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Greenhouse gases emission in Rwanda and their future impacts on economic sectors

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Abstract— Global changes in temperature and precipitation and the regional distribution of those changes are the primary drivers affecting climate-related hazards such as floods, landslides and droughts that have struck Rwanda in recent years with devastating effects on the population. From the livelihoods of rural populations to food security in urban areas, agriculture, transportation, communication, energy, health, water, and institutional systems on which populations depend have failed in some cases. This is resulted from immediate consequence of post-industrial increased Greenhouse Gases (GHG) emissions. This study analyses GHG emission trends in Energy sector of Rwanda for guiding other economic sectors to plan and budget for adaptation and mitigation. The study helped to understand the relationship between energy sector and other economic sectors of Rwanda in terms of climate change and variability related impacts, which in turn will shape Decision makers in future Sector's adaptation and planning. The result of the study provided details about mitigation assessment and mitigation scenarios in Energy sector (electric power generation, industries, buildings and transport). Mitigation assessments were based on a combination of three alternatives approaches namely: activity based approach, outcome based approach and combination of the two approaches. The total greenhouse gases emission reductions have been calculated by developing a business as usual sectoral baseline scenario and alternative scenario based on policy implementation assumptions. The integrated modelling tool of Long-range Energy Alternative Planning (LEAP) software was used to model baseline and mitigation scenario in energy sector. Relevant data for developing baseline and alternatives scenario were collected from different public and private institutions as well as through literature review from different scientific sources. The results shows that greenhouse gas emissions from energy sector will keep on rising exponentially, mainly due to emission from fossils fuel consumption.

Key Words: Emission1, economic sector2, Energy sector3, climate change4, Greenhouse gases5.

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1.1 Introduction

The mean annual temperature oscillating between 18^0C and 22^0C. The central plateau region with a rainfall between 1,100 mm and 1,300 mm received in 90 to 150 days, with annual mean temperature between 180C and 20^0C. The highlands, including Congo –Nile Ridge and volcanic chains benefit from an annual rainfall between 1,300mm and 1,600mm, received in 140 to 210 days with annual mean temperature oscillating between 10^0C and 18^0C. Region [1]around Lake Kivu and Bugarama Plain get annual rainfall of between 1,200mm and 1,500 mm, received in 150 to 200 days, and annual mean temperature oscillating between 18^0C and 22^0C. [1]. Scientific based knowledge on climate variations in Rwanda is limited, but it is fully recognized that the country is one of the most vulnerable nations in the world in regard to climate changes

Many of the specific resources (e.g. water, land, soils) and the ecosystems (e.g. the natural forests, the marshlands and lakes and the highlands) are furthermore overused, very fragile and geographical fragmented (limited in space and not connected). Thus, climate change preparedness for Rwanda is essential both in a local, national and international context Rwanda's economy and its people's livelihoods are highly dependent on natural resources among which energy source is the first requirement. This are under increasing pressure from unsustainable use, soil erosion, deforestation and the impact of increasing climate variability and climate change. As such, unsustainable use of environment and natural resources hinders the achievement of national development objectives. Because of the natural topography in Rwanda, the rural population is vulnerable to natural risks, disasters, especially flooding, and landslides, which are exacerbated by increasingly extreme weather events caused by climate change (2). Currently, the Rwanda urban population density increase exponentially in both rural and urban area and according to the projections, this population could reach around 23 Million by 2050. This exponential increment will be associated with increasing of energy source in various form for instance for cooking, for transportation, for lighting as well as for the increase of population match with the increase of energy use and therefore the increase of greenhouse gases (GHG) emission. This could lead to climate change and climate variability and its impacts including flooding, landslides, and drought. The first sector that is more affected is Agriculture sector. According to Rwanda Energy Sector Strategic Plan (3). The situation of energy consumption in Rwanda up to 2018 is illustrated in the (figure 1). The assumption behind is that GHG emission from Energy sector could be higher than other remaining economic sectors (4). The IPCC Special Report on 1.5°C provides indicators of the benchmarks that need to be achieved globally and in key sectors to align with the temperature goals in the Paris Agreement. These indicators, many of which address the 2030 time frame, can help contextualize mitigation ambition in the NDC enhancement process. At the global

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level (Figure 2), the IPCC notes the following facts **(5):** (1) To limit warming to 1.5°C with no or limited overshoot, global net anthropogenic CO2 emissions decline by about 45 percent from 2010 levels by 2030, reaching net zero around 2050. (2) To limit warming to below 2°C, CO2 emissions decline by about 25 percent by 2030 and reach net zero around 2070. (3) Non-CO2 emissions inpathways that limit global warming to 1.5°C show deep reductions that are similar to those in pathways limiting warming to 2°C. Achieving these emission cuts will require largescale transformation across key sectors. Several studies have quantified the sector-level changes implied by emissions scenarios that achieve given temperature outcomes as shown in the figure 2. Energy GHG emissions are obviously related to the economic growth of any country as the main driver of economy. During the period between 2006 and 2018, the Rwandan economy enjoyed a continuous growth justified by the increase in GDP and GDP per capita. This economic growth is the main reason of the increase in GHG emissions observed over the same period. It is also interesting to note a sharp increase in GHG emissions beyond the change in GDP. This trend could be [2]attributed to the use of indigenous fuels in electricity generation, which are less sensitive to the GDP. As indicated in the Figure 3. (6). In addition, GHG emissions are related to the population growth and the change in lifestyle. However, the adoption of energy efficiency measures and energy conservation policy could keep the later increase in the reasonable ranges.

