OPPORTUNITIES FOR CLIMATE CHANGE MITIGATION IN AGRICULTURE

AND INVESTMENT REQUIREMENTS TO TAKE ADVANTAGE OF THESE OPPORTUNITIES

A report to the UNFCCC Secretariat

Financial and Technical Support Programme

2 July 2007

World Agroforestry Centre
TRANSFORMING LIVES AND LANDSCAPES

Dr. Louis V. Verchot

International Centre for Research in Agroforestry

P.O. Box 30677

Nairobi, Kenya

Units and Conversions:

1 Gt	1 Gigatonne = 1 billion tonnes = 10^9 tonnes
1 Mt	1 Megatonne = 1 million tonnes = 10^6 tonnes
tC	Tonne carbon
1 tCO_2	0.27 tC
1 tC	3.67 tCO_2
$1tN_2O$	310 tCO_2e
$1tCH_4$	21 tCO_2e

Table of Contents

1. Introduction

1.1. Scope

[1] At COP 12, Parties agreed on important mandates requesting the secretariat to undertake work on existing and planned investment flows and finance schemes relevant to the development of an effective and appropriate international response to climate change. These mandates imply a particular focus on developing countries' needs, including their medium- to long-term requirements for investment and finance.

[2] This paper is a contribution for consideration in deliberations on the fourth review of the financial mechanism and to the fourth workshop on the dialogue on long-term cooperative action to address climate change by enhancing implementation of the Convention. The TOR require the consultant to:

- Summarize GHG emissions for the reference or business as usual (BAU) scenario and the mitigation scenario with as much geographic and sub-sectoral detail as possible.
- Provide an overview of current sources of financing (domestic, international, public private) in the agricultural sector.
- Determine the financing needs for the adaptation scenario and how current financing arrangements need to change to meet the requirements of this scenario with as much geographic and sub-sectoral detail as possible.

1.2. Background

[3] Agricultural lands, comprising arable land, permanent crops and pasture, occupy about 40% of the earth's land surface (FAOSTAT, 2007), and these lands are expanding. Most of the agricultural land is under pasture (~70%), and only a small percentage (<3%) are under permanent crops. Over the past four decades, an average of 6 million ha of forest and grassland has been converted to agriculture annually. Agricultural lands will continue to increase in the coming decades, with large increases expected in Latin America and Africa (see Rosegrant et al., 2001 IPCC Ch3).

[4] It is particularly difficult to estimate actual GHG emissions from agriculture and other land uses because of the high degree of both spatial and temporal variability associated with the underlying causes of these emissions. The spatial variability has to do with both the variation in the biophysical environment and variation in farm management. This is particularly problematic for estimation of the non-CO_2 GHGs like nitrous oxide (N_2O) and methane (CH_4), both of which present large variation across landscapes and regions (Verchot et al., 1999; 2000; Davidson et al., 2000; Davidson and Verchot 2000). Temporal variability is driven to a large extent by inter-annual variations in local weather and how farmers respond to these variations.

[5] Our best estimate is that agriculture accounts for about 10-12% of the total global anthropogenic emissions of GHGs or between 5.1 and 6.1 GtCO_2e per annum. Emissions are increasing rapidly in agriculture and between 1990 and 2005; these increases are estimated to have been on the order of 17%. Emissions are expected to continue to increase due to increased demand for food as populations grow, and shifts in diets as societies in developing countries become wealthier and meat consumption increases.

[6] There are two types of emissions from agriculture:

- Non-CO_2 GHGs from management operations = 6.2 Gt CO_2e
- Energy related CO_2 emissions (including emissions from manufacture of fertilizer) = 0.6 Gt CO_2e

[7] Energy related emissions are small from the sector both in absolute magnitude and as a percentage of the emissions from the sector. Non-CO_2 GHG emissions are an order of magnitude greater than the energy emissions. A third type of emission from land-use change is often associated with agriculture is also large at around 7.6 Gt CO_2e. Deforestation emissions will not be addressed in this paper, as it is generally treated as an issue for the forestry sector. The focus of this paper is on emissions within agriculture. Thus, the energy and non-CO_2 GHGs emissions will be treated in separate sections. However, due to the importance of non-CO_2 GHGs, most of the attention of this paper will be focused on mitigation of these emissions.

[8] The paper first presents an analysis of the current situation and likely future trends. Because emissions from agriculture are non-point source emissions and involve, for the most part, changes in management practices and technologies across regions, the approach to estimating a mitigation scenario needs to be based on costs of altering agronomic practices and farming technologies. Thus, reasonable mitigation scenarios for agriculture were constructed using the abatement costs for the individual gases. The abatement costs are used to calculate the financial requirements for mitigation. A review of the current sources of financing (domestic, international, public, private) for agriculture was used to assess of how current financing arrangements need to change to meet the requirements of the mitigation scenario and assess the order of magnitude of the investments required.

[9] In addition to reducing emissions from agricultural production there are opportunities within the agricultural sector for additional measures to mitigate climate change. For example, there is a trend emerging for use of agricultural products to replace fossil-fuel based products, such as biomass energy, bio-plastics, and bio-fuel. This has the potential to reduce fossil-fuel emissions in the future, but emissions of non-CO_2 GHGs will increase, particularly as production systems intensify.

[10] Improved tillage practices have the potential to increase soil carbon storage and reverse the decline of soil carbon in newly converted lands. Thus there is much interest in this practice both from the side of reducing energy use for tillage and for the potential for

agricultural soils to be carbon sinks. In many cases however, infrequent tillage is practiced to control weeds, so the net long-term effects of this practice still needs to be evaluated.

[11] Finally, although not considered in this report, changes in macroeconomic policy and regional patterns of production and demand lead to increased international trade in agricultural products. Increased transportation of agricultural products will lead to increased emissions.

1.3 Mitigation Potential

[12] Mitigation potential in agriculture can be defined as either the technical potential or the economic potential. The technical potential for mitigation options in agriculture by 2030, considering all gases was estimated at around 4500 Mt CO_2e by Caldeira et al (2004). Smith et al (2007a) produced a higher estimate of between 5500 and 6000 Mt CO_2e. These estimates assume no economic barriers. The economic potential is of course considerably lower.

[13] The greatest technical potential for climate change mitigation is in soil carbon. Mitigation of N_2O and CH_4 offer a much smaller opportunity. Uncertainty for these estimates is high. The 95% confidence interval around the mean of 5800 Mt CO_2e obtained by Smith (2007) is 300-11400 Mt CO_2e. The USEPA has developed marginal abatement curves for non-CO_2 GHGs and soil carbon that estimate the abatement potential at different prices of carbon (USEPA 2006b).

[14] Energy emissions are low relative to other emissions in agriculture. Nevertheless, there are some opportunities associated with substituting biofuels for fossil fuels. Reductions can also be achieved through cleaner electricity generation.

[15] The most appropriate mitigation strategy and mix of mitigation practices will vary by region and by country.

2. Soil C and Non-CO_2 GHGs

[16] Agriculture accounts for between 59 and 63% of the world's non-CO_2 GHG emissions (USEPA 2006a, b). This sector accounts for 84% of the global N_2O emissions and 54% of the global CH_4 emissions (USEPA, 2006b). Nitrous oxide emission from soils is the most important emission for the sector, followed by CH_4 from enteric fermentation. The driver of emissions from this sector is production, which will increase in the near future to keep pace with the growing population, particularly in tropical developing countries. A change in diet preferences and increased consumption of meat as societies become more affluent is also an important driver, particularly for emissions from enteric fermentation.

2.1. Baseline Scenario of GHG Emissions from Agriculture

[17] The US Environmental Protection Agency (USEPA) has published 2 baseline scenarios. The first scenario was generated from national GHG inventories and provides disaggregated data at the country level (USEPA 2006a). This report did not present a mitigation scenario for agricultural sources. A second baseline (USEPA 2006b) was generated from some of the same data, but used process models (DAYCENT and DNDC) to improve the estimates of N_2O from soils and both N_2O and CH_4 from rice. The objective of using process models was to better represent the heterogeneous emissions and yield effects over space and time, and the effects of adopting mitigation practices.

[18] It is worth considering the two baseline scenarios here, despite the discrepancies between them. Estimates based on national GHG inventories are useful for making comparisons between countries and regions because the methods are consistent from country to country. However, national inventories are not always transparent with respect to management, particularly when Tier 1 methods are used and thus it is difficult to evaluate the impacts of mitigation options. Because the process models have consistent assumptions for the baseline and mitigation scenarios, they allow for better comparisons than do national GHG inventories. Thus, the second baseline is more appropriate for assessing the mitigation scenario and the costs associated with mitigation.

2.1.1 First Baseline

[19] The baseline scenario for this analysis was taken from a report published by the USEPA (2006a). Baseline estimates of emissions were presented in 5-year increments between 1990 and 2020. These estimates were extended to 2030 based on a reasonable projection of the time series. In most cases, this represented a linear extension of USEPA estimates. In one case, an exponential model was used. In several cases the linear projection was based on only a portion of the data, as there were obvious discontinuities in the baseline because of the assumptions made in projecting forward to 2020. In these

cases, using all of the data for the projection would have led to gross overestimation of the baseline and in a few cases gross underestimation.

[20] In this section we account for 6 types of non-CO_2 GHG emission:

- N_2O from Soil
- N_2O from manure management
- CH_4 from enteric fermentation
- CH_4 from manure management
- CH_4 from rice cultivation
- CH_4 from other sources
  - Savannah burning
  - Burning of agricultural residues
  - Burning from forest clearing
  - Agricultural soils (CH_4)

Table 1. Baseline for non-CO_2 GHG emissions (Mt CO_2e) by source through 2030.

	Year								
Source	1990	1995	2000	2005	2010	2015	2020	2025	2030
N_2O Soil	2284	2405	2610	2782	2996	3252	3542	3774	4006
N_2O manure	196	199	205	219	230	246	261	274	288
CH_4 enteric fermentation	1772	1804	1799	1929	2079	2204	2344	2473	2601
CH_4 manure	223	225	225	235	244	257	269	282	294
CH_4 other	268	274	455	456	456	456	456	456	456
CH_4 rice	601	621	634	672	708	744	776	812	848
Global total	**5343**	**5528**	**5928**	**6291**	**6713**	**7158**	**7648**	**8071**	**8493**

[21] By 2030, non-CO_2 GHG emissions from agriculture are expected to be almost 60% higher than in 1990 (Table 1). Soil emissions from N_2O and CH_4 from enteric fermentation are the two largest sources of non-CO_2 GHGs globally. CH_4 from rice cultivation is the third largest source. The largest increases will be in N_2O emissions from soils (75%), as fertilizer use increases rapidly. Emission from CH_4 from other agricultural sources (predominantly biomass burning) will also increase greatly (70%), but these emissions will still account for only 5% of the total agricultural emissions. Emissions from manure management will still be significant and we expect increases on the order of 31% for N_2O and 47% for CH_4 from this source. Enteric fermentation emissions will still be the second largest source by 2030, but these emissions will only be 47% greater than 1990 emissions. Emissions from the other sources will increase by between 30 and 40%.

[22] Emissions of non-CO_2 GHGs were highest from South and Southeast Asia and from the Latin American and Caribbean regions (Figure 1). Emissions from these regions

are expected to grow rapidly in the BAU scenario. Emissions from sub-Saharan Africa are intermediate, but are also expected to grow rapidly in the BAU scenario. Emissions from CWANA, other developed countries, and Eastern Europe are low, and are expected to grow at a moderate pace. Non-CO_2 GHG emissions are declining in W. Europe. In all regions, the dominant sources are N_2O emissions from soils and CH_4 emissions from enteric fermentation. There are a few specificities for some regions. South and Southeast Asia has high CH_4 emissions from rice. In Sub-Saharan Africa, CH_4 from other agricultural sources (primarily biomass burning) is significant. In Western Europe, CH_4 emissions from manure management are high. All other sources generally represent <10% of the regional emissions.

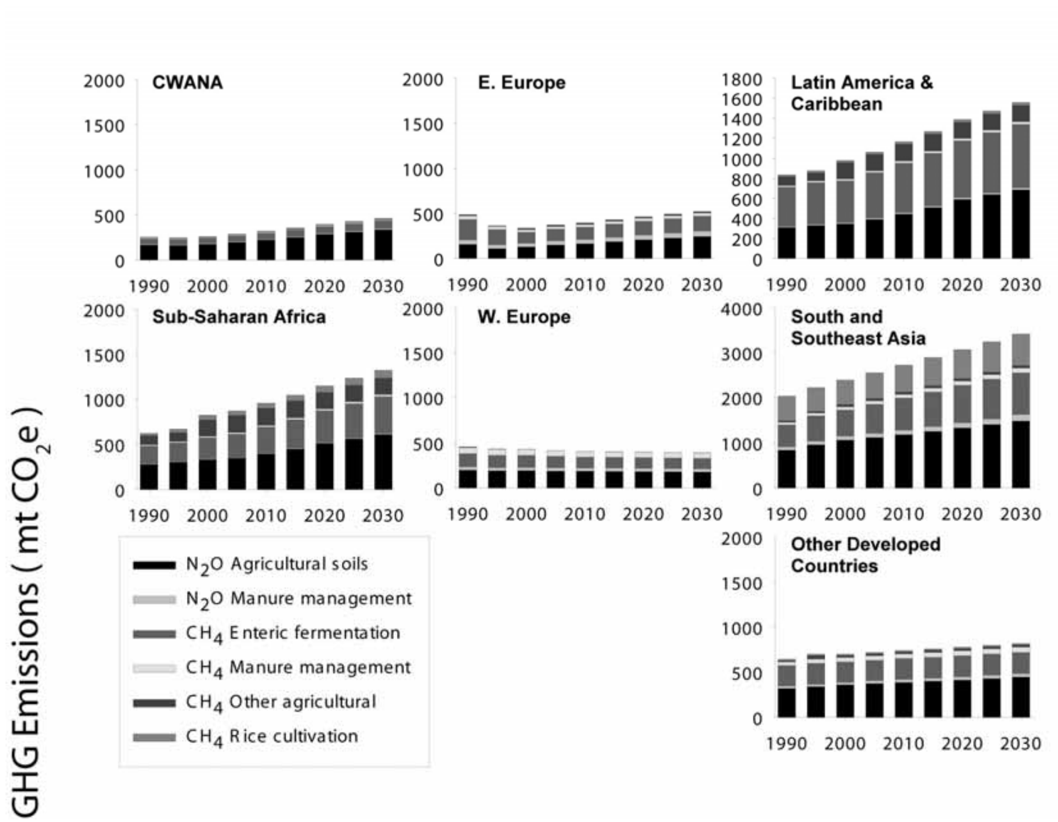

Figure 1. Regional baseline of non-CO_2 GHG emissions from agriculture.

[23] Regional breakdowns are useful for understanding where emissions occur on the globe, and there are some common elements in agricultural systems within regions. However, regions are also very heterogeneous. For example, in the figures cited above, China dominated the emissions for South and Southeast Asia. To better understand the baseline emissions story, emissions from the top 30 polluters are presented in Table 2. There is not much change over the course of the projection. China, India, Brazil, and the USA are clearly the largest polluters. For each year presented, the next largest emitter has less than half of the emissions of the country that was in fourth place.

[24] Another useful way to look at the baseline emissions scenario is through the emissions intensity of agriculture in countries (Table 3). Emissions intensity refers to relative emissions and we can consider several bases for this relative comparison. In this paper, emissions intensity is expressed on a per capita basis for relative comparison by population of the different countries. A more economic index of emissions intensity is presented based on the absolute amount of agricultural GDP or each country. The examination of emissions intensity of different countries provides insight into where emissions reductions might be achieved fairly easily, assuming that countries with high emissions intensity could theoretically adopt technologies from countries with lower intensity. The actual story is, of course, more complicated, as many countries produce for exportation and thus production is not always for local consumption.

Table 2. Top 30 emitters of non-CO_2 GHGs from agriculture ($MtCO_2e$) by year.

Country	1990	Country	2005	Country	2030
China	903	China	1,101	China	1,459
India	575	India	740	India	988
United States	440	Brazil	515	Brazil	731
Brazil	388	United States	486	United States	529
Russian Federation	168	Pakistan	150	Argentina	211
Pakistan	110	Russian Federation	135	Russian Federation	205
Mexico	106	Argentina	130	Pakistan	193
Argentina	106	Indonesia	125	Nigeria	189
France	102	Mexico	115	Mexico	170
Australia	94	Nigeria	112	Indonesia	163
Indonesia	92	Australia	106	Ethiopia	160
Germany	91	France	96	Turkey	127
Turkey	79	Ethiopia	92	Iran	124
Ukraine	76	Turkey	79	Bangladesh	116
Nigeria	73	Bangladesh	77	Australia	112
Ethiopia	70	Thailand	74	Canada	107
Thailand	66	Canada	73	Myanmar	99
Bangladesh	59	Iran	71	France	97
Canada	57	Myanmar	70	Thailand	88
Spain	54	Germany	68	Ukraine	86
United Kingdom	52	Spain	59	Vietnam	83
Iran	49	Vietnam	58	Bolivia	64
South Africa	46	Ukraine	50	Spain	64
Myanmar	45	United Kingdom	48	Venezuela	63
Italy	43	South Africa	48	Colombia	58
Vietnam	42	DR Congo	47	Germany	58
Kazakhstan	39	Venezuela	45	South Africa	57
Poland	37	Colombia	45	DR Congo	54
Colombia	37	Italy	43	New Zealand	51
New Zealand	34	Bolivia	39	Philippines	48

[25] There were no clear regional groupings in the emission intensity analysis (Table 3). Countries with high per capita emissions or high emissions per economic unit of production are candidates for technological transformations to might be able to achieve reductions at lower costs than countries that have relatively lower emissions. Further disaggregating the estimates of intensity by cropping and livestock sub-sectors (Table 4) provides a better indication of the nature of the opportunities to reduce emissions. Some countries are fairly intensive in one sub-sector or the other and can concentrate their efforts at emissions reductions. Others are fairly intensive in both sub-sectors and can spread their efforts.

Table 3. Top 30 countries for agricultural non-CO_2 GHG emission intensity expressed on the bases of per capita and agricultural GDP in 2005.

Per capita emission intensity		Per unit agricultural GDP intensity	
Country	Per capita emissions (tons)	Country	Kg CO_2e per $ agricultural GDP[1]
New Zealand	9.46	Bolivia	11.31
Uruguay	8.51	Myanmar	11.29
Australia	5.21	Mongolia	10.41
Mongolia	4.50	Vietnam	8.92
Ireland	4.42	Uruguay	8.59
Bolivia	4.38	New Zealand	8.46
Myanmar	3.55	Venezuela	6.85
Argentina	3.25	Ecuador	5.08
Bulgaria	3.06	Denmark	4.26
Brazil	2.74	Australia	4.17
Canada	2.22	United States	4.16
Denmark	2.17	Belgium	4.11
Laos	2.17	Brazil	3.99
Venezuela	1.74	Nigeria	3.43
Hungary	1.69	Bulgaria	3.29
United States	1.63	South Africa	3.20
Belarus	1.55	Hungary	3.15
France	1.54	Laos	3.12
Cambodia	1.50	Germany	2.91
Spain	1.45	Senegal	2.75
Ecuador	1.43	Canada	2.74
Iceland	1.37	Ethiopia	2.61
Belgium	1.31	Mexico	2.59
Ethiopia	1.23	United Kingdom	2.53
Thailand	1.14	Sweden	2.37
Turkey	1.13	France	2.34
Turkmenistan	1.11	Argentina	2.28
Kazakhstan	1.09	Belarus	2.12
South Africa	1.09	Ireland	2.03
Ukraine	1.08	Congo, DR	1.91

[1] Agricultural GDP was calculated from GDP and %GDP from agriculture data found on the CIA website (www.cia.gov)

Table 4. Breakdown of emission intensity for top 30 countries for agricultural non-CO_2 GHG emissions by cropping and livestock sub-sectors. Emission intensity is expressed on the bases of per capita and agricultural GDP in 2005.

