabia’s hydrogen export strategy (Hassan et al., 2024).

Table 4. Description of Indicators Selected to Track Progress for Hydrogen Economy Development

Indicator(s) selected to track progress	Description
Hydrogen Economy Development	
Information for the reference point(s), level(s), baseline(s), base year(s) or starting point(s), as appropriate	The Kingdom initiated the development of a National Hydrogen Strategy in 2021
Updates in accordance with any recalculation of the GHG inventory, as appropriate	N/A
Relation to NDC	The indicator is aligned with Saudi Arabia's NDC, aiming to reduce emissions, enhance energy security, and create economic diversification opportunities by developing its hydrogen economy.

3.3.1.5. Utilization of Gas

Saudi Arabia has made significant strides in expanding the utilization of natural gas as part of its broader energy strategy, which aim to have 50-55% of electricity generation capacity come from natural gas by 2030 (Saudi Green Initiatives, 2024). This includes efforts to increase natural gas’ role in electricity generation, water desalination, and key industrial sectors such as petrochemicals, oil refining, cement, fertilizer, and steel (Kingdom of Saudi Arabia, 2021).

To achieve progress in diversifying the energy mix and reducing the intensity of carbon fuels, the Kingdom has planned and implemented several projects and measures, including the expansion of the gas network, enhancement of infrastructure, exploration of unconventional gas fields, and the establishment of underground gas storage facilities. These initiatives are summarized below:

3.3.1.5.1. Natural Gas Supply and Electricity Generation

The natural gas supply in Saudi Arabia has shown a consistent upward trend over the period from 2000 to 2022. Saudi Arabia's natural gas supply has steadily increased from 1,288,661 TJ in 2000 to 3,621,479 TJ in 2022, with significant growth, especially post-2015. This trend is reflected in the rise of natural gas use for electricity generation, which grew from 134,757 GWh in 2015 to 243,932 GWh in 2022, accounting for 58.2% of the country's total electricity generation.

3.3.1.5.2. Expansion of Infrastructure

To support this increasing utilization, Saudi Arabia is expanding its Master Gas system to construct a national gas distribution network (Aramco, 2023a). This expansion maximizes the utilization of gas, supports energy security diversification, and helps boost gas-based economies in line with the broader efforts to diversify the economy.

Currently in its third phase, the expansion aims to increase total network capacity to 12.5 billion standard cubic feet per day (SCFD), adding 821K of additional pipeline across the East West pipeline corridor (Aramco, 2023a; Wallace, 2020). Furthermore, the Kingdom is enhancing its infrastructure with new compression facilities and the construction of the country's first underground gas storage facility, increasing the resilience and flexibility of its gas supply (Aramco, 2023a; Baldauf, 2024).

These concerted efforts, from increasing natural gas supply to enhancing infrastructure and exploring new reserves, are vital for Saudi Arabia's energy strategy.

Table 5. Description of Indicators Selected to Track Progress for Natural Gas Utilization

Indicator(s) selected to track progress	Description
Natural Gas Utilization	
Information for the reference point(s), level(s), baseline(s), base year(s) or starting point(s), as appropriate	In 2021, the Saudi Green Initiative set the goal to have 50-55% of electricity generation capacity come from natural gas by 2030
Updates in accordance with any recalculation of the GHG inventory, as appropriate	N/A
Relation to NDC	The indicator aligns with the NDC by expanding natural gas use in electricity generation, water desalination, and key industries, thus advancing the Kingdom's economic diversification and reducing greenhouse gas (GHG) emissions

3.3.1.6. Methane Management (flaring quantity and fugitive emissions)

Saudi Arabia has made significant efforts in methane management as part of its NDC, aiming for zero gas flaring and improved methane recovery for use in power and petrochemical production. The Kingdom is part of the ZRF, Global Methane Initiative, and the Global Methane Pledge, which aims to achieve a 30% global reduction in methane emissions by 2030 (KSA, 2021; SGI, 2024).

Saudi Arabia’s methane management strategy includes the world’s largest gas collection system, operational since 1982, and a Leak Detection and Repair (LDAR) program, which surveys millions of points across facilities to capture and utilize methane, swiftly addressing any leaks (KSA, 2016; Aramco, 2024). Advanced monitoring technologies, such as Tunable Diode Laser and Fourier

Transform Infrared spectroscopy, are employed to enhance detection and control measures.

Between 2015 and 2022, Saudi Arabia made progress in reducing gas flaring (Figure 2). Flaring volume was 2.2 billion cubic meters in 2015 with an intensity of 0.57 cubic meters per barrel of oil. By 2022, the lowest ever flaring intensity was achieved, with flaring volume declined to 1.9 billion cubic meters, and intensity dropped to 0.48 cubic meters per barrel of oil, reflecting a 4% reduction in total flaring volume and a 10% decrease in intensity from 2012 to 2022 (World Bank, 2023).

In 2019 and 2020, the Upstream Methane Intensity, which measures methane emissions from upstream showed a reduction from 0.06% in 2019-2020 to 0.05% from 2021 onward (Saudi Aramco, 2023).

These initiatives underscore Saudi Arabia's strides to reducing methane emissions through both advanced monitoring and mitigation technologies.

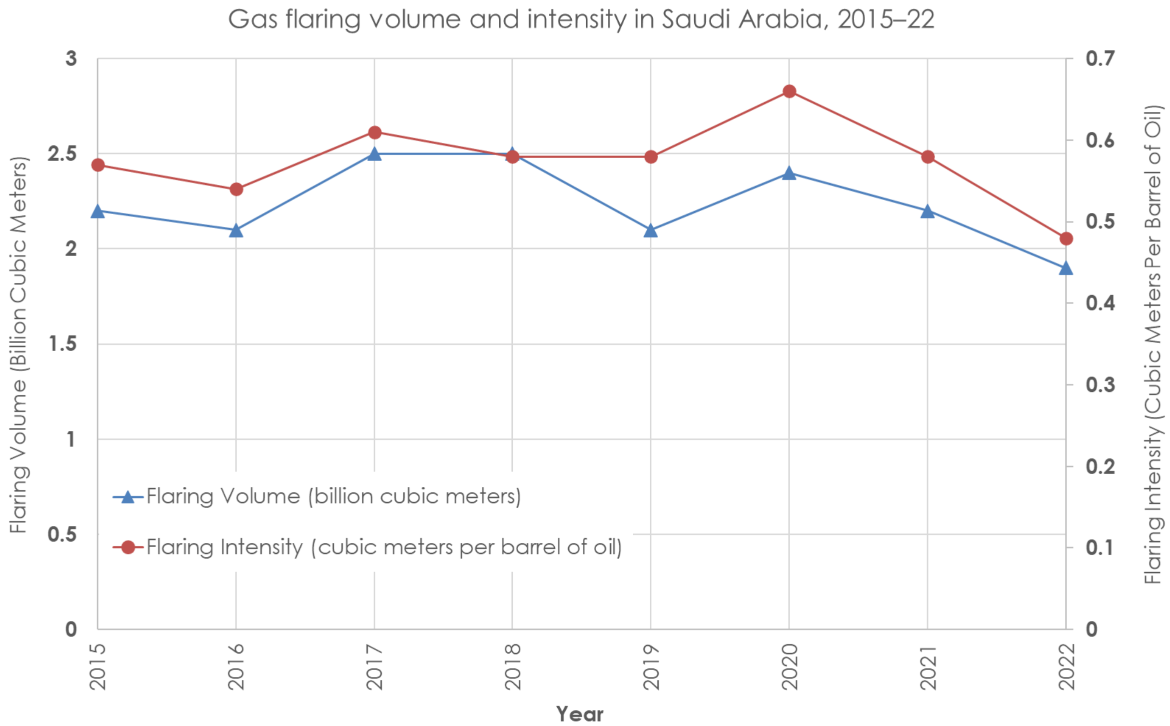

Figure 2. Gas Flaring Volume and Intensity in Saudi Arabia (World Bank, 2023)

Table 6. Description of Indicators Selected to Track Progress for Methane Management

Indicator(s) selected to track progress	Description
Methane Management	
Information for the reference point(s), level(s), baseline(s), base year(s) or starting point(s), as appropriate	Saudi Arabia's methane management strategy, including the world's largest gas collection system operational since 1982, undergoes continuous updates.
Updates in accordance with any recalculation of the GHG inventory, as appropriate	N/A
Relation to NDC	This indicator aligns with Saudi's NDC by advancing efforts to reduce greenhouse gas emissions and supporting economic diversification goals, emphasizing methane management as a vital component of its strategy.

3.3.2 Adaptation with Mitigation Co-Benefits

In tracking progress of the Kingdom of Saudi Arabia's NDC with respect to adaptation, it is crucial to highlight the comprehensive measures that both enhance resilience to climate impacts and provide significant mitigation co-benefits. This dual focus is evident in the efforts across various sectors, including advanced water and wastewater management techniques, marine protection initiatives, and reduced desertification through afforestation. Additionally, urban planning projects and large-scale developments are designed to integrate sustainability principles, thus supporting both adaptation and mitigation goals. By evaluating progress in these areas, Saudi Arabia aims to demonstrate how its adaptation measures contribute to environmental protection, economic growth, and global climate objectives.

3.3.2.1. Water and Wastewater Management

Saudi Arabia's Water Law sets stringent regulations to ensure sustainable water management through the National Water Strategy 2030. Government and private sectors must coordinate with Ministry of Environment, Water and Agriculture (MEWA) for water needs and adhere to rigorous standards for water usage, conservation, and wastewater management. Key objectives include cutting total water demand from 24.8 billion cubic meters in 2018 to 12.5 billion cubic meters by 2030 and reducing agricultural water use from 21.2 billion cubic meters in 2016 to 11.4 billion cubic meters by 2030 (MEWA, 2021). With the aim to increase the reuse of treated wastewater from 14.4% in 2016 to 80% by 2030, supporting conservation efforts and safeguarding freshwater resources (Saudi Arabia Bureau of Experts, 2020). Further details on water and wastewater management are provided in Chapter 4. Adaptation, **(4.3.3 Water & Wastewater Management).**

Table 7. Description of selected indicators for Water and Wastewater Management

Indicator(s) selected to track progress	Description
Water and Wastewater Management	
Information for the reference point(s), level(s), baseline(s), base year(s) or starting point(s), as appropriate	The National Water Strategy of the Kingdom was published in 2018.
Updates in accordance with any recalculation of the GHG inventory, as appropriate	N/A
Relation to NDC	Through the reductions in total water demand, enhancing wastewater reuse, and improving water management efficiency, this indicator directly supports the NDC's objectives to lower greenhouse gas emissions associated with water-intensive processes and to build resilience against water-related climate impacts. This alignment ensures that water conservation and wastewater management contribute to both the mitigation targets and adaptation measures.

3.3.2.2. Marine Protection

Saudi Arabia's Vision 2030 initiative strongly emphasizes environmental protection and the conservation of natural resources. Efforts are focused on enhancing biodiversity, protecting wildlife habitats, and managing marine resources sustainably, through initiatives such as coral reef restoration, the establishment of marine protected areas (MPAs), and blue carbon sequestration. To support these goals, the Kingdom has made significant strides to address marine protection through a set of measures to protect its marine ecosystem and combat climate change (The Kingdom of Saudi Arabia, 2023; Environment fund). Further details on Marine Protected Areas are provided in Chapter 4. Adaptation, **(4.3.5 Marine Ecosystem Initiatives)**

Table 8. Description of selected indicators for Marine Protection

Indicator(s) selected to track progress	Description
Marine Protection	
Information for the reference point(s), level(s), baseline(s), base year(s) or starting point(s), as appropriate	Saudi Arabia has been emphasizing on extensive marine conservation initiatives along its Red Sea and Arabian Gulf coastlines through its Vision 2030 since 2016
Updates in accordance with any recalculation of the GHG inventory, as appropriate	N/A
Relation to NDC	The indicator is aligned with Saudi Arabia's NDC which emphasizes enhancing and safeguarding coastal and marine ecosystem resilience, including efforts to reduce coastal erosion, expand blue carbon sinks, and protect biodiversity.

3.3.2.3. Reduced Desertification/Tree Planting

Saudi Arabia has launched a series of strategic initiatives to address desertification and support afforestation, aligning with its long-term goals for sustainable development, biodiversity conservation, and environmental resilience. The Kingdom aims to tackle desertification by significantly increasing vegetation cover, enhancing natural carbon sinks, and restoring degraded landscapes. Through a combination of tree planting, land rehabilitation, technological innovation, and community engagement, Saudi Arabia seeks to mitigate the impacts of climate change, preserve its ecosystems, and promote sustainable land management practices.

Saudi Arabia has set aspirational plans under these initiatives, including Afforestation and Land Rehabilitation; the SGI aims to rehabilitate extensive land areas, plant 600 million trees, and protect 30% of Saudi Arabia's territory by 2030. Additionally, a study is underway to determine suitable areas for the eventual planting of 10 billion trees, which would contribute to land restoration and mitigate desertification impacts (Saudi Green Initiatives, 2024). Further details on Reduced Desertification/tree planting are provided in Chapter 4. Adaptation, **(4.3.6 Afforestation & Biodiversity Conservations).**

Table 9. Description of selected indicators for Desertification Management and Afforestation

Indicator(s) selected to track progress	Description
Desertification Management and Afforestation	
Information for the reference point(s), level(s), baseline(s), base year(s) or starting point(s), as appropriate	Saudi Arabia undertakes measures to enhance desertification management, building on the Saudi Green Initiative (SGI) launched in 2021.
Updates in accordance with any recalculation of the GHG inventory, as appropriate	N/A
Relation to NDC	The indicator is aligned with Saudi Arabia's NDC, which emphasizes land restoration and enhancement of natural carbon sinks as essential components. Such initiatives support the NDC by promoting sustainable land management, conserving biodiversity, and enhancing ecosystem-based adaptation, which are critical for addressing the adverse impacts of climate change and preserving Saudi Arabia's environmental resources.