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1.2 Objective of the study

This study aimed at analysing the greenhouse gases emission in Rwanda and its future impacts on economic sectors to inform Decision makers for appropriate adaptation and mitigation planning.

1.2.1 Methodology

1.2.1.1 Data collection for baseline scenarios (2006-2015)

The greenhouse inventory was conducted in different energy sector and its associated sub sectors including energy, Transport, Buildings and industries. The data were collected using LEAP. The Long-range Energy Alternatives Planning (LEAP) planning tool to help governments jointly assess greenhouse gases, short-lived climate pollutants (SLCPs) and other air pollutant emissions; build mitigation climate, health and crops

1.2.1.2 . Key features of Long-range Energy Alternatives Planning (LEAP)

It is an integrated, scenario based modelling tool originally developed to track energy consumption, production and resource extraction in all sectors of an economy. It can account for both energy sector and non-energy sector greenhouse gas (GHG) emission sources and sinks.

1.2.1.3 Characterize National emission of greenhouse gases short-lived climate pollutants and other air-pollutants

LEAP allows calculating emission inventories for current and future years for all relevant pollutants. Calculate emission you need to input activity data for a particular source. For each source default emission factors for BC, OC, other PM2.5, SO2 , NH3 , NOX, NMVOCs, CO, CH4 and CO2 are included, and emissions are estimated from Activity x Emission Factors.

1.2.1.4 Understand likely future trends in emission (baseline scenario)

LEAP can be used to develop a baseline scenario by describing how activity and emission factor within different sectors are likely to change in the future and hence how emissions from each sector are likely to change in the future. These variables can be linked to changes in the key socio economic drivers such as growth domestic Product (GDP)

1.2.1.5 Explore alternative emission reduction scenarios

Using LEAP; Policy analysts can create and then evaluate alternative mitigation scenarios by comparing their energy requirements, their social costs and benefits; and their environmental impacts. Mitigation actions can be described in LEAP related to implementing technological changes, efficiency improvements or policy affecting the level of action in a sector (e.g. modelling the shift from people using passenger cars to using buses due to a public transport policy).

1.2.1.6 Calculate pollutant concentration and radioactive forcing using integrated benefits calculator

Using emissions from LEAP-IBC multiplied by the output from the GEOS-Chem global atmospheric chemistry transport model the integrated benefit calcula provide an estimate of population weighted PM2.5and ozone concentration in the target country. A similar methodology is used to estimate the radiative forcing associated with emission of short- lived climate forcers from different parts of the world.

1.3 Key assumptions

key assumptions, specific to different sectors, general assumption include: Population growth from 10.5 million in 2012 to 23 million in 2050 GDP. Growth from USD 756 in 2017 to USD 1,493 in 2024 and 12,476 in 2050 and urbanization rate up to 30% in the provinces and 100% in Kigali City. Electricity access of 34.5%; Industries manufacturing grow at a rate of 7%; Agricultural use of mineral fertilizers increase at 5% annually; Forest cover increased and maintained at 30% of the country land area. **(7).**

Baseline data indicate that GHG emissions per capita (kg per capita) in 2006 were 532.39; with population of 9,007,467 and GDP of 333 (8).It is interesting to note that the slight drop in GHG emissions were related to the drop in both fuel consumption and GDP as indicated in the (Table: 1) **(9)**

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1.4 Data analysis

Data analysis was based on a combination of three alternatives approaches namely Activity Based Approach, Outcome Based Approach and combination of the two approach (10). Research design: Qualitative and quantitative approaches). The total greenhouse gases emission reductions have been calculated by developing a sectoral baseline scenario and alternative scenario based on policy implementation assumptions (Fig 5)
The integrated modelling tool of Long-range Energy Alternative Planning (LEAP) software was used to model baseline and mitigation scenario in energy sectors (11). Relevant data for developing baseline and alternatives scenario were collected from different public and private institutions as well as through literature review from different scientific sources.

2 Result findings

The baseline scenario and mitigation options summarized in Table 1,and 2 respectively, were combined and simulated in the LEAP software to generate Table 3.