Country	Cropping emissions per capita	Country	Cropping emissions (kg CO_2e per $ ag GDP[2]	Country	Livestock emissions per capita	Country	Livestock emissions (kg CO_2e per $ ag GDP[3]
Mongolia	4.54	Myanmar	8.78	N. Zealand	6.04	N. Zealand	5.40
Uruguay	4.13	Bolivia	7.67	Uruguay	4.38	Uruguay	4.42
New Zealand	3.42	Mongolia	6.67	Australia	3.28	Mongolia	3.75
Bolivia	2.97	Uruguay	4.17	Ireland	2.63	Bolivia	3.64
Bulgaria	2.59	Venezuela	3.92	Mongolia	2.55	Venezuela	2.93
Australia	1.93	N. Zealand	3.06	Argentina	1.46	Belgium	2.67
Ireland	1.79	Ecuador	2.91	Bolivia	1.41	Australia	2.62
Argentina	1.79	Denmark	2.80	Brazil	1.27	Myanmar	2.52
Brazil	1.47	Bulgaria	2.79	Spain	0.98	Ecuador	2.17
Denmark	1.43	USA	2.70	Canada	0.98	Germany	1.91
Hungary	1.34	Hungary	2.50	Iceland	0.88	Brazil	1.85
Laos	1.33	Laos	2.33	Belgium	0.85	USA	1.46
Canada	1.24	Nigeria	2.30	Belarus	0.83	Denmark	1.46
Myanmar	1.15	Brazil	2.14	Venezuela	0.74	S. Africa	1.38
USA	1.05	D.R. Congo	1.85	Denmark	0.74	Sweden	1.22
Venezuela	0.99	S. Africa	1.83	Luxembourg	0.74	Canada	1.21
Thailand	0.87	Senegal	1.67	Colombia	0.74	Ireland	1.20
Ecuador	0.82	Australia	1.55	France	0.72	Belarus	1.14
France	0.81	Ethiopia	1.54	Ukraine	0.63	Nigeria	1.13
Iran	0.79	Canada	1.53	Ecuador	0.61	U.K.	1.12
Ethiopia	0.73	Mexico	1.50	Kazakhstan	0.59	France	1.10
D. R. Congo	0.72	Belgium	1.44	Albania	0.58	Mexico	1.09
Belarus	0.71	U.K.	1.41	Azerbaijan	0.57	Senegal	1.08
Turkmenistan	0.70	Jordan	1.28	USA	0.57	Luxembourg	1.07
Turkey	0.67	Argentina	1.25	Netherlands	0.55	Ethiopia	1.07
Uzbekistan	0.64	France	1.24	Estonia	0.54	Kazakhstan	1.03
Slovakia	0.63	Iraq	1.15	Germany	0.54	Argentina	1.03
Finland	0.62	Sweden	1.15	Russia	0.51	Spain	0.95
South Africa	0.62	Peru	1.12	Portugal	0.50	Tajikistan	0.92
Mexico	0.62	Uzbekistan	1.03	Ethiopia	0.50	Switzerland	0.87

[2] Agricultural GDP represents total agricultural GDP and was calculated as in Table 1 above. It was impossible to determine the portion of agricultural GDP related to the livestock sub-sector.
[3] Agricultural GDP represents total agricultural GDP and was calculated as in Table 1 above. It was impossible to determine the portion of agricultural GDP related to the livestock sub-sector.

2.1.2 Second baseline

[26] The baseline scenario for this analysis was taken from the report *'Global Mitigation of Non-CO_2 Greenhouse Gases'* published by the USEPA (2006b). Baseline estimates of emissions were presented in 10-year increments between 1990 and 2020. These estimates were interpolated to estimate the emissions at 5-year increments and extended to 2030 based on a reasonable projection of the time series. The report breaks down the different sources of agricultural emissions. In many cases, the report uses values from the study in the first baseline (USEPA 2006a). New estimates were presented for CO_2 and N_2O emissions from soils and CH_4 and N_2O emissions from rice.

[27] In this section we do not present the disaggregated data either by country or by source, as much would be redundant. These values are presented by source in Appendix 1. The modelled estimates lead to slightly different regional and global estimates, but the regional stories do not change significantly. However, the modelled data are more useful for evaluating emissions reductions scenario because we can introduce improved practices into the model and calculate its effects and costs on a country-by-country basis. Table 5 presents estimates of the agriculture baseline net GHG emissions from cropland management, rice cultivation and livestock management.

Table 5. Baseline emissions for all agriculture (Mt CO_2e) by region through 2030.

Country/Region	2000	2005	2010	2015	2020	2025	2030
Africa	301	332	364	398	431	464	496
Annex I	1,258	1,244	1,230	1,263	1,297	1331	1364
Australia/NZ	104	107	109	110	111	112	113
Brazil	249	271	292	310	327	347	366
Canada	28	31	35	39	43	47	51
China	789	790	791	834	876	919	961
Eastern Europe	86	89	93	96	99	102	106
EU-15	313	304	296	299	303	307	310
India	417	429	441	461	480	496	512
Japan	65	57	49	49	50	51	51
L. America/Caribbean	210	228	246	262	278	295	312
Mexico	57	62	67	70	74	78	82
Middle East	37	42	47	50	53	57	61
Non-EU Europe	21	21	22	23	23	24	24
Non-OECD Annex I	282	268	254	264	274	284	294
OECD	1,018	1,022	1,026	1,053	1,080	1107	1134
OPEC	538	451	363	373	384	395	405
Russian Federation	237	219	201	208	215	222	229
South & SE Asia	1,141	991	842	870	898	926	954
South Korea	24	23	22	23	24	25	26
Turkey	45	48	51	54	56	59	62
Ukraine	23	25	27	29	32	34	36
United States	338	345	351	361	370	378	386
World	**4,563**	**4,490**	**4,417**	**4,619**	**4,822**	**5025**	**5227**

[28] Data from 2000, 2010 and 2020 are taken from the report (USEPA 2006a). Data from 2005 and 2015 were interpolated by taking the midpoint between the two years for which data were provided. The values for 2025 and 2030 were generated from linear projections either from the whole time series, when the relationship was linear, or from the last three data points in the time series when there were discontinuities.

2.2. Mitigation of Non-CO_2 GHGs

[29] There are numerous opportunities for mitigating non CO_2 GHGs in agriculture. GHG emissions can be reduced by managing carbon and nitrogen more efficiently in agricultural ecosystems (Bouwman, 2001; Clemens and Ahlgrimm, 2001). Carbon can be sequestered from the atmosphere and stored in soils or in vegetation, for example in agroforestry systems (Verchot et al., 2007; Lal, 2004a; Albrecht and Kandji, 2003). Crops and residues from agricultural lands can be used as a source of fuel to displace fossil fuel combustion, either directly or after conversion to fuels such as ethanol or diesel (Schneider and McCarl, 2003; Cannell, 2003).

[30] Extrapolating GHG emissions reductions and assessing the cost implications of emissions reductions in agriculture is particularly complicated. The high degree of the spatial and temporal variability of the biophysical conditions and management practices introduces a high degree of uncertainty in the emissions estimates. For example, soil emissions of N_2O or CH_4 from a single management unit can have coefficients of variation that exceed 200% (Verchot et al., 1999; 2000; Davidson et al., 2000). Since most research focuses on farm-level analyses, it is difficult to extrapolate the GHG reductions from these mitigation analyses to larger scales.

[31] In addition to difficulties in assessing emissions reductions, there are a number of other challenges to assessing cost implications of abatement efforts. For example, there is very little regional data from which to estimate the costs of implementing GHG mitigation practices on a regional basis (USEPA 2006b). Not all farmers will adopt new management practices, and it is also not easy to assess how they will respond to different incentive schemes.

[32] In this section, the presentation begins with a summary of mitigation options for each source considered in section 2.1.1. The implications of the mitigation options on emissions are then considered. Only one detailed example will be provided; for more detail the reader is referred to the USEPA report (USEAP 2006b). The global USEPA abatement curves are then presented and used to calculate the costs of the mitigation scenario. For a more detailed breakdown of abatement costs and the implications of the mitigation options on production, the reader is referred to the USEPA non CO_2 GHG project (http://www.epa.gov/nonco2/econ-inv/international.html).

2.2.1 Mitigation measures

[33] There are a large variety of mitigation options for agricultural gases. In many cases there are production or cost tradeoffs that need to be understood in order to design proper incentives for uptake of these practices. Mitigation measures include agronomic measures such as improved crop varieties and different crop rotations. There are a series of soil management measures including improved nutrient management and reduced tillage that will reduce emissions and sequester carbon. Better residue and water management in rice can yield significant reductions of CH_4 emissions. For livestock, there are a wide range of practices associated with grazing land management, manure management, and feeding that can reduce emissions and increase carbon sequestration. Finally, there are a number of changes in farming systems that can contribute to climate change mitigation, including the production of biofuels to reduce the use of fossil fuels and adoption of agroforestry for carbon sequestration. A more detailed list of mitigation practices is presented in Appendix 2.

2.2.2 Specific example: Mitigation options for cropland N_2O emissions

[34] Emissions of N_2O from croplands are often associated with applying fertilizer in excess of crop demands. One mitigation goal might be to reduce excess fertilizer application while maintaining high yields. The USEPA (2006b) produced an estimate of the technical potential to reduce global soil N_2O emissions through a number of agronomic and nutrient management practices using the DayCent model for maize, soybean and wheat. The following mitigation options were considered:

- Split fertilization: Application of the same amount of fertilizer as in the baseline, but divided into three smaller increments. Only the N_2O implications of this practice were considered in this analysis, the emissions from additional energy required to apply the fertilizer are not accounted.
- Simple fertilizer reduction of 10% with a single application, as in the baseline.
- Simple fertilizer reduction of 20% with a single application, as in the baseline.
- Simple fertilizer reduction of 30% with a single application, as in the baseline.
- Application of nitrification inhibitors, which reduce the conversion of ammonium to nitrite.
- Reduced tillage to maintain higher levels of soil organic matter. This practice promotes sequestration of soil carbon, but tends to increase N_2O emissions.

[35] The modelling exercise showed that reduced N fertilization had little impact on emissions, while the use of reduced tillage and nitrification inhibitors had the greatest impact (Figure 2). Furthermore, reducing N inputs reduced soil carbon stocks, offsetting the small reductions in N_2O emissions. Greater reductions were achieved by the use of nitrification inhibitors such as nitrapyrin, diycaydiamide, or DMPP (3,4-dimethylpyrazole phosphate). Reduced tillage and splitting of fertilizer application to better match plant demand also greatly reduced emissions.

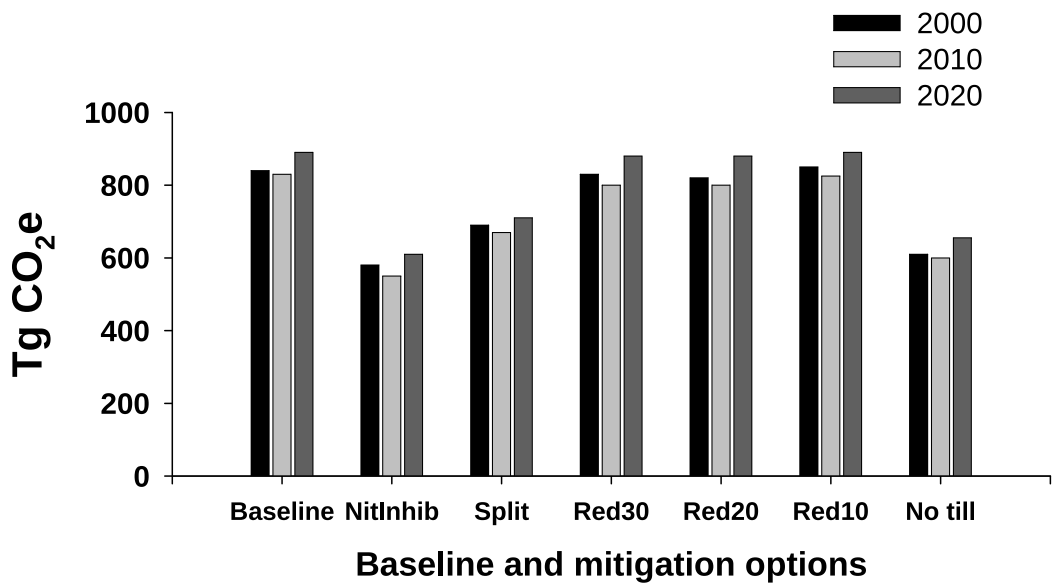

Figure 2: Global net GHG emissions from croplands (N_2O and soil carbon) estimated by DAYCENT under baseline and mitigation scenarios. Figure adapted from USEPA 2006b).

2.3 Cost of Mitigation

[36] This section draws very heavily on the USEPA report *'Global Mitigation of Non-CO_2 Greenhouse Gases'* (USEPA 2006b). The USEPA constructed marginal abatement curves for different regions and different sectors by estimating the carbon price at which the present value benefits and costs for each mitigation option equilibrates (present value of benefits = present value of cost). This produced a stepwise curve that reflects the average price and reduction potential if a mitigation technology were applied across the sector within a given region.

[37] Costs included capital, or one-time costs, and operation and maintenance costs, or recurring costs. The calculation included a tax rate of 40% and used a 10% discount rate. Benefits included the intrinsic value of CH_4 as either a natural gas or as fuel for electricity or heat generation, non-GHG benefits of abatement (e.g. improved nutrient use efficiency), and the value of abating the gas given a GHG price. The breakeven price calculations do not include transactions costs. All calculations were in US$ from the year 2000. More details on the construction of these curves can be found in the report.

[38] Marginal abatement curves showed the amount of emissions abatement in $MtCO_2e$ on the ordinate and the abscissa shows the break-even price (or cost) in $per tCO_2e required to achieve the level of abatement. Thus, moving from left to right along the

curve, the lowest cost abatement options are adopted first. The curve becomes vertical at the point of maximum total abatement potential.

[39] Most of the abatement curves indicate negative costs for some level of abatement. This means that some GHG emission reduction is already feasible and cost effective. These activities have not yet been implemented because there are non-monetary barriers that need to be overcome. These opportunities are often referred to as "no regret" options. The curves all become very steep or even vertical at around $30. Thus, for this analysis, we will assume that this is the maximum economic level of abatement and we will calculate the abatement potentials at this level of cost.

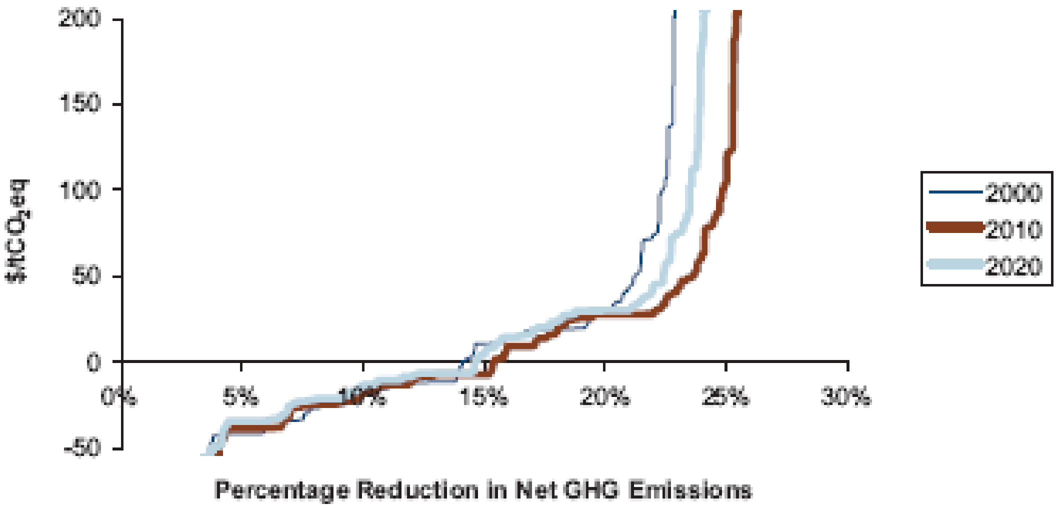

Figure 3: Global marginal abatement curve for net GHG emissions form croplands, holding area constant. Source: USEPA 2006b.

2.3.1 Croplands

[40] The report presents tables showing regional breakdowns of different mitigation technologies for key crops that report the change in yield compared to the baseline, the breakeven cost per tCO_2e, and both the absolute and relative emissions reduction associated with the technology. These tables are extensive will not be presented here.

[41] Regional abatement curves were generated as was a globally aggregated abatement curve (Figure 3). The curve assumes a constant cultivated area, which is reasonable for analyses over short time frames. This curve was used to generate the summary of net reductions at different carbon prices for croplands that is presented in Table 6. Projected abatement for 2030 was based on the 2020 abatement curve and an estimated baseline emission from constant rates of emission increases between 2010 and 2030. These reductions are for both N_2O emissions and soil C, relative to the croplands portion of the baseline presented in section 2.1.2 of this report.

[42] Globally, approximately 15% of the net emissions from croplands can be mitigated at a net benefit or at no cost (< \$0/tCO_2e). There is little change in the relationship between cost and abatement between 2000 and 2030. For example, 22 to 23% of the net emissions can be mitigated for less than \$30/tCO_2e (or about 190 MtCO_2e). Beyond this point, costs rise rapidly. The greatest potentials for negative- and low-cost reductions are in the Russian Federation, Non-OECD Annex I countries, Australia/New Zealand, and the United States. Moderate potential exists in most other countries, with the exception of Brazil, China, India and countries from South and Southeast Asia.

Table 6: Potential reductions (MtCO_2e) of net emissions (N_2O and soil carbon) from croplands for selected countries and regions with emissions reductions costs of \$0 and \$30 per tCO_2e (costs are in 2000\$). Table adapted from USEPA (2006b).

	2010		2020		2030	
Country/Region	\$0	\$30	\$0	\$30	\$0	\$30
Africa	3.6	4.4	3.8	4.9	4.2	5.4
Annex 1	99.7	143.7	102.1	126.1	109.4	135.0
Australia/New Zealand	3.6	4.2	3.7	4.4	3.7	4.4
Brazil	1.6	4.0	1.4	3.7	1.4	3.7
China	6.2	6.5	6.0	7.6	6.4	8.1
Eastern	5.7	8.2	5.5	8.5	5.8	8.9
EU-15	11.1	12.1	10.9	11.5	11.8	12.4
India	4.3	7.9	4.2	8.4	4.5	8.9
Japan	-	-	-	-	-	-
Mexico	1.7	3.7	2.9	6.5	4.2	9.3
Non-OECD Annex 1	34.8	58.8	34.7	39.3	35.0	39.6
OECD	60.8	80.4	63.4	82.1	69.4	89.8
Russian Fed	34.8	58.8	34.7	39.3	35.0	39.6
S&SE Asia	2.1	2.5	2.3	3.1	2.5	3.3
United States	38.8	51.0	40.6	53.0	44.9	58.6
Global Total	**127.8**	**182.6**	**130.4**	**167.9**	**139.6**	**179.7**

2.3.2 Rice cultivation

[43] Rice cultivation is an important agricultural activity in South and Southeast Asia, with China and India being the largest producers. The USEPA report (2006b) presents tables showing the breakdowns of different mitigation technologies for these countries that report the change in yield compared to the baseline, the breakeven cost per tCO_2e and both the absolute and relative emissions reduction associated with the technology. These tables are extensive will not be presented here.

[44] Regional abatement curves were generated as was a globally aggregated abatement curve. The curve assumes a constant cultivated area, which is reasonable for analyses over short time frames. This curve was used to generate the summary of net percentage reductions at different carbon prices for croplands that is presented in Table 7. These reductions are for both non CO_2 GHG emissions and soil C, relative to the rice cultivation

portion of the baseline presented in section 2.1.2 of this report. There is a significant shift in the abatement curve between 2000 and 2010, due to a substantial shift in the baseline emissions. An important factor behind this change in the baseline comes from the projection that China will greatly reduce its baseline during this period and there will be fewer emissions to abate in the future.

[45] Globally, in 2000 approximately 3% of the net emissions from rice cultivation could be mitigated at a net benefit or at no cost (< $0/tCO_2e). At a price of $30/tCO_2e, 13 percent could be mitigated in 2000, after which costs rise sharply. With the shift in the abatement curve, mitigation potentials rise to 11% at a net benefit or no cost in 2010 and to 22% at $30/tCO_2e or. Between 2010 and 2020, the abatement curves are similar, so abatement levels remain similar for the different carbon prices. Projections for 2030 were done in the same way as for croplands. The greatest potentials for negative- and low-cost reductions are in China and other South and Southeast Asia countries (not including India). Low potential exists in most other regions.

Table 7: Potential reductions ($MtCO_2e$) of emissions from rice cultivation for selected countries and regions with carbon prices at $0 and $30 per tCO_2e. Table adapted from USEPA (2006b).

	2010		2020		2030	
Country/Region	$0	$30	$0	$30	$0	$30
Annex I	0.4	6.7	0.4	6.6	0.4	6.3
China	47.6	90.3	39.6	81.5	39.7	81.8
India	--	27.4	--	31.6	--	34.4
Japan	0.4	6.7	0.4	6.6	0.4	6.3
OECD	1.7	10.7	1.9	10.8	1.9	10.8
S&SE Asia	60.6	97.9	71.9	113.5	73.2	115.6
Global Total	**109.0**	**226.3**	**113.6**	**237.9**	**116.2**	**243.3**

2.3.3 Livestock management

[46] The USEPA report presents tables showing the breakdowns of different mitigation technologies for these countries that report the change in yield compared to the baseline, the breakeven cost per tCO_2e.