3.3.2.4. Urban Planning

Saudi Arabia's urban planning strategies align with its NDC, advancing sustainable growth, enhanced transportation infrastructure, and waste management. The Kingdom's urban planning initiatives, embedded in the National Spatial Strategy, aim to balance development between urban and rural areas, foster sustainable infrastructure, and mitigate environmental challenges associated with rapid urbanization.

3.3.2.4.1. National Spatial Strategy

Saudi Arabia's National Spatial Strategy focuses on integrating regional strategies, enhancing urban planning, and attracting investments across six focus areas: global positioning, urban modernization, regional development, quality of life, sustainable economy, and governance mechanisms (Al-Qabbani, 2023). The Ministry of Municipal and Rural Affairs (MOMRA) has developed the National Urban Observatory to measure urban indicators, and the Medina Region Development Authority Urban Observatory guides urban development policies (KSA National Portal, 2020; Madina Urban Observatory, 2024). This strategy addresses environmental challenges posed by rapid urbanization, such as air pollution and water scarcity, promoting sustainable growth, sustainable infrastructure, and mixed-use developments to mitigate these impacts (Almulhim et al., 2024).

3.3.2.4.2. Transport (Railway projects, Integrated Public Transport Projects)

Saudi Arabia's transport infrastructure is undergoing significant advancements to meet the Kingdom's sustainable growth and reduce greenhouse gas emissions. Further details on transportation are provided in Chapter 4. Adaptation, **(4.3.2.3 Transportation Initiatives).**

3.3.2.4.3. Solid Waste Management

The National Center for Waste Management (MWAN), oversees waste management in Saudi Arabia, promoting a circular economy through investment, licensing, capacity building, and research. Under the SGI, the Kingdom targets a 94% diversion rate for Riyadh's waste and composting of 1.3 million tons of biodegradable waste by 2035 (PIF, 2023; SIRC, 2024; SGI, 2024). Further details on Solid Waste Management are provided in Chapter 4. Adaptation, **(4.3.2.4 Solid Waste Management).**

Table 10. Description of selected indicators for Urban Planning

Indicator(s) selected to track progress	Description
Urban Planning	
Information for the reference point(s), level(s), baseline(s), base year(s) or starting point(s), as appropriate	The Kingdom's urban planning initiatives, embedded in the National Spatial Strategy (NSS) and the National Urban Strategy 2030 (NUS), aim to balance development between urban and rural areas, foster sustainable infrastructure, and mitigate environmental challenges associated with rapid urbanization. Formal efforts to update the NSS and NUS have taken place in 2022 and 2024 respectively.
Updates in accordance with any recalculation of the GHG inventory, as appropriate	N/A
Relation to NDC	The indicator aligns with the NDC goals for climate mitigation and adaptation, by enhancing the overall quality of life, transportation infrastructure and promoting sustainable building and waste management. These efforts reduce GHG emissions, and improve energy efficiency thereby contributing to the Kingdom's climate goals

3.3.3. Adaptation Undertakings

Recognizing the importance of adapting to climate change, the Kingdom has incorporated adaptation efforts as part of its NDC. Through efforts outlined in this section, Saudi Arabia aims to build resilience and reduce vulnerability to adverse climate impacts. Advancing the progress on these efforts aims to address the resilience of the Kingdom, while also supporting its sustainable growth and economic diversification journey, through a combination of integrated planning practices, infrastructure and cities design, and employment of technology.

3.3.3.1 Integrated Coastal Zone Management Planning (ICZM)

Saudi Arabia has undertaken several integrated coastal zone management (ICZM) initiatives to address the challenges posed by environmental changes and human activities along its extensive coastlines, and risks of rising sea levels which threaten infrastructure and ecological zones like mangroves and coral reefs (Babu et al., 2012). In the eastern region, particularly in Al-Qatif, efforts have been made to manage seawater intrusion into coastal aquifers through hydrogeological and hydrochemical assessments, resulting in recommendations for reduced groundwater abstraction and continuous monitoring to protect freshwater resources (Benaafi et al., 2022). In the northwestern region, geophysical techniques have been employed to identify seawater intrusion zones, aiding in development of management strategies to mitigate its impact (Alhumimidi, 2020). In the western region, the Jeddah Coastal Information System (CIS) represents a technological approach to ICZM, providing real-time data and forecasts to support decision-making in managing coastal waters, navigation, and pollution control (Mayerle et al., 2016). These initiatives reflect a comprehensive approach to managing Saudi Arabia's coastal zones, integrating scientific assessments, technological systems, and policy frameworks to ensure sustainable development and environmental protection.

Table 11. Description of selected indicators for Integrated Coastal Zone Management Planning

Indicator(s) selected to track progress	Description
Integrated Coastal Zone Management Planning	
Information for the reference point(s), level(s), baseline(s), base year(s) or starting point(s), as appropriate	Efforts under this indicator started in 2006
Updates in accordance with any recalculation of the GHG inventory, as appropriate	N/A
Relation to NDC	The ICZM serves as an indicator under Saudi Arabia's NDC, reflecting progress in enhancing sustainable management of coastal areas. The Kingdom considers the ICZM as an adaptation undertaking to take the necessary action to develop and implement plans that would take into account the protection of coastal infrastructures.

3.3.3.2. Early Warning Systems (EWS)

Saudi Arabia recognizes the importance of resilience against extreme weather events, including rainstorms, floods, and dust and sandstorms. The Kingdom has invested in developing an Early Warning System (EWS) that aims to reduce vulnerability by providing communities and authorities with timely and accurate information. The EWS framework includes weather monitoring stations, rainfall gauges, and other sensors to gather real-time meteorological data, supporting effective disaster preparedness and response (Kingdom of Saudi Arabia, 2021;

Ministry of Environment, Water, and Agriculture, 2023; General Directorate of Civil Defense, 2023). Further details on EWS are provided in Chapter 4. Adaptation, **(4.3.2.2 Early Warning Systems EWS).**

Table 12. Description of selected indicators for Early Warning Systems (EWS)

Indicator(s) selected to track progress	Description
Early Warning Systems (EWS)	
Information for the reference point(s), level(s), baseline(s), base year(s) or starting point(s), as appropriate	The Kingdom Early Warning Systems (EWS) was established in 2019
Updates in accordance with any recalculation of the GHG inventory, as appropriate	N/A
Relation to NDC	The EWS serves as a critical adaptation indicator within Saudi Arabia's NDC, with an aim reduce vulnerability to extreme weather events such as rainstorms, flash floods, and dust storms. The development, upgrade, and operationalization of EWS directly support the NDC's focus on climate adaptation by increasing infrastructure resilience and protecting public safety.

3.3.3.3. Integrated Water Management Planning

Saudi Arabia's National Water Strategy guides the planning and implementation of integrated water management efforts, advancing programs in legal frameworks, management, innovation, capacity building, and service quality. The strategy aims to address water challenges, leverage existing studies, and improve the water and wastewater sectors to ensure sustainable resource development while providing high-quality, affordable services.

Under this strategy, the Kingdom has prioritized renewable water use in agriculture to conserve freshwater resources. Efforts include construction of pumping stations with irrigation networks along with establishing quality control laboratories for treated water, expected by 2025 (Saudi Green Initiative, 2024). Additionally, the Kingdom aims to increase dam water utilization for agriculture, targeting the use of 80 million m^3 of water collected and stored in dam water by 2025 to reach a water reuse rate of 8% by 2030 (Saudi Green Initiative, 2024).

Saudi Arabia has also advanced in desalination, essential for the country with limited renewable groundwater resources and low recharge rate.

The AlKhafji Desalination Plant, the largest solar-powered desalination facility globally, is designed to produce up to 90,000 m^3 of potable water per day, meeting regional water needs sustainably. By utilizing solar energy, the plant demonstrates the effective integration of renewable resources in desalination technology (Vision 2030).

Another critical project is the Zero Liquid Discharge (ZLD) desalination plant in Jubail, scheduled for completion by 2026. Designed to reduce saline brine discharge, the ZLD plant will produce up to 2 million m^3 of desalinated water annually, contributing to sustainable water resource management (Saudi Green Initiative, 2024).

Table 13. Description of selected indicators for Integrated Water Management Planning

Indicator(s) selected to track progress	Description
Integrated Water Management Planning	
Information for the reference point(s), level(s), baseline(s), base year(s) or starting point(s), as appropriate	Law of Preservation of Water Resources was approved by Royal Decree in 1979 and has been continuously updated.
Updates in accordance with any recalculation of the GHG inventory, as appropriate	N/A
Relation to NDC	IWMP is a critical indicator in Saudi Arabia's NDC, demonstrating the Kingdom's commitment to addressing water scarcity and ensuring sustainable water resource management in its arid environment. IWMP aligns with the NDC's adaptation goals by prioritizing innovative strategies, including leveraging renewable water sources, reforming the water and wastewater sectors, and promoting high-quality, affordable water services. By integrating advanced desalination technologies and renewable energy.

3.3.3.4. Infrastructure and Cities Designs

The Kingdom has established multiple industrial zones and economic cities, highlighting the importance of urban resilience considerations in urban planning and policymaking. Without these initiatives, urban migration would have continued to strain resources, leading to overcrowding, diminished quality of life, and pressure on rural lands. Rural areas would remain underdeveloped, exacerbating disparities and limiting national growth. Efforts to combat desertification, such as sand dune stabilization, tree planting, and green belt establishment, would lack the necessary support, risking infrastructure and ecosystem health (Kingdom of Saudi Arabia, 2011). Further details on Infrastructure and Cities Designs are provided in Chapter 4. Adaptation, **(4.3.2 Infrastructure)**

Table 14. Description of selected indicators for Infrastructure and City Design

Indicator(s) selected to track progress	Description
Infrastructure and City Design	
Information for the reference point(s), level(s), baseline(s), base year(s) or starting point(s), as appropriate	The Kingdom has introduced several Infrastructure and City Design initiatives as part of Vision 2030, launched in 2016.
Updates in accordance with any recalculation of the GHG inventory, as appropriate	N/A
Relation to NDC	Infrastructure and City Design is an adaptation indicator in Saudi Arabia's NDC aiming to enhance economic and industrial development while reducing vulnerability to climate impacts. The focus on efficient resource use, and strategic investments aligns with the NDC's objectives of fostering economic diversification and sustainability.

Table 15. Mitigation policies and measures, actions and plans, including those with mitigation co-benefits resulting from adaptation actions and economic diversification plans

No.	Name [c]	Description [d,e, f]	Objectives	Type of instrument [g]	Status [h]	Sector(s) affected [i]	Gases affected	Start year of implementation	Implementing entity or entities	Estimates of GHG emission reductions (kt CO_2eq) [j, k]	
										Achieved	Expected
1	**Vision 2030**	A comprehensive national strategic framework that includes economic diversification and sustainability as key pillars.	Diversify the country's economy, develop and enhance key sectors, ensure sustainable development.	A strategic framework supported by actionable programs, projects, and initiatives.	Some actions, plans, and policies are adopted, and some are implemented partially or fully.	Energy, transport, industrial processes, agriculture, LULUCF, and waste management	CO_2, CH_4, and N_2O	2016	Council of Economic and Development Affairs	fx	fx
2	**Saudi Green Initiative (SGI)**	Comprehensive national initiative aimed at achieving a balance between economic growth and sustainable development.	Reducing GHG emissions, increasing vegetative cover, and protecting terrestrial and marine ecosystems	Regulatory and economic instrument	Some actions, plans, and projects are adopted, and some are implemented partially or fully.	Energy, transport, industrial processes, waste management, agriculture and LULUCF	CO_2, CH_4, and N_2O	2021	Council of Economic and Development Affairs	fx	fx
3	**Circular Carbon Economy (CCE) Framework**	An approach to address GHG emissions using the 4Rs of reduce, reuse, recycle, and remove strategies.	A lever to compliment the pathway to net-zero emissions through advanced carbon management technologies..	Regulatory and technical initiatives.	Adopted	Energy and industrial processes.	CO2, CH4, and N2O	2020	Ministry of Energy	fx	fx

No.	Name [c]	Description [d,e, f]	Objectives	Type of instrument [g]	Status [h]	Sector(s) affected [i]	Gases affected	Start year of implementation	Implementing entity or entities	Estimates of GHG emission reductions (kt CO_2eq) [j, k]	
										Achieved	Expected
4	**Saudi Energy Efficiency Program (SEEP)**	National program for energy efficiency.	Improve energy efficiency across key sectors, including industry, building and transportation.	Regulatory and Economic Reform	Implemented	Energy, buildings, transport, industrial processes	CO_2, CH_4, and N_2O	2012	Saudi Energy Efficiency Center (SEEC), Ministry of Energy	fx	fx
4(a)	**Building Sector Energy Efficiency Standards**	Energy standards, including air conditioners, appliances, and insulation materials.	Reduce building sector energy consumption; Improve appliance efficiency	Regulatory	Implemented	Buildings	CO2	2018	Saudi Standards, Metrology, and Quality Organization (SASO)	fx	fx
4(b)	**Corporate Average Fuel Economy (CAFE) Standards**	Fuel economy improvements for light-duty vehicles.	Improve energy efficiency in the transportation sector	Regulatory	Implemented	Transport	CO_2	2016	Saudi Standards, Metrology, and Quality Organization (SASO)	fx	fx
5	**National Renewable Energy Program (NREP)**	The program aims to maximize and optimize the renewables' share in the Kingdom, designed to balance the local energy mix	Achieve 45-50% renewable energy in electricity mix by 2030	Economic reform and infrastructure	Adopted	Energy	CO_2, CH_4, and N_2O	2017	Ministry of Energy	fx	fx