2.1 Energy Sector

The evolution of major fuels simulated in the modelled LEAP software shows that the electric generation will be dominated by peat and hydropower plants with 43.48% and 42.01% respectively in 2050 The biomass will be the least contributor to total generation with only 0.24%. (Fig 6)..
The mitigation scenarios for electricity generation based on Government targets to increase the renewable energy power generation while reducing the liquid fuels for power generation. Considering the expected economic growth from upper middle-income country with a GDP of USD 4,035 in 2035 to high-income country with a GDP of USD 12,476 in 2050, an additional on grid capacities would be estimated at 604.5 MW and 200 MW solar PV generation capacity, respectively. This additional capacity would replace the diesel and some peat-fueled power plants. The 604.5 MW are suggested to be implemented in three batches: 304.5 MW between 2015 and 2030, 100 MW between 2030 and 2040 and 200 MW between 2040 and 2050. The large solar PV capacity are suggested to be implemented in two phases: 100 MW between 2015 and 2030 and the remaining 100 MW between 2030 and 2050. The main mitigation scenario is the use of large renewable energies (Large hydro and solar PV plants) scenario.
The baseline electricity generation modelled through LEAP is projected to grow substantially from 1,089,800 GJ in 2012 to 21,394,800 GJ in 2050 and GHG emission in the baseline scenario will increase from 106.12 Gg CO2eq to 3,346.27 Gg CO2eq. Under the mitigation scenario, the GHG emissions for electricity supply will increase 106.100 Gg CO2eq. to 1,300.90 Gg CO2eq. The mitigation scenario for energy generation simulated in the transformation module of LEAP software is projected to generate a cumulative emissions reduction of 20,377.80 Gg CO2 eq. by 2050.

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2.2 Industries

The modelled baseline GHG emissions from industrial sector are expected to increase from 50.19 Gg CO2eq to 1170.82 Gg CO2eq in 2050 (Table 2). The non-metallic mineral industries will remain the main contributor to GHG emissions through the year 2050 and the food industries will be the least contributor (Figure 8)
The results of the simulated mitigation scenario and the baseline scenario are shown on Figure 8. The implementation of mitigation measures will decrease the GHG emissions from various industries from 1,170.82 Gg CO2 eq.in 2012 to 1,087.56 GgCO2 eq.in 2050 (a cumulative reduction of 83.26 Gg CO2 eq.)

2.3 Building

The energy in buildings encompasses the energy consumption for cooking, heating (room heating and water heating), cooling (air-conditioning), lightening and operating electrical appliances. The baseline GHG emissions from buildings are expected to increase from 2,183 Gg CO2eq in 2012 to 6,145.40 Gg CO2eq in 2050 (Table 2). The projected baseline GHG emission will be generated by combustion activities of various fuel including wood and wood wastes, kerosene, LPG, diesel and biogas.
The proposed mitigation scenario also referred to as efficient building consists of the efficient and sustainable use in residential and commercial buildings, the use of the efficient lighting and the use of solar heaters for hot water in buildings. Besides the environmental benefit, the adoption and/or strengthening of the latter options will provide some other socioeconomic benefits such as the indoor clean air, etc.
The projected baseline GHG emissions will be generated by combustion activities of various fuel including wood and wood wastes, kerosene, LPG, diesel, and biogas. The analysis of the baseline GHG emissions per fuel shows that the wood and wood waste is the main contributor to total GHG emissions for the period between 2012 and 2045 (Figure 10). However, for the remaining period, the GHG emissions from diesel are predominant due to rapid growth in service sector stimulated by the high GDP growth expected over this period.

2.4 Transport

GHG emission from the transportation sector are mainly generated from fuel combustion,(cars and motorcycles) activities in various categories of vehicles. The baseline scenario developed in the LEAP software shows that GHG emissions will increase from 447.57Gg CO2eq in 2012 to 1678.25 Gg CO2 eq in 2050 (Table 1). GHG emissions from motocycles are expected to be the dominant contributor to total GHG emission from transport. (Figure 12). The proposed mitigation options consist of an integration of various options including the adoption of electric cars combined with the fuel efficiency and the implementation of the recently signed agreement to construct an electric rail between Isaka and Kigali. The implementation of the electric railway will reduce significantly the diesel and gasoline consumption by heavy-duty trucks and buses to 0% and by 80%, respectively from 2020. This reduction in fuel consumption will be followed by a substantive reduction in GHG emissions. Diesel fuelled cars will be partially replaced by electric cars starting from 2020. This mitigation option was proposed following the Volkswagen plans to install a car assembling plant in Rwanda. It is planned to produce 5,000 cars annually from 2020.Electric cars are expected to replace 150,000 passenger cars by 2050. The electric cars will require an average of 30 kWh per 100 km. The mitigation options were integrated in a single mitigation option and modelled in the LEAP software **(Fig:14**)

3 Discussion of results

Generally in energy sector the projection indicate that peat and hydropower plant will be dominating at 43.48% and 42.01% respectively in 2050; The main mitigation scenario are the use of large renewable energies (large hydropower plants, solar PV, and Methane Gas).

Industry sector expects emission increase for 50.19 Gg CO2eq to 1170.82GgCO2eq in 2050. The main contributor will remain non- metallic industries while the least contributors will be the food industries. Mitigation measures will decrease GHG from 1170.82GgCO2eq in 2012 to 1087.56GgCO2eq.in 20250

In Building sector emissions are expected to increase from 2183GgCO2eqin 2012 to 6145.40GgCO2eq in 2050. These will be mainly caused by combustion activity of fossil fuel (wood , wood wastes, kerosene,LPG, diesel, and biogas). The mitigation measures include Efficient and sustainable use of residential building and efficient lighting and use of solar heaters for hot water in building.

In transport sector emission, expect to increase from 447.57GgCO2eq in 2012 to 1678.25 GgCO2eq in2050. The main contributor will be motorcycle. Proposed mitigation option are using electric motorcycle as well as electric car. In addition to these options, the construction of railways from Isaka to Kigali will reduce significantly the diesel and gasoline consumption by heavy-duty trucks and buses to 0% and by 80%, once the project is implemented.

