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Republic of Rwanda: Greenhouse gas emissions baseline projection

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Abbreviations

AEEI	autonomous energy efficiency improvement
CH_4	methane
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
FAO	Food and Agricultural Organization of the United Nations
GDP	gross domestic product
GHG	greenhouse gas
GWh	gigawatt hour
ha	hectare
IPCC	Intergovernmental Panel on Climate Change
Ktoe	kilotonne oil equivalent
LULUCF	land use, land-use change and forestry
MT	megatonne
N_2O	nitrous oxide
NAMA	nationally appropriate mitigation action
toe	tonnes of oil equivlaent

1.0 Introduction

Rwanda is interested in the development of nationally appropriate mitigation actions (NAMAs). This emissions baseline projection report helps to identify the potential for NAMAs to reduce emissions and contributes to building capacity in Rwanda to select, design and implement NAMAs.

This report describes the methodology used to develop an emissions baseline projection to 2030 for the entire Rwandan economy as well as by sector. The information is organized by the seven sectors: agriculture, land use, land-use change and forestry, energy (both energy supply and energy demand), transportation, industrial processes and waste. This baseline scenario is not suitable for reporting to the United Nations Framework Convention on Climate Change, but is a very strong starting point and can easily be built on. The purpose of developing the baseline emissions projection is to provide a business-as-usual or reference scenario against which mitigation policies and measures can be evaluated. As such, the baseline emissions projection should be a plausible and consistent description of how these sectors might evolve in the future in the absence of explicit policies or regulation directed at greenhouse gas (GHG) emissions.

This report builds on the work that Rwanda has undertaken in the preparation for their second national communication to the United Nations Framework Convention on Climate Change. This work includes the development of a GHG inventory and identification of measures to mitigate climate change. The second national communication includes estimates of GHG emissions between 2003 and 2006. No emissions inventory data is currently available for years after 2006.

Section 2 describes and provides context for the overall emissions baseline projection. Sections 3 through 9 provide the specific methodologies and data used to generate an emissions baseline reference case (to 2030) for each of the seven sectors.

2.0 *Emissions Baseline*

As illustrated in Figures 2 and 3 on page 5, the reference case includes the development of an inventory of historical emissions from 1990 to 2010, and the projection of annual emissions out to 2030. This forms the reference case—or the baseline—against which it is possible to demonstrate the abatement potential of low-carbon development options out to 2030. This baseline is meant to represent a conservative estimate of future emissions that considers existing climate policies and regulations in Rwanda and does not reflect aspirational targets and goals under Vision 2020 that will require additional financing (Ministry of Finance and Economic Planning, 2009). The report focuses on a single baseline reference case for ease of analysis. A more detailed mitigation or low-carbon analysis might assess uncertainty by considering multiple baseline reference cases.

All emission data presented in this section is based on our own modelling results. Details on how these emissions were calculated by sector are provided in Sections 3 through 9.

2.1 Historical GHG Emissions

Trends in historical GHG emissions were based on and calibrated against the second national communication emissions inventory, which is referred to as the **SNC inventory** (SNC) in this report (Ministry of Natural Resources, 2012). The SNC inventory divides emissions between five major sectors that align with the 1996 Intergovernmental Panel on Climate Change (IPCC) guidelines for conducting emissions inventories.

In order to develop this emissions baseline projection, it was necessary to reproduce historical emissions estimated in the SNC inventory using appropriate activity data, emission factors and methodologies. We began this process by collecting this data and using a spreadsheet model to calculate historical emissions from 2003 to 2006 using the same Tier 1 methodology approaches undertaken in the SNC Inventory. This may seem like a duplication of effort; however, it is critically important when developing projections because future changes in emissions are dependent on changes in activity data, as well as potential changes in emission factors and parameters. Reliable emission projections therefore must be based on this type of bottom-up analysis. An additional advantage of reproducing the SNC inventory is that assumptions and data are independently reviewed and questioned, which may lead to more robust and accurate emission inventories in the future. Within this report, we discuss extensively how emission data may be improved over time.

Emissions in this report deviate from the SNC inventory in a few cases. Differences between the SNC inventory and the emissions baseline projection were informed by a review of the literature and are documented in this report for each of the seven sectors.

The relationship between the seven sectors of the low-carbon analysis and the major IPCC sectors in the SNC inventory and 1996 guidelines is set out in Table 1.

TABLE 1: RELATIONSHIP OF EMISSION BASELINE REFERENCE CASE SECTORS TO INVENTORY SECTORS

MITIGATION ANALYSIS SECTORS	SNC INVENTORY SECTORS (BASED ON 1996 IPCC GUIDELINES)
Energy demand	Energy
Energy supply	
Transportation	
Industrial processes	Industrial processes
Agriculture	Agriculture
Land use, land-use change and forestry (LULUCF)	Land use, land-use change and forestry (LULUCF)
Waste	Waste

Source: IPCC (1996); UNFCCC (1999)

As there is considerable uncertainty in emissions and removals from the land use, land-use change and forestry (LULUCF) sector, results are presented with and without the LULUCF sector in this report. Figure 1 and Table 2 illustrate the specific sources that contributed to the total estimated emissions in 2010.