No.	Name (c)	Description (d,e, f)	Objectives	Type of instrument (g)	Status (h)	Sector(s) affected (i)	Gases affected	Start year of implementation	Implementing entity or entities	Estimates of GHG emission reductions (kt CO_2eq) (j, k)	
										Achieved	Expected
5(a)	**Renewable Energy based Desalination Plant**	AlKhafji Desalination Plant is the World's largest solar-powered desalination facility producing up to 90,000 m³/day.	Ensure water security sustainably.	Infrastructure	Implemented	Water and Energy	CO_2, CH_4, and N_2O	2018	Corporate	fx	fx
6	**CCUS Hubs**	Large-scale hubs in Jubail and Yanbu to capture 44 Mt CO_2 annually by 2035.	Deploy carbon capture for emissions reduction.	Infrastructure and Technology	Planned	Industry	CO_2	2021	Ministry of Energy, corporates	fx	fx
7	**Green Hydrogen Development**	This project at NEOM is projected to produce 600 metric tons/day using solar and wind energy.	Promote clean hydrogen production and export.	Technology, Private Investment	Adopted	Energy	CO_2, CH_4, and N_2O	2020	Corporates	fx	fx
8	**Master Gas System Expansion**	Expanding capacity to 12.5 billion SCFD.	Enhance energy security and reduce emissions.	Infrastructure Expansion	Adopted	Energy	CO_2, CH_4	2015	Corporate	fx	fx

No.	Name [c]	Description [d,e, f]	Objectives	Type of instrument [g]	Status [h]	Sector(s) affected [i]	Gases affected	Start year of implementation	Implementing entity or entities	Estimates of GHG emission reductions (kt CO_2eq) [j, k]	
										Achieved	Expected
9	**New methane emissions detection technology Pilot**	• A Tunable Diode Laser Absorption Spectroscopy Methane Detection System • A remote sensing Fourier Transform Infrared spectroscopy system.	Reduce methane intensity in oil and gas production.	Monitoring	Implemented	Energy	CH_4	2023	Corporate	fx	fx
10	**Public Transportatio n**	The Riyadh Metro Project consists of six metro lines and a bus network.	Promote public transport, reduce emissions.	Infrastructure	Implemented	Transport	CO_2, CH_4, and N_2O	2014	Royal Commission for Riyadh City	fx	fx
		Jeddah Public Transport Program is a Multi-modal transit options (metro, tram, bus).	Enhance sustainable mobility.	Infrastructure	Implemented	Transport	CO_2, CH_4, and N_2O	2015	Corporate	fx	fx
11	**Saudi Arabia's Protected Areas System Plan**	A comprehensive roadmap for the creation and management of protected areas across the Kingdom.	Protect 30% of Saudi Arabia's terrestrial and marine areas by 2030	Plan	Adopted	LULUCF		2024	National Center for Wildlife, Ministry of Environment, Water, and Agriculture	fx	fx

No.	Name (c)	Description (d,e, f)	Objectives	Type of instrument (g)	Status (h)	Sector(s) affected (i)	Gases affected	Start year of implementation	Implementing entity or entities	Estimates of GHG emission reductions (kt CO_2eq) (j, k)	
										Achieved	Expected
12	**Flaring Gas Recovery System**	Reduce flaring in operations and adopt flaring reduction technologies.	Zero Routine Flaring by 2030	Plan	implemented	Energy	CO_2, CH_4, and N_2O	2019	Ministry of Energy, Corporate	fx	fx
13	**Sustainable and Climate-Resilient Infrastructure Development**	A subsidiary of the Public Investment Fund implementing infrastructure development initiatives to enhance the quality of life and catalyze economic activity in 12 cities across Saudi Arabia	Diversify the economy and drive economic growth	Infrastructure and economic	Adopted	LULUCF, Energy, and Transport	CO_2, CH_4, and N_2O	2022	Public Investment Fund	fx	fx
		NEOM is a sustainable development project in northwest Saudi Arabia	aims to foster and expand innovation, technology, and renewable energy.	Infrastructure	Some actions, plans, and policies are adopted, and some are implemented partially or fully.	Energy, LULUCF, and Transport	CO_2, CH_4, and N_2O	2017	Public Investment Fund	fx	fx

No.	Name (c)	Description (d,e, f)	Objectives	Type of instrument (g)	Status (h)	Sector(s) affected (i)	Gases affected	Start year of implementation	Implementing entity or entities	Estimates of GHG emission reductions (kt CO_2eq) (j, k)	
										Achieved	Expected
		The Red Sea Global is a multi project developer along the red sea region.	Contribute to protecting marine ecosystem, enhancing the tourism sector, preserving cultural heritage, and to diversify the economy	Infrastructure	Some actions, plans, and policies are adopted, and some are implemented partially or fully.	Energy, LULUCF, and Transport	CO_2, CH_4, and N_2O	2023	Public Investment Fund	fx	fx
14	**National Water Strategy 2030**	Comprehensive water and wastewater management framework targeting significant reductions in water demand.	Aims to reduce total water demand from 24.8 to 12.5 billion m³ by 2030	Regulatory, Economic	Some actions, plans, and policies are adopted, and some are implemented partially or fully.	Water	CO_2, CH_4, and N_2O	2018	Ministry of Environment, Water and Agriculture	fx	fx

3.4. Impact of Climate Change Response Measures

In line with paragraph 78 of Modalities, Procedures, and Guidelines (18/CMA.1) of the ETF this section provides a description of the Kingdom's efforts address the social and economic consequences of response measures.

3.4.1. Economic Diversification

The Kingdom of Saudi Arabia has adopted a comprehensive and integrated approach in its commitment to addressing the adverse impacts of climate change response measures. Economic diversification is a key aspect of this approach serving as a strategy to mitigate vulnerabilities to climate risks and fluctuations in global markets, especially for resource-dependent countries. Economic diversification supports sustainable development while supporting climate change adaptation and mitigation goals.

Economic diversification is defined as a multifaceted process aimed at reducing reliance on primary sectors by fostering a more diverse industrial and service-based economy.

The Kingdom's Fourth National Communication (NC4) underscores that while global efforts to reduce GHG emissions are necessary, they can impose economic burdens, particularly on Developing Country Parties. Saudi Arabia advocates for a balanced, multilateral approach to climate policy, ensuring that international climate actions to reduce emissions should not hinder the economic and social development of Developing Country Parties. It is crucial to effectively manage these impacts to prevent exacerbating global inequalities, highlighting the need for careful assessment and mitigation of the potential socioeconomic effects of response measures at all levels. This approach ensures that climate policies not only address environmental concerns but also support broader sustainable development goals.

The Kingdom recognizes the importance of enhancing energy efficiency, expanding the use of renewable energy sources, and other initiatives that reduce, abate, and remove GHG remissions as key elements of sustainable development. These initiatives reflect a broader energy strategy towards a more diversified and sustainable economic structure that balances continued growth with environmental stewardship.

This strategy helps reduce the Kingdom's GHG emissions while encouraging innovation and job creation across various sectors.

3.4.1.1. Circular Carbon Economy (CCE)

The Circular Carbon Economy (CCE) approach is integral to Saudi Arabia's economic diversification efforts. Based on the principles of Reduce, Reuse, Recycle and Remove, the CCE provides a comprehensive and pragmatic approach to managing emissions, promoting sustainable practices, and promoting resource efficiency. This approach supports the development of low-emission energy, resource efficiency and waste management technologies, allowing Saudi Arabia to reduce its environmental impact while fostering new economic opportunities. The adoption of the CCE is a key element in the Kingdom's strategy for achieving a balanced, low-emission future.

3.4.1.2. Addressing Socioeconomic Vulnerabilities

Economic diversification also addresses critical socioeconomic vulnerabilities, particularly those related to population growth and employment. As the Kingdom's population continues to grow, especially with a young, increasingly educated workforce, it is vital to create new sectors that offer sustainable, long-term employment opportunities. By developing industries such as technology, renewable energy and smart infrastructure, Saudi Arabia is promoting innovation and creating new avenues for economic growth, which will help reduce unemployment and ensure that the benefits of diversification are widely shared. To address vulnerabilities related to water scarcity and food security, Saudi Arabia has invested in sustainable agriculture, advanced water and wastewater management, and desalination technologies. These sectors are vital not only for the Kingdom's environmental goals but also for its social and economic stability, contributing to a more resilient and sustainable future.

3.4.1.3. Building on Lessons Learned

The Kingdom's experience with economic diversification highlights the importance of aligning economic, social, and sustainable objectives through effective policies, regulatory frameworks, and investments in human capital and infrastructure. Collaboration between the public and private sectors is essential to drive innovation, attract investment and scale up the deployment of clean technologies, while international cooperation plays a crucial role in facilitating knowledge sharing, accessing financial resources and promoting best practices that can accelerate the Kingdom's efforts towards a more diversified and sustainable economy.

To manage the impacts of climate change, the Kingdom adopted a multifaceted approach by implementing and combining policy development, economic diversification, and strategic initiatives with Vision 2030 as the foundational plan. To demonstrate this in action, the SGI and MGI were established to further address regional and global sustainability challenges, particularly those related to climate change. In addition, the Kingdom has also invested in key adaptation efforts, including water and wastewater management, marine protection, combating desertification, and supporting afforestation. Saudi Arabia's NDC and CCE approach further guide efforts toward efficient resource use and emissions reductions. Clear examples of these efforts include improvements in energy efficiency, methane management, development of renewable energy including green hydrogen, and the use of CCUS technologies, such as blue hydrogen.

3.4.2. Economic Diversification Initiatives Across Key Sectors

As part of the economic diversification strategy, significant investments are being made across various sectors to foster sustainable economic growth and job creation, particularly in tourism, entertainment, sports, trade, transportation, health, and education. These efforts represent Saudi Arabia's broader vision of fostering long-term economic resilience while improving quality of life.

3.4.2.1. Economic Growth and Job Creation

3.4.2.1.1. Trade and Transport

Saudi Arabia's strategic location and historical role in global trade drive its economic growth and align with one of Vision 2030's goals of becoming a global logistics hub. Central to this vision is the enhancement of the Kingdom's infrastructure to facilitate trade and connect with international markets. The National Strategy for Transport and Logistics modernizes infrastructure to streamline trade and enhance international connectivity, focusing on adopting advanced transportation systems and leveraging technology to improve the logistics sector.

Expansion of key ports, including the Jeddah Islamic Port that is increasing its capacity to 6.2 million standard containers (MAWANI, 2024), and King Abdullah Port in King Abdullah Economic City—the region's first privately operated port—has strengthened Saudi Arabia's position as a logistics hub. The

Kingdom’s seaports recently advanced from 16th to 15th on Lloyd’s List of the world’s 100 largest ports for 2024, reflecting its rising position in global trade.

3.4.2.1.2. Real-Estate Development

Population growth and urban expansion in Saudi Arabia have made real-estate development a central element of the Kingdom's national development strategy, supporting Vision 2030’s target of 70% homeownership. Mega-projects such as NEOM, the Red Sea Project, and developments by Roshn are transforming urban landscapes to meet growing demand. These initiatives contribute to the broader goals of Vision 2030, including in urban design and infrastructure, stimulating job creation, and enhancing quality of life.

3.4.2.1.3. Entertainment

The establishment of the General Entertainment Authority (GEA) marked a transformative shift in Saudi Arabia's entertainment sector, positioning it to lead and regulate the industry while ensuring sustainable growth by attracting investments and launching high-quality projects. Recent data shows that 90% of residents aged 15 and older visited entertainment venues between mid-2022 and mid-2023 (GSTAT 2023), and the number of companies specializing in this sector rose by 149%, reaching 4,159 in 2023 (GEA 2024), indicating rapid industry expansion.

Large-scale initiatives like Qiddiya, exemplify the Kingdom's entertainment ambitions. Designed as an entertainment destination with theme parks, hotels, and cultural attractions, it has created over 100,000 jobs during construction and is projected to generate 325,000 permanent jobs upon completion (Qiddiya, 2023). As the entertainment sector grows, it continues to attract international tourism and investment.

3.4.2.1.4. Sports

The Kingdom is also prioritizing the sports sector through hosting prominent international sports events, such as the Saudi F1 Grand Prix, and World Cup 2034, resulting in tangible economic benefits, contributing to increased productivity, employment generation, and sustained growth (General Authority for Statistics, 2023; Ministry of Sport, 2023). Investments in sports also foster social and health improvements by encouraging active lifestyles, leading to potential health cost savings aligned with Vision 2030's quality-of-life goals (Vision 2030 Quality of Life Program, 2023).

3.4.2.2. Human Capital Development

Strengthening the health and educational systems equips individuals with the necessary skills and well-being to thrive in diverse economic sectors. This holistic approach to capacity-building fosters innovation, productivity, and global competitiveness.

3.4.2.2.1. Health

Vision 2030 and the National Transformation Program prioritize healthcare improvements, through the enhancement of the health system and improvement of the quality of care across the Kingdom. A key element of this transformation is the expansion of e-health services, such as the Sehhaty app, which streamlines access to healthcare and enables individuals to manage their health more effectively.