4 Conclusion and Recommendation

GHG emissions are related to the population growth and the change in lifestyle. However, the adoption of energy efficiency measures and energy conservation policy could keep the later increase in the reasonable ranges. Increase of greenhouse gases in atmosphere results in unpredictable impacts that impede the socioeconomic development of the country by loss of population lives, properties, infrastructures and mostly reducing crop yield. These GHG are generated from different sector processes including energy, Industry, Building and Transport. In addition to the current situation, the vulnerability of Rwanda's sectors is projected to increase with the projected impacts of climate change. To reduce the observed vulnerabilities from sectoral perspective, and to prepare the country for future climate change impacts, specific adaptation measures were proposed and prioritized. The adaptation measures include policies, strategies and project activities to increase the adaptive capacity of the Rwandan population while reducing sectoral exposure and sensitivity. It was highly recommended that further studies should be conducted to fill the gaps in data from all sectors and in consideration of projected use of nuclear energy in Rwanda. This will give more accuracy in assessing vulnerability of those sectors hence more ambitious adaptation measures

Acknowledgements. Special thanks to University of Lay Adventist of Kigali for the administrative support in the conduct of this study.

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Figures and tables :

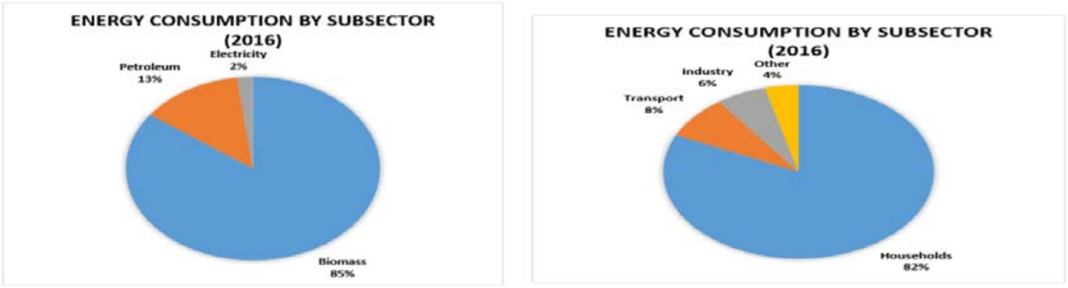
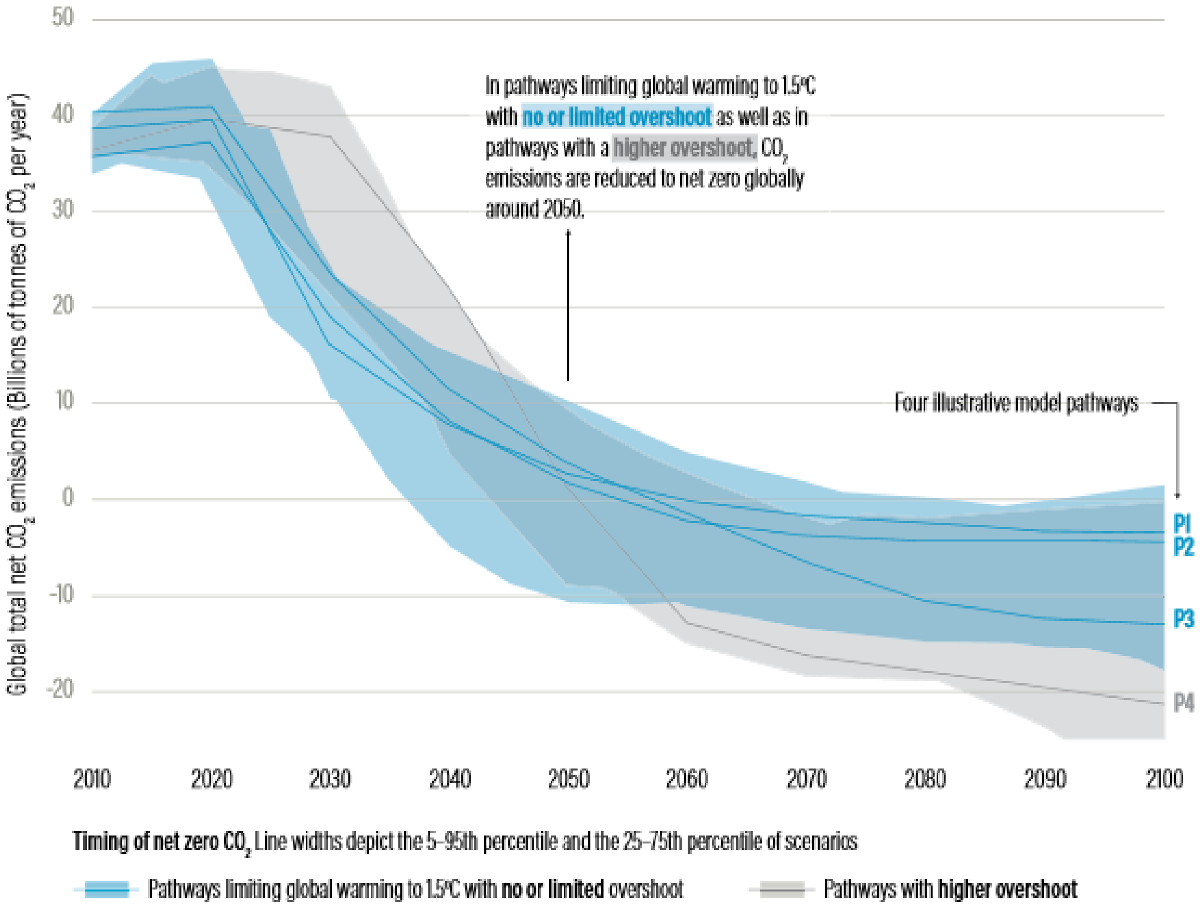