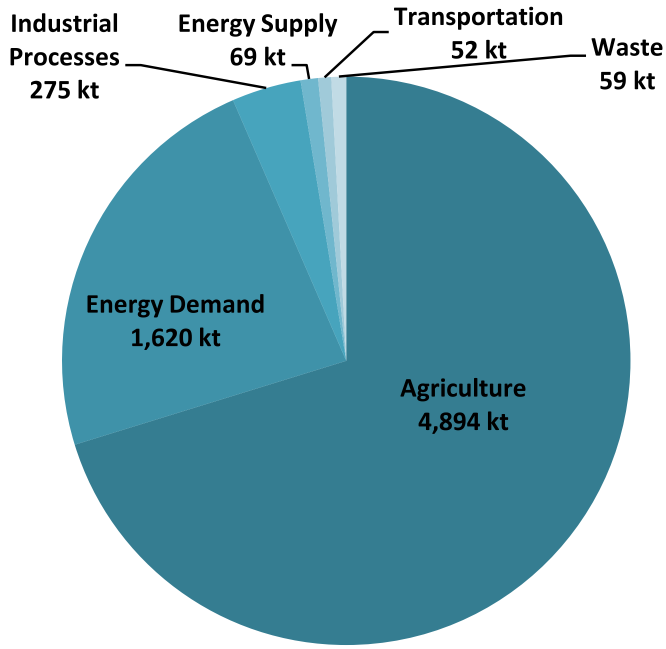

FIGURE 1: TOTAL EMISSIONS BY SECTOR IN 2010 (IN KILOTONNES OF CARBON DIOXIDE EQUIVALENT [KTCO$_2$E], EXCLUDING LULUCF)

TABLE 2: HISTORICAL NET EMISSIONS: 2000, 2005 AND 2010 (IN KILOTONNES CO_2E [$KTCO_2E$])

SECTOR	2003	2007	2010
Agriculture	3,477	4,179	4,894
Energy demand	969	1,342	1,620
Industrial processes	154	270	275
Energy supply	52	65	69
Transportation	35	44	52
Waste	47	59	59
LULUCF	-14,238	-7,168	-1,866
Total (without LULUCF)	**4,734**	**5,950**	**6,969**
Total (with LULUCF)	**-9,504**	**-1.218**	**5,103**

Note: Negative values denote net removals

In the LULUCF sector, removals due to the sequestration of carbon or growth of biomass are larger than emissions, resulting in a net sink every year from 2000 to 2010. LULUCF net emissions were estimated to be -14,238 kt in the year 2000 and -1,866 kt in 2010, where negative emissions denote emission removals or sinks. This historical trend is very significant, as it suggests that Rwanda as a whole is moving from being a considerable sink (-9,504 kt in 2000) to a small contributor to global emissions in 2010 (5,103 kt in 2010). However, the trend is based solely on limited forestry data from the Food and Agriculture Organization (FAO) that has a high degree of uncertainty and does not consider all sources and removals of GHGs from all land-use types (FAO, 2010).

The agriculture sector is the largest emitting sector, accounting for approximately 65 per cent of non-LULUCF emissions in 2010, mainly due to emissions from cultivating soils. Energy demand is the second largest emitting sector, accounting for 23 per cent of non-LULUCF emissions in 2010. Energy demand emissions are dominated by methane and nitrous oxide (N_2O) emissions from biomass combustion. Industrial processes was the next largest emitting sector in 2010, accounting for about 4 per cent of non-LULUCF emissions, followed by energy supply at about 1 per cent.

Figure 2 illustrates the trend in total emissions over time for non-LULUCF sectors and Figure 3 presents both emissions and removals, including LULUCF and the resulting net emissions over time.

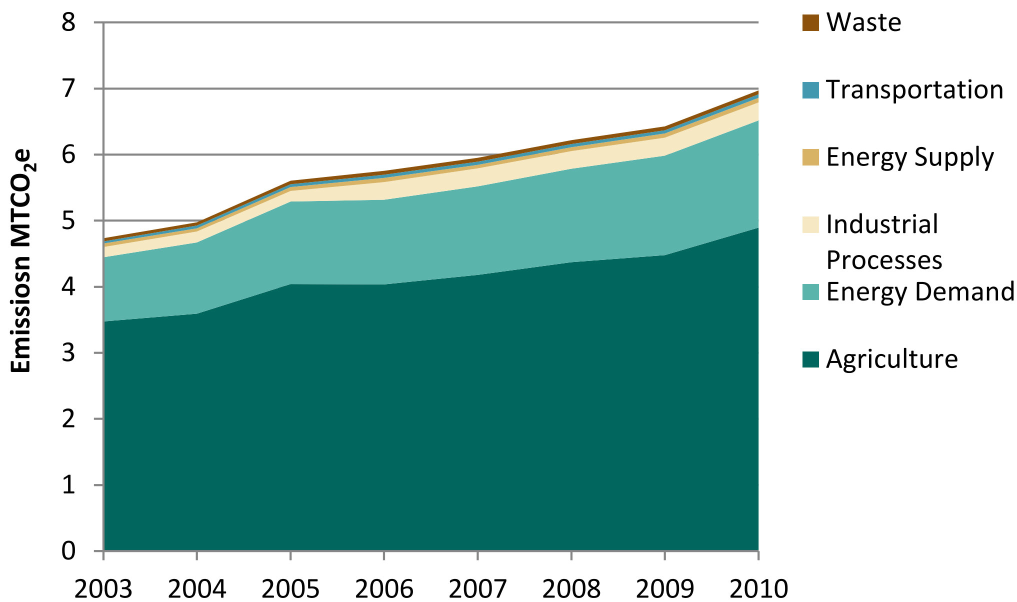

FIGURE 2: TOTAL EMISSIONS BY SECTOR 2000-2010 ($MTCO_2E$ EXCLUDING LULUCF)