Additionally, the Kingdom is implementing measures to improve healthcare delivery, including the introduction of assigned family physicians. This initiative aims to provide personalized care, focusing on primary healthcare to facilitate early detection and better management of health issues, improving long-term health outcomes for citizens. In 2022, the Kingdom allocated 8% of its total budgetary expenditure to the health sector, a commitment that has further increased in 2023 (Ministry of Health, 2023). This significant investment reflects the Kingdom’s commitment to strengthening the healthcare infrastructure, expanding service access, and enhancing the quality of care.

3.4.2.2.2. Education

Education is recognized as a cornerstone of human development and assumes a vital role in Saudi Arabia's strategy for economic diversification. Since the introduction of the Kingdom’s First Development Plan in 1970, there has been a concerted effort by the government to invest in educational infrastructure and resources to improve individual achievement and eradicate illiteracy. This investment aims to equip the workforce with the skills necessary to meet the evolving demands of a diversified economy (Saudi Vision 2030, 2023). As a result, the Kingdom has devoted significant resources to developing human capacity and manpower skills, ensuring that education remains aligned with the evolving needs of the economy.

Additionally, Saudi Vision 2030 seeks to promote gender equality in education, resulting in an increasing trend of female graduates, with approximately 55% of higher education graduates being women (Saudi Vision 2030, 2023).

3.4.2.3. Community Development

3.4.2.3.1. Tourism

Tourism has become a crucial sector in Saudi Arabia's economic diversification strategy, contributing significantly to job creation and enhancing the overall quality of life. The recognition of multiple UNESCO World Heritage Sites highlights the Kingdom's rich cultural heritage and historical significance (UNESCO World Heritage Centre, 2022). Traditionally, the Kingdom’s tourism has centered around the holy cities of Makkah and Madinah, attracting millions of pilgrims annually. However, recent efforts have expanded the tourism landscape to include a variety of cities, cultural festivals, and heritage sites, thereby appealing to both domestic and international visitors. This expansion diversifies the tourism experience and stimulates economic activity across various regions of Saudi Arabia (Saudi Ministry of Tourism, 2023).

3.4.2.3.2. Urban Development

Urban development in Saudi Arabia prioritizes sustainability, efficiency, and connectivity. The Kingdom is focused on leveraging advanced digital technology to improve urban living by optimizing energy use, reducing waste, and promoting sustainability. The integration of digital technologies in urban planning is central to achieving these goals.

3.4.2.3.3. Information and Communication Technology (ICT) & Digitalization

Information and Communication Technology (ICT) has significantly advanced in the Kingdom, assuming a key role in the ongoing digital transformation. Through ICT and digitalization, Saudi Arabia is becoming more efficient, and innovative. This progress is exemplified by the National Digital Transformation Program, which aims to streamline and enhance government services through digital innovation.

Previously time-consuming processes have been consolidated into efficient, user-friendly platforms, as demonstrated by the 2024 Digital Experience Maturity Index, which awarded an advanced score of 85%, based on feedback from 175,000 users across 39 platforms (Digital Government Authority, 2024). Through fostering innovation and promoting cross-sector collaboration the Kingdom has built a sustainable digital framework and created employment opportunities across various sectors.

3.4.3. Global Challenges

3.4.3.1. Energy security: SDG7 and ensuring universal access to energy.

Energy poverty remains a critical global issue, affecting millions of people across various regions. The lack of access to reliable, and affordable energy sources perpetuates inequality, hinders social and economic development and has severe and multifaceted implications impacting health, education, and livelihoods, and contributing to ongoing cycles of poverty.

In 2020, about 789 million people globally lacked electricity, and 2.6 billion lacked clean cooking facilities. By 2023, approximately 745.7 million people still lacked electricity access, and 2.3 billion continued to rely on polluting fuels for cooking. The trajectory indicates that by 2030, about 660 million will still lack electricity access, with nearly 2 billion still relying on polluting fuels and technologies for cooking.

As such addressing energy poverty on a global scale necessitates a pragmatic and agnostic approach to energy sources acknowledging the diverse geographical, economic, and social conditions worldwide.

The Kingdom has consistently demonstrated its commitment to progress Sustainable Development Goal 7 (SDG7), aimed at ensuring access to affordable, reliable, and sustainable energy for all. As a recognized leader in energy security, the Kingdom is also enhancing its role to become a major energy supplier of all sources of energy.

The Kingdom ranks as one of the most efficient oil-producing countries globally, boasting one of the lowest GHG intensity footprints per barrel of oil produced. This efficiency is largely due to natural geological and environmental conditions as well as a combination of high-efficiency operations, stringent practices, and advanced practices in oil extraction and processing, alongside a highly effective gas collection and utilization system that results in exceptionally low methane emission intensity. (Kingdom of Saudi Arabia, Ministry of Energy, 2023).

As part of its broader energy strategy, Saudi Arabia is investing heavily in technologies, aligning with global sustainability goals. The CCE Program aims for carbon circularity offering a comprehensive, technology-neutral, and cost-effective approach to climate change mitigation at various levels. CCE extends the circular economy's three ‹Rs› - reduce, recycle, and reuse - by introducing a fourth ‹R› for removal, while concentrating on energy and emissions flows rather than materials and products.

The Kingdom is also pursuing hydrogen production, aiming to become a leading producer and exporter by 2030, with significant investments in green hydrogen technology, particularly through projects like the NEOM Green Hydrogen Plant (National Hydrogen Strategy, 2023).

A major component of Saudi Arabia's energy transitions journey is abatement and removal technologies. Saudi Arabia's commitment to technology development extends to carbon capture, utilization, and storage (CCUS), where it is projected to increase CO_2 abatement capacity from 1.3 million tons annually in 2023 to 44 million tons by 2035 (International Panel on Climate Change [IPCC], 2023).

Liquid Displacement Program supports the Kingdom's energy mix transformation by switching remaining liquid fuel in power generation to natural gas. The program aims to displace more than 1 million barrels of liquid fuel consumed daily by 2030 (95% reduction) across three main sectors (Power Plants & Desalination Facilities, Industry and Agriculture). Since 2019, the program has reduced liquid fuel consumption by 7.5% and is currently converting one of the world’s largest desalination plants to gas, contributing to the energy ecosystem strategy’s goal of achieving a 50% gas and 50% renewable generation capacity mix by 2030.

In addition to its focus on reducing emissions and increasing efficiency, the Kingdom is also addressing global energy poverty through initiatives like clean fuel solutions for cooking. Launched in 2021 as part of the MGI, Clean Fuel Solutions for Cooking provides cleaner cooking fuel to more than 750 million people worldwide, where traditional cooking fuels like wood and coal have severe health and environmental consequences.

Saudi Arabia’s approach to energy poverty is inclusive and flexible, recognizing the varied energy needs of different regions. Its strategy includes a wide array of energy sources—fossil fuels, renewable energy, and emerging technologies—to provide sustainable and reliable energy solutions. By doing so, Saudi Arabia contributes to the global transition towards a sustainable energy future while addressing the urgent need for affordable energy access in underserved regions.

Moreover, the Kingdom's commitment is demonstrated in its substantial investments in both traditional energy infrastructure and innovative renewable energy projects. These investments are a testament to fostering a balanced energy transition that seeks to reduce emissions while ensuring that energy remains accessible and affordable to all populations, particularly those in energy-impoverished regions.

In conclusion, Saudi Arabia is not only enhancing its own energy security but also leading global efforts to tackle energy poverty. Through its diversified energy strategy, investments in innovation, and partnerships in international energy dialogues, the Kingdom is demonstrating its pivotal role in shaping a more sustainable and equitable energy future.

3.4.3.2. Water scarcity

Water security is increasingly critical in addressing both climate change and the growing demands of the global population. Climate change is altering precipitation patterns, increasing the frequency of droughts, and intensifying water scarcity, especially in arid regions like Saudi Arabia, where water resources are already under significant pressure. As a result, effective water resource management is essential to ensure sustainable development and resilience against the adverse effects of climate change.

To mitigate these impacts, strategies such as improved water conservation, efficient water management, and the development of alternative water sources (e.g., desalination) are necessary. Climate adaptation efforts should include investment in water-efficient technologies and infrastructure, as well as policies that integrate water management with broader sustainable development goals (SDGs) (United Nations Environment Programme [UNEP], 2023).

Water resource management in Saudi Arabia is closely aligned with the SDGs, particularly SDG 6 (Clean Water and Sanitation). The Kingdom has implemented a range of policies to ensure the sustainable use of water, including investments in desalination, wastewater treatment, and advanced irrigation techniques. The development of energy-efficient desalination plants, such as those using reverse osmosis, can help reduce the significant energy requirements of desalination processes, thereby addressing both water and energy security challenges (King Abdullah City for Atomic and Renewable Energy, 2023). The National Water Strategy, for instance, outlines measures to optimize water consumption, reduce wastage, and improve water use efficiency in agriculture, industry, and urban areas (Saudi Ministry of Environment, Water, and Agriculture, 2023).

3.4.3.2.1. Cross-Sectoral Impact and Synergies

The impacts of water scarcity extend across multiple sectors, including agriculture, energy production, and human health. Each sector's reliance on water necessitates integrated management approaches to mitigate risks and enhance resilience.

- Agriculture: The agricultural sector's reliance on groundwater has led to significant depletion, posing risks to food security. Climate adaptation strategies, such as selecting drought-resistant crops and reducing water-intensive agricultural practices, are essential for mitigating these risks. Additionally, the Kingdom is exploring controlled-environment agriculture, such as hydroponics, to optimize water use in food production (Saudi Ministry of Environment, Water, and Agriculture, 2023).
- Energy Production: Desalination and energy generation are interconnected, as desalination requires substantial energy inputs. Expanding energy-efficient desalination technology, such as reverse osmosis, can reduce the strain on both water and energy resources while ensuring a stable water supply for the growing population. Expanding the use of renewable energy for desalination can further reduce the environmental impact of these processes (King Abdullah City for Atomic and Renewable Energy, 2023).
- Human Health: Water scarcity has direct implications for public health, particularly in rural and underserved areas where access to clean water and sanitation is limited. Limited access to clean water increases vulnerability to waterborne diseases, which can be exacerbated by extreme weather events.

3.4.3.2.2. Synergies with Other Response Measures

To effectively address water scarcity, Saudi Arabia is integrating water management strategies with broader initiatives aimed at ensuring food and energy security. Addressing food security amid water scarcity in Saudi Arabia requires a holistic approach that incorporates efficient water use in agriculture, food import diversification, and advancements in agricultural technology. This includes promoting sustainable agricultural practices, such as efficient irrigation and soil moisture retention, which help to mitigate the impact of water scarcity on food production. Additionally, the Kingdom is investing in technologies that enable the reuse of water in industrial processes and agriculture, ensuring that water resources are used more efficiently across sectors (United Nations, 2023).

In conclusion, water security in Saudi Arabia is closely linked to climate change mitigation and adaptation strategies. The Kingdom is proactively addressing water scarcity through innovative technologies and policies that promote water efficiency, sustainability, and resilience. By aligning water resource management with sustainable development goals and integrating cross-sectoral approaches, Saudi Arabia is positioning itself as a leader in addressing global water security challenges.

3.4.4. Energy Sector Adaptability and Technological Innovation

3.4.4.1. Energy Efficiency

Saudi Arabia's energy efficiency initiatives are integral to Saudi Arabia’s broader sustainability goals under Vision 2030, focusing on reducing energy consumption while enhancing the adaptability of the economy. Several key programs have been implemented across aimed at enhancing energy efficiency, particularly in key sectors like power generation, water management, building systems, and industry. The role of technology in these efforts is significant, with smart systems and advanced energy management solutions assuming an integral role in optimizing energy use across industries.

Despite advancements, challenges persist, such as ensuring the availability and integration of mature technologies capable of efficiently managing large-scale operations in Saudi Arabia's unique climatic conditions. Additionally, gaps in skilled workforce development and high initial costs for implementing energy-efficient technologies present obstacles. However, through continuous investment in technological innovation and capacity-building programs, the Kingdom is working to overcome these barriers and achieve long-term energy efficiency.

3.4.4.2. CCUS Hubs

CCUS is a crucial element to diversify the economy and achieve Saudi Arabia's Nationally Determined Contribution (NDC). Global advancements in CCUS technologies could play a critical role in reducing global CO_2 emissions, potentially contributing to a 14% reduction by 2050 (GCCSI, 2017b).

The strategy emphasizes prioritizing pilot projects, research, and demonstrations to enhance technology readiness and reduce costs, particularly in crucial industries such as aviation, shipping, petrochemicals, and steel.

3.4.4.3. Technology and removals

Technological advancements in removal approaches offer innovative solutions that allow industries to thrive while delivering significant environmental benefits. These approaches are adaptable to a range of conditions and requirements, which enhances their feasibility and adaptability.

3.4.4.3.1. Direct Air Capture (DAC)

A process that captures CO_2 directly from the atmosphere to be utilized or stored. A major breakthrough has been made during the development of Aramco-KAUST 7, a material that has proved highly effective in capturing CO_2 at low atmospheric concentrations. After proving successful, it is now being scaled up to be used in a pilot facility in the eastern region of Saudi Arabia (Aramco, 2024).

DAC technology requires significant research and development investment along with global collaboration to help advance it and support its transformative potential.

3.4.4.3.2. Nature-Based Solutions and/or Ecosystem-Based Approaches

Saudi Arabia's afforestation efforts support biodiversity, carbon sequestration, and align with broader climate goals. However, while Nature-Based Solutions (NBS) like afforestation offer significant environmental benefits, they also come with challenges. Large-scale tree planting and afforestation is resource-intensive and requires extensive land, which can compete with the habitat of certain species (UNEN, 2020). Despite these challenges, Saudi Arabia's afforestation initiatives represent a significant step toward enhancing sustainability and resilience across the region.