[47] There are two ways to calculate the abatement curves: one could hold the number of animals constant, or one could hold production constant. Regional abatement curves were generated as was a globally aggregated abatement curve. These curves were used to generate the summary of net percentage reductions at different carbon prices for croplands that is presented in Table 8. These reductions are for both enteric fermentation and manure management, relative to these portions of the baseline presented in section 2.1.2 of this report. Potential abatement for 2030 was calculated as in croplands and rice management.

[48] The global estimate, holding the number of animals constant, is approximately 3% of the net emissions from livestock management could be mitigated at a net benefit or at no cost (< $0/tCO_2e$). Holding production constant, this number rises to 7%. At a price of $30/$tCO_2e$, almost 6 percent could be mitigated at constant herd size and around 9% at constant production. The abatement curves for livestock management do not have the sharp, almost vertical rise in price, which suggests opportunities for greater reductions at higher prices. The greatest potentials for negative- and low-cost reductions are in the United States, EU-15, OECD countries, and Annex I countries. Moderate potential exists in most other regions.

Table 8: Potential reductions ($MtCO_2e$) of emissions from enteric fermentation and manure management for selected countries and regions with carbon prices at $0 and $30 per tCO_2e, with constant herd size. Table adapted from USEPA (2006b).

	2010		2020		2030	
Country/Region	$0	$30	$0	$30	$0	$30
Africa	2.3	8.6	2.0	10.3	2.3	11.9
Annex 1	35.9	72.5	36.7	77.0	38.1	80.1
Australia/New Zealand	3.8	6.3	3.9	6.8	4.0	6.8
Brazil	7.6	12.9	8.6	14.6	9.6	16.2
China	7.8	14.5	9.4	17.4	11.0	20.3
Eastern	1.5	1.5	1.6	1.6	1.7	1.7
EU-15	12.8	26.4	12.9	24.6	12.9	24.5
India	3.1	6.5	3.4	7.2	3.7	7.8
Japan	0.8	0.9	0.9	0.9	0.9	0.9
Mexico	1.7	1.7	1.9	1.9	2.1	2.1
Non-OECD Annex 1	3.3	3.3	3.6	3.6	4.1	4.1
OECD	34.8	71.5	35.1	75.6	36.1	77.7
Russian Fed	1.9	1.9	2.2	2.2	2.5	2.5
S&SE Asia	9.0	14.2	9.7	16.6	11.2	19.2
United States	11.1	29.8	10.8	33.9	10.6	33.5
Global Total	76.4	142.7	83.1	157.7	92.4	175.2

2.3.4 Total agriculture

[49] There are two ways to calculate the global aggregate abatement curves for agriculture: one could hold the cultivated area and number of animals constant, or one could hold production constant. Regional abatement curves were generated as was a globally aggregated abatement curve (Figure 4).

[50] These curves were used to generate the summary of net reductions at different carbon prices in different regions of the world that is presented in Table 9. These reductions are relative to the baseline presented in section 2.1.2 of this report. Potential abatement shifts significantly between 2000 and 2010, in large part due to the shift observed earlier in rice production, but also due to regional shifts not presented in this paper for other categories (e.g. cropland abatement in the former Soviet Union). The extrapolation to 2030 was based on the 2020 abatement curve.

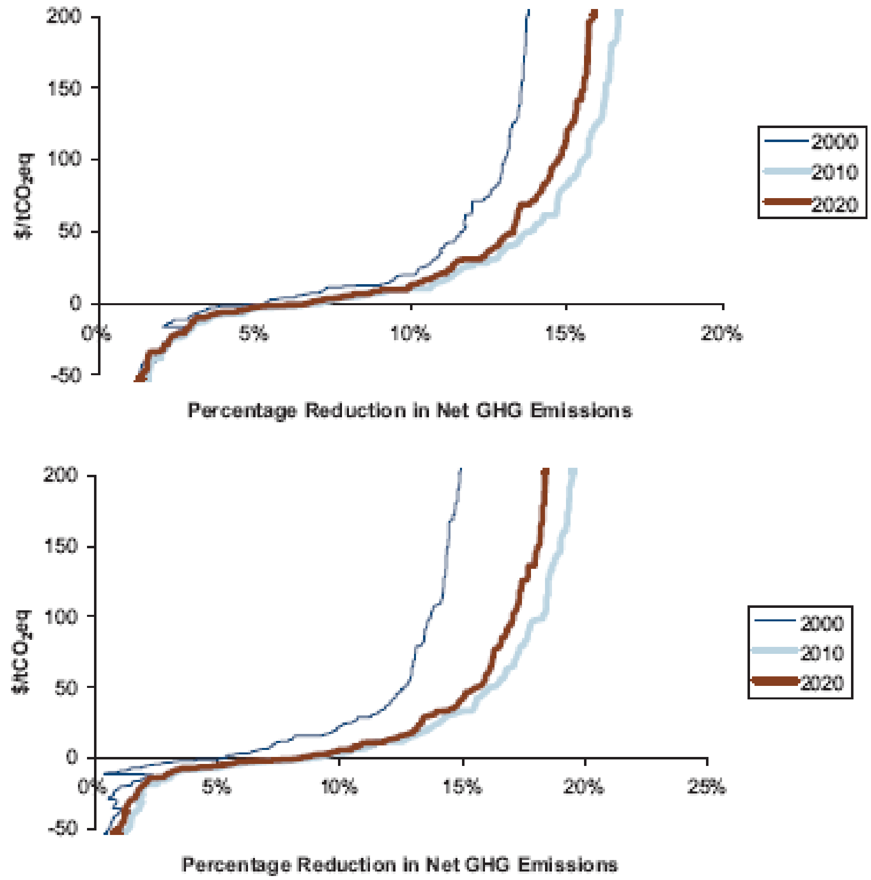

Figure 4: Global aggregate marginal abatement curves for net GHG emissions from agriculture, holding cultivated area and number of animals constant (top panel) and production constant (bottom panel). Source: USEPA 2006b.

[51] The global estimate, holding cultivated area and the number of animals constant, is approximately 6% of the net emissions from agriculture could be mitigated at a net benefit or at no cost (< $0/tCO_2e$) in 2000. Holding production constant, this number is around 5%. With the shift in the abatement curve, these numbers increase only slightly to 7% and 9% for constant area/animals and constant production, respectively.

[52] The difference in abatement potentials between 2000 and later years is felt more strongly at higher carbon prices. At a price of $30/tCO_2e$, 11 percent could be mitigated at constant area/animals in 2000, while around 13% could be mitigated in 2010 or 2020. When production is held constant these numbers are slightly larger at 12% for 2000 and around 16% for 2010 through 2030. The global aggregated abatement curves for agriculture rise sharply after $30/tCO_2e$ and become nearly vertical at $150/tCO_2e$, which suggests that there are a few opportunities for greater reductions at higher carbon prices.

Table 9: Potential total reductions ($MtCO_2e$) of emissions from agriculture for selected countries and regions with carbon prices at \$0 and \$30 per tCO_2e, with constant herd size. Table adapted from USEPA (2006b).

	2010		2020		2030	
Country/Region	\$0	\$30	\$0	\$30	\$0	\$30
Africa	5.8	13.1	6.0	15.1	6.9	17.4
Annex I	136.5	222.6	140.1	210.1	147.3	221.0
Australia/New Zealand	7.3	10.4	7.7	11.3	7.8	11.5
Brazil	9.3	16.9	10.1	18.3	11.3	20.5
China	61.7	111.5	55.2	106.0	60.5	116.3
Eastern Europe	7.2	9.7	7.1	10.2	7.6	10.9
EU-15	24.0	38.5	23.9	36.4	24.5	37.2
India	7.1	41.9	7.2	44.6	7.7	47.6
Japan	1.3	7.6	1.4	7.8	1.4	7.9
Mexico	3.5	5.6	4.3	6.8	4.1	6.6
Non-OECD Annex I	38.1	62.0	38.4	43.0	41.2	46.2
OECD	97.5	162.1	100.4	168.5	105.5	176.9
Russian Fed	36.6	60.5	37.0	41.5	39.4	44.2
South & SE Asia	71.6	115.4	82.6	131.1	87.8	139.3
United States	49.8	80.4	51.1	86.6	53.3	90.3
World	313.6	552.1	323.1	559.4	350.2	606.3

[53] Globally, approximately 7% of the net emissions from agriculture can be mitigated at a net benefit or at no cost (< \$0/tCO_2e). At higher C prices the abatement potential rises. For example, 11 to 12% of the net emissions can be mitigated for less than \$30/tCO_2e (or about 190 $MtCO_2e$). Beyond this point, costs rise rapidly. The greatest potentials for negative- and low-cost reductions are in the Russian Federation, the non-OECD Annex I countries and the United States, EU-15 (Table 9). Moderate amounts of zero or low cost reductions are available in most other countries or regions, with the exception of Africa, Brazil, India, and Japan. .

2.3.5 Investments required for abatement of soil C and non-CO_2 GHGs

[54] To evaluate the investment required for abatement of soil C and non-CO_2 GHGs, the mitigation scenario was determined by the abatement curves presented above. For a number of gases, the maximum economic abatement potential corresponded to \$30 per $MtCO_2e$. For several other sources, it was clear that additional reductions were feasible, but generally beyond the level of \$30 per $MtCO_2e$, the returns on the investment were decreasing rapidly.

[55] To determine the reductions and the costs after 2020, which was the timeframe of the abatement curve analysis, the abatement curve for 2020 was used to calculate reductions and costs for 2025 and 2030. Note that these curves assume constant harvested area and constant number of animals through time. Given the expected growth in population and the changes in diets to include more animal products as countries

become more affluent, the estimates generated by this method are conservative. In fact, as projections extend beyond the initial year for the analysis (2000), the degree of underestimation grows.

[56] The projections for abatement costs range from $16 to 20 billion (Table 10). Greatest reductions and greatest investments for these reductions are associated with mitigating emissions from rice. The smallest reductions and the smallest investments will be in the livestock sub-sector.

Table 10: Estimate of the reductions of emissions from non-CO_2 and soil carbon GHGs ($MtCO_2e$) and the investment needed to achieve these reductions ($ billion) between 2000 and 2030 at a cost of $30 tCO_2e (2000$).

	Year							
	2000		2005		2010		2015	
Sub-Sector	Reductions	Cost	Reductions	Cost	Reductions	Cost	Reductions	Cost
Cropland	172	7.74	177	5.32	183	5.48	175	5.26
Rice	200	6.00	213	6.39	226	6.79	232	6.96
Livestock	131	3.93	137	4.11	143	4.28	150	4.51
Total	**529**	**15.88**	**563**	**16.88**	**596**	**17.89**	**614**	**18.41**

	Year					
	2020		2025		2030	
	Reductions	Cost	Reductions	Cost	Reductions	Cost
Cropland	168	5.04	174	5.21	180	5.39
Rice	238	7.14	241	7.22	243	7.30
Livestock	158	4.73	167	5.00	175	5.26
Total	**631**	**18.92**	**657**	**19.72**	**684**	**20.51**

3. Carbon Sequestration Through Land Use Change and Management

[57] The agricultural sector offers a number of mitigation opportunities, primarily through sequestration of atmospheric carbon, associated with land-use change and management. Increased carbon stocks can be achieved through a change in land use to one with higher carbon stock potential, usually revealed by a change in land cover. The IPCC Special Report on Land Use, Land-Use Change and Forestry (2000) identified a number of categories of activities on agricultural lands that generate benefits:

- Agroforestry (including conversion from forests to slash-and-burn to agroforests after deforestation, conversion from low-productivity croplands to sequential agroforestry in Africa, integration of trees into farming systems and agricultural landscapes).
- Improved grassland management (including improved grazing management, fertilization, irrigation and use of improved species and legumes).
- Restoration of severely degraded lands (including salt-affected soils, badly eroded and desertified soils, mine spoils, and industrially polluted sites).

[58] Many of these practices lead to increased carbon stocks in the soil and in the vegetation. Carbon accumulation from a change in land use and management is not be sustained indefinitely. Eventually, inputs and losses balance, and carbon stocks approach a new, higher equilibrium (Davidson and Ackerman, 1993; IPCC 2000). The effect of the land-use change on atmospheric GHGs must be determined from a whole system point of view. In many "managed" ecosystems, there is significant removal of carbon in harvested products, some of which may accumulate in long-term storage pools (e.g., wood products), while some rapidly returns to the atmosphere via respiration. Additionally, increases in soil organic carbon are often associated with increases in N_2O emissions (Li et al., 2005). In wetlands, the effects of changes in land-use on soil CH_4 emissions also need to be considered.

3.1 Potential C Sequestration in Agriculture

[59] Agricultural ecosystems have significant potential to increase carbon storage, thereby reducing atmospheric concentrations of CO_2 by sequestering C in soils and vegetation (Lal, 2004; Albrecht and Kandji, 2003). Agricultural lands also remove CH4 from the atmosphere by oxidation, though less than forests (Tate *et al.*, 2006; Verchot et al., 2000), but this effect is small compared to other GHG fluxes (Smith and Conen, 2004).

[60] Two types of land management in the agricultural sector offer significant opportunities for carbon sequestration (Figure 5; IPCC 2000): improved grassland management and agroforestry. For improved grasslands, high rates of sequestration can

be achieved through introduction of more productive grass species and legumes. Improved nutrient management and irrigation can also increase productivity and sequester more carbon. About 60 percent of the grazing lands available for carbon sequestration are in non-Annex 1 countries.

[61] Compared to other types of land-use change and compared to a number of management options, improved grazing land management and agroforestry offer the highest potential for carbon sequestration in non-Annex I countries (Figure 5; IPCC, 2000). Agroforestry has such a high potential because it is the land use category with the second highest carbon density, after forests and because there is such a large area that is susceptible for the land use change. Grazing land management, despite the low carbon densities in these lands, has a high potential because of the large amount of land susceptible for this improvement (3.4 billion ha). Agroforestry also offers the potential for synergies between expanding the role of agroforestry in mitigation programs and adaptation to climate change (Verchot et al., 2007). In many instances, improved agroforestry systems can reduce the vulnerability of small-scale farmers to inter-annual climate variability and help them adapt to changing conditions.

[62] Other land-use options such as rehabilitation of degraded land and wetland restoration have relatively low potentials, globally, to contribute to mitigation, although locally their potential may be significant. These low values are the combined result of low area availability and slow carbon accumulation rates.

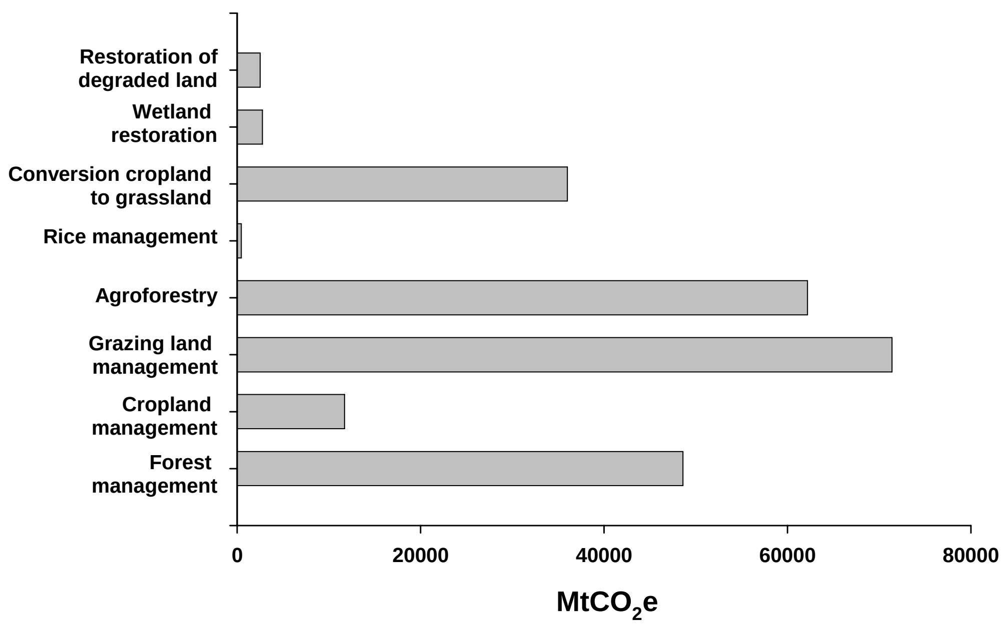

Figure 5: Technical potential for carbon sequestration of different land use and management options over a 30 year period (adapted from IPCC 2000)

[63] A rigorous analysis of costs and mitigation potential does not presently exist in the literature and there is no basis to develop this at the moment. The IPCC (2000) Special Report presented an illustration of the potential of carbon sequestration to contribute to climate change mitigation. What I propose here is an expansion of the IPCC Special Report scenario, which will illustrate the potential for carbon sequestration in the agricultural sector and the costs of achieving that sequestration. The results of this analysis will only be semi-quantitative, but it is reasonable to expect them to be indicative of the order of magnitude of the potentials and costs

[64] The IPCC scenario suggested that it would be possible, with considerable international effort, that 10 percent of the land available for improved pasture management could be under this improved management by 2010 and that as much as 20 percent could be under improved management by 2040. Likewise for agroforestry, the report suggested that 20 percent of the available land could be under this land management practice by 2010 and 40 percent by 2040. These suggested targets have not been achieved and we are at almost the same state of land availability as we were in 2000, when the report was written, so we will use these values in this exercise.

[65] For this analysis, consider an example of a moderately intensive agroforestry system, which has been modelled using the ENCOFOR decision support Carbon Model (www.joanneum.at/encofor; Figure 6). The system produces timber, with some food or cash crops grown in the understorey. Examples of this system might be the rotational woodlots of Tanzania, the pine-coffee-banana systems of central Java, Eucalyptus and Poplar based agroforestry systems of the Indo-Gangetic Plain (Bekele-Tesemma, 2007).

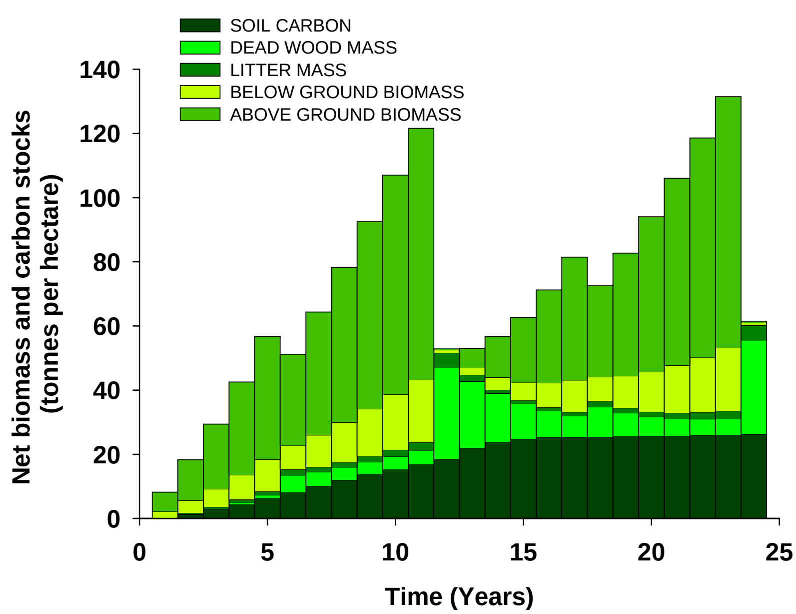

Figure 6: Projection of carbon accumulation in a multi-strata agroforestry system.

[66] In this system, the trees are harvested after 12 years, and regenerated. The ENCOFOR model suggests that the average annual accumulation in this example over 30 years is 1.26 tonnes C per ha and over 60 years, this average figure drops to 0.52 tonnes per ha per year. The IPCC Special Report suggested an average carbon accumulation rate in an agroforestry system was about 3.1 tonnes per ha for a 30 to 50 year time horizon. These values are appropriate for a multi-strata system that is kept in place over a long period of time, such as the home garden systems of Africa or the jungle rubber agroforestry systems of Indonesia.

[67] These two examples are used because they provide useful bounds to our calculations. In one case we have a system which is regularly harvested and therefore has lower annual accumulation rates because the aboveground biomass is regularly brought back to zero. In the other case, we have a permanent tree-based farming system.