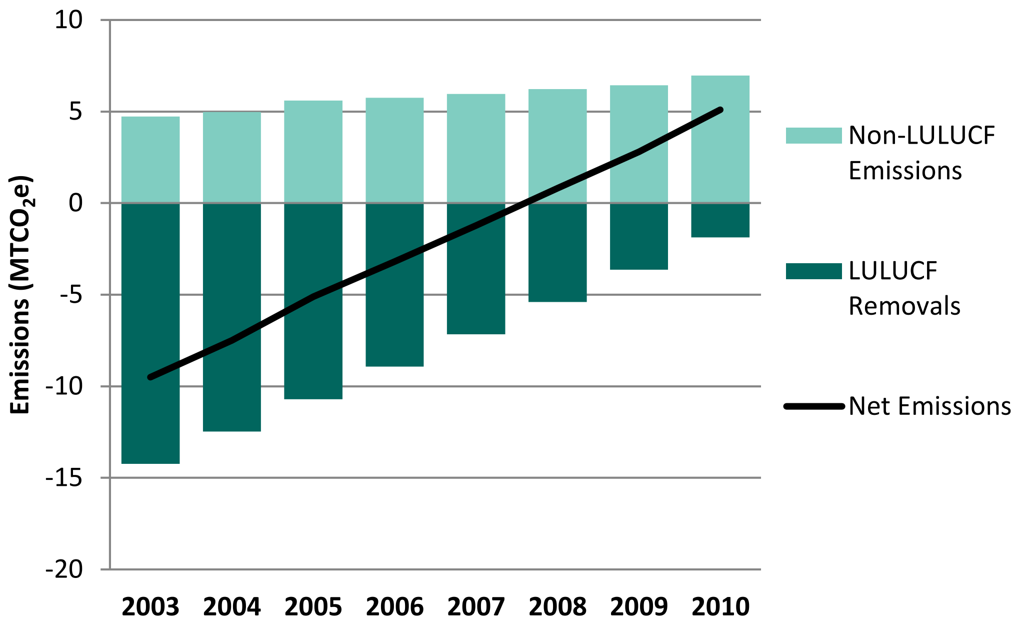

FIGURE 3: TOTAL EMISSIONS BY SECTOR IN 2000–2010 ($MTCO_2E$)

2.2 Projection of baseline emissions

Projections of growth in activity and changes in emission factors were then used to forecast annual emissions to 2030 for a baseline scenario. These growth projections were based primarily on forecasts for economic growth and population change. Results of the baseline projection are illustrated in Figure 4 excluding LULUCF and in Figure 5 including LULUCF.

These projected emissions to 2030 shape the baseline reference case that is used as the counterfactual against which abatement potential of NAMAs can be demonstrated. Projections of LULUCF sources and removal of GHGs are highly uncertain and based on a simple model that assumes historical trends in forest carbon stocks estimated by the FAO will continue. In-country experts may be able to provide better estimates based on more reliable data.

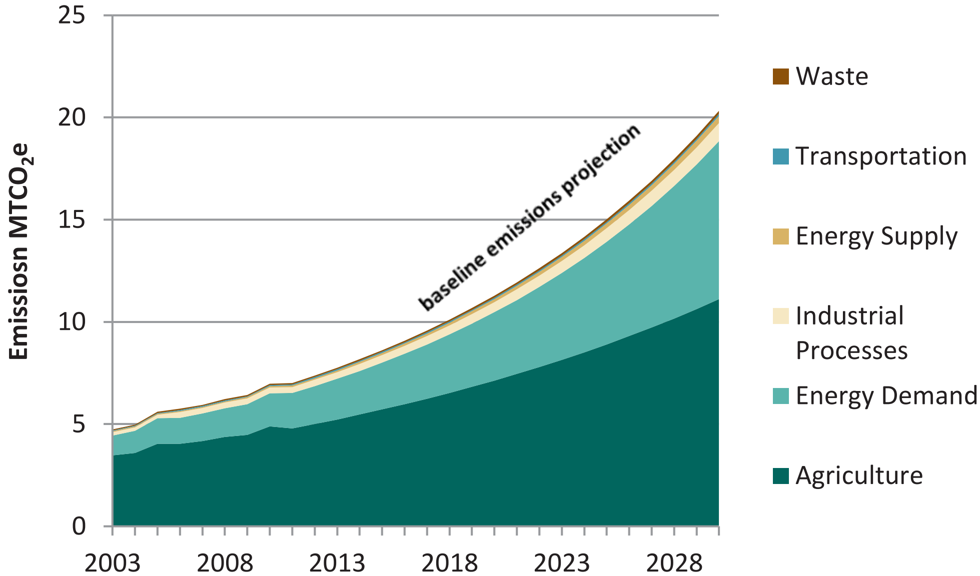

FIGURE 4: EMISSIONS BASELINE PROJECTIONS (EXCLUDING LULUCF)

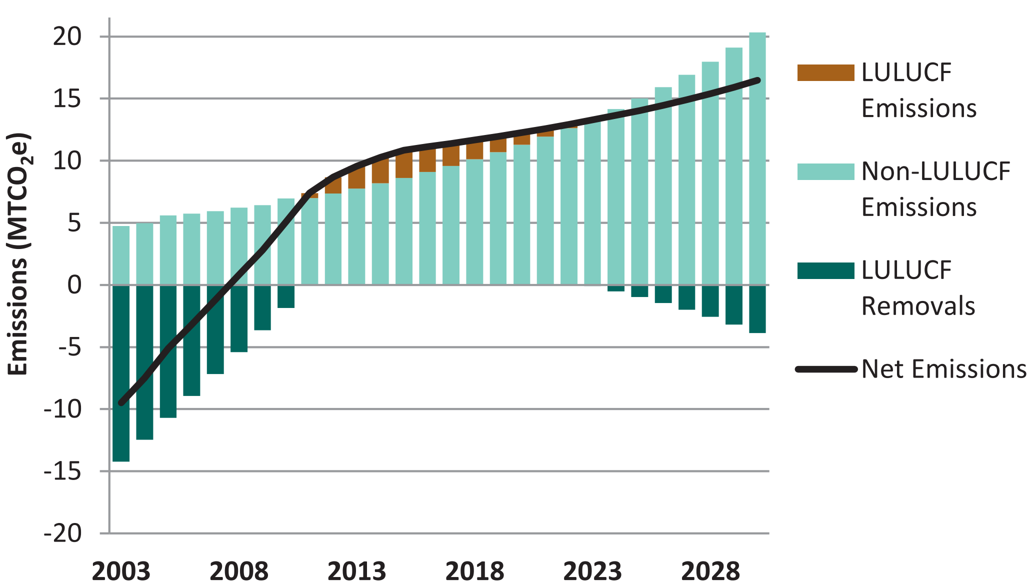

FIGURE 5: TOTAL EMISSIONS AND REMOVALS BY SECTOR 2000–2030

3.0 Agriculture

3.1 Methodology and Data

In the 2006 IPCC guidelines, the agriculture sector is combined with the forestry and other land-use sector for developing emission inventories. This report examines the agriculture sector separately from the forestry and other land-use sector to enable an assessment of agricultural emissions alone. The LULUCF sector analysis includes all carbon releases and sinks that are a result of a land conversion from one type to another.