3.4.4.4. Methane

Saudi Arabia's commitment to reducing methane emissions in the energy sector began in the 1970s and has evolved through continuous amendments. These foundational efforts set the stage for significant milestones, such as achieving the Kingdom's lowest flaring intensity in 2022. Central to these achievements is the Master Gas System - a comprehensive network designed to capture, process, and utilize gas that would otherwise be flared, reducing emissions and optimizing resource use. Supported by advanced technologies, Saudi Arabia has developed one of the most effective methane management frameworks worldwide.

3.4.4.4.1. Leak Detection and Repair (LDAR) Programs

The Kingdom's LDAR program complements its methane monitoring and control systems by implementing ground-based and aerial monitoring to detect leaks in real time. This proactive approach has played a key role in lowering methane emissions, and recent advancements in the program have helped reduce methane intensity levels. However, limitations in detection sensitivity for smaller leaks, compounded by high temperatures and dust, necessitate frequent recalibration of equipment (United Nations Economic Commission for Europe [UNECE], 2019), and combining bottom-up and top-down approaches can enhance the overall quality of detection and measurements (KAPSARC, 2023).

3.4.4.4.2. Flaring Gas Recovery System (FGRS)

Saudi Arabia has also prioritized the reduction of flaring through the use of Flare Gas Recovery Systems (FGRS). These systems capture and repurpose gas that would otherwise be flared, aligning with the World Bank's "Zero Routine Flaring by 2030" initiative. These ongoing efforts have positioned the Kingdom among the world leaders in flaring intensity. A challenge that faces FGRS is scalability - FGRS systems are typically more feasible in large-scale, centralized facilities where the volume of flare gas justifies the high installation and operational costs. While FGRS may be more challenging to deploy in smaller or remote locations, these sites present opportunities to innovate cost-efficient solutions and adapt the technology to various scales.

3.4.4.5. Hydrogen

Hydrogen stands at the forefront of several projects that align with the Kingdom's Vision 2030 strategy, emphasizing economic diversification and sustainable energy solutions.

Hydrogen production and transport bring unique challenges that drive innovation in efficiency, resource management, and infrastructure development. These challenges are opportunities to advance technology and create resilient energy systems, supporting hydrogen's role as a sustainable solution in global energy markets.

3.4.4.6. Renewable energy

Saudi Arabia's efforts to achieve the renewable energy ambitions of Vision 2030 heavily depend on the role of technology. Programs like the National Renewable Energy Program (NREP) and initiatives by King Abdullah City for Atomic and Renewable Energy (K.A.CARE) focus on integrating renewable technologies, such as solar, wind, and green hydrogen production, into the national energy portfolio. Technology plays a critical role in enabling this integration, with localized innovation and R&D ensuring sustainability and scalability. However, the maturity of these technologies varies.

Challenges remain in scaling these technologies, such as localizing complex technologies and ensuring they meet the unique environmental conditions of the region. Additionally, the need for a skilled workforce and overcoming initial costs associated with technology localization are hurdles that Saudi Arabia is addressing through initiatives like human capacity development programs.

3.4.5. Climate Change Policies

Addressing the multifaceted challenges of global climate change mitigation necessitates a nuanced understanding of both the ecological benefits and economic repercussions associated with greenhouse gas (GHG) emission reductions. While these efforts are universally beneficial in curbing climate change, they often impose significant economic costs, particularly on Developing Country Parties striving towards sustainable development.

As highlighted by Article 3.14 of the Kyoto Protocol, Article 3.5 of the Convention, and Article 4.15 of the Paris Agreement— it is essential to address the socio-economic concerns of developing countries regarding the potential adverse effects of climate action. Both domestic and international climate policies must ensure that their implementation does not stifle economic growth, job creation, or competitiveness, particularly in developing countries heavily reliant on export-import dynamics. A robust framework is necessary to support developing country parties in identifying, assessing, and mitigating the negative effects of such measures, thus enabling them to pursue climate action that is synergistic with their goals for poverty eradication, sustainable development, and economic diversification.

A multilateral approach to climate action is vital to ensure that response measures do not exacerbate global inequality. This requires a conscientious and well-planned engagement at all stages of policymaking.

Table 16. Information necessary to track progress on the implementation and achievement of the domestic policies and measures implemented to address the social and economic consequences of response measures

Sectors and activities associated with the response measures	Social and economic consequences of the response measures	Challenges in and barriers to addressing the consequences	Actions to address the consequences
1. Economic Diversification with Mitigation Co-benefits			
Energy	• Instability of global energy supply and demand will result in economic repercussions on the national level. • The Kingdom's challenges associated with the global energy markets involves expanding its industrial infrastructure, amongst other activities, to diversify its economy. • Economic diversification stipulates creating job opportunities for the growing youth population. • Investing in youth capacity building to align with the demand across all sectors governing the economic diversification	• Instability of global energy markets. • Pressure on the financial markets' to move investments away from needed investments in fossil fuels and related technologies despite global energy security considerations as well as the Paris Agreement's focus on emissions and not sources. • Need to accelerate development and transfer of technologies. • Need to accelerate deployment of energy efficient technologies for energy sector. • Need to upscale research and investment in carbon capture, utilization and storage (CCUS). • Education, training and capacity building needs.	**1.Energy Efficiency** Saudi Energy Efficiency Program (SEEP) **2. Renewable Energy** The National Renewable Energy Program (NREP) **3. Carbon Capture, Utilization and Storage (CCUS)** **4. Utilization of Gas** Integration of gas as part of the Kingdom's broader energy strategy **5. Methane Management** a. Leak Detection and Repair (LDAR) Programs b. Flaring Gas Recovery System (FGRS)

2. Adaptation with Mitigation Co-benefits			
2.1. Water and Wastewater	Agriculture sector consumption of non-renewable groundwater will strain available water resources	Large-scale investments and efficient resource allocation are needed to implement these key projects: • Building new desalination plants. • Construction of new energy-efficient desalination plants using Reverse Osmosis (RO) technology and renewable energy. • Reducing agricultural water use through efficient irrigation, policy reforms, and improved resource management. • Construction of dams to store surface water runoff. • Construction and update of sewerage networks. • Construction of a treated wastewater distribution pipeline network for reuse in irrigation. • Development of new irrigation technologies to reduce water consumption in agriculture.	• Water Demand Management • Preservation of Non-renewable Water resources • Use of Reverse Osmosis Technology • Use of Renewable Energy in Desalination • Monitor and control of leaks in distribution lines • Increasing Treated Wastewater Reuse in Irrigation • Storage of Surface Water Runoff • Employing New and Latest Irrigation Techniques to Conserve Water

2.2. Marine Protection	• Protection of marine resources will impact communities reliant on fishery as a source of income and food • The increase of marine protected areas will limit access to coastal resources.	**Development and protection of marine resources:** 1. Protection and expansion of mangrove areas. 2. Protection and expansion of Coral Reefs in the Red Sea. • Increasing the marine and terrestrial protected areas to enhance biodiversity. • Deployment of new technologies to enhance the restoration of coral reefs.	**Biodiversity and Marine Ecosystem Initiatives:** 1. Blue Carbon Initiatives 2. The Saudi Green Initiative (SGI): protecting 30% of terrestrial and marine areas by 2030
2.3. Reduced Desertification/ Tree Planting	• Reducing desertification through tree planting will limit water resources.	• Planting indigenous trees in the Kingdom and in the middle east region. • Arranging irrigation water for these plantations.	• Tree planting and Land Rehabilitation Initiatives • Establishment of Vegetative Green Belts Around Urban Areas and Roadways
2.4. Urban Planning	• Urban planning and development stipulates a comprehensive approach to address population and economic growth.	• Implementation of several public transport systems in different cities of the Kingdom • Development and transfer of new technologies to substantially divert landfilling of solid waste	**Public transport initiatives:** 1. Haramain High-Speed Rail 2. Riyadh Public Transit Network Project 3. Makkah Monorail Project 4. Jeddah Public Transport Project • Saudi Arabian Railways • Solid Waste Management Initiative

3.4.6. Summary of GHG Emissions and Removals

Refer to NIR Annex II

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Chapter 4

Climate Change Impacts and Adaptation

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4.1. Introduction

Saudi Arabia faces critical climate challenges, including extreme heat, temperature rise, water scarcity, drought, and desertification, which impact its landscapes and way of life. In response, Saudi Arabia has integrated resilience-enhancing and vulnerability-reducing policies into its Nationally Determined Contribution, positioning climate adaptation as a strategic priority.

Guided by Vision 2030, Saudi Arabia's adaptation measures prioritize sustainable development and diversification across key sectors, including agriculture, water management, infrastructure, healthcare, and urban development. These efforts are tailored to Saudi Arabia's unique environmental conditions, with targeted investments to preserve biodiversity across its land, coastlines, and seas. Acknowledging the importance of global climate goals, Saudi Arabia's approach to adaptation is guided by the goal of holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels.

Aligned with the Global Goal on Adaptation (GGA) under Article 7 of the Paris Agreement, Saudi Arabia's approach focuses on enhancing adaptive capacity, strengthening resilience, and reducing vulnerability to support sustainable development and ensure an effective adaptation response.

The following sections provide a detailed analysis of the challenges, risks and vulnerabilities that Saudi Arabia faces while also highlighting the adaptation strategies, policies, objectives and actions that are being implemented.

4.2. Vulnerabilities, Impact & Risk Assessment

Saudi Arabia faces increasing climate risks, including desertification and land degradation, reduced agricultural productivity, coastal erosion, frequent and intense extreme weather events, such as sandstorms, floods, and droughts. These challenges are exacerbated by the Kingdom's unique geographic and climatic conditions which intensify the impacts, risks, and vulnerabilities associated with climate change.

The Kingdom is an arid country with a harsh climate and sensitive ecosystem and is thus particularly vulnerable to climate change with most of its land being non-arable land. Coordinated efforts at national and local levels are essential to strengthen resilience, enhance adaptive capacity, and ensure sustainable development.

4.2.1. Desertification

Desertification is defined by UNCCD as "any form of land degradation in arid, semi-arid, and dry subhumid areas caused by both natural and human activities" (UNCCD). It results from many factors, including human activities and climatic variations such as deforestation, overgrazing, unsustainable agricultural practices, and climate change. The range and intensity of desertification has increased in some dryland areas over the past several decades (IPCC, 2019). As desertification progresses, it leads to reduced soil fertility, loss of vegetation, and increased vulnerability to extreme weather events like droughts and sandstorms (IPCC, 2019).

Saudi Arabia is highly vulnerable to desertification (NC4, Kingdom of Saudi Arabia, 2022), with this vulnerability expected to increase in the north-western parts of the country in the coming decades. It poses a significant challenge to the climate in the Kingdom impacting agriculture, biodiversity, and economic stability and is a critical concern in a country where over 80% of the land is desert and a dry climate prevails. Yahiya (2012) found that Jazan, south-western Saudi Arabia, lost about 46% of its vegetation cover from 1987 to 2002 (IPCC, SRCCL, 2019).

Some of the important drivers of desertification in Saudi Arabia include, water scarcity, urbanization, overgrazing, unsustainable agricultural practices, sand dune encroachment, wind and costal erosion, salinization, and floods, influenced by both socioeconomic and natural factors, such as Climate Change. For example, improving the efficiency of water management in Saudi Arabia through the development of aquifers, water recycling and rainwater harvesting, is part of a suite of policy actions to combat desertification (Bazza, et al. 2018; Kingdom of Saudi Arabia 2016).

Based on the aridity index (AI), the Kingdom is classified between arid to hyper-arid area (IPCC, 2019). The anticipated increase in aridity from 2030 to 2080 due to climate change exacerbates this issue (NC4, Kingdom of Saudi Arabia, 2022). Climate models predict rising temperatures and reduced rainfall in the future, exacerbating the desertification process. These changes result in lower soil moisture levels and higher evaporation rates, further straining the Kingdom's limited water supplies.

4.2.2. Dust and Sandstorms

A dust or sandstorm is a significant meteorological phenomenon common in arid and semi-arid regions (WMO, 2022). In desert areas, dust and sandstorms are most commonly caused by thunderstorm outflows, or by strong pressure gradients which cause an increase in wind velocity over a wide area. As such, dust storms are a severe weather occurrence in Saudi Arabia influenced by the Kingdom's arid climate and expansive desert terrains.

The Kingdom faces some of the most frequent dust/sandstorms globally (Alshammari, Alrwais and Aksoy, 2024). The loss of vegetation and desertification consequences increases the frequency of dust and sandstorms (IPCC, 2019). As a result, these sandstorms pose significant risks to public health and disrupt transportation and solar and wind energy harvesting (IPCC, 2019).

The frequency and intensity of dust storms have increased over the last few decades due to land use and land cover changes and climate-related factors in many dryland areas resulting in increasing negative impacts on human health, in regions such as the Arabian Peninsula and broader Middle East, and Central Asia (IPCC, SRCCL, 2019). Dust and sandstorms are caused by many factors namely wind erosion and transport, gust fronts and thunderstorms, strong pressure gradients, and atmospheric unstable conditions.

There are economic, health and environmental impacts of sand and dust storms. The health effects include risk of respiratory diseases including asthma, bronchitis, lung infections, cardiovascular diseases, eye irritation and skin problems. The sand and dust storms also cause disruption of ecosystems due to dust deposition on plants and water bodies. Sand and dust storms also cause land and air traffic disruptions due to low visibility, damage to solar panels, vehicles and machinery due to dust accumulation and increased maintenance costs for cities, roads and industrial facilities.