Fig 1: a & b Energy Consumption in Rwanda (Source: ESSP, 2015)



Note: General characteristics of the evolution of anthropogenic net emissions of CO_2, and total emissions of methane, black carbon, and nitrous oxide in model pathways that limit warming to 1.5°C with no or limited overshoot. Net emissions are defined as anthropogenic emissions reduced by anthropogenic removals.
Source: IPCC Special Report on Global Warming of 1.5°C.

Fig 2: Mitigation ambition at global scale (Source: Enhancing NDCS: a guide to strengthening national climate plans by 2020)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Total emissions with FOLU (Gg CO2 eq.)	-5,933.19	-5,556.22	-5,260.04	-4,957.49	-4,632.26	-4,460.63	-4,536.70	-4,357.87	-4,330.53	-3,769.09
Change with respect to 2006 (%)	0.00	6.35	5.33	5.75	6.56	3.71	-1.71	3.94	0.63	12.96
Change with respect to previous year		6.78	5.63	6.10	7.02	3.85	-1.68	4.10	0.63	14.90
GHG emissions without FOLU (Gg CO2 eq.)	4,795.45	5,242.10	5,608.45	5,981.33	6,337.19	6,640.50	6,682.44	6,897.63	6,987.43	7,590.76
Change with respect to 2006 (%)	0.00	8.52	14.50	19.83	24.33	27.78	28.24	30.48	31.37	36.83
Change with respect to previous year		8.52	6.53	6.23	5.62	4.57	0.63	3.12	1.29	7.95
Total removal (Gg CO2 eq.)	-10,728.64	-10,798.32	-10,868.49	-10,938.82	-10,969.46	-11,101.13	-11,219.13	-11,255.49	-11,317.96	-11,359.85
Change with respect to 2006 (%)	0.00	0.65	1.29	1.92	2.20	3.36	4.37	4.68	5.21	5.56
Change with respect to previous year		0.65	0.65	0.64	0.28	1.19	1.05	0.32	0.55	0.37
Total fuel consumption (TJ)	80,693.50	81,947.50	82,512.67	82,750.10	84,347.48	87,484.26	90,555.65	93,508.50	96,120.12	98,908.21
Change with respect to 2006 (%)	0.00	1.53	2.20	2.49	4.33	7.76	10.89	13.70	16.05	18.42
Change with respect to previous year		1.53	0.68	0.29	1.89	3.59	3.39	3.16	2.72	2.82
GDP (USD)	333.00	391.00	480.00	547.00	572.00	627.00	689.00	701.00	719.00	720.00

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Change with respect to 2006 (%)	0.00	14.83	30.63	39.12	41.78	46.89	51.67	52.50	53.69	53.75
Change with respect to previous year		14.83	18.54	12.25	4.37	8.77	9.00	1.71	2.50	0.14
GHG Emission per GDP (Gg/USD)	14.40	13.41	11.68	10.93	11.08	10.59	9.70	9.84	9.72	10.54
Change with respect to 2006 (%)	0.00	-7.41	-23.25	-31.70	-29.98	-35.97	-48.48	-46.35	-48.18	-36.59
Change with respect to previous year		-7.41	-14.74	-6.85	1.30	-4.61	-9.20	1.43	-1.25	7.82
Energy GHG Emission per fuel (Ton/TJ)	13.12	13.82	14.08	14.07	13.64	14.27	14.83	15.20	15.27	15.43
Change with respect to 2006 (%)	0.00	5.08	6.79	6.77	3.83	8.05	11.54	13.68	14.10	14.98
Change with respect to previous year		5.08	1.81	-0.02	-3.16	4.40	3.79	2.43	0.48	1.02
Population	9,007,467.00	9,241,661.00	9,481,944.00	9,728,475.00	9,981,415.00	10,240,932.00	10,482,641.00	10,725,541.00	10,973,254.00	11,225,190.00
Change with respect to 2006 (%)	0.00	2.53	5.00	7.41	9.76	12.04	14.07	16.02	17.91	19.76
Change with respect to previous year		2.53	2.53	2.53	2.53	2.53	2.31	2.26	2.26	2.24
GHG emissions per capita (kg per capita)	532.39	567.22	591.49	614.83	634.90	648.43	637.48	643.10	636.77	676.23