The agricultural sector does not include energy emissions from fuel combustion, which are included within other sectors, such as transportation and the energy demand sectors.

The agricultural sector is currently the largest net source of GHG emissions of all sectors. Almost two thirds of total non-LULUCF emissions are from this sector alone. Despite its prevalence, data required to calculate GHG emissions is lacking and there is higher uncertainty in the calculation of agricultural emissions compared to the energy demand, energy supply and industrial processes.

Four different types of emission sources are considered in SNC Inventory and in this analysis:

- Enteric fermentation and manure management from livestock
- Burning of savannah
- Burning of agricultural residues
- Cultivated soils
- Flooding rice

Insufficient information is presented in the SNC inventory to back-calculate burning of savannah, burning of agricultural residues and cultivated soils emissions. In this case, we have accepted these emissions as is without identifying appropriate emission factors or activity data. For others sources, the emissions baseline uses the same Tier 1 methodologies, activity data and emission factors as the SNC inventory.

3.2 Data and Assumptions

Enteric Fermentation and Manure Management Emissions from Livestock

Historic livestock populations summarized in Table 3 were obtained from the SNC inventory and from recent statistics (National Institute of Statistics of Rwanda, 2012).

TABLE 3: HISTORIC LIVESTOCK POPULATION (HEAD OF LIVESTOCK)

	2003	2004	2005	2006	2007	2008	2009	2010
Non-dairy Cattle	991,697	1,006,572	1,077,206	1,122,179	1,147,000	1,195,000	1,219,000	1,335,000
Goats	1,270,903	1,263,962	1,663,551	1,688,279	2,238,000	2,520,000	2,735,000	2,971,000
Sheep	371,766	686,837	689,556	695,367	704,000	718,000	743,000	799,000
Pigs	211,918	326,652	456,043	527,531	571,000	587,000	602,000	706,000
Poultry	2,482,124	2,482,124	2,109,196	1,776,027	1,868,000	2,218,000	2,848,000	4,081,000
Rabbits	498,401	520,057	427,444	418,361	423,000	451,000	790,000	844,000

Source: Ministry of Natural Resources, Republic of Rwanda (2012); National Institute of Statistics of Rwanda (2012)

Default emission factors to calculate emissions are taken from the 2006 IPCC guidelines and are based on regional defaults for Africa and developing countries. Data are provided in Table 4. Emission factors were not reported directly in the SNC inventory, but overall emissions calculated with these values match those in the SNC inventory.

TABLE 4: EMISSION FACTORS FOR DIFFERENT TYPES OF LIVESTOCK

TYPE OF LIVESTOCK	EMISSIONS FACTOR ENTERIC FERMENTATION KG CH_4/HEAD/YR	EMISSIONS FACTOR MANURE MANAGEMENT KG CH_4/HEAD/YR
Non Dairy Cattle	31	1
Sheep	5	0.21
Goats	5	0.22
Pigs	1	1
Rabbits	0	0.08
Poultry	0	0.023

Source: IPCC (2006)

Historic livestock populations increased significantly between 2000 and 2010. For example, the cattle population increased by 6 per cent and the goat population increased nearly 15 per cent over this time period. It is likely that future growth rates of livestock will also be positive and grow with the economy as a whole. No evidence was identified that would limit population growth in the medium term, such as constraints on pasturelands. As a result, we have assumed that livestock populations would grow at the pace of long-term estimates of GDP growth for the agriculture sector. This GDP growth was estimated based on long-term estimates of overall GDP growth of 6 per cent per year (World Bank, 2008), as well as an historical adjustment factor that accounts for slower growth in the agricultural sector (National Institute of Statistics of Rwanda, 2012). This factor was calculated as the ratio in GDP growth between the agricultural sector and the overall economy between 2006 and 2011, which was 75 per cent. Combining these estimates results in a baseline growth rate of 4.53 per cent.

Burning of Savannah

The total area of savannah in Rwanda is identified in the *SNC inventory* as 3,726 hectares (ha). The SNC does not document assumptions regarding the fraction of area of savannah burned or other parameters, including biomass density and living biomass fraction. Emissions are reported as 1.3 tonnes of CH_4 and 0.02 tonnes of N_2O. In our calculations, this would correspond to a small fraction of savannah burned, around 100 ha, or less than 5 per cent of the total savannah area. However, we do not have any additional data to update this information so we have adopted the emissions reported in the SNC. These calculations should be reviewed; however, source emissions from burning of savannah are so small that any changes are not likely to impact the overall trend in emissions.

The baseline projection assumes no changes in the area of savannah and the burning frequency over time and, as a result, emissions levels do not change over time. This assumption may be outdated, as there is evidence that Rwanda has introduced regulations that could reduce the amount of savannah burned.

Burning of Agricultural Residues

Crop production where agricultural residues may be burned is identified in Table 5.

TABLE 5: PRODUCTION OF CROPS IN 2010 (HECTARES)

TYPE OF CROP OR LAND	2006 (HA)
Sorghum	196,732
Maize	109,400
Wheat	24,157
Rice	13,922
Beans	313,019
Peas	34,796
Groundnuts	16,011
Soybeans	42,119
Irish potatoes	135,622
Sweet potatoes	148,526
Colocase, yams	26,537
Cassava	115,694
Bananas, plantains	361,251
Fruits/vegetables	81,777
Coffee	20,100
Tea	11,390
Pyrethrum	3,191

Source: Ministry of Natural Resources, Republic of Rwanda (2012)

The SNC does not document assumptions regarding the fraction of residue produced to crop area or identify the percentage of cropland that is burned by type of crop. Emissions are reported as 0.41 tonnes of CH_4 and 0.1 tonnes of N_2O. Without additional data we have adopted the emissions reported in the SNC.