Vegetative barriers and green belts, sustainable land and water management, and dust storm early warning systems are important mitigation and adaptation steps and strategies to control and minimize the causes and impacts of sand and dust storms. The application of sand dune stabilization techniques contributes to reducing sand and dust storms. Agroforestry practices and shelterbelts help reduce soil erosion and sequester carbon. Afforestation programs aimed at creating windbreaks in the form of ‘green walls’ and ‘green dams can help stabilize and reduce dust storms, avert wind erosion, and serve as carbon sinks, particularly when done with locally adapted native and other climate resilient tree species (IPCC, 2019).

4.2.3. Droughts

Drought is one of the serious challenges facing Saudi Arabia, having an arid to hyper-arid climate and extremely low annual rainfall. Considering Saudi Arabia's heavy reliance on non-renewable groundwater and desalinated water, prolonged droughts exacerbate water scarcity, desertification, and economic stress on agriculture and food security.

In the Synthesis Report (SYR) of the AR5, drought is defined as "a period of abnormally dry weather long enough to cause a serious hydrological imbalance" (Mach et al. 2014). Although drought is considered abnormal relative to the water availability under the mean climatic characteristics, it is also a recurrent element of any climate, not only in drylands, but also in humid areas (Cook et al. 2014b; Seneviratne and Ciais 2017; Spinoni et al. 2019; Turkeş 1999; Wilhite et al. 2014). Climate change is projected to increase the intensity or frequency of droughts in some regions across the world (Hoegh-Guldberg et al. 2018) including the Mediterranean, west Asia, many parts of South America, much of Africa, and north-eastern Asia and warming has resulted in an increased frequency, intensity and duration of heat-related events, including heatwaves in most land regions (IPCC, 2019). Climate analysis has indicated a generally increasing dryness over the West Asia and Middle East region (AlSarmi and Washington 2011; Tanarhte et al. 2015).

Droughts often intensify the effects of unsustainable land management practices, especially in drylands, leading to land degradation (Cook et al. 2009; Hornbeck 2012). Especially in the context of climate change, the recurrent nature of droughts requires proactively planned policy instruments both to be well-prepared to respond to droughts when they occur and also undertake ex ante actions to mitigate their impacts by strengthening societal resilience against droughts (Gerber and Mirzabaev 2017).

In Saudi Arabia, droughts are driven by a combination of natural and human induced factors which include low rainfall, higher evaporation rates, overextraction of groundwater, deforestation, land degradation, and urbanization.

Droughts and frequent dust storms were shown to impose adverse impacts over Saudi Arabia, especially under global warming and future climate change (Hasanean et al. 2015; IPCC, SRCCL, 2019). Important impacts of drought include reduction in crop yield, reduction of grazing lands and acceleration of desertification, increased sand and dust storms and biodiversity loss. Globally, climate change is predicted to intensify the occurrence and severity of droughts (IPCC, SRCCL, 2019; Dai 2013; Sheffield and Wood 2008; Swann et al. 2016; Wang 2005; Zhao and Dai 2015; Carrao et al. 2017; Naumann et al. 2018).

Drought remains a major challenge to Saudi Arabia's environment, economy, and water security. Water conservation and management including expansion of desalination, wastewater treatment and reuse, rainwater harvesting, efficient irrigation water techniques, drought resistant crops, afforestation initiatives are some of the important strategies adopted by Saudi Arabia to combat drought. Saudi Arabia is actively investing in innovative water solutions, sustainable land management, and afforestation to adapt to climate change and ensure long-term sustainability.

4.2.4. Water Scarcity

Groundwater resources in Saudi Arabia are characterized by significant challenges and complexities due to the country's arid climate, high evaporation rates, and limited renewable water sources. With limited rainfall averaging 100-150mm per year, no perennial rivers, and the impacts of climate change, water scarcity is a continued concern in Saudi Arabia (NC4, Kingdom of Saudi Arabia, 2022). The Kingdom relies on a variety of water sources, including surface water, groundwater, desalinated water, and treated wastewater, with groundwater from renewable aquifers playing a crucial role in meeting domestic, agricultural, and industrial needs (NDC, Kingdom of Saudi Arabia, 2021). Agriculture, which consumes approximately 87% of the available water supply, intensifies the scarcity problem (M. Amin Mir and M. Waqar Ashraf, 2023).

Saudi Arabia's surface water resources are primarily derived from rainfall runoff collected in dams. As of 2021, the estimated surface water runoff storage capacity was 2.59 billion cubic meters, supported by 574 dams across the country. These dams primarily serve as flood control, drinking water supply, and the recharge of irrigation wells for agricultural use (MEWA, 2021).

Groundwater in Saudi Arabia is classified into shallow and deep aquifers. Shallow aquifers are located within alluvial soils, while deep aquifers are embedded in sandstone and limestone formations. These deep aquifers have limited natural recharge and are considered non-renewable, having formed over millennia (Alodah, 2023). Hydrogeochemical processes such as evaporation, rock-water interactions, and ion exchange affect groundwater quality, leading to salinization and contamination from anthropogenic activities (Gomaa et al., 2023). The quality of groundwater varies significantly, with many areas showing poor to unsuitable conditions for drinking, although some regions still maintain moderate to good quality for irrigation (Osta et al., 2022).

4.2.5. Floods

There has been an increase in the intensity of heavy precipitation events at a global scale (IPCC, 2019). While Saudi Arabia is known for its arid and hyper arid climate and desert landscape, flash floods are a significant and recurring natural hazard. Despite low annual rainfall, when storms do occur, they can cause sudden and severe flooding due to the country's dry soil, poor drainage, and urbanization.

Saudi Arabia is projected to experience a 1.8°C–4.1°C increase in temperatures by 2050, which is forecast to raise agricultural water demand by 5–15% in order to maintain production levels equal to those of 2011 (Chowdhury and Al-Zahrani 2013). The increase of temperatures and variable pattern of rainfall over the central, north and south-western regions of Saudi Arabia may pose challenges for sustainable water resource management (Tarawneh and Chowdhury 2018). Moreover, future climate scenarios are expected to increase the frequency of floods and flash floods, such as in the coastal areas along the central parts of the Red Sea and the south-southwestern areas of Saudi Arabia (Almazroui et al. 2017).

Saudi Arabia experiences torrential rains (intense, short duration rainstorms) specially during the winter months from November – April. The water of the rainfall is not absorbed in the land due to lack of vegetation. The wadis (valleys) get overflow of the rainfall leading to flash floods. Rising global temperatures may be increasing the frequency and intensity of storms in the regions may result in higher flood risks in urban and rural areas. Urbanization and poor drainage systems, deforestation and land degradation may be few other causes of flash floods.

Saudi Arabia has experienced major flash food in the near past in different parts of Saudi Arabia including Jeddah, Makkah, Medina, Riyadh and Eastern Province.

Flooding in Saudi Arabia is an increasing concern due to urbanization, poor drainage, and extreme weather events. While efforts are being made to improve infrastructure, water management, and emergency response, long-term solutions require better urban planning, afforestation, and climate adaptation measures.

The impacts of flooding include loss of life and property, displacement of communities, traffic disruptions, financial losses, land and soil erosion, and contamination of groundwater and water supplies. Saudi Arabia is investing and funding stormwater drainage projects, expansion of sewerage networks and flood tunnels to handle excess precipitation water, building new dams to slow down water flow, avoiding construction in flood prone zones and developing and strengthening early warning systems and emergency response.

4.2.6. Soil Erosion

Erosion refers to removal of soil by the physical forces of water, wind, or often caused by farming activities such as tillage (Ginoux et al. 2012). The global estimates of soil erosion differ significantly, depending on scale, study period and method used (García-Ruiz et al. 2015), ranging from approximately 20 Gt yr–1 to more than 200 Gt yr–1 (Boix-Fayos et al. 2006; FAO 2015). There is significant potential for climate change to increase soil erosion by water, particularly in those regions where precipitation volumes and intensity are projected to increase (Panthou et al. 2014; Nearing et al. 2015). On the other hand, while it is a dominant form of erosion in areas such as West Asia and the Arabian Peninsula (Prakash et al. 2015; Kling Müller et al. 2016), there is limited evidence concerning climate change impacts on wind erosion (IPCC, SRCCL, 2019).

Soil erosion is a challenge in Saudi Arabia, driven by desertification, unsustainable land use, and extreme weather events like windstorms and flash floods. Strong winds in desert regions lift and transport loose, dry soil, leading to loss of topsoil. Prevailing northwesterly winds frequently cause sand and dust storms, eroding soil in exposed areas. On the other hand, despite low rainfall, intense, short rainstorms cause flash floods that wash away soil. Wadi (valley) regions experience rapid erosion when sudden rain occurs. Increased evaporation due to high temperatures dries out topsoil, making it more vulnerable to erosion. Overgrazing removes protective vegetation, exposing soil to wind and water erosion. Deforestation also causes exposing soil to wind and water erosion.

Soil erosion reduces crop productivity leading to increased food imports due to loss of fertile topsoil, damage pasture lands affecting livestock pastoral communities. Soil erosion accelerates the transformation of land into barren desert, making restoration difficult. Soil erosion also causes increased runoff leading to loss of rainwater infiltration and reducing groundwater recharge.

Soil erosion is a challenge in Saudi Arabia, threatening agriculture, biodiversity, and water security. However, the government is actively investing in afforestation, and land management. Unsustainable land management is increasing the risks from droughts, floods and dust storms (IPCC, SRCCL, 2019). Policy actions promoting the adoption of SLM practices in dryland areas, based on both indigenous and local knowledge and modern science, and expanding alternative livelihood opportunities outside agriculture can contribute to climate change adaptation and mitigation, addressing desertification, with co-benefits for poverty eradication and food security (Cowie et al. 2018; Liniger et al. 2017; Safriel and Adeel 2008; Stafford-Smith et al. 2017).

4.2.7. Heatwaves

Saudi Arabia is facing an increased frequency of heatwaves due to climate change, posing a significant risk to health, and infrastructure. Research indicates that summers are expected to be hotter, with an increase in the number of days of extreme heat each year, compounded by temperatures and reduced rainfall (NC4, Kingdom of Saudi Arabia). Additionally, the increasing frequency of heatwaves contributes to the ongoing desertification process, which is already a critical concern for the Kingdom. These impacts underline the urgent need for adaptation strategies to mitigate the effects of extreme heat on public health and environmental stability.

4.3. Adaptation and Resilience

4.3.1. Resilient Development - Holistic Approach (Economic, Social, and Environmental, Ecosystem, Socio-Economic dimensions)

Saudi Arabia recognized the urgent need for resilient development in the face of climate change challenges and therefore adopts a holistic approach that integrates economic, social, and environmental dimensions for building resilience across the Kingdom. By promoting sustainable practices and encouraging innovation, the Kingdom aims to achieve ambitious economic and social benefits including creating job opportunities that not only drive economic growth but also strengthen environmental sustainability.

A key element of this approach is the promotion of adaptation strategies that yield mitigation co-benefits. The Kingdom's CCE framework plays a critical role in its adaptation strategy. This comprehensive approach includes the "4Rs"—Reduce, Reuse, Recycle, and Remove—to manage emissions across all sectors. The CCE emphasizes the efficient management of energy, materials, and GHG flows.

In terms of adaptation benefits, water recycling, reuse, and leakage control can improve the efficiency of water management, enhance their use for human consumption, in agriculture, dams, or hydropower, as well as reduce costs.

Likewise, nature-based adaptation strategies related to water resources management can work in concert with other adaptation-related measures, such as the expansion of tree cover in watershed management, which can in turn further enhance water availability.

Through these actions, Saudi Arabia is not only addressing climate adaptation but also generating mitigation co-benefits. For instance, investments in hydrogen and CCUS enhance energy security while reducing emissions and strengthening adaptation efforts through economic diversification. Saudi Arabia is working to integrate adaptation considerations into its short, medium, and long-term planning and strategies related to climate change as well as to infrastructure and economic development.

Adaptation initiatives like afforestation and sustainable land management are key to combating desertification and enhancing soil health. By combining traditional ecological practices with modern conservation techniques, Saudi Arabia aims to bolster the resilience of natural resources.

The SGI supports Saudi Arabia's goal of achieving its adaptation and mitigation ambitions including emissions reduction, afforestation, and protection of land and sea. Since its launch, SGI has activated more than 85 initiatives corresponding with these ambitions.

Finally, this holistic approach to resilient development in Saudi Arabia involves integrating economic, social, and environmental dimensions to build a robust foundation for adaptation. The Kingdom effectively navigates climate change challenges through robust adaptation measures, policies, and initiatives to ensure a sustainable and resilient future.

4.3.2. Infrastructure

4.3.2.1. Building Climate Resilient Cities (e.g. building codes)

Saudi Arabia has embarked on several climate-resilient city initiatives, with a focus on improving energy efficiency and aligning with the Saudi Vision 2030. Urban resilience is key with integration of climate vulnerability considerations into urban planning and policymaking (Almulhim & Cobbinah, 2024).

The country faces significant water scarcity issues, exacerbated by climate change, leading to a heavy reliance on desalination process for producing potable water. This has prompted innovative infrastructure resilience strategies in major cities like Riyadh and Jeddah, which are crucial for adapting to environmental disruptions (Mani & Goniewicz, 2023). Sustainable urban planning strategies are also being implemented, with initiatives such as urban greening, and public transportation.