[68] Carbon sequestration potential can be calculated by taking the time frame proposed in the IPCC Special Report, taking the projections of area of land adopting the improved practices, and using both the IPCC and ENCOFOR projections for carbon accumulation rates, and the IPCC projection for grassland management. Table 11 presents the scenarios for agroforestry and grassland management. If we take the sum of the annual accumulation rates over the next 30 years, the results suggest that the total potential sequestration is on the order of 12 to 19 Gt of carbon or 45 to 70 Gt of CO_2e. This does not account for the carbon sequestered in harvested wood products from the agroforestry plantations.

Table 11: Estimates of C sequestration in agricultural lands for the two practices with the highest potential over 30 years. Two scenarios are presented for agroforestry, one based on the IPCC (2000) LULUCF report and one based on the projections of the ENCOFOR Carbon Model. The time period for the analysis is 30 years.

			Permanent agroforestry (IPCC)		Rotational Agroforestry (ENCOFOR)	
Time (years)	Land area available (M ha)	Adoption/ conversion of area (%)	Rate of C gain (tC ha^{-1} y^{-1})	Carbon (Mt y^{-1})	Rate of C gain (tC ha^{-1} y^{-1})	Carbon (Mt y^{-1})
Agroforestry						
10	630	20	3.1	391	1.26	159
15		23		456		186
20		27		521		212
25		30		586		239
30		33		651		265
Grassland management						
10	3400	10	0.7	238		
15		12		278		
20		13		317		
25		15		357		
30		17		397		

3.2 Additional investments required in carbon sequestration

[69] To begin to evaluate the investments required to achieve these levels of carbon sequestration, it is best to continue with the agroforestry example developed above. Costs of tree planting projects include those associated with plantation establishment, maintenance costs like pruning, and measurement and monitoring of the carbon sequestered. In many cases, extension and farmer education is required to teach farmers about new agroforestry systems. To calculate these costs, the ENCOFOR financial analysis tool was used. Values are in 2005$. Establishment costs include the purchase of seedlings, labour for site preparation and planting, and costs of protection (fencing, guarding, etc). The cost of establishing these agroforestry plantations comes to around US$780 for the two rotations of a 1 ha plantation of 1000 trees. Operating costs include weeding, thinning and pruning the trees, which come to $440 per ha. Additional costs of preparing documentation for carbon crediting under the different types of systems that currently exist come to $60 per ha and the costs of monitoring and verifying are $190 per ha. Thus, the total cost in this scenario is $1470 per ha.

[70] From the example above, an agroforestry plantation contains an average 80t of biomass over its lifetime or 40 tonnes of C per ha in 5 carbon pools (aboveground biomass, belowground biomass, deadwood, litter, and soil carbon). The costs of establishment and maintenance of these plantations comes to US$36.75 per tonne of carbon, or $10.02 per tonne of CO_2e.

[71] However, not all of these costs need to be borne by the international community or by outside investors. Agroforestry systems are profitable in their own right. The example given here has a 22% internal rate of return. Agroforestry systems vary considerably across regions and have varying income generation potential. This means that the costs of expanding the adoption of agroforestry do not have to be fully borne by external investors. Costs can be shared with rural farmers who will benefit from these profitable systems. In most cases agroforestry systems are more profitable than subsistence agriculture.

[72] The idea of additionality in financing carbon sequestration is already embodied in the UNFCCC and its Kyoto Protocol. Additionality is the criteria for carbon offset projects to determine offsets that occur in addition to business as usual. Additionality is determined by analyzing barriers. Many barriers to adoption of these systems exist, and prevent them from contributing more fully to rural development, including:

- Delayed returns on investments: In most cases it takes 3 to 5 years to recoup initial investments in agroforestry systems. This is prohibitively long for smallholder, subsistence farmers. Alternative and shorter-term income sources are required to bridge the gap between planting and income generation.

➢ Lack of knowledge: In many instances farmers lack knowledge about how to grow trees and the potential for income generation of agroforestry systems. Rural extension systems, where they function, often do not have the information on these systems to pass along to farmers. Improvement of extension services is required to overcome this barrier.

➢ Labour shortages: Agroforestry systems are generally more labour intensive than cropping systems. Farming families in rural areas in the developing world often have labour shortages during rainy seasons and therefore are not capable of taking full advantage of these periods. In many areas, men and women have left to find employment in cities and send remittances back to the family that remains in the villages. Funding to purchase additional labour or lure family members back from the cities could help in overcoming this barrier.

[73] Investments to facilitate wider adoption of higher carbon and higher profit production systems need to target removing these or other barriers that exist in rural areas. In the example above, one of the most important barriers for resource poor farmers to engage in this type of project is financial. Figure 7 shows that the cash flow for this type of plantation is negative for the first three years of the project. This is fairly common in agroforestry projects. A second barrier is lack of knowledge about agroforestry systems. Thus, despite the favourable internal rate of return resource poor farmers cannot undertake this type of production system because of the financial barrier early in the conversion phase to a new production system and because of the knowledge barrier.

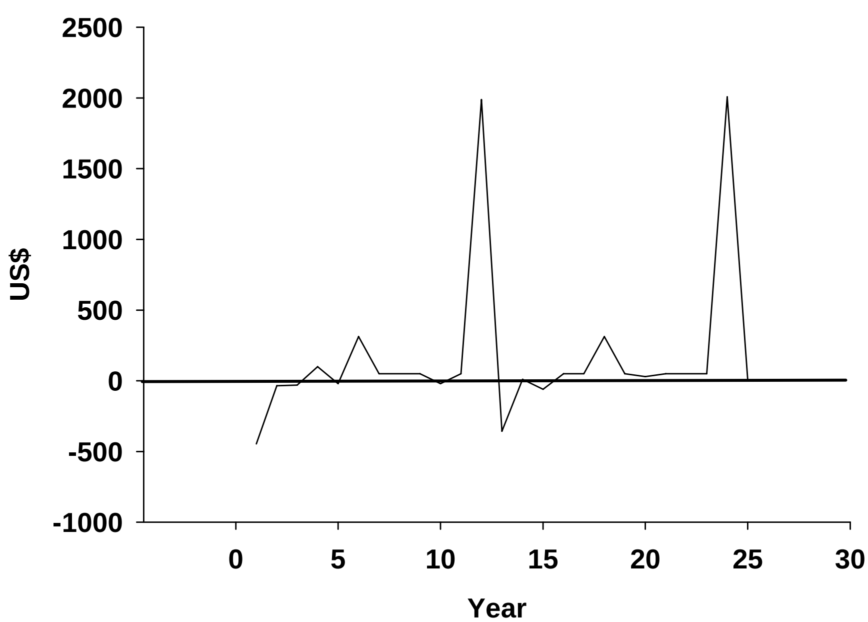

Figure 7: Cash flow over two rotations of a moderately intensive agroforestry plantation in the tropics. Values are in 2005$.

[74] If additional investments were to be made to overcome these barriers, wider adoption of agroforestry could occur. In this case, investments of \$640 per ha would be required and the cost of sequestering the carbon would be only \$16.00 per tonne of carbon or 4.36 per tCO_2e. For the case of permanent agroforestry, assuming similar establishment and operating costs, the cost per tonne decreases to \$4.32 because of the higher productivity of the system. Assuming similar costs to overcome barriers for these types of plantations, the cost of removing the barriers would be only \$1.77 per tonne. Finally, to put this in a global perspective, the technical potential C sequestration of this scenario is 30.8 $GtCO_2e$ for a total cost of \$134.4 billion. The actual potential suggested by the IPCC scenario analyzed in Section 3.1 is given in Table 12.

Table 12: Calculations of actual sequestration and costs for agroforestry using the IPCC scenario for adoption/conversion. Costs are calculated using total costs per hectare and the values suggested for investments aimed at removing barriers only.

		Sequestration potential		Implementation costs	
Time (years)	Adoption/ conversion of area	Permanent agroforestry ($MtCO_2e\ y^{-1}$)	Rotational Agroforestry ($MtCO_2e\ y^{-1}$)	Full (\$M)	Barriers only (\$M)
10	20	1,434	583	5,843	2,544
15	23	1,672	682	6,836	2,976
20	27	1,910	777	7,791	3,392
25	30	2,149	876	8,783	3,824
30	33	2,387	972	9,739	4,240

[75] Greater consideration of these land-use mitigation options is warranted, as these types of activities can offer multiple benefits. If well designed, agroforestry, grassland management, land rehabilitation, and wetland rehabilitation projects can contribute to biodiversity conservation, watershed protection, reduction of desertification, sustainable land management, and poverty reduction.

4. Energy

[76] Mitigation of energy related emissions in agriculture are rarely discussed in the agricultural climate change literature. Even the IPCC Fourth Assessment Report is silent on the issue. The energy discussion in agriculture generally refers to biofuels and the possibility of agriculture to provide feedstock from waste products for energy generation to offset fossil fuel generated energy.

[77] The projection of energy use and associated GHG emissions into the future is always subject to assumptions and uncertainties. These assumptions relate to expectations of implementation and funding of policies and measures that have been adopted but not yet funded; to the development, adoption, and efficiency of technologies not yet tested; and to the pace of future economic growth.

4.1 Energy Baseline

[78] To calculate the baseline emissions, IEA country level data of energy consumption by agriculture were used, broken down by source. The five energy source data categories in this data set were: coal, petroleum products, gas, combustible renewables and waste, and electricity. Values in this dataset were in kilo-tonnes of oil equivalent. These values were converted to tons of CO_2 by multiplying by the IEA carbon emission factors (CEF, Table 13). CEFs for electricity were calculated from country level IEA data (IEA 2006).

Table 13: IEA emission factors for different fuel sources. Source: CO_2 Emission from Fuel Combustion (2006 edition)

Source	CEF (tCO_2/ktoe)
Coal	3960.713
Petroleum Products (Diesel)	3101.023
Gas	2348.795
Combustible renewable and waste	4590.128

[79] Energy related emissions from agriculture are a minor source for the sector (Table 14). The global emissions from this source were only 11% of the total non-CO_2 GHG emissions in baseline 1 and 14% of the non-CO_2 GHG and soil emissions in baseline 2. Petroleum products were the major sources of emissions in most regions. In South and Southeast Asia, the situation was different as electricity was the major source of emissions. As might be expected, Sub-Saharan Africa had the lowest emission from energy use.

Table 14: Baseline scenario for 2000, showing energy related emissions ($MtCO_2e$) disaggregated by region and by fuel source.

Region	Coal	Petroleum Products	Gas	Combustible renewable and waste	Electricity	Total
W. Europe	0.3	41.5	9.8	4.0	14.2	69.8
E. Europe	5.5	54.3	2.3	3.4	22.4	87.9
CWANA	0.0	18.6	0.4	0.0	36.0	55.0
L. America & Caribbean	0.1	35.2	0.0	14.0	6.3	55.5
Sub-Saharan Africa	1.6	5.4	0.0	3.9	4.6	15.6
South & Southeast Asia	40.9	79.9	0.4	0.0	138.2	259.4
Other developed countries	0.1	78.1	1.4	0.0	5.4	85.0
Total	**48.4**	**313.0**	**14.2**	**25.3**	**227.2**	**628.1**

4.2 Mitigation scenario

[80] No energy mitigation scenarios exist in the literature specifically for agriculture, probably because energy related emissions are a minor source in agriculture. Additionally, most of the mitigation options are linked to the power generation sector. Mitigation scenarios rightly focus on the major sources in this sector. Nevertheless, with increased mechanization of agriculture, fossil fuel emissions can be expected to rise. Recycling of agricultural waste products and increased use of renewable energy sources offer opportunities to reduce emissions. Because most of the world depends on petroleum based products, biodiesel and ethanol could be substituted to reduce emissions. In South and Southeast Asia, where energy related emissions are highest, biodiesel and electricity generation with renewable energy sources offer meaningful opportunities to reduce emissions.

4.3 Bioenergy

[81] Agriculture has a significant role to play in reducing the use of fossil fuel for energy generation. Analyses are still being developed, but it is worth mentioning here that biomass produced in agriculture as bio-energy feedstock may provide significant reductions in GHG emissions from the power generation sector. Smith et al. (in press) have suggested that at current market prices for CO_2, over 600 $MtCO_2e$ of net GHG benefits could be derived from bio-energy (Table 15)

Table 15: potential GHG reductions at a given price for bioenergy and the total investment required.

Price ($/$tCO_2e$)	$MtCO_2e$	Investment ($million)
20	640	12,800
50	2,240	112,000
100	16,000	1,600,000

5. BAU Investments in Agriculture

[82] Government spending patterns vary across regions and have changed significantly over the past three decades (Table 16). Globally, government expenditures in agriculture are increasing in real terms by about 2.5 percent annually. In relative terms of total government expenditures, agriculture is receiving a smaller share, indicating changing priorities. In Asia, agriculture accounted for 9 percent of government spending in 2002, which is down from 15 percent in 1980. In Latin America, agriculture spending was only about 2.5% of total government expenditures.

[83] One useful way to look at expenditures is as a percentage of the GDP related to that sector. In developed countries, government expenditures are generally about 20% of agricultural GDP. In developing countries, agricultural spending as a percentage of agricultural GDP is much lower, averaging less than 10 percent. In Africa, agriculture expenditure as a percentage of agricultural GDP decreased slightly from 7.4 percent in 1980 to 5.7 percent in 2000 (Fan et al., 2007). About half of African countries decreased agricultural expenditures relative to agricultural GDP during the 20-year period analyzed. Asia's investment was much higher, where its percentage remained constant at 8.5 - 9.5 percent. For Latin America, agricultural spending as a percentage of agricultural GDP decreased from 19.5 percent in 1980 to only 6.8 percent in 1990, but recovered to 11.1 percent in 2000 (Fan et al., 2007).

[84] Total government expenditures in agriculture have been growing in real terms over the past twenty years (Table 16). In Africa, government expenditure on agriculture increased at an annual rate of about 1.5 percent. Agricultural expenditures are highest in Asia and more than doubled in the past two decades, with an annual growth rate of around 4.0 percent. Latin America and the Caribbean was the only region that reduced its spending in agriculture, but there was some recovery between 1990 and 2000. Average annual growth during this recovery was 4.6 percent.

Table 16: Total agricultural expenditures in developing regions (billions of 2000$). Table is adapted from Fan et al. (2007); original data for 1980-2000 are from International Monetary Fund's Government Financial Statistics Yearbook (various issues). Projections for 2010 – 2030 are linear projections of the trends from 1980-2000, except for LAC, where the projection is based on the increment in spending between 1990 and 2000.

	Year					
Region	1980	1990	2000	2010	2020	2030
Africa	7.33	7.85	9.90	10.93	12.22	13.50
Asia	74.00	106.54	162.84	203.30	247.72	292.14
Latin America/Caribbean	30.48	11.52	18.16	24.80	31.44	38.08
Total	111.81	125.91	190.90	239.03	291.37	343.72

5.1 *Gross Capital Formation*

[85] There are a number of ways of measuring investment. For national accounts, gross capital formation (GCF) is a useful measure of new investment and growth in physical or capital stock in an economy. GCF is the sum of fixed capital investment, the increase in value of inventories held, and lending to foreign countries during the accounting period. Table 17 presents GCF in the crop sub-sector, with IEA projections to 2030. Table 18 presents GCF in the livestock sub-sector; these figures do not include investments in farm animals. GCF generally does not include human capital and does not represent investments in research.

[86] There appear to be some anomalies in the projections for 2005 in the model associated with initializing the model (OECD, personal communication), yet the magnitudes of the trends are indicative of regional and country differences. It is best to analyze trends beginning in 2010 in this time series.

[87] OECD projections for cropping agriculture show rapid and accelerating growth in investment in Africa and the Middle East. Projections are for moderate growth in most developed countries and declining investments in Japan. Emerging economies and economies in transition show moderate growth in GCF. In the livestock sub-sector, projections are for high growth in investment in Africa, India, South and Southeast Asia Middle East, and Turkey. Similar to the cropping sub-sector, projections are for moderate growth in most developed countries and declining investments in Japan. Emerging economies and economies in transition show moderate growth in GCF.

Table 17: Gross capital formation in crop sub-sector of agriculture from 2005 to 2030. Values are in millions of 2001$. Projections are from OECD.

	2005	2010	2015	2020	2025	2030
Africa	9,690	8,007	10,404	12,539	14,945	17,654
Australia/NZ	1,477	1,944	2,043	2,306	2,580	2,834
Brazil	2,171	5,054	5,692	6,439	7,200	8,083
Canada	840	1,704	1,913	1,987	2,070	2,223
China	6,724	7,458	8,208	9,079	10,041	10,922
EU-15	3,416	6,653	7,481	8,201	8,774	9,077
India	5,794	7,027	8,299	9,619	11,046	12,484
Japan	3,573	6,005	5,571	5,735	5,783	5,817
Latin America/Caribbean	9,064	10,432	12,094	13,796	15,624	17,716
Mexico	-	1,642	1,292	1,688	1,878	1,981
Middle East	2,309	2,258	3,095	3,689	4,197	4,741
Russian Federation	694	646	733	831	905	945
South & SE Asia	8,990	10,852	12,701	14,758	16,966	19,202
South Korea	127	298	295	299	322	296
Turkey	1,142	2,075	2,144	2,206	2,265	2,319
United States	8,592	10,771	11,917	12,139	12,664	13,411
Global Totals	64,603	82,826	93,882	105,311	117,260	129,705

Table 18: Gross capital formation in livestock sub-sector of agriculture from 2005 to 2030. Projections are from OECD.

Country/region	2005	2010	2015	2020	2025	2030
Africa	3,278	3,440	4,316	5,328	6,499	7,849
Australia/NZ	1,387	1,573	1,578	1,780	1,970	2,147
Brazil	2,654	3,060	3,368	3,805	4,267	4,749
Canada	872	1,163	1,280	1,431	1,566	1,684
China	6,180	7,861	9,810	11,600	13,275	14,789
EU-15	3,441	3,950	4,369	4,712	4,977	5,215
India	2,673	3,693	4,691	5,716	6,796	7,917
Japan	527	965	957	1,052	1,127	1,199
Latin America/Caribbean	4,992	5,309	5,983	6,807	7,681	8,601
Mexico	419	495	634	755	856	943
Middle East	979	1,292	1,812	2,359	2,952	3,625
Russian Federation	257	295	379	454	511	556
South & SE Asia	3,603	4,939	6,266	7,636	9,077	10,574
South Korea	47	45	52	62	73	79
Turkey	289	438	562	670	778	891
United States	3,074	3,140	3,442	3,598	3,725	3,881
Global Totals	34,672	41,658	49,499	57,765	66,130	74,699

5.2 Official Development Assistance

[88] ODA investments in agriculture continue to make up a significant portion of investments in developing countries although these investments have been declining since the early 1990s. A recent report by DFID (2004), estimates that global assistance to agriculture (expressed in 2002$) decreased from US$ 6.2 billion to US$ 2.3 billion between 1980 and 2002, despite an overall increase in ODA. Most of this decrease occurred during the 1990s. The share of agricultural investment as a portion of total ODA has fallen from a peak of 17% in 1982 to 3.7% of total ODA in 2002. Cuts have been deepest among the multilateral donors, who have cut spending on agriculture from $US 3.4 billion to US$ 0.5 billion. Bilateral donors reduced spending from US$ 2.8 billion to US$ 1.7 billion (DFID 2004).

[89] Regionally, the deepest cuts in ODA support to agriculture have occurred in Asia, but even in sub-Saharan Africa, ODA has declined in real terms by 50%. The DFID report cites a number of reasons including loss of confidence among donors for agricultural investments to deliver poverty reduction, changes in development policy in favour of market-led approaches and shifting emphasis to health and education in ODA investments.

[90] The trends in the 2000s have begun to reverse and we have seed a significant increase over the past several years, although ODA volumes for agriculture are still about one-third of what they were in the 1980s in real terms. There is still quite a bit of variation in investments from year to year (Table 19). The biggest resurgence has been with multilateral funding. The focus in investments is also changing rapidly. Investment in water resources is increasing significantly and topped the list in 2005. Investments in food crop production, which was given priority during the Green Revolution, is low and declined between 2000 and 2005. Investments in extension are among the lowest.

Table 19: ODA investments in the agricultural sector in millions US$. Source: OECD DAC_CRS website (http://www.oecd.org/dataoecd/50/15/5037782.htm).