Future growth in the amount of agricultural residues burned was assumed to be the same as long-term estimates of GDP growth for the agriculture sector. This GDP growth was estimated based on long-term estimates of overall GDP growth of 6 per cent per year (World Bank, 2008), as well as an historical adjustment factor that accounts for slower growth in the agricultural sector (National Institute of Statistics of Rwanda, 2012). This factor was calculated as the ratio in GDP growth between the agricultural sector and the overall economy between 2006 and 2011, which was 75 per cent. Combining these estimates results in a baseline growth rate of 4.53 per cent. This assumption may be outdated as there is evidence that Rwanda has introduced regulations banning burning of agricultural lands; however, in this analysis, we are not able to estimate the impact of the regulations.

Flooding Rice

The area of historic rice cultivation was taken from the SNC inventory and is provided in Table 6.

TABLE 6: AREA OF RICE UNDER CULTIVATION BETWEEN 2003 AND 2006

METRIC	2003	2004	2005	2006
Area (ha)	7,667	12,167	13,922	13,123

Source: Ministry of Natural Resources, Republic of Rwanda (2012)

Emission factors were based on the same emission factors used in the SNC inventory.

Future growth in rice production in the baseline is directly correlated to an estimated future annual growth of 2.9 per cent in total population between 2010 and 2030.

Cultivated Soils

Emissions for cultivated soils were taken directly from the SNC inventory. Future growth in emissions from cultivated soils is primarily dependent on the application of manure to soils and, therefore, the population of livestock. Emissions are also dependent to a lesser degree on the application of artificial nitrogen fertilizers. Future growth in emissions was assumed to the same as long-term estimates of GDP growth for the agriculture sector. This GDP growth was estimated based on long-term estimates of overall GDP growth of 6 per cent per year (World Bank, 2008), as well as an historical adjustment factor that accounts for slower growth in the agricultural sector. This factor was calculated as the ratio in GDP growth between the agricultural sector and the overall economy between 2006 and 2011, which was 75 per cent. Combining these estimates results in a baseline growth rate of 4.53 per cent.

3.3 Data Availability and Uncertainty

The agricultural sector is the second largest source of non-LULUCF GHG emissions of the sectors considered in this study. Despite the size and prevalence of the sector, data required to calculate GHG emissions is lacking and considerable uncertainty remains in the calculation of emissions when compared to the energy demand, energy supply, industrial processes and waste sectors.

Cultivated soil emissions account for approximately 70 per cent of total emissions in Rwanda (excluding LULUCF) in 2010, yet it is not possible to reproduce emission estimates from the limited data provided in the *SNC inventory*. The uncertainty of these emission factors is reported to be in the range of ± 30 per cent to 50 per cent (IPCC, 2006).

Emissions from the burning of savannah and agricultural residues may also be overestimated n this analysis, as different regulations on burning have been introduced that may have reduced the level of burning from historic levels. Further study is recommended to identify the impact of these regulations.

4.0 LULUCF

4.1 Methodology

Very little information and data has been published on carbon stocks in Rwanda. The *SNC inventory* indicates that Rwanda does not have its own methodology for estimating national emissions and absorptions of GHGs. The SNC inventory indicates that the net GHG emissions were -13.1 $MTCO_2e$ (i.e., a sink of 13.1 $MTCO_2e$) in 2005; however, there is no supporting information for this calculation.

As a result, we have estimated historic baseline emissions from estimates of total changes in above-ground biomass, below-ground biomass, soil carbon and litter carbon pools of forests from the FAO (2010). This approach does not consider transitions of other land-use types, but is a reasonable proxy given that this is the predominant source of carbon emissions and removals in Rwanda, and there is no other available information. The FAO data considers a forestation rate of approximately 2.3 per cent per year between 2000 and 2005 and 2.47 per cent between 2005 and 2010.

TABLE 7: NET EMISSIONS FROM LULUCF BETWEEN 2001 AND 2010

YEAR	TOTAL FOREST AND WOODLAND AREA (HA)	TOTAL CARBON STOCK OF FORESTS (MTC)	NET EMISSIONS ($MTCO_2E/YR$)
2000	405,159	38.2	--
2001	413,007	43.0	-17.8
2002	421,033	47.4	-16.0
2003	429,243	51.3	-14.2
2004	437,640	54.7	-12.5
2005	446,228	57.6	-10.7
2006	455,746	60.0	-8.94
2007	465,499	62.0	-7.17
2008	475,493	63.5	-5.40
2009	485,734	64.4	-3.63
2010	496,228	65.0	-1.87

Source: FAO (2010)

The calculation of annual changes in historic emissions is consistent with revised IPCC 1996 guideline methodologies. This method considers the difference between biomass stocks, for a given land-use area and two points in time.

Future changes in forest carbon stocks are difficult to predict without the use of detailed spatially explicit models that can track changes in carbon pools due to deforestation, wood harvesting, transitions from other land types to forest, fire and biomass growth. To generate a rough estimate, we use a simple model that considers changes in the forest area, removals of wood and average biomass growth.

4.2 Data and Assumptions

Future trends in LULUCF emissions are based on assumptions regarding the change in the total forest area, removals of wood and average biomass growth. A myriad of other potential factors that impact carbon pools are simply assumed to balance to net zero emissions.

Forest and woodland areas in our baseline emissions projection are assumed to increase linearly from 496,228 ha in 2010 to 586,827 ha in 2030. This achieves a total national forest cover equivalent to 20 per cent by 2030. Although this forest cover is less than the 30 per cent—forest cover targeted in *Vision 2020*—it is a reasonable target given that the business-as-usual scenario considers only existing policies and no new policies.