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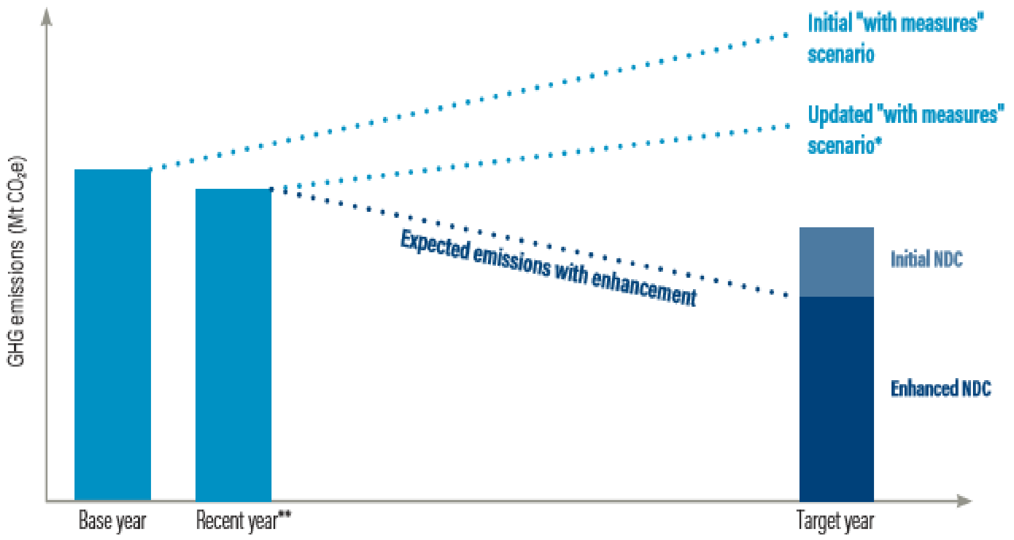
(**Table 1**).**Data collection for baseline scenarios (2006-2015) Source**: REMA Report, 2015



*May be lower or higher than initial 'with measures' scenario
**The most recent year for which data are available

Source: Adapted from Levin et al. 2015.

Fig 3: Aggregating the GHG impact of NDC Enhancement Options

Sector	Subsector	2012	2015	2020	2025	2030	2035	2040	2045	2050
Energy	Electric power generation	106.1	82.0	234.2	407.2	692.8	1204.4	2093.5	3231.8	3346.3
	Energy Industries	50.2	91.2	129.8	185.4	265.8	382.7	553.1	803.0	1170.8
	Buildings	912.5	955.2	1133.3	1386.9	1718.5	2183.0	2995.8	4215.4	6145.4
	Transportation	447.6	510.4	601.5	706.5	833.1	986.5	1172.8	1400.1	1678.3
	Total energy	1516.4	1638.7	2098.7	2686.0	3510.3	4756.5	6815.3	9650.3	12340.8

Table 2: Summarized emission simulation (Gg CO2 eq.) in baseline scenarios

MITIGATION SCENARIOS										
Sector	**Subsector**	2012	2015	2020	2025	2030	2035	2040	2045	2050
Energy	Electric power generation	106.1	82.0	191.5	306.4	412.1	716.3	1109.3	1817.4	1954.6
	Energy Industries	50.2	91.2	127.6	179.1	253.5	361.6	519.0	749.3	1087.6
	Buildings	912.5	955.2	960.2	910.4	919.9	1064.5	1422.3	2136.2	3463.0
	Transportation	447.6	510.4	474.0	548.4	635.8	738.6	859.4	1001.7	1169.4
	Total energy	1516.4	1638.7	1753.2	1944.3	2221.3	2880.9	3910.0	5704.6	7674.6

Table :3 Summarized emission simulation (Gg CO2 eq.) in mitigation scenarios

EMISSION REDUCED										
Sector	**Subsector**	2012	2015	2020	2025	2030	2035	2040	2045	2050
Energy	Electric power generation	0.0	0.0	42.7	100.8	280.8	488.1	984.2	1414.4	1391.7
	Energy Industries	0.0	0.0	2.2	6.3	12.3	21.1	34.1	53.7	83.3
	Buildings	0.0	0.0	173.1	476.6	798.6	1118.5	1573.6	2079.2	2682.4
	Transportation	0.0	0.0	127.5	158.1	197.3	247.9	313.4	398.3	508.8
	Total energy	0.0	0.0	345.5	741.7	1289.0	1875.6	2905.2	3945.7	4666.1

Table : Summarized emission simulation (Gg CO2 eq.) reduced in mitigation scenarios