Investment type	2000 Bi-lateral	2000 Multi-lateral	2000 Total	2005 Bi-lateral	2005 Multi-lateral	2005 Total
Agricultural water resources	93.6	285.6	379.2	601.1	1,115.2	1,716.3
Agricultural policy & admin. mgmt	579.7	2,442.0	3,021.7	532.2	434.9	967.1
Agricultural development	284.8	153.6	438.4	335.8	478.7	814.5
Agricultural land resources	160.9	8.6	169.5	84.4	267.5	352.0
Agricultural research	56.1	51.9	108.0	244.7	78.6	323.2
Food crop production	36.9	271.8	308.7	79.6	153.7	233.4
Agricultural alternative development	0.2		0.2	186.2		186.2
Agricultural financial services	10.0	74.3	84.3	33.9	133.9	167.8
Livestock	34.5	45.3	79.8	30.1	94.3	124.4
Agricultural education/training	37.8	2.0	39.8	87.6		87.6
Agricultural services	19.4	0.8	20.2	50.0	33.3	83.4
Agricultural inputs	136.6		136.6	66.3		66.3
Agricultural co-operatives	13.1	0.7	13.8	37.3	0.3	37.7
Agricultural extension	26.8		26.8	37.0		37.0
Plant/post-harvest prot. & pest ctrl	16.2	1.9	18.1	16.1	15.0	31.1
Livestock/veterinary services	17.8	0.3	18.1	10.6	19.0	29.7
Agrarian reform	4.1	51.3	55.4	27.5		27.5
Industrial crops/export crops	5.8	38.5	44.3	22.5		22.5
Total	**1,534.5**	**3,428.4**	**4,962.8**	**2,483.0**	**2,824.5**	**5,307.5**

5.3 Research Investments

[91] Between 1970 and 1998, research investments rose from $2.7 billion to $4.0 billion (Figure 8). Prior to 1980, public sector investment exceeded private sector investment slightly. Since the mid 1980s, increases in investment have remained fairly constant and the gap between public and private sector investment has grown. It is reasonable to expect the trend to continue. By 2030 we expect investment in agricultural research to reach $12 billion, with 60 percent of this investment coming from the private sector. Public sector investment is likely to increase by 15 percent over the 2005 level, while private sector investment is likely to increase by 35 percent.

[92] Among all types of agricultural expenditures, agricultural research and development is the most crucial to growth in agricultural and food production. Beintema and Stads (2004) show that agricultural research and development (R&D) expenditures as a percentage of agricultural GDP have been flat in the last three decades. For example, in 2000, the share of agricultural R&D expenditure in agricultural GDP in Africa and Asia was between 0.5–0.9 percent, and Latin America's share was 0.98 percent. These rates are relatively low compared to 2–3 percent in developed countries.

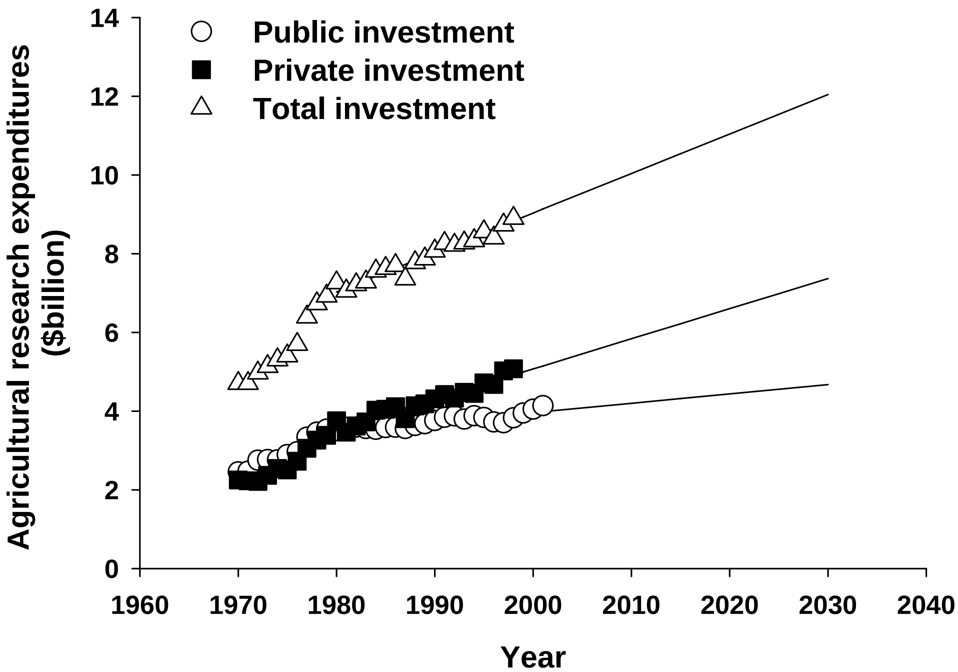

Figure 8: Actual agricultural research expenditures (symbols) from 1970 to 1998 and projected expenditures (lines) through 2030. Projections assume linear relationship based on trend in actual expenditures since 1980. Public numbers based on data from the National Science Foundation and USDA Current Research Information System. Private numbers based on Klotz et al. (1995), updated by Klotz-Ingram through 1998.

6. Additional Investments Required for Mitigation

[93] There are different levels of sophistication in the analyses of the opportunities for climate change mitigation in the agricultural sector analyzed in this paper. The analysis for mitigation of emissions of non-CO_2 GHGs and soil carbon is fairly well developed through a modelling framework. We have shown that energy related emissions make up a very small portion of the emissions from the sector and mitigation in this area needs to target the power generation industry rather than agricultural industries. There are also a number of land-use change options, many of which occur in the tropics that have considerable potential for mitigating climate change, but the economic evaluation of these options remains fairly unsophisticated and we have little idea of how the costs are likely to vary with time or with region.

[94] The abatement curves used in Section 2 assume that abatement actions are put in place immediately (i.e. in 2000) and the emissions reductions and costs are representative of the situation in each year. That is, the emissions reductions in 2020 in Table 10 are the emissions reductions in tons relative to the baseline in 2020 and the costs in that table are the costs incurred in 2020, assuming that the investments had been made beginning in 2000 and sustained.

[95] These costs are substantial. To put the costs in context, the annual additional investments in non-CO_2 GHG and soil carbon abatement, at $30 per tonne will be around 42 percent of the annual GFC from developing countries in Tables 16 and 17 (sum of Australia/New Zealand, Canada, EU-15, Japan, Russian Federation and USA). The additional investment will exceed the global expenditure on research by over 70 percent.

[96] Sequestration appears to be much more cost effective than emissions reductions, at least in the short to medium term, but there is uncertainty about permanence. If the systems that sequester carbon are economically more viable permanence of carbon storage should be assured. However, it is difficult to assess economic superiority for very long periods. Sequestration appears to be a useful medium term solution to reducing atmospheric concentrations of CO_2 as economies slowly make the transition to less dependence on fossil fuel. This analysis suggests that sequestration of 0.7 – 2.1 $GtCO_2e$ could be achieved per year for a total between $7 and 21 billion per year. This is 25 to 77 percent of the GCF of developed countries in 2005. The lower value is equivalent to the total investment in agricultural research in 2005.

7. Conclusion

[97] The principle sources of emissions from agriculture are land-use change, N_2O emissions from soils and manure management, and CH_4 emissions from enteric fermentation. Non-CO_2 GHGs are also produced by rice cultivation, biomass burning, and manure management. Energy related emissions make up a small portion of the climate change impact of agriculture.

[98] Emissions from land-use change are greater than emissions from non-CO_2 GHGs and energy emissions combined. As population grows, promoting intensification of subsistence agriculture is essential to reversing this trend. Costs associated with this have been dealt with in the companion report on Forestry.

[99] Global non-CO_2 GHG emissions from agriculture are currently around 6.2 $GtCO_2e$. By 2030, emissions are expected to be 60% greater than in 1990. The largest increases are expected in soil emissions of N_2O as fertilizer use increases and of CH_4 from enteric fermentation as animal herds increase. Emissions of non-CO_2 GHGs are high in many developing regions, particularly, South and Southeast Asia and the Latin American and Caribbean regions and are expected to grow rapidly in the BAU scenario. Emissions from CWANA, other developed countries, and Eastern Europe are low and are expected to grow at a moderate pace. Non-CO_2 GHG emissions are declining in W. Europe.

[100] There are many opportunities for mitigating non-CO_2 GHG and soil carbon emissions in agriculture. Emissions can be reduced by managing carbon and nitrogen more efficiently in agricultural ecosystems. Carbon can also be sequestered from the atmosphere and stored in soils or in vegetation, for example in agroforestry systems. Crops and residues from agricultural lands can be used as a source of fuel to displace fossil fuel combustion, either directly or after conversion to fuels such as ethanol or diesel. The opportunities and investments required are summarized in Table 20. In the text, values for abatement of non-CO_2 GHG were in 2000$ whereas carbon sequestration values were in 2005$. To make these values comparable a 4 percent discount rate was used and all values are presented in $2000. For biofuels, it was not clear what dollar values were used.

[101] There are opportunities for small emissions reductions at a net benefit or at zero cost, and these need to be pursued. There is potential for abatement of all sources, but with current technologies and the prevailing economic conditions these potentials are all low. The analysis presented here suggests that 11-13 percent of non-CO_2 GHG and soil carbon emissions could be abated at reasonable costs.

[102] Sequestration offers significant and cost effective means of reducing atmospheric concentrations of GHGs. There are large potentials in a number of practices in agriculture. In the examples worked out in this report on agroforestry, total costs for sequestration were on the order of $10 per tCO_2e and the estimates of global feasibility are between 0.7 and 2.1 $GtCO_2e$ per year. Many of these practices are economically beneficial, but do not occur due to a number of barriers. Investment targeted at overcoming these

barriers is much less than the total cost, and therefore, there are opportunities to share costs with other beneficiaries. The analysis suggests that the cost associated with overcoming these barriers is less than \$4.50 per tCO_2e.

Table 20: Summary of mitigation opportunities and additional costs in the agriculture sector. Cost values, except for bioenergy, are in 2000\$.

		2010		2020		2030	
Source	Cost \$/tCO_2e	$MtCO_2e$	\$million	$MtCO_2e$	\$million	$MtCO_2e$	\$million
Non-CO_2 GHG							
Croplands	0	128	0	130	0	140	0
	30	183	5,478	168	5,037	180	5,392
Rice	0	109	0	114	0	116	0
	30	226	6,789	238	7,137	243	7,298
Livestock	0	76	0	83	0	92	0
	30	143	4,281	158	4,731	175	5,257
Total	0	314	0	323	0	350	0
	30	552	16,564	559	16,781	606	18,190
C sequestration							
Agroforestry (IPCC)	4.5			1,672	6,836	2,149	8,783
Agroforestry (ENCOFOR)	10			682	6,836	876	8,783
Bioenergy	20			640	12,800		
	50			2,240	112,000		
	100			16,000	1,600,000		

[103] Abatement costs are significant compared to current and projected rates of global investment in agriculture. Improved abatement options likely require increases in public research funding. Investments, particularly in developing countries, need to increase. Reductions in investment by developing countries and reduction in the share of ODA for agriculture over the past three decades have led to land degradation and extensification of subsistence agriculture systems, as populations have grown. This has led to large-scale losses in carbon from natural ecosystems. Investments aimed at sequestration and intensification of agricultural systems can reverse this trend.

[104] Cost effectiveness in the agriculture sector, defined in purely financial terms follows the order Bioenergy > C sequestration > emissions abatement. There are several social and equity issues associated with bioenergy, which are beyond the scope of this report, but which need to be considered. Carbon sequestration approaches offer opportunities to combine GHG abatement with generating other social benefits, particularly in developing countries. These activities can often be done in ways that contribute to climate change adaptation in vulnerable smallholder farming systems and that contribute to sustainable land management and poverty reduction in rural areas of the developing world. Synergistic activities should be given priority in public investment

8. References

Albrecht A and Kandji ST 2003, Carbon sequestration in tropical agroforestry systems. *Agriculture, Ecosystems and Environment*. **99**: pp.15-27

Beintema, NM, and Stads, GJ. 2004, Sub-Saharan African agricultural research: Recent investment trends. *Outlook on Agriculture*. **33(4)** pp. 239–246

Bekele-Tesemma A. 2007. Profitable Agroforestry Innovatoins for Eastern Africa. RELMA World Agroforestry Centre, Nairobi, Kenya.

Bouwman A. 2001, *Global Estimates of Gaseous Emissions from Agricultural Land*. Rome: Food and Agriculture Organization (FAO)

Caldeira K., Morgan MG, Baldocchi D, Brewer PG, Chen CTA, Nabuurs GJ, Nakicenovic N, and Robertson GP. 2004. A portfolio of carbon management options. In CB Field, and MR Raupach (eds). *The Global Carbon Cycle. Integrating Humans, Climate, and the Natural World*,. SCOPE 62, Island Press, Washington DC, pp.103-129

Cannell MGR. 2003. Carbon sequestration and biomass energy offset: theoretical, potential and achievable capacities globally, in Europe and the UK. *Biomass & Bioenergy*. **24**: pp. 97-116

Clemens J, and Ahlgrimm HJ. 2001. Greenhouse gases from animal husbandry: mitigation options. *Nutrient Cycling in Agroecosystems*. **60**: pp.287-300

Davidson EA and Ackerman IL. 1993. Changes in soil carbon inventories following cultivation of previously untilled soils. *Biogeochemistry* **20**: pp.161-193

Davidson EA and Verchot LV. 2000. Testing the hole-in-the-pipe model of nitric and nitrous oxide emissions from soils using the TRAGNET database. *Global Biogeochemical Cycles*. **14**: pp.1035-1042

Davidson EA, Verchot LV, Cattânio JH, Ackerman IL and Carvalho JEM. 2000. Effects of soil water content on soil respiration in forests and cattle pastures of eastern Amazonia. *Biogeochemistry*. **48**: pp.53-69

Department for InternationalDevelopment (DFID), 1994, Official development assistance to agriculture. www.**dfid-agriculture**-consultation.nri.org/summaries/wp9.pdf.

Fan S., Yu B, and Saurkar A. 2007. Public Spending in Developing Countries: Trends, Determination and Impact, In S. Fan (ed) *Public Expenditures, Growth and Poverty in Developing Countries: Issues, Methods, and Findings*. Baltimore: The Johns Hopkins University Press.

Intergovernmental Panel on Climate Change (IPCC). 2000. *IPCC Special Report on Land Use, Land-Use Change and Forestry*. Cambridge: Cambridge University Press

International Energy Agency (IEA). 2006. CO_2 Emissions from Fuel Combustion 1971-2004 -- 2006 Editions. Paris: IEA

International Energy Agency (IEA). 2006. *CO_2 Emissions from Fuel Combustion 1971-2004* -- 2006 Edition, Paris: IEA pp. 556

Klotz CA, Fuglie KO, and Pray CE. 1995. *Private-Sector Agricultural Research Expenditures in the United States, 1960-92,* AGES9525. Econ. Res. Serv., U.S. Dept. of Agr.,

Lal R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science*. **304**: 1623-1627

Li C, Frolking S, and Butterbach Ball K. 2005. Carbon sequestration in arable soils is likely to increase nitrous oxide emissions, offsetting reductions in climate radiative forcing. *Climatic Change*. **72**: pp.321-338. doi10.1007/s10584-005-6791-5

Rosegrant M, Paisner MS, and Meijer S. 2001. *Long-Term Prospects for Agriculture and the Resource Base*. The World Bank Rural Development Family. Rural Development Strategy Background Paper #1. Washington DC: The World Bank

Schneider UA and McCarl, BA. 2003. Economic potential of biomass based fuels for greenhouse gas emission mitigation. *Environmental and Resource Economics*. **24**: pp.291-312

Smith KA and Conen F. 2004. Impacts of land management on fluxes of trace greenhouse gases. *Soil Use and Management*. **20**: 255-263

Smith P, Martino D, Cai Z, Gwary D, Janzen HH, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes RJ, Sirotenko O, Howden M, McAllister T, Pan G, Romanenkov V, Schneider U, Towprayoon S, Wattenbach M, and Smith JU. 2007. Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society, B*.

Tate KR, Ross DJ, Scott NA, Rodda NJ, Townsend JA, and Arnold GC. 2006. Post-harvest patterns of carbon dioxide production, methane uptake and nitrous oxide production in a *Pinus radiata* D. Don plantation. *Forest Ecology and Management* **228**: pp.40-50

US Environmental Protection Agency (USEPA). 2006a. *Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990-2020*. Washington DC: USEPA

US Environmental Protection Agency (USEPA). 2006b. *Global Mitigation of Non-CO_2 Greenhouse Gases*. Washington DC: USEPA

Verchot LV, Davidson EA, Cattânio JH, and Ackerman IL. 2000. Land-use change and biogeochemical controls of methane fluxes in soils of eastern Amazonia. *Ecosystems*, **3**: pp.41-56

Verchot LV, Davidson EA, Cattânio JH, Ackerman IL, Erickson HE, and Keller M. 1999. Land-use change and biogeochemical controls of nitrogen oxide emissions from soils in eastern Amazonia. *Global Biogeochemical Cycles*. **13**: pp31-46

Verchot LV, Place F, Shepherd KD, and Jama B. 2007. Science and Technological Innovations for Improving Soil Fertility and Management in Africa. *ICRAF Working Paper No 31*. Nairobi: ICRAF

Verchot LV, van Noordwijk M, Kandji S, Tomich T, Ong C, Albrecht A, Mackensen J, Bantilan C, Anupama CK, and Palm C. 2007. Climate change: Linking adaptation and mitigation through agroforestry. *Mitigation and Adaptation Strategies for Global Change,* **12**: pp.1381-2386. DOI 10.1007/s11027-007-9105-6

Appendix 1. Non-CO_2 GHG emissions from Agriculture with projections through 2030

Table A1-1: Methane Emissions from Enteric Fermentation

	MtCO$_2$e							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Albania	1.2	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5
Algeria	3.4	3.3	4.0	4.5	5.1	6.0	7.6	8.4	9.2
Argentina	54.9	56.4	51.8	55.7	59.9	62.5	65.3	68.7	72.1
Armenia	0.9	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8
Australia	67.5	63.0	64.4	63.7	65.0	65.3	65.6	66.1	66.6
Austria	3.6	3.4	3.2	3.2	3.1	3.0	2.9	2.8	2.7
Azerbaijan	3.4	3.2	3.3	3.3	3.2	3.2	3.2	3.2	3.2
Bangladesh	10.9	10.8	10.7	11.7	12.9	13.9	15.1	16.2	17.3
Belarus	9.9	7.5	6.2	6.1	5.9	5.8	5.6	5.5	5.4
Belgium	4.5	4.5	4.2	4.1	4.0	3.9	3.8	3.7	3.6
Bolivia	9.2	9.8	10.9	11.8	12.9	13.8	14.8	15.8	16.7
Brazil	184.9	200.4	208.0	226.3	246.4	262.1	278.9	295.3	311.8
Bulgaria	3.8	1.8	1.7	2.2	2.3	2.2	2.2	2.3	2.3
Cambodia	2.9	3.4	3.6	4.8	6.0	8.0	10.1	11.7	13.3
Canada	18.7	21.3	20.8	23.4	25.7	28.7	31.7	33.7	35.8
Chile	5.6	6.5	6.9	7.4	8.1	8.6	9.2	9.8	10.4
China	186.3	221.3	230.8	258.9	291.3	320.2	352.7	379.8	406.9
Colombia	25.9	29.1	28.9	30.8	32.9	34.7	36.5	38.4	40.4
Croatia	1.3	0.8	0.7	0.9	1.0	1.0	1.0	1.0	1.0
Czech Republic	3.3	2.1	1.7	1.7	1.8	1.8	1.8	1.9	1.9
Democratic Republic of Congo (Kinshasa)	1.5	1.3	1.1	1.2	1.4	1.5	1.7	1.9	2.0
Denmark	3.1	3.1	2.9	2.7	2.6	2.5	2.5	2.4	2.2
Ecuador	5.9	6.7	6.9	7.6	8.2	8.8	9.5	10.1	10.8
Egypt	6.8	7.6	8.5	8.8	9.3	9.6	9.9	10.4	10.9
Estonia	1.1	0.6	0.4	0.6	0.7	0.7	0.7	0.8	0.8
Ethiopia	28.8	28.0	32.1	36.0	40.3	44.2	48.4	52.4	56.5
Finland	1.9	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4
France	30.9	29.6	29.2	29.1	29.0	29.1	29.2	29.3	29.3
Georgia	1.6	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.0
Germany	34.3	28.5	26.6	22.3	18.8	18.9	18.9	19.0	19.0
Greece	2.9	2.8	2.9	2.9	2.9	2.9	2.9	2.9	2.8
Hungary	3.0	1.8	1.8	2.2	2.7	3.4	4.1	4.6	5.2
Iceland	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
India	179.8	190.6	201.9	217.8	235.0	246.4	258.4	272.0	285.5
Indonesia	17.7	18.9	18.0	20.4	23.2	25.0	27.0	29.2	31.5
Iran	9.8	10.9	13.0	15.8	19.6	20.7	21.9	24.2	26.6
Iraq	2.6	1.9	2.0	2.2	2.3	2.5	2.6	2.7	2.9
Ireland	9.2	9.6	9.9	8.7	7.8	6.9	6.2	5.3	4.4
Israel	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Italy	12.3	12.5	12.2	12.0	11.5	11.2	10.8	10.5	10.1
Japan	7.2	7.1	6.8	7.0	7.2	7.4	7.6	7.8	8.0
Jordan	0.4	0.5	0.4	0.5	0.5	0.5	0.6	0.6	0.6
Kazakhstan	14.6	14.1	7.1	7.1	7.2	7.3	7.5	7.6	7.7