Projections of wood removals are assumed to increase linearly with the projected increase in future usage of fuel wood estimated in Section 6. Based on these assumptions wood removals are expected to increase from current demand of 4.57 MT (dry mass) in 2010 to 7.69 MT in 2030. This growth in wood demand is based on estimated population growth between 2010 and 2030. Population growth was used to estimate demand, as it is not expected that wood supply can match the expected baseline growth in GDP of 6.0 per cent between 2010 and 2030. Population growth is also similar to the 2.3 per cent growth rate in wood demand applied in *Vision 2020* forecasts.

These projections demonstrate positive net emissions in 2011 of 2.86 $MTCO_2e$, then falling until by 2023 when Rwanda again is projected to have a net sink of LULUCF emissions. In essence, what is happening is that increases in wood removals will continue to decrease the carbon density on a per-hectare basis, but this effect is countered by an increase in forest area and overall biomass growth over time.

TABLE 8: NET EMISSION PROJECTIONS FROM LULUCF BETWEEN 2010 AND 2030 ($MTCO_2E/YR$)

YEAR	TOTAL FOREST AND WOODLAND AREA (HA)	TOTAL CARBON STOCK OF FORESTS (MTC)	NET EMISSIONS ($MTCO_2E/YR$)
2011	439,363	64.2	2.857
2012	443,537	63.4	2.729
2013	447,750	62.7	2.584
2014	452,004	62.1	2.420
2015	456,298	61.5	2.237
2016	460,633	60.9	2.034
2017	465,009	60.4	1.808
2018	469,426	60.0	1.559
2019	473,886	59.6	1.285
2020	478,388	59.4	0.985
2021	482,932	59.2	0.657
2022	487,520	59.1	0.299
2023	492,152	59.1	-0.090
2024	496,827	59.3	-0.513
2025	501,547	59.5	-0.970
2026	506,312	59.9	-1.465
2027	511,122	60.5	-2.000
2028	515,977	61.2	-2.576
2029	520,879	62.1	-3.196
2030	525,827	63.1	-3.863

4.3 Data Availability and Uncertainty

GHG emissions trends in the forestry sector are difficult to determine because of the uncertainty in measuring biomass carbon pools for the entire country. The SNC inventory indicates that LULUCF emissions have an uncertainty of ±40 per cent. Conducting forest and land-use inventories of carbon stocks is complex and a detailed forestry inventory and projection is beyond the scope of the research undertaken for this report.

The model employed to estimate sequestration of carbon is very basic because resources or data were not available to conduct detailed modelling. The uncertainty in these estimates is very high, certainly higher than ±40 per cent for the inventory, as the modelling does not account for numerous important factors including: conversions of land to different types (e.g., agriculture, settlement), the age of forests, specific biomass growth rates of different forest types and forest fires. In addition, small changes in model input values for the emissions baseline can lead to drastically different results. It is recommended that reliable estimates of LULUCF emissions be developed to reduce uncertainty. For example, detailed Tier 3 modelling could be conducted using consistent spatially explicit observations of land use and land-use change using remote sensing and geographic information systems.

5.0 Electricity Generation

5.1 Methodology

Developing a reference case for Rwanda's electricity sector is challenging because of some uncertainty in the amount of fossil fuels that are consumed by the sector and how the sector may expand in the future. Current and projected growth rates are very large in an effort to meet a large suppressed demand for electricity; however, the main constraint on growth is the capital investment to add capacity and connect potential customers. Historical annual growth in electricity consumption in Rwanda exceeds 10 per cent annually between 2004 and 2011 (National Institute of Statistics of Rwanda, 2012). This high growth rate is expected to continue and there are 83 megawatts of methane capacity that may be commissioned by 2013.

An emissions baseline for the electricity sector is developed by estimating the total fossil fuel consumption of different generation technologies and then multiplying the total consumption by appropriate emission factors. This method is the same as the Tier 1 approach used in the SNC inventory for stationary combustion sources.

5.2 Data and Assumptions

In recent years, thermal generation has increased to nearly 50 per cent of total electricity production in Rwanda. It is estimated that approximately 40 megawatts of thermal capacity was installed by the end of 2011.

The SNC estimates fuel consumption for electricity generation for 2005 and 2006. Additional years were estimated based on an annual growth rate of 9 per cent per year to match the growth rate of thermal electricity generated over the period 2006 to 2010.

TABLE 9: DIESEL FUEL CONSUMPTION FOR ELECTRICITY GENERATION (TONNES OF OIL EQUIVALENT [TOE])

2003	2004	2005	2006	2007	2008	2009	2010	2011
11,963	13,160	14,478	29,298	31,964	34,872	38,046	41,508	15,070

Source: Ministry of Natural Resources, Republic of Rwanda, 2012; Ministry of Infrastructure (2011)

The data used to convert total future generation of fossil fuel technologies into GHG emissions is provided in Table 10; emission factors are from IPCC's 2006 guidelines.

TABLE 10: EMISSION FACTORS FOR DIESEL GENERATORS

TECHNOLOGY	KGCO$_2$E / TJ	KGCO$_2$E / GWH (KGCO$_2$E / TJ) X (3,6 GWH/TJ) X (AVERAGE CONVERSION EFFICIENCY)
Diesel Generators	74,100	762,171

Source: IPCC (2006)

Thermal electricity consumption has increased from approximately 70.5 gigawatt hours (GWh) in 2005 to 196 GWh in 2011 (Ministry of Infrastructure, 2011). It is likely that high growth will continue in the future as additional customers are added to the electricity grid; however, the choice of electricity generation technology will play an important factor. The emissions baseline assumes that demand for diesel fuel for electricity generation will increase until 2030 at the rate of 10 per cent per year between 2010 and 2030. It may be that methane gas will be the fossil fuel that sees highest growth (Ministry of Infrastructure, 2011). This assumed rate is substantially higher than GDP growth forecasts but still considerably lower than Vision 2020 growth forecasts in electricity production of 17.1 per cent (Ministry of Finance and Economic Planning, 2009).

5.3 Data Availability and Uncertainty

There are a number of studies available that examine electricity supply in the short term for Rwanda. However, it is difficult to estimate fossil fuel demand from this information as it focuses on overall generation and not specifically thermal generation. As a result, there is a high degree of uncertainty related to the installed capacity of thermal plants and their consumption of fossil fuels.