Among the notable initiatives is the "Mostadam" rating system, established under Vision 2030, which focuses on creating sustainable residential buildings that minimize energy consumption and emissions, thus contributing to overall urban sustainability (Balabel & Alwetaishi, 2021).

The Saudi Building Code (SBC) has undergone updates to incorporate sustainable practices, including stringent energy codes for residential buildings, resulting in marked improvements in energy efficiency (Jamoussi et al., 2022). Furthermore, Saudi Arabia is developing a sustainable energy framework aimed at integrating renewable energy sources to establish a resilient energy system by 2050 (Hassan et al., 2024).

4.3.2.2. Early Warning Systems

Saudi Arabia has undertaken substantial efforts to develop an EWS that plays a critical role in climate resilience and disaster preparedness across the Kingdom. Established in 2019, the EWS color-coded system is used to indicate different levels of weather alerts, from early notifications to severe warnings. Severe warnings, red alerts, activate Civil Defense measures to ensure the safety of residents and travelers in affected areas. Real-time updates are made accessible enabling both residents and authorities to respond promptly to emerging threats (Ministry of Media, 2024).

The Kingdom aims to expand its monitoring capacity from 32% to a projected 70% by increasing the number of surface and upper atmospheric stations. Additionally, remote sensing technologies such as weather radars and marine observation platforms are being integrated to capture extensive meteorological data, improving the accuracy of precipitation forecasts, valley monitoring, and early detection of severe weather events.

Integrating satellite data, meteorological analysis, and machine learning provides a comprehensive approach for forecasting and managing dust and sandstorms in Saudi Arabia.

Through these coordinated actions, Saudi Arabia is building a robust, integrated EWS infrastructure that enhances resilience by addressing environmental, agricultural, and land management challenges. This holistic approach aims to safeguard the Kingdom’s population, resources, and landscapes.

4.3.2.3. Transportation Initiatives

To increase transportation efficiency, Saudi Arabia is focusing on decreasing the reliance on private automobiles while meeting the population’s mobility demands. These initiatives are in various stages of development and implementation, aimed at enhancing mobility options while supporting resilient infrastructure.

4.3.2.3.1. Saudi Arabian Railway (SAR)

The Saudi Arabian Railway (SAR) is a national rail network that supports the Kingdom's goals to develop an efficient logistics and transportation hub. Operating 117 stations across the North and East networks, SAR enhances freight and passenger transport efficiency reducing reliance on road transport. Additionally, the Haramain High-Speed Railway (HHR) is designed to connect the holy cities of Mecca and Medina, with multiple stops at key regions facilitating efficient, high-capacity transport for pilgrims (Haramain High Speed Railway, 2021). SAR represents a critical component of Saudi Arabia's sustainable transport system, linking key regions and reducing the environmental impact of road transport. Future expansions are planned, including a dedicated railway network within Jubail Industrial City to meet industrial transport needs (Saudi Arabia, 2024).

4.3.2.3.2. Riyadh Public Transit Network Project (King Abdulaziz Project for Riyadh Public Transport)

The King Abdulaziz Project for Riyadh Public Transport, led by the Royal Commission for Riyadh City, aims to alleviate traffic congestion and provide a high-capacity, and accessible public transportation network for the city. This extensive network includes six metro lines (176 km), along with 80 bus routes. In its initial phase, the metro system can accommodate 1.2 million passengers daily, with a potential capacity increase to 3.6 million.

4.3.2.3.3. Jeddah Public Transport Program (JPTP)

The Jeddah Public Transport Program (JPTP) is another comprehensive initiative that combines multiple transit options, including an automated metro, and light rail. These projects aim to enhance accessibility, reduce reliance on private vehicles, and contribute to sustainable urban growth (Saudi Arabia, 2024; Almatar, 2024).

Collectively these projects represent Saudi Arabia's efforts to building a resilient, sustainable, and interconnected urban infrastructure. By prioritizing public transit, the Kingdom is improving air quality, reducing consumption, optimizing resource use, and enhancing quality of life across its cities.

4.3.2.4. Solid Waste Management

Saudi Arabia is advancing innovative solid waste management practices that promote resource efficiency and environmental protection. Central to this effort is MWAN, whose approach is grounded in circular carbon economy principles, aiming to optimize resource use, reduce waste, and promote sustainable development throughout the country (MWAN, n.d.).

SGI aims to divert 94% of waste from landfills in Riyadh by 2035, a significant step towards reducing the environmental impact of waste disposal (SGI, 2024). To further the Kingdom’s greater initiative, in 2022, Saudi Investment Recycling Company (SIRC) successfully processed 600,000 tons of industrial waste and recycled 16 million tons of construction and demolition materials (SIRC, n.d.).

This holistic approach promotes sustainable waste management, economic growth, and public health enhancement in alignment with Saudi Arabia’s Vision 2030 objectives.

4.3.3. Water & Wastewater Management

In response to the Kingdom's scarce water resources and growing demand, the Kingdom has made significant advances in water and wastewater management as part of its adaptation plan.

Key goals include expanding network coverage across the country, increasing the volume of collected wastewater to reduce the environmental impact of untreated sewage, and enhancing the availability of sewage treatment plants (STPs) throughout the Kingdom.

Currently, the wastewater network coverage stands at 60%, with an aim to reach 95%-100% by 2030. As the network coverage expands, the volume of collected wastewater is projected to increase to 10.8 million m^3 per day by 2030 (SWPC, 2020). As of 2022, Saudi Arabia had 143 sewage treatment plants, with 434 million m^3, or 22.5%, of treated water being reused. The Kingdom is also focusing on increasing energy-efficient Reverse Osmosis technology, gradually replacing the energy-intensive thermal MSF and MED technologies (SWCC, 2022).

4.3.3.1. Ministry of Environment, Water, and Agriculture (MEWA)

The National Water Strategy, developed by the Ministry of Environment, Water, and Agriculture (MEWA), addresses the Kingdom's limited groundwater resources and arid climate. This strategy aims to ensure the availability of safe water, improve water demand management, and maintain water quality. In support of these objectives, MEWA will also implement Water Law and Resource Management Regulations that will establish a comprehensive range of policies and create a legal and regulatory framework for managing water resources (MEWA, n.d.).

4.3.3.2. National Water Company (NWC)

The National Transformation Program, operated through the National Water Company, aims to enhance water infrastructure and expand wastewater services (NWC, .d). To cater to urban growth, NWC is expanding its wastewater services, with an aim of increasing coverage to 63% by 2025 (NWC, n.d.). It is focusing on maximizing treated sewage effluent (TSE) reuse as an alternative water source, rehabilitating existing treatment plants, and establishing new ones to improve treated water quality water, with an aim of reusing 25% of TSE by 2025 (NWC, n.d.).

4.3.3.3. The National Water Efficiency and the Conservation Center (MAEE)

MAEE was established to enhance water efficiency and promote conservation efforts. Its aim is to coordinate the efforts of both government and non-government entities to improve water efficiency throughout the supply chain, promoting water conservation, increasing public awareness, and developing advanced techniques and capabilities (MAEE, 2024). MAEE supports the objectives of Vision 2030 and the National Water Strategy by offering consulting and technical services to urban, agricultural, and industrial sectors (MAEE, 2024).

4.3.3.4. Saudi Water Authority (SWA)

SWA manages an extensive water distribution network, ensuring reliable access to drinking water across urban and rural areas. The authority also oversees wastewater management, with treated wastewater being repurposed for irrigation and other uses, reducing reliance on natural water resources.

The water treatment process employed by SWA is comprehensive, utilizing a triple-stage approach that includes mechanical filtration, chemical processes, and biological treatments to ensure water quality. Treated water is not merely discarded; instead, it is recycled for multiple applications, including industrial processes, cleaning, and irrigation purposes, further conserving freshwater resources (SWA, 2024).

4.3.3.5. The Saudi Irrigation Organization (SIO)

SIO complements these efforts by advancing agricultural water management, providing farmers with water-saving devices, and developing models to estimate water needs. Through conservation campaigns and a technical center for advanced irrigation, SIO is promoting efficient dam water use and supporting sustainable agriculture (SWCC, 2022a; SWC, 2022b; SIO, 2024a; SIO, 2024b).

These efforts align with the Saudi Green Initiative, which promotes the development of new technologies for treating and utilizing water. Through these initiatives, Saudi Arabia aims to ensure a sustainable water future, preserving its vital resources while achieving the ambitious goals outlined in Vision 2030.

4.3.4. Nature-Based Solutions and/or Ecosystem-Based Approaches

The Kingdom is implementing a range of nature-based solutions and/or ecosystem-based approaches aimed at preserving ecosystems, restoring biodiversity, and promoting sustainable resource management. These efforts focus on enhancing marine and coastal resilience, protecting natural habitats, and addressing challenges posed by desertification.

4.3.4.1. Blue Carbon Initiatives

Saudi Arabia recognizes the importance of blue carbon as crucial adaptive measures in its environmental strategy. Blue carbon refers to the carbon stored in coastal and marine ecosystems, including mangroves, seagrasses, salt marshes, and seaweed. The King Abdullah University of Science and Technology (KAUST) is at the forefront of research on carbon with its Red Sea Research Center conducting studies to understand how these ecosystems help combat climate change. By studying the carbon sequestration potential of these habitats, researchers can develop conservation and restoration plans. Notably, mangroves play a key role as a CO_2 storage source and their presence in the Red Sea region has expanded by 30% due to national efforts (KAUST, 2017).

National entities have undertaken significant habitat protection initiatives, including the establishment of a 64 km^2 mangrove eco-park featuring mangrove forests, salt marshes, and seagrasses. Collectively, these efforts have resulted in the planting of over 4.3 million mangrove trees along the Arabian Gulf and Red Sea coasts, with an additional 2 million mangrove seedlings being planted in Yanbu. These projects underscore the Kingdom's commitment to safeguarding coastal ecosystems and enhancing blue carbon resources as part of its environmental and conservation goals (Aramco, n.d.).

4.3.5. Marine Ecosystem Initiatives

Saudi Arabia is prioritizing coastal preservation, nature reserves, and island ecosystems to support biodiversity conservation as part of Vision 2030. To achieve these objectives, Saudi Arabia has implemented various national regulations such as the General Environmental Law, Wildlife Protected Areas Regulation, Wildlife Animal and Bird Hunting Regulation, and the Regulation on Trafficking of Endangered Wildlife Species and their Products. Through the SGI, Saudi Arabia aims to protect 30% of its terrestrial and marine areas by the year 2030, with current protection extending to 6.5% of marine environments (Saudi & Middle East Green Initiatives, n.d.) (Ibid).

The coastal regions of Saudi Arabia, especially along the Red Sea and Arabian Gulf, are home to coral reefs that play a vital role in supporting marine life. In 2021, several offshore floating nurseries have been established to sustain and grow rescued corals, achieving a 97% success rate (Red Sea Global, n.d.; Saudi & Middle East Green Initiatives, n.d.).

Moreover, the Kingdom has joined international treaties, including the United Nations Convention on Biological Diversity, highlighting its dedication to global environmental stewardship (Unified National Platform, 2020a).

4.3.6. Afforestation & Biodiversity Conservations

The Kingdom is concentrating on improving rural arid and semi-arid areas through conservation efforts that enhance biodiversity and adopt ecosystem-based adaptation measures. These initiatives aim to enhance soil health, water conservation, grazing lands and wildlife habitats by establishing a network of protected zones and reserves. By 2030, the Kingdom aims to increase protected land coverage to over 30%, equating to approximately 600,000 square kilometers (Kingdom of Saudi Arabia Green Financing Framework, 2024).

Since its establishment in 2021, the SGI has made substantial progress, with over 49 million trees and shrubs planted and 94,000 hectares of degraded land rehabilitated. These endeavors are expected to restore essential ecological functions, improve air quality, and reduce the impact of sandstorms. (Saudi & Middle East Green Initiatives, n.d.).

The Kingdom also pursues efforts in sand stabilization, through establishing vegetative green belts around urban areas and roadways to stabilize sand movement, enhance CO_2 absorption, and support ecosystem resilience (Kingdom of Saudi Arabia, 2021).

4.3.7. Hajj and Health

4.3.7.1. Background

The Hajj pilgrimage is one of the five pillars of Islam, mandating that every Muslim must undertake this pilgrimage to Mecca at least once in their lifetime (Fadhly et al., 2024). Over time, the logistics of the pilgrimage have evolved, with modern transportation methods such as air travel facilitating the journey for millions of Muslims globally.

The pilgrimage is not only a religious obligation but also a significant event that necessitates extensive preparation and planning, drawing over two million people annually (Gatrad & Sheikh, 2005). This influx of large diverse populations poses logistical challenges, such as ensuring adequate safety measures, resources, and managing health risks, particularly the spread of infectious diseases due to the high density and varied sanitation conditions (Kawasi et al., 2024).

4.3.7.2. Demography of Hajj Pilgrims

The Hajj pilgrimage draws millions of Muslims from around the world to Mecca, Saudi Arabia. The age distribution of Hajj pilgrims is notably skewed towards older adults, with nearly half of the pilgrims being 56 years of age or older (Memish, 2018). In terms of numbers, the Hajj pilgrimage has seen substantial fluctuations over the years. Historically, the number of pilgrims was relatively small, with about 60,000 visiting Mecca annually until 1946, primarily from the Arabian Peninsula. However, this number has surged to millions, driven by factors such as global population growth, improved safety, and the availability of affordable mass transport (Lecocq, 2012). In recent history, the pilgrimage has attracted around two and a half million pilgrims annually (Gatrad & Sheikh, 2001), with expectations that the numbers could grow to 4.5 million by 2030 as part of Saudi Arabia's Vision 2030 initiative, as depicted in figure 1 below (Memish, 2018).