	MtCO2e							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Kuwait	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Kyrgyzstan	2.6	1.6	1.7	1.7	1.8	1.8	1.9	1.9	2.0
Laos	2.1	2.5	2.3	2.5	2.8	3.1	3.4	3.6	3.8
Latvia	2.1	0.8	0.6	0.5	0.6	0.6	0.6	0.7	0.7
Liechtenstein	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lithuania	3.3	2.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Luxembourg	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Macedonia	1.0	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5
Mexico	47.3	44.6	41.5	44.9	48.6	51.9	55.5	59.0	62.5
Moldova	1.7	1.5	0.8	0.8	0.8	0.7	0.7	0.7	0.7
Mongolia	4.9	5.4	6.0	6.3	6.7	7.1	7.5	7.8	8.2
Myanmar	8.3	9.3	10.2	11.4	12.7	14.1	15.5	16.7	17.9
Nepal	10.2	11.1	11.8	12.4	13.1	13.8	14.5	15.2	15.9
Netherlands	7.3	7.0	6.4	6.3	6.0	5.8	5.6	5.4	5.2
New Zealand	21.5	22.2	23.1	23.9	23.7	24.0	24.3	24.5	24.8
Nigeria	23.1	25.3	30.9	34.1	37.7	41.0	44.6	48.2	51.9
North Korea	1.2	1.0	0.9	0.9	1.0	1.0	1.1	1.1	1.1
Norway	1.7	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.9
Pakistan	40.5	44.9	51.3	57.1	63.9	68.7	74.7	80.6	86.4
Peru	7.3	7.7	8.6	9.4	10.4	11.3	12.3	13.2	14.2
Philippines	5.5	5.6	6.0	6.8	7.6	8.4	9.3	10.0	10.6
Poland	16.7	11.9	9.1	8.3	7.7	7.1	6.5	5.9	5.2
Portugal	2.6	2.6	2.6	2.6	2.7	2.7	2.8	2.8	2.9
Romania	11.2	6.6	5.7	6.4	7.1	8.0	8.8	9.6	10.4
Russian Federation	93.0	68.3	43.6	47.8	52.1	57.0	62.0	66.5	71.1
Saudi Arabia	1.6	1.8	1.8	1.9	2.1	2.1	2.2	2.3	2.4
Senegal	2.8	3.2	3.6	4.0	4.5	5.0	5.6	6.1	6.5
Singapore	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Slovak Republic	2.4	1.5	1.1	1.2	1.2	1.1	1.1	1.1	1.1
Slovenia	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
South Africa	19.2	17.5	18.0	18.5	19.1	19.2	19.3	19.7	20.0
South Korea	2.6	3.8	2.8	3.1	3.3	3.6	3.9	4.1	4.4
Spain	12.7	12.9	14.3	14.6	14.9	15.3	15.7	16.0	16.4
Sweden	3.0	3.1	2.9	2.8	2.8	2.8	2.8	2.8	2.8
Switzerland	2.8	2.6	2.5	2.5	2.4	2.4	2.3	2.2	2.2
Tajikistan	2.6	2.1	1.8	1.8	1.9	1.9	2.0	2.0	2.1
Thailand	13.0	12.7	10.3	11.7	13.3	14.6	16.1	16.1	16.1
Turkey	25.5	23.9	21.4	22.3	23.2	23.9	24.6	24.6	24.6
Turkmenistan	2.4	1.8	1.5	1.5	1.6	1.6	1.7	1.7	1.8
Uganda	4.1	4.5	5.1	5.7	6.3	6.8	7.4	7.9	8.5
Ukraine	36.5	28.8	16.2	18.4	19.1	20.8	22.6	24.1	25.6
United Arab Emirates	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
United Kingdom	18.2	18.0	17.3	17.1	16.8	16.6	16.4	16.1	15.8
United States	117.9	123.0	115.6	112.9	114.7	110.5	108.6	106.2	103.8
Uruguay	12.4	13.7	13.4	14.6	16.0	17.3	18.6	19.6	20.6

	$MtCO_2e$							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Uzbekistan	5.8	6.4	6.1	6.3	6.5	6.6	6.8	6.9	7.1
Venezuela	13.4	15.0	16.1	17.7	19.5	21.0	22.7	24.2	25.8
Viet Nam	6.5	7.2	7.7	8.6	9.7	10.7	11.9	12.9	14.0
								0.0	0.0
Rest of Africa	123.9	133.5	150.2	167.3	186.6	204.4	224.4	243.3	262.3
Rest of Latin America	29.8	31.4	31.1	34.1	37.3	40.1	43.2	46.3	49.3
Rest of Middle East	4.6	4.4	5.2	5.6	6.0	6.4	6.7	7.1	7.5
Rest of Non-EU Eastern Europe	4.1	4.2	3.3	3.3	3.2	3.1	3.1	3.0	2.9
Rest of OECD90 & EU	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Rest of SE Asia	9.5	9.9	9.5	10.4	11.3	12.2	13.1	13.1	13.1
Global	**1772**	**1804**	**1799**	**1929**	**2079**	**2204**	**2344**	**2473**	**2601**
E. Europe	231	175	126	135	141	149	158	164	171
W. Europe	149	142	138	132	126	125	124	122	121
CWANA	63	63	60	65	72	76	80	86	91
SSE Asia	497	553	578	639	707	764	827	882	938
L. America	397	421	424	460	500	532	567	601	634
SS Africa	203	213	241	267	296	322	351	380	408
Other developed	233	237	231	231	236	236	238	238	239
World Totals	**1772**	**1804**	**1799**	**1929**	**2079**	**2204**	**2344**	**2473**	**2601**

Table A1-2: Methane Emissions from Rice Cultivation

	$MtCO_2e$							New Projections	
Country	1990	1995	2000	2005	2010	2015	2020	2025	2030
Albania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Algeria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Argentina	0.3	0.8	0.8	0.8	0.9	0.9	1.0	1.0	1.1
Armenia									
Australia	0.5	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Austria									
Azerbaijan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bangladesh	16.1	15.4	16.5	18.3	20.0	21.7	23.4	25.1	26.8
Belarus									
Belgium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bolivia	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Brazil	5.0	6.0	5.1	5.4	5.7	5.9	6.2	6.5	6.7
Bulgaria	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cambodia	3.1	3.2	3.3	3.7	4.2	4.7	5.1	5.5	6.0
Canada									
Chile	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
China	237.3	220.2	215.9	223.9	231.1	237.5	242.1	248.7	255.2
Colombia	3.5	3.0	3.3	3.6	3.8	4.1	4.3	4.6	4.8
Croatia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Czech Republic									
Democratic Republic of Congo (Kinshasa)	2.5	3.0	2.3	2.6	3.0	3.5	3.9	4.4	4.8
Denmark	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ecuador	2.2	3.2	3.1	3.4	3.6	3.8	4.0	4.2	4.5
Egypt	4.0	5.4	6.0	6.7	7.4	8.0	8.6	9.3	9.9
Estonia									
Ethiopia									
Finland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
France	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Georgia									
Germany									
Greece	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Hungary	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Iceland									
India	85.7	85.9	89.5	96.5	103.3	109.7	115.5	120.9	126.3
Indonesia	41.2	47.9	48.3	51.4	54.4	57.1	59.5	62.4	65.2
Iran	2.2	2.4	2.6	2.6	2.7	2.8	2.8	2.9	3.0
Iraq	0.5	1.0	0.8	0.9	1.0	1.1	1.2	1.4	1.5
Ireland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Israel									
Italy	1.5	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Japan	7.1	7.2	6.0	6.2	6.4	6.6	6.8	7.0	7.1
Jordan									

	MtCO$_2$e							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Kazakhstan	1.2	1.4	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Kuwait									
Kyrgyzstan	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Laos	3.3	2.8	3.5	3.9	4.3	4.8	5.2	5.7	6.2
Latvia									
Liechtenstein									
Lithuania									
Luxembourg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Macedonia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mexico	0.4	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.5
Moldova									
Mongolia									
Myanmar	27.9	35.3	35.2	37.5	39.5	41.2	42.8	45.0	47.1
Nepal	5.9	6.4	6.9	7.4	7.9	8.1	8.3	8.7	9.1
Netherlands									
New Zealand									
Nigeria	15.3	22.8	26.2	29.7	33.3	36.9	40.4	44.3	48.3
North Korea	3.0	2.7	2.5	2.6	2.6	2.6	2.7	2.8	2.8
Norway									
Pakistan	4.6	4.7	5.0	5.6	6.4	7.2	8.0	8.7	9.5
Peru	1.1	1.2	1.7	1.8	2.0	2.1	2.2	2.4	2.5
Philippines	12.6	14.3	15.3	16.8	18.2	19.5	20.8	22.1	23.5
Poland									
Portugal	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Romania	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Russian Federation	2.4	1.4	1.5	1.4	1.4	1.3	1.3	1.2	1.2
Saudi Arabia									
Senegal	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3
Singapore									
Slovak Republic									
Slovenia									
South Africa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South Korea	8.6	7.3	7.2	7.4	7.6	7.6	7.7	7.8	7.9
Spain	0.2	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Sweden									
Switzerland									
Tajikistan	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Thailand	42.8	44.3	45.3	45.7	46.2	46.6	47.1	47.8	48.4
Turkey	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.5
Turkmenistan	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Uganda	0.5	0.7	0.9	1.1	1.3	1.5	1.8	2.0	2.2
Ukraine	0.4	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
United Arab Emirates									
United Kingdom									
United States	7.1	7.6	7.5	7.6	6.8	6.9	6.9	6.8	6.7

	MtCO$_2$e							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Uruguay	1.5	2.7	3.4	3.6	3.7	3.8	3.9	4.0	4.1
Uzbekistan	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.2	0.2
Venezuela	0.5	0.7	0.6	0.7	0.7	0.8	0.8	0.9	1.0
Viet Nam	29.2	32.8	37.1	39.6	42.3	44.9	47.5	50.5	53.5
Rest of Africa	7.3	11.7	13.8	15.9	18.2	20.8	23.6	26.1	28.7
Rest of Latin America	2.3	2.4	2.6	2.8	2.9	3.1	3.2	3.4	3.5
Rest of Middle East	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rest of Non-EU Eastern Europe									
Rest of OECD90 & EU									
Rest of SE Asia	8.5	8.2	8.0	8.9	9.7	10.4	11.1	11.9	12.7
Global	**601**	**621**	**634**	**672**	**708**	**744**	**776**	**812**	**848**
E. Europe	3	2	2	2	2	2	2	2	2
W. Europe	2	2	2	2	2	2	2	2	2
CWANA	8	11	11	12	13	14	15	15	16
SSE Asia	530	531	539	569	597	624	647	674	700
L. America	17	21	21	23	24	25	26	28	29
SS Africa	26	38	43	49	56	63	70	77	84
Other developed	15	15	14	15	14	14	14	14	15
World Totals	**601**	**621**	**634**	**672**	**708**	**744**	**776**	**812**	**848**

Appendix 1-3: Methane Emissions from Manure Management

	MtCO2e							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Albania	0.1	0.1	0.3	0.5	0.7	0.8	0.8	1.0	1.1
Algeria	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.4	0.4
Argentina	2.2	2.4	2.0	2.2	2.4	2.5	2.7	2.8	3.0
Armenia	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.1
Australia	1.5	1.7	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Austria	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8
Azerbaijan	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Bangladesh	1.5	1.5	1.5	1.7	1.8	2.0	2.2	2.3	2.5
Belarus	1.2	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.7
Belgium	2.6	2.7	2.7	2.7	2.6	2.6	2.6	2.6	2.6
Bolivia	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.7	0.7
Brazil	7.1	7.9	8.0	8.7	9.4	10.1	10.8	11.4	12.0
Bulgaria	1.5	0.7	0.6	0.7	0.8	0.7	0.8	0.8	0.8
Cambodia	0.4	0.5	0.5	0.7	0.8	1.1	1.4	1.6	1.8
Canada	3.1	3.4	3.3	3.8	4.1	4.6	5.1	5.5	5.9
Chile	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5
China	15.7	18.9	19.8	21.9	24.3	26.2	28.3	30.4	32.4
Colombia	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1.0	1.0
Croatia	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Czech Republic	1.0	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.8
Democratic Republic of Congo (Kinshasa)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
Denmark	0.7	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.6
Ecuador	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.4
Egypt	0.5	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.9
Estonia	0.4	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Ethiopia	1.1	1.0	1.2	1.3	1.5	1.6	1.8	1.9	2.0
Finland	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
France	13.8	13.7	13.3	13.3	13.2	13.3	13.3	13.3	13.3
Georgia	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Germany	27.1	23.8	23.3	19.6	16.5	16.6	16.6	16.7	16.7
Greece	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Hungary	0.8	0.5	0.5	0.7	0.8	0.8	0.8	0.8	0.8
Iceland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
India	18.8	20.1	21.5	23.2	25.0	26.2	27.5	29.0	30.5
Indonesia	1.1	1.3	1.0	1.1	1.3	1.4	1.5	1.6	1.7
Iran	0.4	0.4	0.6	0.7	0.8	0.9	0.9	1.0	1.1
Iraq	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Ireland	1.3	1.4	1.4	1.2	1.1	1.0	0.9	0.8	0.6
Israel	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3
Italy	4.0	3.9	3.9	4.0	4.1	4.2	4.3	4.4	4.5
Japan	1.1	1.0	0.9	1.0	1.0	1.0	1.0	1.1	1.1
Jordan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kazakhstan	1.7	1.0	0.5	0.5	0.6	0.6	0.6	0.6	0.6

	MtCO₂e							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Kuwait	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kyrgyzstan	0.4	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Laos	0.3	0.4	0.3	0.3	0.4	0.4	0.4	0.5	0.5
Latvia	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Liechtenstein	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lithuania	0.5	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Luxembourg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Macedonia	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
Mexico	0.9	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
Moldova	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Mongolia	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3
Myanmar	0.9	1.1	1.3	1.4	1.6	1.7	1.8	2.0	2.1
Nepal	0.7	0.7	0.8	0.8	0.8	0.9	0.9	1.0	1.0
Netherlands	3.0	3.0	2.7	2.5	2.4	2.3	2.2	2.0	1.9
New Zealand	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7
Nigeria	1.2	1.3	1.6	1.7	1.9	2.1	2.3	2.4	2.6
North Korea	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Norway	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Pakistan	3.7	4.1	4.9	5.4	6.0	6.5	7.1	7.7	8.3
Peru	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.4
Philippines	1.4	1.4	1.5	1.7	2.0	2.2	2.5	2.6	2.8
Poland	1.2	1.0	0.8	0.7	0.7	0.7	0.7	0.7	0.6
Portugal	1.6	1.4	1.4	1.5	1.5	1.5	1.5	1.6	1.6
Romania	3.9	2.4	1.9	2.1	2.3	2.5	2.7	2.9	3.1
Russian Federation	10.5	8.0	5.1	5.8	6.0	6.5	7.0	7.5	8.0
Saudi Arabia	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Senegal	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3
Singapore	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Slovak Republic	0.4	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Slovenia	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
South Africa	1.8	1.6	1.7	1.7	1.8	1.8	1.8	1.9	1.9
South Korea	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5
Spain	6.2	7.1	8.4	9.0	9.4	10.0	10.5	11.2	11.9
Sweden	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Switzerland	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Tajikistan	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Thailand	2.7	2.9	2.7	3.1	3.5	3.9	4.3	4.6	5.0
Turkey	8.4	8.3	7.6	7.9	8.2	8.4	8.6	8.9	9.1
Turkmenistan	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Uganda	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3
Ukraine	4.6	3.5	2.2	2.5	2.6	2.9	3.1	3.3	3.5
United Arab Emirates	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
United Kingdom	2.9	2.9	2.8	2.6	2.5	2.5	2.6	2.5	2.5
United States	31.2	36.1	38.1	39.2	40.1	42.3	43.8	45.3	46.8
Uruguay	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.5

	$MtCO_2e$							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Uzbekistan	0.8	0.9	0.8	0.8	0.9	0.9	0.9	0.9	1.0
Venezuela	0.5	0.6	0.7	0.8	0.9	0.9	1.0	1.1	1.1
Viet Nam	2.2	2.9	3.5	3.9	4.4	4.9	5.3	5.8	6.4
Rest of Africa	5.7	6.1	6.9	7.6	8.5	9.3	10.3	11.0	11.8
Rest of Latin America	1.1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.7
Rest of Middle East	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.4
Rest of Non-EU Eastern Europe	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Rest of OECD90 & EU	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Rest of SE Asia	2.3	2.7	2.3	2.5	2.7	2.9	3.1	3.2	3.3
Global	**223**	**225**	**225**	**235**	**244**	**257**	**269**	**282**	**294**
E. Europe	38	30	23	26	27	28	29	30	32
W. Europe	66	63	63	60	57	57	58	58	58
CWANA	5	5	5	5	5	5	6	6	6
SSE Asia	52	59	62	68	75	81	87	93	99
L. America	14	15	16	17	18	19	21	22	23
SS Africa	10	11	12	13	14	15	17	18	19
Other developed	38	43	45	47	48	51	53	55	57
World Totals	**223**	**225**	**225**	**235**	**244**	**257**	**269**	**282**	**294**

Table A1-4: Methane Emissions from Other Agricultural Sources

	$MtCO_2e$							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Albania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Algeria	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Argentina	2.5	1.8	8.3	8.3	8.3	8.3	8.3	8.3	8.3
Armenia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Australia	9.6	9.5	19.2	19.2	19.2	19.2	19.2	19.2	19.2
Austria	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Azerbaijan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bangladesh	0.1	0.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Belarus	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Belgium	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Bolivia	6.4	6.2	16.4	16.4	16.4	16.4	16.4	16.4	16.4
Brazil	54.3	48.4	98.4	98.4	98.4	98.4	98.4	98.4	98.4
Bulgaria	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cambodia	1.6	1.7	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Canada	4.4	32.1	4.6	4.6	4.6	4.6	4.6	4.6	4.6
Chile	1.7	1.5	0.7	0.7	0.7	0.7	0.7	0.7	0.7
China	2.0	0.4	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Colombia	4.2	3.6	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Croatia	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Czech Republic	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Democratic Republic of Congo (Kinshasa)	18.8	18.9	38.7	38.7	38.7	38.7	38.7	38.7	38.7
Denmark	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ecuador	2.5	2.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Egypt			0.0	0.0	0.0	0.0	0.0	0.0	0.0
Estonia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ethiopia	3.3	3.7	5.3	5.3	5.3	5.3	5.3	5.3	5.3
Finland	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
France	1.3	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Georgia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Germany	-0.1	-0.5	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Greece	0.4	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Hungary	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Iceland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
India	1.3	1.0	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Indonesia	12.7	12.2	21.5	21.5	21.5	21.5	21.5	21.5	21.5
Iran	0.6	0.7	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Iraq			0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ireland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Israel	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Italy	1.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Japan	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Jordan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kazakhstan	0.4	0.2	0.6	0.6	0.6	0.6	0.6	0.6	0.6

	MtCO2e							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Kuwait	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kyrgyzstan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Laos	1.4	1.5	4.6	4.6	4.6	4.6	4.6	4.6	4.6
Latvia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Liechtenstein			0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lithuania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Luxembourg	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0
Macedonia	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mexico	3.1	2.8	9.7	9.7	9.7	9.7	9.7	9.7	9.7
Moldova	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Mongolia	0.6	0.6	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Myanmar	4.2	4.1	10.8	10.8	10.8	10.8	10.8	10.8	10.8
Nepal	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Netherlands	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
New Zealand	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	3.9	4.0	5.6	5.6	5.6	5.6	5.6	5.6	5.6
North Korea			0.1	0.1	0.1	0.1	0.1	0.1	0.1
Norway	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pakistan	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Peru	2.8	2.5	2.1	2.1	2.1	2.1	2.1	2.1	2.1
Philippines	3.4	3.1	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Poland	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Portugal	0.7	0.9	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Romania	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Russian Federation	6.8	2.4	12.8	12.8	12.8	12.8	12.8	12.8	12.8
Saudi Arabia	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Senegal	1.3	1.3	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Singapore	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Slovak Republic	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Slovenia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South Africa	2.9	2.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
South Korea	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Spain	1.6	0.8	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Sweden	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Switzerland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tajikistan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thailand	2.8	2.2	5.4	5.4	5.4	5.4	5.4	5.4	5.4
Turkey	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Turkmenistan	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Uganda	1.7	1.7	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Ukraine	0.6	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6
United Arab Emirates	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
United Kingdom	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
United States	0.7	0.7	0.8	0.8	0.9	0.9	1.0	1.0	1.1
Uruguay	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