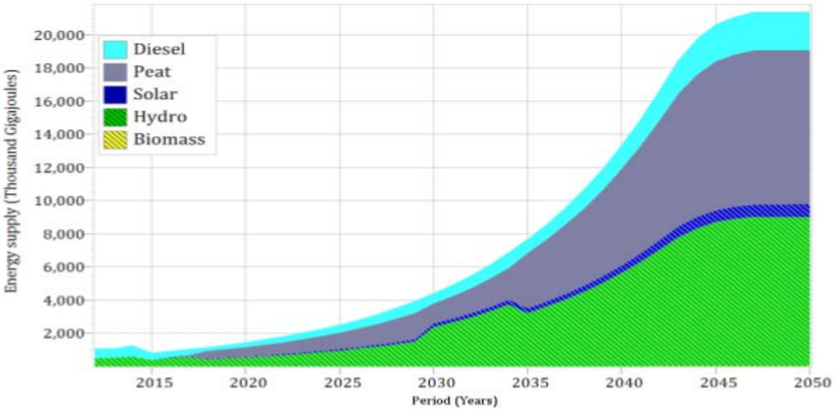


Fig 4: Contributions of various fuels to energy supply between 2012 and 2050

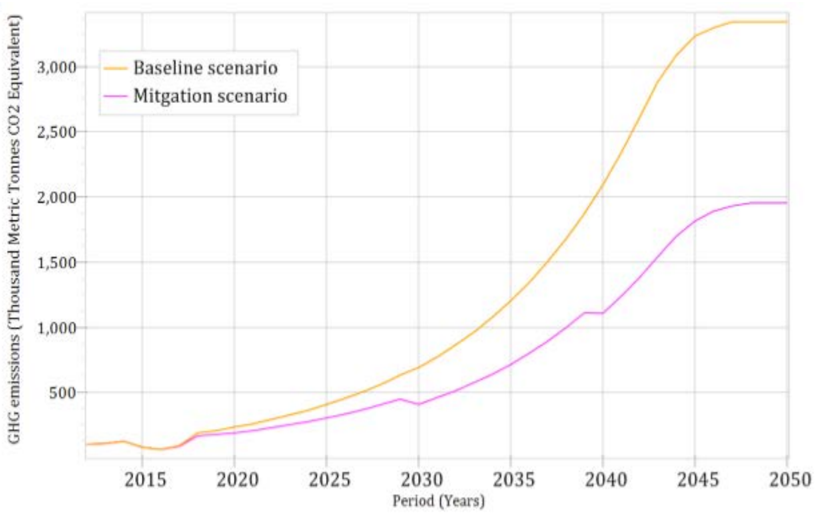


Fig 5: Simulated GHG emissions under baseline and mitigation scenarios (2012-2050)

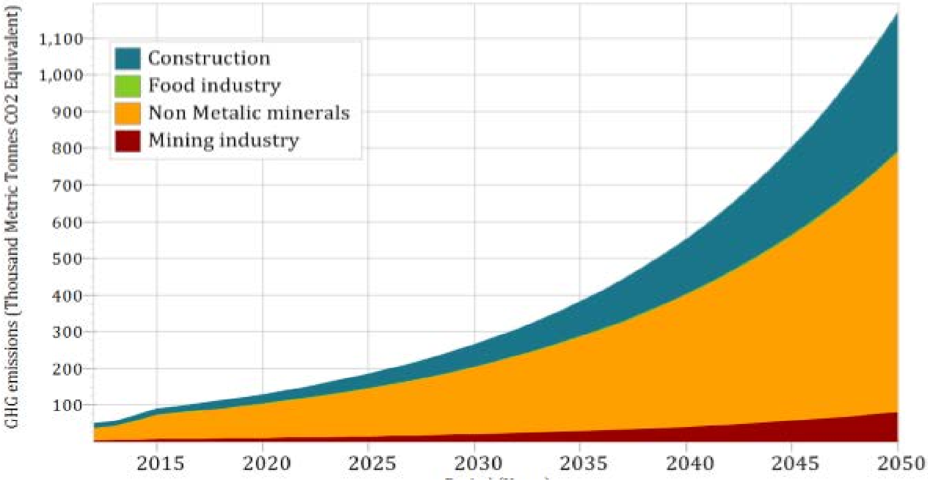


Fig 6: Baseline GHG emissions from major industries in Rwanda (2012–2050)

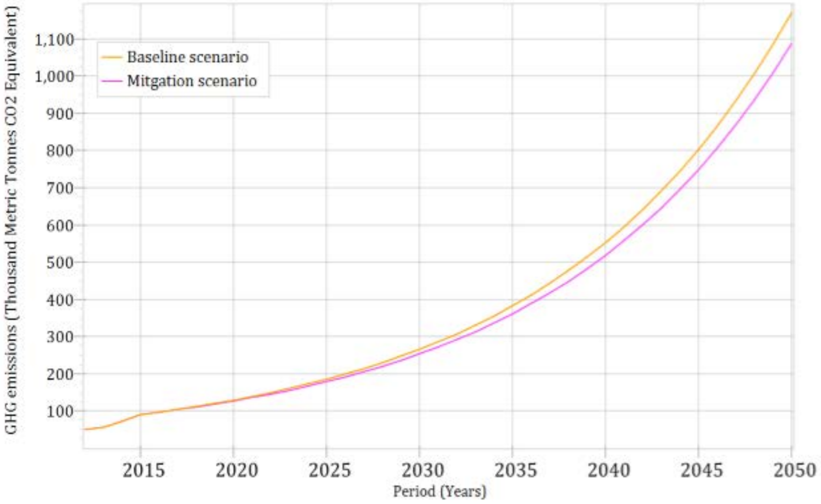


Fig 7: Simulated GHG emissions under baseline and mitigation scenarios (2012-2050)