6.0 Energy Demand

6.1 Methodology

An emissions baseline for the energy demand sector is developed by estimating the total fossil fuel consumption and then multiplying the total consumption by appropriate emission factors. This method is the same as the Tier 1 approach used in the SNC inventory.

6.2 Data and Assumptions

Data on the total energy use for each major fossil fuel consumed is limited to years between 2003 and 2006 in the SNC inventory. Additional data sources were sought to establish total fuel consumption over the 2003 to 2010 period. The following data sources were compiled and balances in fuel consumption by sector were developed.

- Ministry of Infrastructure (May 2011), *National Energy Policy and Strategy*.
- National Institute of Statistics of Rwanda (2012), *Statistical Year Book 2012*.
- Rwanda Environment Management Authority (2009), *Rwanda State of Environment Outlook: Our Environment for Economic Development*.
- United Nations Environment Programme (2011), *Rwanda: From Post-conflict to Environmentally Sustainable Development*. United Nations Environment Programme.

These sources of information were in general agreement; however, in the case of discrepancy, the most recent data from the *Statistical Year Book 2012* was used as the main source. All fuel consumption was divided between specific sectors including household, transportation, electricity and industrial. Transportation fuels and fuels for electricity generation are included in the transportation and electricity supply sectors (see Sections 5 and 7).

Table 11 identifies the total consumption of each specific fuel in the energy demand sector, expressed as tonne oil equivalent (toe). This metric expresses the energy content of all fuels on a comparable basis, using the nominal energy content of crude oil by mass. Wood fuel consumed for charcoal production is also included.

TABLE 11: FUEL CONSUMPTION OF THE HOUSEHOLD AND INDUSTRIAL ENERGY SECTORS (TOE)

SECTOR	FUEL TYPE	2003	2004	2005	2006	2007	2008	2009	2010
Residential	Kerosene	17,976	17,847	27,070	11,587	20,715	21,463	22,237	23,040
	LPG	268	243	350	380	353	329	306	284
	Wood	639,431	705,247	758,900	796,751	816,307	836,188	877,247	942,367
	Charcoal	50,969	56,215	60,492	63,509	65,068	66,653	69,926	75,116
Industry	Fuel oil	14,229	14,145	15,161	17,791	14,802	15,946	17,179	18,508
	Wood	71,808	78,856	84,584	88,621	90,701	92,809	97,149	104,006
	Charcoal	2,712	2,978	3,194	3,346	3,425	3,505	3,668	3,927
	Wood for charcoal production	447,340	493,276	530,718	557,131	570,775	584,644	613,284	658,697

Source: Ministry of Natural Resources, Republic of Rwanda (2012; Ministry of Infrastructure (2011); National Institute of Statistics of Rwanda (2012); United Nations Environment Programme (2011)

Future growth in petroleum product consumption is projected in the *Vision 2020* document at 10.1 per cent (Ministry of Finance and Economic Planning, 2009). This contrasts with expected long-term GDP growth of 6 per cent between 2007 and 2027. Baseline projections assume that demand for fossil fuels will fall between these growth rates. The mid value is used and a correction for autonomous energy efficiency improvement (AEEI) is also applied. AEEI is estimated to be -1 per cent per year. This AEEI is based on research that end-uses of fuels such as cookstoves become more fuel-efficient over time, reducing the overall demand for energy (Graus et al., 2009). Combining these estimates results in a total growth rate of 9.1 per cent per year for petroleum products. Future biomass consumption has not increased in the same manner. Historic growth in biomass fuels has been around 5 per cent between 2003 and 2010. There is a significant constraint of biomass growth based on the available supply of biomass fuels in the baseline. Without significant efforts to restore, protect and manage forests, demand for wood will continue to lead to deforestation in Rwanda and deplete existing sustainable wood supplies. Because of these constraints, we have limited growth in biomass fuels to the forecast population growth rate of 2.6 per cent, which is based on historical growth rates between 2000 and 2012 (National Institute of Statistics of Rwanda, 2012). This aligns reasonably well with the projected *Vision 2020* growth rate for biomass of 2.3 per cent (Ministry of Finance and Economic Planning, 2009).

Emission factors for fuel consumption are the same as the emission factors used in the SNC inventory report and are based on IPCC default values.

6.3 Data Availability and Uncertainty

Uncertainty in the emissions reference case is relatively low for the total emissions of fossil fuels, as there is a low degree of uncertainty related to the total consumption of these fuels in Rwanda during the historic period and the related emission factors. The uncertainty is higher for biomass fuels, as the data on total biomass fuels consumed in Rwanda is based on limited surveys. It is likely that the range of uncertainty for these types of surveys is within 30–60 per cent (IPCC, 2006).

7.0 Transportation

7.1 Methodology

An emissions reference case for the transportation sector is developed for historical emissions by estimating the total fossil fuel consumption and then multiplying the total consumption by the appropriate emission factors. This method is the same as the Tier 1 approach used in SNC inventory for mobile combustion sources.

7.2 Data and Assumptions

Table 12 identifies the total consumption of each specific fuel in the transportation sector, expressed as tonne oil equivalent. This metric expresses the energy content of all fuels on a comparable basis, using the nominal energy content of crude oil by mass.