	MtCO$_2$e							New Projections	
Country	1990	1995	2000	2005	2010	2015	2020	2025	2030
Uzbekistan	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Venezuela	5.0	4.6	8.9	8.9	8.9	8.9	8.9	8.9	8.9
Viet Nam	1.8	1.8	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Rest of Africa	70.8	70.0	130.3	130.3	130.3	130.3	130.3	130.3	130.3
Rest of Latin America	7.8	7.6	13.2	13.2	13.2	13.2	13.2	13.2	13.2
Rest of Middle East	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Rest of Non-EU Eastern Europe	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Rest of OECD90 & EU	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rest of SE Asia	7.7	8.3	5.6	5.6	5.6	5.6	5.6	5.6	5.6
Global	**268**	**274**	**455**	**456**	**456**	**456**	**456**	**456**	**456**
E. Europe	11	6	17	17	17	17	17	17	17
W. Europe	6	2	1	1	1	1	1	1	1
CWANA	3	2	2	2	2	2	2	2	2
SSE Asia	40	37	60	60	60	60	60	60	60
L. America	90	81	165	165	165	165	165	165	165
SS Africa	103	102	186	186	186	186	186	186	186
Other developed	15	43	25	25	25	25	25	25	25
World Totals	**268**	**274**	**455**	**456**	**456**	**456**	**456**	**456**	**456**

Table A1-5: Methane Emissions from All Agricultural Sources

	$MtCO_2e$							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Albania	1.3	1.7	1.9	2.1	2.3	2.4	2.4	2.6	2.7
Algeria	3.9	3.7	4.2	4.7	5.4	6.3	7.9	8.8	9.6
Argentina	59.8	61.4	62.9	67.0	71.4	74.3	77.2	80.8	84.4
Armenia	1.0	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9
Australia	79.1	74.9	86.3	85.6	86.9	87.2	87.6	88.1	88.6
Austria	4.7	4.5	4.2	4.1	4.0	3.9	3.8	3.7	3.5
Azerbaijan	4.1	3.9	4.0	3.9	3.9	3.9	3.9	3.8	3.8
Bangladesh	28.7	27.7	29.8	32.7	35.8	38.7	41.7	44.7	47.7
Belarus	11.2	8.6	7.1	7.0	6.8	6.7	6.5	6.4	6.2
Belgium	7.2	7.4	7.0	6.9	6.8	6.7	6.5	6.4	6.3
Bolivia	16.1	16.6	27.9	28.9	30.0	31.0	32.1	33.1	34.1
Brazil	251.4	262.7	319.5	338.7	359.9	376.5	394.2	411.5	428.9
Bulgaria	5.5	2.6	2.4	3.1	3.2	3.1	3.2	3.2	3.2
Cambodia	8.0	8.8	9.3	11.1	12.8	15.6	18.4	20.7	23.0
Canada	26.2	56.8	28.8	31.8	34.4	37.9	41.3	43.9	46.4
Chile	7.6	8.4	8.0	8.6	9.2	9.8	10.5	11.1	11.7
China	441.3	460.8	468.2	506.4	548.5	585.6	624.8	660.5	696.2
Colombia	34.3	36.4	39.5	41.7	44.0	46.1	48.3	50.5	52.7
Croatia	1.6	1.1	1.0	1.1	1.2	1.2	1.2	1.2	1.2
Czech Republic	4.4	2.9	2.5	2.5	2.6	2.6	2.7	2.7	2.8
Democratic Republic of Congo (Kinshasa)	22.9	23.3	42.1	42.6	43.2	43.8	44.5	45.1	45.7
Denmark	4.0	4.0	3.8	3.6	3.4	3.3	3.2	3.0	2.9
Ecuador	10.8	12.5	10.7	11.6	12.5	13.3	14.2	15.1	16.0
Egypt	11.3	13.6	15.2	16.2	17.4	18.4	19.4	20.5	21.7
Estonia	1.5	0.8	0.4	0.7	0.8	0.8	0.8	0.9	0.9
Ethiopia	33.2	32.8	38.6	42.6	47.1	51.1	55.4	59.6	63.8
Finland	2.2	1.9	1.8	1.6	1.6	1.6	1.6	1.6	1.6
France	46.1	43.8	42.9	42.8	42.6	42.8	42.9	42.9	43.0
Georgia	1.9	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.3
Germany	61.3	51.8	49.4	41.5	34.9	35.0	35.1	35.2	35.4
Greece	3.9	3.7	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Hungary	4.1	2.5	2.5	3.2	3.6	4.3	5.0	5.6	6.2
Iceland	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
India	285.6	297.6	317.3	341.9	367.7	386.7	405.7	426.2	446.7
Indonesia	72.7	80.3	88.7	94.4	100.3	105.0	109.5	114.7	119.9
Iran	13.0	14.4	16.6	19.6	23.5	24.8	26.1	28.6	31.1
Iraq	3.2	3.1	2.9	3.1	3.4	3.7	4.0	4.2	4.5
Ireland	10.5	11.0	11.4	10.0	8.9	8.0	7.1	6.1	5.0
Israel	0.9	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1
Italy	19.0	18.3	18.0	17.8	17.5	17.2	17.0	16.7	16.4
Japan	15.5	15.5	13.9	14.4	14.8	15.2	15.6	16.0	16.5
Jordan	0.4	0.6	0.5	0.5	0.5	0.6	0.6	0.6	0.6
Kazakhstan	17.9	16.7	9.5	9.5	9.6	9.7	9.9	10.0	10.1

	$MtCO_2e$							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Kuwait	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
Kyrgyzstan	3.0	1.9	2.0	2.1	2.1	2.2	2.3	2.3	2.4
Laos	7.1	7.2	10.6	11.3	12.1	12.8	13.6	14.3	15.0
Latvia	2.4	1.0	0.7	0.6	0.7	0.7	0.8	0.8	0.8
Liechtenstein	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lithuania	3.8	2.6	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Luxembourg	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Macedonia	1.2	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Mexico	51.7	48.9	52.8	56.3	60.1	63.6	67.3	70.9	74.6
Moldova	2.1	1.7	1.0	1.0	0.9	0.9	0.9	0.9	0.9
Mongolia	5.7	6.2	6.4	6.8	7.2	7.6	8.0	8.4	8.8
Myanmar	41.3	49.9	57.4	61.1	64.5	67.7	70.9	74.4	77.9
Nepal	17.1	18.5	19.5	20.7	21.9	22.9	23.8	24.9	26.1
Netherlands	10.4	10.1	9.1	8.8	8.5	8.1	7.8	7.5	7.1
New Zealand	22.2	22.8	23.7	24.5	24.3	24.7	25.0	25.3	25.5
Nigeria	43.4	53.3	64.2	71.1	78.4	85.5	92.8	100.6	108.4
North Korea	4.4	3.8	3.5	3.7	3.8	3.9	4.0	4.1	4.2
Norway	2.0	2.1	2.1	2.1	2.1	2.1	2.1	2.2	2.2
Pakistan	49.1	53.9	61.2	68.2	76.3	82.5	89.8	97.0	104.2
Peru	11.4	11.6	12.7	13.7	14.8	15.9	17.1	18.1	19.2
Philippines	22.9	24.4	23.5	25.9	28.4	30.7	33.2	35.4	37.6
Poland	18.3	13.3	10.3	9.5	8.8	8.2	7.6	7.0	6.3
Portugal	5.2	5.1	4.2	4.3	4.4	4.5	4.6	4.7	4.7
Romania	15.5	9.3	7.9	8.8	9.7	10.8	11.8	12.8	13.8
Russian Federation	112.7	80.1	62.9	67.8	72.2	77.6	83.1	88.1	93.1
Saudi Arabia	1.9	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
Senegal	4.3	4.8	4.9	5.3	5.9	6.4	7.0	7.5	8.1
Singapore	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Slovak Republic	2.9	1.9	1.3	1.5	1.5	1.5	1.5	1.4	1.4
Slovenia	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
South Africa	23.9	21.8	23.2	23.8	24.4	24.6	24.7	25.1	25.5
South Korea	11.8	11.8	10.7	11.2	11.7	12.0	12.4	12.8	13.2
Spain	20.7	20.9	23.2	24.1	24.9	25.8	26.7	27.8	28.8
Sweden	3.5	3.6	3.3	3.2	3.1	3.1	3.1	3.1	3.1
Switzerland	3.3	3.1	2.9	2.9	2.8	2.8	2.7	2.6	2.6
Tajikistan	2.9	2.3	2.1	2.1	2.2	2.2	2.3	2.3	2.4
Thailand	61.4	62.1	63.8	65.9	68.3	70.5	72.9	73.9	75.0
Turkey	35.6	33.9	30.8	32.0	33.3	34.2	35.2	35.4	35.7
Turkmenistan	2.9	2.3	2.0	2.0	2.1	2.2	2.2	2.3	2.3
Uganda	6.5	7.1	8.2	8.9	9.8	10.6	11.5	12.3	13.0
Ukraine	42.2	32.9	19.1	21.5	22.3	24.3	26.2	28.0	29.7
United Arab Emirates	0.3	0.4	0.5	0.6	0.6	0.7	0.9	1.0	1.1
United Kingdom	21.4	20.9	20.2	19.8	19.4	19.2	19.0	18.7	18.3
United States	156.9	167.3	162.0	160.5	162.5	160.7	160.3	159.3	158.3
Uruguay	14.2	16.9	17.2	18.7	20.2	21.6	23.1	24.2	25.4

	$MtCO_2e$							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Uzbekistan	7.1	7.7	7.2	7.4	7.6	7.8	8.0	8.2	8.3
Venezuela	19.5	21.0	26.3	28.1	29.9	31.6	33.4	35.1	36.8
Viet Nam	39.7	44.6	50.1	54.1	58.3	62.4	66.5	71.2	75.8
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rest of Africa	207.7	221.4	301.3	321.1	343.6	364.9	388.6	410.8	433.1
Rest of Latin America	41.0	42.5	48.2	51.3	54.8	57.9	61.3	64.5	67.8
Rest of Middle East	4.9	4.9	5.6	6.0	6.5	6.8	7.2	7.6	8.1
Rest of Non-EU Eastern Europe	4.9	5.0	4.1	4.1	4.0	3.9	3.8	3.8	3.7
Rest of OECD90 & EU	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5
Rest of SE Asia	28.1	29.2	25.4	27.3	29.3	31.0	32.9	33.7	34.6
Global	**2863**	**2925**	**3113**	**3291**	**3487**	**3660**	**3846**	**4023**	**4200**
E. Europe	283	213	169	179	187	196	205	213	221
W. Europe	222	209	205	195	186	185	185	183	182
CWANA	79	81	78	84	92	97	103	109	115
SSE Asia	1119	1181	1239	1336	1440	1528	1620	1709	1797
L. America	518	539	626	665	707	742	779	815	851
SS Africa	342	364	482	516	552	587	625	661	697
Other developed	300	337	315	317	323	326	330	333	335
World Totals	**2863**	**2925**	**3113**	**3291**	**3487**	**3660**	**3846**	**4023**	**4200**

Table A1-6: Nitrous Oxide Emissions from Agricultural Soils

	Mt CO_2e							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Algeria	7.0	6.8	8.1	9.1	10.3	11.7	13.3	14.4	15.5
Argentina	45.4	46.6	53.3	62.2	73.2	87.2	105.1	115.2	125.2
Armenia	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Australia	14.7	14.9	18.1	19.2	19.1	19.6	20.2	21.2	22.1
Austria	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Azerbaijan	0.6	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Bangladesh	30.3	39.5	40.4	43.9	47.4	53.1	58.9	63.2	67.5
Belarus	9.7	6.7	6.9	7.2	7.7	8.1	8.7	9.1	9.5
Belgium	4.9	4.8	4.9	4.6	4.6	4.4	4.3	4.2	4.1
Bolivia	6.6	7.5	8.4	10.1	13.0	18.4	29.4	29.4	29.4
Brazil	133.0	149.8	152.1	172.6	196.2	223.5	255.4	275.3	295.3
Bulgaria	16.7	11.5	15.1	18.9	20.1	23.5	24.7	27.3	29.9
Canada	27.4	30.4	33.4	36.3	39.3	42.9	46.5	49.6	52.8
Chile	5.0	4.9	4.9	5.5	6.2	6.9	7.7	8.4	9.1
China	411.8	495.2	503.1	529.3	556.4	586.9	618.5	649.1	679.7
Colombia	2.1	1.6	2.3	2.5	2.8	3.2	3.6	3.9	4.3
Croatia	0.9	1.1	1.4	1.7	2.0	2.4	2.9	3.2	3.5
Czech Republic	0.6	0.6	5.3	5.3	5.3	5.3	5.3	5.3	5.3
Democratic Republic of Congo (Kinshasa)	3.8	3.9	3.5	4.1	4.8	5.6	6.6	7.4	8.2
Denmark	9.8	8.6	8.1	7.8	7.6	7.3	7.1	6.7	6.3
Ecuador	4.7	5.5	6.6	7.4	8.2	9.2	10.2	11.1	12.0
Egypt	6.5	8.4	8.7	10.0	11.5	13.3	15.3	16.7	18.1
Estonia	0.9	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5
Ethiopia	36.3	37.8	41.4	48.9	57.8	68.3	80.6	88.1	95.7
Finland	4.4	3.8	3.4	3.2	3.2	2.9	2.9	2.7	2.5
France	52.9	50.1	51.2	50.5	50.0	50.3	50.7	50.7	50.7
Georgia	0.9	0.3	0.4	0.4	0.4	0.5	0.5	0.5	0.6
Germany	26.4	23.7	24.5	23.9	23.2	22.6	22.0	21.4	20.8
Greece	6.4	5.7	5.9	5.6	5.2	4.9	4.7	4.4	4.1
Hungary	24.8	9.8	10.3	13.2	14.7	17.8	21.0	23.6	26.2
Iceland	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
India	283.8	294.4	370.4	391.8	415.1	441.2	470.0	502.0	534.0
Indonesia	16.2	20.0	25.4	26.7	28.1	29.5	31.0	33.4	35.8
Iran	36.2	39.2	45.3	51.5	58.8	67.3	78.2	85.2	92.2
Iraq	6.0	5.6	6.2	7.1	8.1	9.2	10.5	11.6	12.6
Ireland	6.4	6.9	7.1	7.3	7.4	7.5	7.7	7.9	8.0
Israel	0.6	0.8	1.1	1.3	1.5	1.7	2.0	2.2	2.5
Italy	20.2	20.9	21.4	21.2	20.9	20.6	20.4	20.1	19.8
Japan	1.2	1.0	1.0	1.0	1.1	1.2	1.3	1.4	1.5
Jordan	0.9	1.2	1.2	1.3	1.5	1.7	2.0	2.1	2.3
Kazakhstan	18.0	12.1	5.7	5.8	6.0	6.2	6.4	6.5	6.7
Kuwait	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	Mt CO_2e							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Latvia	3.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Liechtenstein	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lithuania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Luxembourg	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Mexico	52.4	49.3	50.7	56.4	62.9	70.1	78.2	85.1	91.9
Moldova	0.7	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Monaco	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mongolia	8.1	9.4	11.6	12.6	13.6	14.7	15.8	17.1	18.4
Myanmar	2.1	3.4	4.7	6.0	7.4	9.3	11.2	12.7	14.2
Nepal	5.6	6.3	6.9	7.7	8.7	9.8	11.1	12.0	12.9
Netherlands	6.7	8.3	7.8	7.7	7.4	7.1	6.9	6.6	6.4
New Zealand	11.4	11.6	11.9	13.9	15.6	18.1	20.5	22.7	24.8
Nigeria	28.8	29.9	33.7	39.8	47.1	55.7	66.0	72.3	78.6
North Korea (DPRK)	8.4	2.1	2.9	3.0	3.2	3.4	3.6	3.8	4.0
Norway	2.7	2.6	2.6	2.7	2.7	2.8	2.9	2.9	3.0
Pakistan	60.6	73.1	79.3	80.4	81.6	82.9	84.7	86.0	87.4
Peru	10.4	11.1	11.9	13.3	14.9	16.7	18.8	20.2	21.6
Philippines	5.7	5.6	5.9	6.2	6.5	6.9	7.2	7.5	7.8
Poland	12.7	9.6	11.0	11.4	11.9	12.3	12.5	12.9	13.3
Portugal	4.6	4.8	5.0	5.0	4.7	4.6	4.5	4.4	4.3
Romania	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4
Russian Federation	34.4	34.4	40.1	48.1	53.8	62.9	72.0	78.6	85.1
Saudi Arabia	6.8	6.4	7.6	8.7	9.9	11.2	12.8	13.8	14.9
Senegal	4.3	5.3	5.6	5.6	5.7	5.7	5.7	5.8	5.8
Singapore	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Slovakia	3.9	2.2	1.9	3.4	3.6	3.6	3.6	4.0	4.3
Slovenia	0.4	0.4	0.6	0.7	0.8	0.9	1.0	1.1	1.2
South Africa	21.8	21.1	22.5	23.8	25.2	26.7	28.4	29.6	30.8
South Korea (ROK)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4
Spain	18.0	15.8	18.5	18.5	18.6	18.6	18.7	18.8	18.8
Sweden	3.8	3.7	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Switzerland	2.4	2.3	2.1	2.1	2.0	2.0	2.0	1.9	1.9
Thailand	2.8	3.6	5.1	5.4	5.7	5.9	6.3	6.5	6.8
Turkey	41.4	37.0	39.0	45.1	52.4	61.0	71.1	79.2	87.2
Turkmenistan	3.5	3.2	3.1	3.3	3.5	3.8	4.1	4.4	4.6
Uganda	5.7	4.9	6.9	8.1	9.7	11.6	13.9	15.6	17.3
Ukraine	24.5	13.4	16.1	20.3	23.8	29.5	35.2	39.9	44.6
United Arab Emirates	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
United Kingdom	29.5	28.0	28.0	26.7	26.1	25.2	24.3	23.5	22.7
Uruguay	9.9	10.0	9.4	10.5	11.7	13.0	14.5	15.8	17.1
US	267.2	283.3	297.7	306.4	315.0	320.8	326.9	336.6	346.3
Uzbekistan	10.5	9.1	16.3	17.3	18.3	19.3	20.5	21.5	22.6
Venezuela	12.3	14.0	14.4	16.0	17.9	19.9	22.2	23.8	25.4
Vietnam	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.7	1.8

	Mt CO_2e							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Rest of Africa	179.3	202.2	220.3	218.1	246.2	277.9	313.7	345.5	377.3
Rest of China/CPA	3.2	3.9	3.8	4.8	5.2	5.7	6.3	6.8	7.3
Rest of Eastern Europe	8.9	7.1	6.7	6.5	7.0	7.6	8.4	9.1	9.8
Rest of FSU	6.4	6.7	4.0	3.7	3.9	4.1	4.2	4.4	4.6
Rest of Latin America	29.7	30.6	32.7	34.3	38.2	42.6	47.5	52.0	56.4
Rest of Middle East	22.5	21.6	22.4	23.9	26.9	30.3	34.1	37.0	40.0
Rest of OECD 90	0.3	0.3	0.5	0.5	0.6	0.7	0.8	0.9	0.9
Rest of S&E Asia	14.3	15.0	19.3	20.7	23.2	25.8	29.2	31.7	34.2
Global	**2284**	**2405**	**2610**	**2782**	**2996**	**3252**	**3542**	**3774**	**4006**
E. Europe	157	111	129	151	164	187	208	227	246
W. Europe	201	193	194	190	188	186	184	182	180
CWANA	168	161	176	197	222	251	286	312	338
SSE Asia	846	963	1069	1128	1190	1262	1340	1417	1494
L. America	311	331	347	391	445	511	593	640	688
SS Africa	280	305	334	349	396	451	515	564	614
Other developed	322	341	362	377	390	403	415	431	448
World Totals	**2284**	**2405**	**2610**	**2782**	**2996**	**3252**	**3542**	**3774**	**4006**