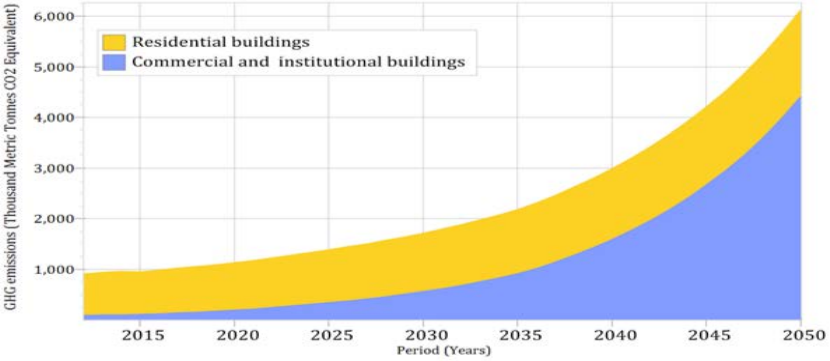


Fig 8: Baseline GHG emissions in buildings between 2012 and 2050

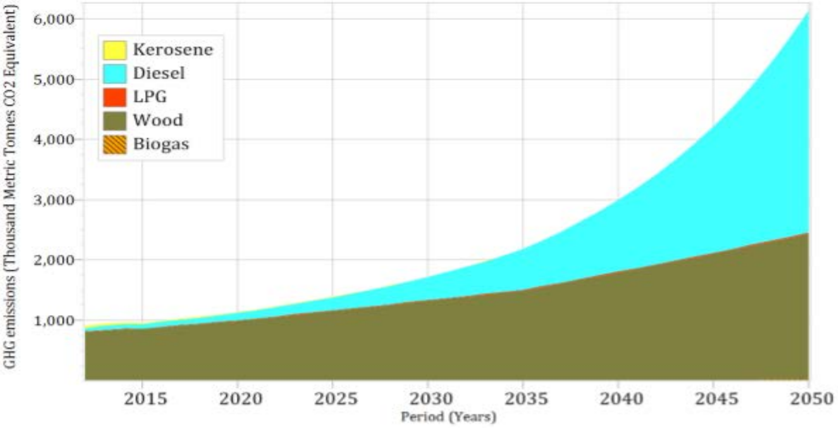


Fig 9: Baseline GHG emissions per fuel between 2012 and 2050

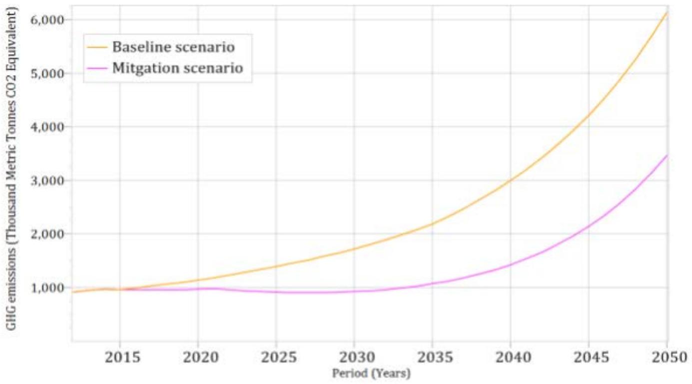


Fig 10: Simulated GHG emissions from buildings under baseline and mitigation scenarios(2012-2050)

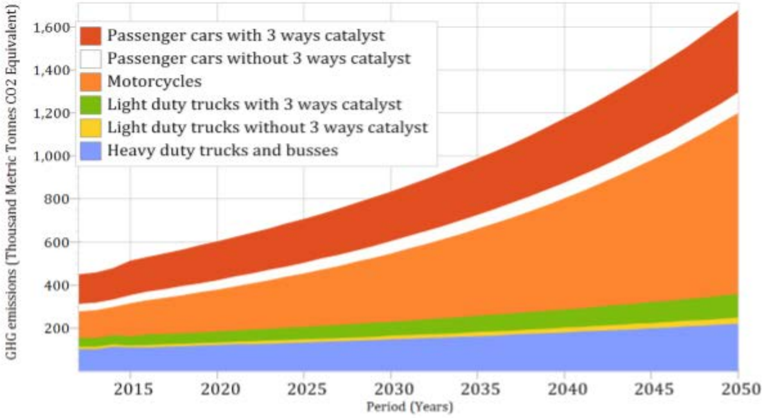


Fig 11: GHG emissions in transport sector under baseline scenario between 2012 and 2050

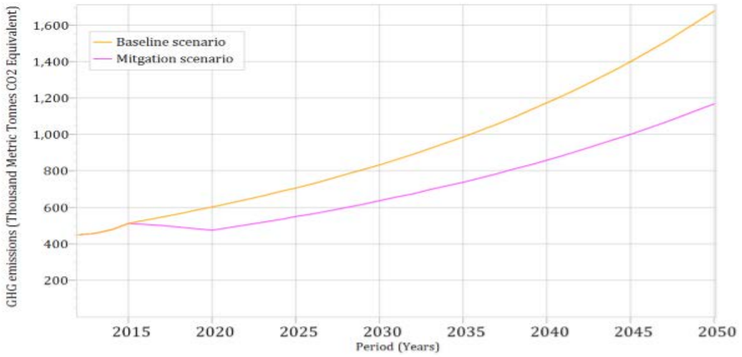


Fig 12: Simulated emissions from transportation under baseline and mitigation scenarios (2012-2050)

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