TABLE 12: FUEL CONSUMPTION OF TRANSPORTATION SECTOR (TOE)

FUEL TYPE	2003	2004	2005	2006	2007	2008	2009	2010
Gasoline	43,502	45,305	45,964	53,266	53,499	55,977	58,569	61,282
Jet kerosene	703	293	4,116	4,717	5,158	5,639	6,165	6,740
Diesel	29,124	44,883	59,381	48,845	46,318	52,015	58,412	65,596
BUNKER FUELS	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Jet kerosene	2,109	880	12,349	14,152	15,473	16,917	18,496	20,221

Source: Ministry of Natural Resources, Republic of Rwanda (2012); Ministry of Infrastructure (2011); National Institute of Statistics of Rwanda (2012); United Nations Environment Programme (2011)

Future growth in petroleum product consumption is projected in the *Vision 2020* document at 10.1 per cent (Ministry of Finance and Economic Planning, 2009). This contrasts with expected long-term GDP growth of 6 per cent between 2007 and 2027. Projections of the baseline assume that demand for fossil fuels will fall between these growth rates. The mid value is used and a correction for AEEI is also applied. The AEEI is estimated to be -1 per cent per year. This AEEI is based on research that end-uses of fuels such as cookstoves become more fuel-efficient over time, reducing the overall demand for energy (Graus et al., 2009). Combining these estimates results in a total growth rate of 9.1 per cent per year for petroleum products.

The SNC inventory does not report international bunker fuels separately. Aviation fuel usage has been adjusted in this baseline emissions projection to account for only domestic use, as international use of aviation bunker fuels is not included in national inventories. It was assumed that 25 per cent of jet kerosene was used for domestic flights. This assumption is based on expert opinion only and has not been locally verified. Improved estimates could be made by analyzing flight destinations between major airports in Rwanda and aligning this with total fuel usage to determine domestic use.

Emission factors for transportation fuel consumption are the same as the emission factors used in the SNC inventory report and are based on IPCC default values.

7.3 Data Availability and Uncertainty

Uncertainty in the overall fuel demand and historic emissions from the transportation sector is fairly low, as these estimates are based on total reported fuel usage from national statistics.

For the domestic aviation sector, estimates of the fuel demand were based on a crude approximation of the fuel demand between international bunker fuels for international aviation flights, which are not included in the domestic GHG inventory, and domestic usage. This split in fuel consumption could be improved if flight data for the entire country was available.

8.0 Industrial Processes

8.1 Methodology

The main industrial processes emission sources in Rwanda are releases from processes that chemically or physically transform materials (for example, the manufacture of cement is a process that release a significant amount of CO_2). Different GHGs—including CO_2, CH_4, N_2O, hydrofluorocarbons and perfluorocarbons—can be produced during these processes.

Only the major industries with significant emissions from industrial processes that were identified in the SNC inventory were considered: cement and lime production. Emissions from products such as refrigerators, foams or aerosol cans were not included in the analysis, as these emissions were not included in the SNC inventory. These emissions are likely to be relatively small.

In general, the emissions baseline for the industrial process sector was developed by estimating the total production of an industrial product that in its transformation contributes to GHG emissions, and then multiplying this value by appropriate emission factors. The methods used follow the same Tier 1 approach used in the SNC inventory.

8.2 Data and Assumptions

Historical production data was used to estimate emissions from industrial processes. The source and values of historical production data for 2003 to 2007 were taken from the SNC inventory. Data for additional years was estimated based on additional data available from the U.S. Geological Society's 2009 Minerals Yearbook. Production data is provided in Table 13.

TABLE 13: RWANDA DOMESTIC INDUSTRIAL PRODUCTION DATA FOR SELECT INDUSTRIES

INDUSTRY	RWANDA DOMESTIC PRODUCTION (TONNES)							
	2003	2004	2005	2006	2007	2008	2009	2010
Cement	105,105	104,288	101,128	102,588	103,034	103,244	108,191	113,375
Lime	186,389	201,558	206,917	398,768	398,768	398,768	398,768	398,768

Source: Ministry of Natural Resources, Republic of Rwanda (2012); U.S. Geological Survey (2011)

Emissions factors are based on the Tier 1 1996 IPCC guidelines emission factors that were used in the SNC inventory. An annual average growth rate between 2010 and 2030 is based on a long-term GDP growth rate of 6 per cent (World Bank, 2008). The efficiency per unit of production for cement and lime does not change over time because the release of CO_2 is an unavoidable aspect of the process.

Table 14 identifies default emission parameters and factors that were used to convert tonnes of production of the various industries into GHG emissions.

TABLE 14: EMISSION PARAMETERS AND FACTORS

SECTOR	TIER 1 EMISSION FACTORS TCO_2 / T PRODUCED (2010)	FUTURE GROWTH RATE (2010 TO 2030)
Cement	0.4985	6%
Lime	0.776	6%

Source: Ministry of Natural Resources, Republic of Rwanda (2012); IPCC (2006)

8.3 Data Availability and Uncertainty

Uncertainty is primarily associated with the use of default emission factors and, to a lesser degree, to the production values available. The 2006 IPCC guidelines express the default uncertainty of production values for cement and lime to be likely in the range of 1 to 2 per cent, compared to an uncertainty in the range of 8 to 20 per cent for their different emission factors. Specific uncertainty in production values may be higher in Rwanda, depending on the rigour of reporting requirements.

Emission estimates from GHGs used in products such as refrigerators, foams or aerosol cans have not been estimated in this analysis, as they were not estimated in the SNC inventory.

9.0 Waste

9.1 Methodology

The emissions baseline for the waste sector is adopted directly from the *SNC inventory*. There was insufficient data available to develop independent projections.

Future growth in emissions from the waste sector was based on the urban population growth rate of 5.2 per cent per year (National Institute of Statistics of Rwanda, 2012).

9.2 Data and Assumptions

Table 15 contains the methane emissions for the waste sector identified in the *SNC inventory* for the years 2003 to 2006.

TABLE 15: EMISSIONS FROM WASTEWATER AND SLUDGE TREATMENT (2003–2006)

GHG EMISSION	WASTE SECTOR METHANE EMISSIONS (TONNES)			
	2003	2004	2005	2006
CH_4	2,230	2,460	2,550	2,800

Source: Ministry of Natural Resources, Republic of Rwanda (2012)

9.3 Data Availability and Uncertainty

There is limited reliable data available on rates of waste generation, composition and management practices in Rwanda. A national survey to characterize formal and informal waste sites in the country would be useful for the development of future emission inventories. Survey data should include the amount of wastes deposited, the average depth of waste at sites and a description of management practices.

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