Table A1-7: Nitrous Oxide Emissions from Manure Management

	Mt CO_2e							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Algeria	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Argentina	0.3	0.4	0.5	0.6	0.7	0.7	0.8	0.9	1.0
Armenia	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Australia	0.3	0.5	0.6	0.7	0.7	0.8	0.8	0.9	0.9
Austria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Azerbaijan	0.5	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.9
Bangladesh	0.5	0.6	0.6	0.7	0.7	0.8	0.9	1.0	1.1
Belarus	2.1	1.7	1.7	1.7	1.8	1.8	1.9	2.0	2.0
Belgium	1.9	1.9	1.9	2.0	2.0	1.9	1.9	1.8	1.8
Bolivia	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6
Brazil	3.9	4.3	3.7	4.1	4.5	5.1	5.6	6.1	6.6
Bulgaria	1.0	0.5	0.5	0.5	0.6	0.7	0.8	0.9	1.0
Canada	3.7	4.2	4.3	5.2	5.7	6.4	7.1	7.7	8.2
Chile	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
China	49.5	60.0	62.4	65.6	68.7	72.5	76.2	79.5	82.8
Colombia	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7
Croatia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Czech Republic	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Democratic Republic of Congo (Kinshasa)	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4
Denmark	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Ecuador	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7
Egypt	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Estonia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ethiopia	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.6
Finland	0.6	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
France	3.2	3.1	3.1	3.1	3.0	3.1	3.1	3.1	3.1
Georgia	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.5
Germany	3.4	2.7	2.5	2.4	2.3	2.2	1.9	1.7	1.6
Greece	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Hungary	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Iceland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
India	5.2	5.5	6.0	6.1	6.3	6.5	6.7	6.9	7.1
Indonesia	3.0	3.6	3.7	4.1	4.5	5.4	5.8	6.4	6.9
Iran	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.4
Iraq	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ireland	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Israel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Italy	3.8	3.8	4.0	3.9	3.7	3.5	3.4	3.2	3.0
Japan	4.2	3.8	3.7	3.8	3.9	4.0	4.1	4.2	4.3
Jordan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kazakhstan	2.9	2.2	1.3	1.4	1.4	1.5	1.5	1.6	1.6
Latvia	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Liechtenstein	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	Mt CO_2e							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Lithuania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Luxembourg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mexico	1.7	1.9	1.8	2.0	2.2	2.4	2.7	3.0	3.2
Moldova	0.5	0.4	0.2	0.2	0.3	0.3	0.3	0.3	0.3
Monaco	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mongolia	0.5	0.5	0.6	0.7	0.7	0.8	0.8	0.9	1.0
Myanmar	1.7	1.9	2.1	2.7	3.3	4.3	5.3	6.2	7.1
Nepal	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.5
Netherlands	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3
New Zealand	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Nigeria	0.6	0.8	0.9	1.1	1.2	1.5	1.7	1.9	2.1
North Korea (DPRK)	0.7	0.4	0.4	0.4	0.5	0.6	0.6	0.7	0.7
Norway	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pakistan	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.6	1.7
Peru	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6
Philippines	1.1	1.3	1.6	1.7	1.8	2.0	2.2	2.4	2.6
Poland	6.2	6.2	6.1	6.3	6.6	6.8	6.9	7.2	7.4
Portugal	1.0	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Romania	2.7	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Russian Federation	21.3	16.6	17.2	19.5	20.3	22.1	24.0	25.6	27.2
Saudi Arabia	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Senegal	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Singapore	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Slovakia	1.1	0.7	0.5	0.6	0.6	0.6	0.6	0.6	0.6
Slovenia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South Africa	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
South Korea (ROK)	0.8	1.2	1.2	1.3	1.4	1.5	1.6	1.7	1.8
Spain	15.2	14.5	16.1	16.1	16.1	16.1	16.1	16.1	16.1
Sweden	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Switzerland	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Thailand	1.5	1.8	1.8	2.3	2.9	3.6	4.5	5.2	5.9
Turkey	2.0	2.0	1.9	2.2	2.5	2.8	3.2	3.5	3.8
Turkmenistan	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Uganda	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.5
Ukraine	9.4	7.3	7.6	8.6	9.0	9.8	10.7	11.4	12.1
United Kingdom	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Uruguay	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
US	16.0	16.4	17.7	19.0	19.9	20.9	21.9	22.9	24.0
Uzbekistan	1.4	1.5	1.4	1.4	1.5	1.5	1.6	1.6	1.7
Venezuela	0.3	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.1
Vietnam	1.8	2.2	2.8	3.1	3.4	4.0	4.6	5.0	5.5
Rest of Africa	2.5	2.7	2.8	3.1	3.4	3.8	4.2	4.6	5.0
Rest of China/CPA	0.8	1.0	1.1	1.2	1.3	1.5	1.7	1.9	2.0
Rest of Eastern Europe	2.0	1.7	1.6	1.6	1.7	1.7	1.8	1.9	1.9
Rest of FSU	1.5	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8

	Mt CO_2e							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Rest of Latin America	1.0	1.1	1.2	1.4	1.5	1.7	1.9	2.1	2.2
Rest of Middle East	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Rest of OECD 90	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Rest of S&E Asia									
Global	**195.6**	**198.6**	**204.9**	**219.1**	**230.2**	**245.5**	**260.8**	**274.4**	**288.0**
E. Europe	48.8	39.2	39.4	43.2	45.0	48.1	51.1	54.0	56.8
W. Europe	34.8	32.4	34.0	34.0	33.6	33.3	32.8	32.5	32.2
CWANA	7.6	7.0	6.1	6.6	7.1	7.7	8.3	8.9	9.5
SE Asia	67.6	80.6	84.7	90.5	96.4	104.3	112.1	118.9	125.6
L. America	8.6	9.7	9.6	10.6	11.8	13.2	14.6	15.9	17.2
SS Africa	4.1	4.5	4.7	5.3	6.0	6.8	7.7	8.4	9.2
Other developed	24.2	25.0	26.4	28.8	30.3	32.2	34.0	35.8	37.5
World Totals	**195.6**	**198.6**	**204.9**	**219.1**	**230.2**	**245.5**	**260.8**	**274.4**	**288.0**

Table A1-8: Total Direct $N_2$0 Emissions from Manure Management and Soils

	Mt CO_2e							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Algeria	7.1	6.9	8.1	9.2	10.4	11.8	13.4	14.5	15.6
Argentina	45.7	47.0	53.8	62.8	73.9	87.9	105.9	116.0	126.1
Armenia	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3
Australia	15.0	15.4	18.6	19.9	19.8	20.4	21.0	22.0	23.1
Austria	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Azerbaijan	1.1	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9
Bangladesh	30.8	40.1	41.0	44.6	48.2	54.0	59.8	64.2	68.5
Belarus	11.8	8.4	8.5	9.0	9.5	10.0	10.6	11.0	11.5
Belgium	6.8	6.7	6.8	6.7	6.6	6.4	6.2	6.0	5.9
Bolivia	6.8	7.8	8.7	10.5	13.4	18.8	29.9	30.0	30.0
Brazil	136.9	154.1	155.8	176.6	200.7	228.6	261.0	281.5	301.9
Bulgaria	17.8	12.0	15.6	19.5	20.8	24.2	25.5	28.2	30.9
Canada	31.0	34.6	37.7	41.6	45.0	49.3	53.5	57.3	61.0
Chile	5.1	5.1	5.2	5.8	6.5	7.2	8.0	8.7	9.4
China	461.3	555.2	565.5	594.9	625.2	659.4	694.7	728.6	762.5
Colombia	2.4	2.0	2.7	3.0	3.3	3.7	4.2	4.6	5.0
Croatia	0.9	1.1	1.4	1.7	2.0	2.4	2.9	3.2	3.5
Czech Republic	1.1	1.1	5.7	5.8	5.8	5.8	5.8	5.8	5.8
Democratic Republic of Congo (Kinshasa)	4.0	4.1	3.6	4.3	5.0	5.9	7.0	7.8	8.6
Denmark	10.3	9.1	8.5	8.2	8.0	7.8	7.6	7.2	6.8
Ecuador	5.0	5.8	7.0	7.8	8.7	9.7	10.8	11.8	12.8
Egypt	6.6	8.5	8.7	10.1	11.6	13.4	15.5	16.9	18.3
Estonia	1.0	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5
Ethiopia	36.5	38.1	41.7	49.2	58.1	68.7	81.1	88.7	96.3
Finland	4.9	4.3	3.8	3.6	3.6	3.3	3.3	3.1	2.9
France	56.1	53.3	54.3	53.6	53.0	53.4	53.8	53.8	53.8
Georgia	1.4	0.6	0.7	0.8	0.8	0.9	0.9	1.0	1.0
Germany	29.8	26.4	27.0	26.3	25.5	24.8	23.9	23.1	22.4
Greece	6.5	5.9	6.1	5.7	5.4	5.1	4.8	4.6	4.3
Hungary	25.3	10.3	10.8	13.7	15.2	18.3	21.5	24.1	26.7
Iceland	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
India	289.0	299.9	376.4	398.0	421.4	447.7	476.7	508.9	541.1
Indonesia	19.2	23.6	29.1	30.9	32.6	34.9	36.8	39.7	42.7
Iran	36.4	39.4	45.5	51.7	59.0	67.6	78.5	85.5	92.5
Iraq	6.0	5.6	6.2	7.1	8.1	9.2	10.5	11.6	12.7
Ireland	7.1	7.6	7.8	8.0	8.1	8.3	8.4	8.6	8.7
Israel	0.6	0.8	1.2	1.3	1.5	1.8	2.0	2.3	2.5
Italy	24.0	24.7	25.4	25.1	24.6	24.2	23.7	23.3	22.9
Japan	5.4	4.9	4.7	4.8	5.0	5.2	5.4	5.6	5.8
Jordan	0.9	1.2	1.2	1.3	1.5	1.7	2.0	2.1	2.3
Kazakhstan	20.9	14.3	7.0	7.2	7.4	7.6	7.9	8.1	8.3
Kuwait	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Latvia	3.1	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1

	Mt CO_2e							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Liechtenstein	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lithuania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Luxembourg	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Mexico	54.1	51.1	52.5	58.4	65.1	72.6	80.9	88.0	95.1
Moldova	1.2	0.5	0.3	0.3	0.3	0.4	0.4	0.4	0.4
Monaco	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mongolia	8.6	9.9	12.2	13.3	14.3	15.5	16.7	18.0	19.4
Myanmar	3.8	5.3	6.8	8.8	10.8	13.6	16.5	18.9	21.2
Nepal	5.8	6.5	7.1	8.0	9.0	10.2	11.5	12.5	13.4
Netherlands	6.9	8.6	8.0	8.0	7.7	7.4	7.1	6.9	6.6
New Zealand	11.5	11.7	12.0	14.0	15.7	18.2	20.7	22.8	25.0
Nigeria	29.5	30.7	34.6	40.9	48.4	57.2	67.7	74.2	80.7
North Korea (DPRK)	9.1	2.5	3.3	3.5	3.7	4.0	4.3	4.5	4.8
Norway	2.7	2.6	2.6	2.7	2.7	2.8	2.9	2.9	3.0
Pakistan	61.3	74.0	80.2	81.4	82.7	84.2	86.2	87.6	89.1
Peru	10.7	11.4	12.2	13.7	15.3	17.2	19.3	20.8	22.2
Philippines	6.8	6.9	7.5	7.9	8.4	8.9	9.4	9.9	10.3
Poland	18.9	15.8	17.2	17.7	18.6	19.1	19.4	20.0	20.6
Portugal	5.6	6.0	6.2	6.2	6.0	5.9	5.8	5.7	5.6
Romania	9.1	8.1	7.9	7.9	7.9	7.9	7.9	7.9	7.9
Russian Federation	55.7	51.0	57.3	67.6	74.1	85.0	96.0	104.2	112.3
Saudi Arabia	6.8	6.5	7.7	8.7	9.9	11.3	12.9	13.9	15.0
Senegal	4.3	5.4	5.7	5.7	5.8	5.8	5.9	5.9	6.0
Singapore	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
Slovakia	5.0	2.9	2.4	4.0	4.2	4.2	4.2	4.5	4.9
Slovenia	0.4	0.4	0.6	0.7	0.8	0.9	1.0	1.1	1.2
South Africa	22.2	21.5	22.9	24.2	25.6	27.1	28.8	30.0	31.2
South Korea (ROK)	1.1	1.5	1.5	1.6	1.7	1.8	1.9	2.0	2.2
Spain	33.2	30.3	34.6	34.6	34.7	34.8	34.8	34.9	35.0
Sweden	4.5	4.3	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Switzerland	2.9	2.7	2.5	2.5	2.4	2.4	2.4	2.3	2.3
Thailand	4.4	5.4	7.0	7.7	8.5	9.6	10.8	11.7	12.7
Turkey	43.3	39.0	40.9	47.3	54.9	63.8	74.3	82.7	91.0
Turkmenistan	3.9	3.6	3.4	3.6	3.8	4.1	4.4	4.7	5.0
Uganda	5.8	5.1	7.1	8.4	9.9	11.9	14.2	16.0	17.8
Ukraine	33.9	20.7	23.7	28.9	32.8	39.3	45.8	51.3	56.8
United Arab Emirates	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
United Kingdom	31.1	29.6	29.6	28.3	27.7	26.8	25.9	25.1	24.3
Uruguay	9.9	10.0	9.4	10.5	11.7	13.1	14.6	15.9	17.2
US	283.2	299.7	315.4	325.4	334.9	341.7	348.8	359.5	370.3
Uzbekistan	12.0	10.5	17.7	18.7	19.7	20.9	22.1	23.2	24.3
Venezuela	12.7	14.5	14.9	16.7	18.6	20.7	23.1	24.8	26.5
Vietnam	2.5	3.1	3.8	4.2	4.6	5.3	6.1	6.7	7.2

	Mt CO_2e							New Projections	
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Rest of Africa	181.7	204.9	223.1	221.2	249.6	281.7	317.9	350.1	382.3
Rest of China/CPA	4.0	5.0	4.9	6.0	6.5	7.2	8.0	8.7	9.3
Rest of Eastern Europe	10.9	8.9	8.2	8.1	8.7	9.4	10.2	11.0	11.7
Rest of FSU	7.9	7.4	4.7	4.4	4.6	4.8	5.0	5.2	5.4
Rest of Latin America	30.6	31.7	33.9	35.7	39.7	44.3	49.4	54.0	58.6
Rest of Middle East	22.5	21.7	22.5	24.0	27.0	30.4	34.2	37.2	40.2
Rest of OECD 90	0.4	0.4	0.5	0.5	0.6	0.8	0.9	1.0	1.1
Rest of S&E Asia	15.4	16.3	20.7	22.4	25.1	28.1	31.9	34.8	37.7
Global	**2481**	**2605**	**2817**	**3002**	**3228**	**3500**	**3805**	**4051**	**4297**
E. Europe	205	150	169	194	209	236	260	281	302
W. Europe	235	225	228	224	221	219	217	215	212
CWANA	176	168	182	204	229	259	294	321	347
SE Asia	915	1045	1155	1220	1289	1369	1455	1539	1623
L. America	320	341	356	401	457	524	607	656	705
SS Africa	284	310	339	354	402	458	523	573	623
Other developed	346	366	388	406	420	435	449	467	485
World Totals	**2481**	**2605**	**2817**	**3002**	**3228**	**3500**	**3805**	**4051**	**4297**

Appendix 2. Mitigation Measures for Non-CO_2 GHGs and Soil Carbon

Table A2-1: Examples of mitigation practices in cropping, rangeland management and livestock systems. Compiled from Verchot et al., (2007); IPCC WGIII, (2007) and USEPA (2006b).

Mitigation activity	Description	GHG effect
Agronomy		
Improved crop varieties	Use crop varieties that require fewer inputs.	Fossil fuel, N_2O
Extending crop rotations	Incorporate perennial crops in crop rotations to build up soil organic matter.	C sequestration
Catch crops	Provide temporary vegetative cover between vines or in orchards to increase soil organic matter and to absorb excess nitrogen.	C sequestration, N_2O
Nutrient management		
Precision agriculture	Apply nutrients where and when crops need them.	N_2O
Use organic fertilizer	A portion of the crop's nutrient needs can be met	Reduce fossil fuel emissions from fertilizer manufacture, uncertain for N_2O.
Tillage and residue management		
Reduced/no tillage	With better weed control, it is now feasible to reduce or abandon tillage altogether	Increased soil C, uncertain for N_2O
Retain crop residues on soil	Crop residues are left on the soil surface to protect against erosion following cultivation.	Increased soil C, reduced burning emissions,
Rice management		
Improved water management	Rice paddies can be drained once or several times over the course of the growing season.	Reduced CH_4, increased N_2O emissions.
Better residue management	Improved residue management can be achieved through improving the quality (e.g. composting) and timing (e.g apply straw off season) of residues applied to soils.	Reduced CH_4 and N_2O and reduced so C.
Shallow flooding	Reducing the depth of water during flooding periods	Reduced CH_4 and N_2O and reduced soil C.
Ammonium sulfate	Replace urea and ammonium bicarbonate with ammonium sulfate fertilizer.	Sulfate reduces CH_4 production.
Slow release fertilizer	Reducing N release by coating fertilizer pellets or tablets increases fertilizer use efficiency.	Reduced N_2O emission.
Shift rice production to uplands	Upland rice is not flooded so emissions due to high water content are avoided. Tradeoffs need to be evaluated as upland rice yields are much lower than paddy-grown rice.	Reduced CH_4 emission. Tradeoffs vis-à-vis soil C and N_2O need to be evaluated per unit of rice produced.
Grazing land management		
Grazing intensity	Intensity and timing of grazing can influence standing biomass and composition of grazing lands.	Generally increased carbon in soil, uncertain for N_2O.
Nutrient and water management	Fertilization and irrigation of pastures and grazing lands.	Improved nutrient ad water management can increase standing stocks of biomass and soil organic matter. The effects on non-CO_2 GHGs are variable.

Mitigation activity	Description	GHG effect
Fire management	Reduce fire frequency and extent of fires	Reduces emissions of CH_4, ozone precursors, and aerosols. Increases standing stock of biomass.
Management of species composition	Improving pastures and grazing lands can involve introducing grass species with higher productivity or with greater C allocation to the roots, or introducing N-fixing legumes into these areas.	Increased C sequestration in the soil and perhaps increased N_2O emissions.
Livestock management		
Improved feeding practices	Replace a portion of forages in animal diets with concentrates or add oils and oil seeds to animal feed.	Concentrates may increase daily CH_4 emissions per animal, but generally increase productivity so animals are slaughtered at younger ages and herd sizes can be reduced while productivity is maintained.
Specific dietary additives	➢ Ionophores are antibiotics that reduce CH_4 production. ➢ Halogenated compounds inhibit methanogenic bacteria ➢ Novel plant-derived compounds such as condensed tannins, saponins, or essential oils may reduce CH_4. ➢ Propionate precursors (e.g. fumarate, malate) reduce CH_4 production. ➢ Bovine somatotropin and hormonal growth implants do not reduce CH_4 production, but they raise productivity and thus reduce emission per kg of animal product.	Reduction of CH_4 production
Breeding	Increased productivity through both breeding and better management raise productivity and thus reduce emission per kg of animal product.	Reduction of CH_4 production can often be achieved, but whole system accounting is required to verify this.
Manure Management		
Improved lagoon and tank management	Emissions can be reduced by cooling or covering lagoosn, separating solids from the slurry, or by capturing CH_4 produced.	Reduced CH_4 and N_2O emissions
Anaerobic digestion	Anaerobic digestion produces CH_4, which can be captured and burned as an alternative energy source. There are a number of digester technologies available.	Reduced CH_4 emission and displaced fossil fuel emissions.
Bioenergy	Agricultural residues can be used as sources of feed stocks for energy to displace fossil fuels. Increasingly, agricultural crops are being grown as feed stocks.	Displaced fossil fuel emissions.

Land cover change		
Fallowing	Removing land temporarily from production or setting land aside and allowing natural revegetation.	C sequestration in soil and aboveground biomass.
Rehabilitation of degraded land	Degraded lands are extensive in tropical countries and generally have low carbon stocks. Revegetation and improving soil fertility on these lands can restore productivity.	C sequestration, but greater emissions of N_2O.
Agroforestry	Agroforestry refers to a wide variety of practices that integrate trees into agricultural lands. These practices include shelter belts and border plantings, alley cropping, multistrata systems (e.g shade coffee), riparian management, etc.	Agroforestry systems have higher carbon stocks aboveground than most agricultural systems. Effects on N_2O depend on presence of N fixing trees.