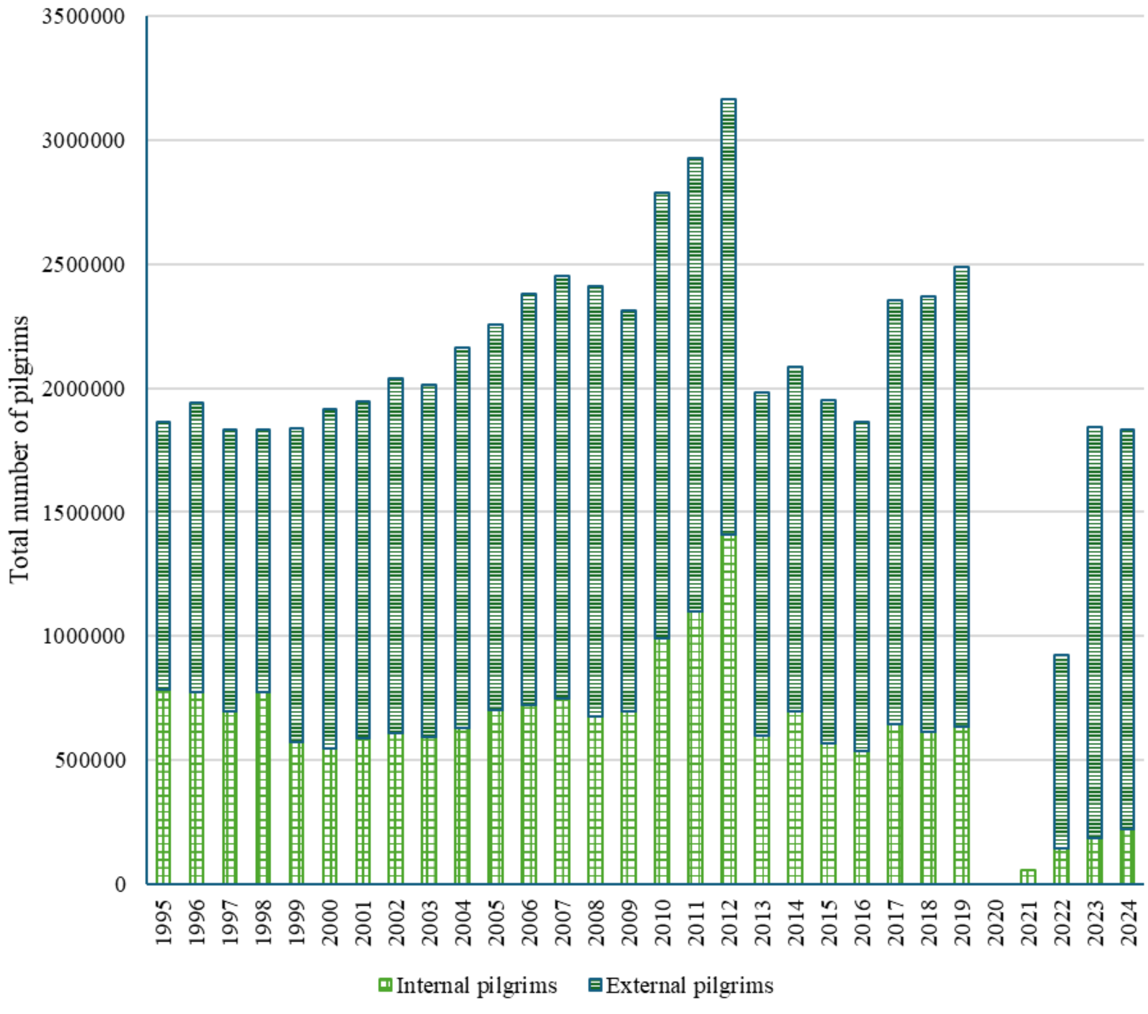

Figure 1. Annual trend of the number of Hajj pilgrims (GASTAT, 2024).

4.3.7.3. Recent Infrastructure and Service Provision Initiatives by Saudi Arabia

Recent development in infrastructure and support for the Hajj pilgrimage by the Kingdom have focused on enhancing transportation, health, safety, and security to accommodate the millions of pilgrims who attend annually. Saudi Arabia has invested significantly in transportation systems, including buses, trains, and pedestrian routes, to manage the movement of pilgrims between ritual sites (Owaidah et al., 2023). Moreover, it has invested in the implementation of intelligent transportation systems that utilize AI to predict traffic patterns and optimize routes, thereby reducing congestion and travel time during the Hajj (Bandarupalli, 2024). To address the logistical challenges posed by the massive influx of pilgrims, Saudi authorities have implemented advanced planning and communication strategies, including the use of real-time database management systems for immigration processing (Khwaja, 2017). Overall, the evolution of Hajj infrastructure and services reflects a complex interplay of historical, technological, and cultural factors, aimed at accommodating a growing and diverse population of pilgrims.

4.3.7.4. Health Support Provided by the Kingdom

Saudi Arabia has implemented comprehensive health support measures during the Hajj pilgrimage to ensure the safety and well-being of millions of pilgrims who gather annually in Mecca. These measures are particularly crucial given the diverse backgrounds of pilgrims, many of whom come from countries with varying levels of healthcare infrastructure and disease prevalence (Memish, 2018). The Kingdom has developed a robust healthcare system that includes free healthcare services for all pilgrims (Falatah et al., 2021). For instance, the Kingdom has introduced a range of measures to alleviate the risks associated with heat strokes such as water sprinklers and provision of free water bottles and umbrellas, as well as air conditioned heat-resistant tents, especially during the summer season where risks of heat strokes increase (Yezli et al., 2024). The Kingdom has also established an infectious disease surveillance system that operates year-round and is enhanced during Hajj to ensure timely reporting and response to potential outbreaks (Alotaibi et al., 2017). This system was particularly effective during the COVID-19 pandemic, where a multidisciplinary team successfully implemented a risk mitigation plan that resulted in zero COVID-19 cases during the 2020 Hajj (Jokhdar et al., 2021). Vaccination strategies are a critical component of the health support provided, with mandatory vaccinations for diseases such as meningococcal meningitis, polio, and yellow fever, and recommended vaccinations for influenza and COVID-19 (Alshamrani et al., 2024).

The Saudi Ministry of Health collaborates with international organizations like the World Health Organization to strengthen these efforts and ensure compliance with international health regulations (Memish et al., 2012). Additionally, primary healthcare centers play a vital role in managing common health issues among pilgrims, such as respiratory and musculoskeletal diseases, by providing timely medical consultations and dispensing necessary medications (Yezli et al., 2022). Significant resources are allocated to health communication and prevention programs to ensure the safety of over two million pilgrims attending annually, addressing challenges such as crowd crush, sunstroke, and contagious diseases (Taibah et al., 2020). Overall, the Kingdom's health support during Hajj is a multifaceted approach that combines preventive measures, real-time surveillance, and international collaboration to safeguard the health of pilgrims and prevent the spread of infectious diseases globally (Hashim et al., 2021).

4.4. Conclusion

The Kingdom of Saudi Arabia recognizes adaptation as a global challenge with national, regional and international dimensions, as outlined in Article 7 of the Paris Agreement. As a country particularly vulnerable to climate impacts, Saudi Arabia has developed a comprehensive approach to adaptation that enhances adaptive capacity, strengthens resilience, and reduces vulnerability in line with the Global Goal on Adaptation.

The Kingdom faces distinct physical and socioeconomic vulnerabilities that necessitate robust adaptation action. As an arid country with sensitive ecosystems, Saudi Arabia contends with significant challenges including water scarcity, desertification, and extreme weather events such as heat waves and dust storms. These physical vulnerabilities are compounded by socioeconomic factors that require careful consideration in adaptation planning. The Kingdom recognizes that addressing these challenges requires sustained investment in adaptation measures that protect both natural resources and human wellbeing, while supporting economic diversification efforts that enhance overall resilience. This is particularly important given the Kingdom's young and growing population, which requires sustainable economic opportunities and reliable access to resources in a changing climate.

Through Vision 2030 and the Saudi Green Initiative, the Kingdom has made remarkable progress in implementing adaptation measures across multiple sectors. These include developing climate-resilient infrastructure, advancing water security through innovative management solutions, protecting marine and terrestrial ecosystems, and promoting sustainable urban development. The Kingdom's CCE framework further demonstrates how adaptation efforts can yield mitigation co-benefits while supporting economic diversification.

Saudi Arabia emphasizes that successful adaptation requires adequate support and international cooperation, particularly for developing countries, in accordance with the UNFCCC and Paris Agreement principles and goals. The Kingdom continues to demonstrate leadership both regionally and globally through initiatives like the Middle East Green Initiative, while maintaining that adaptation actions must be country-driven and aligned with national circumstances and development.

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Chapter 5

Financial, Technology Transfer, and Capacity Building Support

Table of Contents

5.1. Capacity Building Support Provided

The Kingdom of Saudi Arabia has engaged in multiple knowledge sharing and capacity building initiatives across sectors. For example, the Circular Carbon Economy Regional Collaboration (CCERC), established under the MGI, aims to foster cooperation among MENA countries in achieving their climate goals. The CCERC focuses on four pillars: capacity building, technology knowledge development and transfer, policy dialogue, and joint investments. Significant progress has been achieved under the capacity building and technology knowledge pillars, with targeted initiatives addressing the specific needs of the region.

The Capacity building efforts under the CCERC have been implemented through workshops, training programs, and knowledge-sharing platforms. These initiatives have focused on key areas such as energy efficiency, renewable energy, CCUS, clean hydrogen, and methane emissions abatement. These initiatives have supported regional stakeholders by fostering collaboration, sharing knowledge, and enhancing technical expertise.

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Workshops organized by the CCERC have provided a platform for MENA countries, regional stakeholders, and international organizations to exchange knowledge and best practices. Workshops focusing on energy efficiency and

CCUS, for example, have facilitated the dissemination of tools and strategies to address regional challenges while aligning with global climate commitments.

In addition to workshops, the CCERC has delivered targeted training programs in collaboration with entities such as **SEEC**, universities, and international think tanks. These training sessions have focused on practical topics, including energy efficiency fundamentals, CCE technologies, and methane emissions reduction, equipping participants with the knowledge and skills necessary to implement effective solutions.

A key initiative under the CCERC is the establishment of the **CCE Knowledge Hub**, a digital platform designed to support knowledge-sharing efforts. The Knowledge Hub provides access to information on CCE approaches, technologies, case studies, and best practices, enabling stakeholders across the region to benefit from a centralized resource. Officially announced by HRH Prince Abdulaziz Bin Salman, the Minister of Energy, during the second SGI Forum in Sharm El-Sheikh in November 2022, the platform demonstrates the CCERC's commitment to sustained capacity building and regional cooperation.

These efforts reflect the CCERC's role in enhancing the capacity of MENA countries to address climate challenges. By promoting collaboration, providing technical resources, and fostering knowledge exchange, the CCERC supports the region in advancing its climate objectives and adopting sustainable practices.

5.2. Support Received

The implementation of the Kingdom’s NDC is not contingent on receiving international financial support. However, in its economic diversification efforts, Saudi Arabia recognizes that the development of a skilled and knowledgeable young workforce is essential to achieving its long-term goals. With a rapidly growing population and a significant percentage under the age of 30, the

Kingdom has prioritized capacity building and knowledge transfer to equip its youth with the expertise and competencies needed to thrive in emerging industries, including renewable energy, advanced technologies, and sustainable development. To support these efforts, Saudi Arabia has sought and received crucial capacity building support. One significant avenue of this support has been the National IPCC Software Workshop, which aimed to train local professionals in using the IPCC software essential for compiling accurate greenhouse gas inventories. This capability is critical for Saudi Arabia to monitor its emissions effectively and align with international standards, thus demonstrating its commitment to transparency in climate reporting.

Furthermore, Saudi Arabia hosted a regional Workshop on the Implementation of the Enhanced Transparency Framework (ETF), which focused on building national and regional capacities for data collection, reporting, and verification. This initiative was particularly important as it enhances technical expertise in complying with the expanded requirements established by the Paris Agreement. By engaging in these capacity-building efforts, the Kingdom is better equipped to manage its climate-related data and implement effective policies.

Overall, the support received through these workshops has been instrumental in increasing Saudi Arabia’s national capacities to further enhance its climate monitoring and reporting systems.

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Chapter 6

Flexibility Provisions

Saudi Arabia, as a developing country Party, implemented flexibility provisions, as needed, under the ETF of the Paris Agreement in its national greenhouse gas inventory reporting.

In accordance with paragraph 48 of 1/CMA.18, the Kingdom will focus on reporting emissions of the three main greenhouse gases (CO_2, CH_4, and N_2O). Regarding uncertainty analysis, the Kingdom will provide qualitative discussions of uncertainty for key categories using the IPCC guidelines, as per paragraph 29 of the MPGs. The Kingdom will also identify key categories using a threshold no lower than 85 per cent, as per paragraph 25 of 18/CMA.1. Due to capacity and technical constraints, data was not readily available for a time series starting from 1990, therefore the flexibility specified in paragraph 57 has been utilized.

In tracking progress towards the NDC, flexibilities have been applied in accordance with paragraphs 85 and 92 of 18/CMA.1

These flexibility provisions are being applied in line with the Kingdom's national circumstances and capabilities while maintaining the Kingdom's commitment to enhancing the inventory preparation process and NDC tracking over time through continuous improvement of the national reporting and greenhouse gas inventory systems over the coming years.