ENERGY AND EMISSIONS MODELLING IN ETHIOPIA'S TRANSPORT SECTOR

O NNENE[1]*, M ZUIDGEEST[1], D SENSHAW[2]*, B OBERHOLZER[2]** and S GRAFAKOS[2]*****

[1]Department of Civil Engineering, University of Cape Town, Rondebosch, Cape Town
7700, Western Cape, South Africa; Email: *obiora.nnene@uct.ac.za;
**mark.zuidgeest@uct.ac.za
[2]Global Green Growth Institute, 19F Jeongdong Building, 21-15 Jeongdong-gil, Seoul,
04518, Jung-gu, Republic of Korea; Email: *dereje.senshaw@gggi.org;
**basil.oberholzer@gggi.org; ***stelios.grafakos@gggi.org

ABSTRACT

This paper discusses emissions and energy modelling in Ethiopia's transport sector as a component of the development of a wider cross-sectoral Long-term Low Emissions Development Strategy (LT-LEDS) for the country. The LT-LEDS is a key requirement of the Paris Agreement 2015 to which Ethiopia is a signatory. It aims to support growth of key economic sectors while ensuring the alignment of developmental goals with climate commitments and environmental sustainability. The transport sector is identified as a key part of this effort given its significant contribution to GHG emissions and climate change globally. The main activities involved in developing the low emissions pathways are the modelling of baseline and mitigation scenarios which capture historic emission and energy trends in the transport sector and estimates future emissions linked with the growth of the sector respectively. A bottom-up modelling technique is employed for the study. This involves collecting and analysing disaggregate transport activity data to provide a fundamental understanding of transport sector energy consumption and how it affects the long-term transitions. The results of the scenario building highlight the road sector as the main contributor to transport sector emissions in the country. This calls for the implementation of strategies and interventions to reduce emissions and guarantee a climate friendly and environmentally sustainable growth.

1. INTRODUCTION

In response to its commitment to the goals of the 2015 Paris Agreement, the Federal Democratic Republic of Ethiopia has initiated a series of actions and strategies to reduce greenhouse gas (GHG) emissions. Doing its part in contributing towards the Paris Agreement goals is particularly important for a country like Ethiopia, given its relatively high vulnerability to the effects of climate change. One of Ethiopia's main actions is developing and updating its Nationally Determined Contribution (NDC) (FDRE, 2021) as a statement of its ambition to tackle the effects of climate change by achieving a 68% GHG emissions reduction by 2030. Thus, the NDC highlights vital economic sectors and areas that should be prioritised to ensure that Ethiopia can attain its goals of becoming a middle-income country in an environmentally sustainable manner. Therefore, the strategy should lead to actions that can address the priority areas highlighted in the NDC strategy.

As part of these efforts, a Long-Term Low Emissions Development Strategy (LT-LEDS) is being developed for the country through a partnership between the Government of

Ethiopia (GoE) and its development partners like the Agence Française de Développement (AFD) and the Global Green Growth Institute (GGGI). The key mandate for the LT-LEDS is to support economic growth in key economic sectors while ensuring the country's developmental goals align with its climate commitments and environmental sustainability. This involves establishing a sectoral baseline or Business-As-Usual (BAU) scenario for energy consumption and GHG emissions across key sectors of the economy. The baseline scenario will then inform the development of mitigation scenarios which are backed by policy actions that will ultimately lead to low-carbon economic development looking towards the target year of 2050.

The transport sector was identified as a critical part of this effort, given its significant contribution to global GHG emissions and climate change. According to the MoT, (2018) 15% of 2015 global greenhouse gas emissions arose from transportation and its GHG emissions are strongly coupled with economic development (Pachauri et al., 2014). This paper outlines the result of a sectoral LT-LEDS baseline and mitigation scenarios for Ethiopia's transport sector. The BAU scenario, with the base year 2010, outlines the trajectory of historical energy consumption and GHG emissions projected towards the target year of 2050 within the context of current official policies, targets, and existing technologies in Ethiopia's transport sector, which comprises all land-based, water-based, and air-based transport modes. On the other hand, the mitigation or low-carbon scenarios profile the sectoral emissions and energy consumption trajectory given low-carbon policy interventions by the government.

The main activities involved in developing the low emissions pathways are modelling the baseline and mitigation scenarios which capture and estimate future emissions linked with the sector's growth. The modelling activity is guided by extensive policy review and stakeholder participation. However, this paper focuses on the modelling component of the work. A bottom-up modelling technique is employed for the study. This involves collecting and analysing disaggregated transport activity data to provide a fundamental understanding of transport sector energy consumption and how it affects long-term transitions. The Low Energy Analysis Platform (Heaps, 2020) was used to develop the models. The tool was developed to support energy policy analyses and climate-change mitigation assessments. The results highlight the road sector as the primary contributor to transport sector emissions in the country. This calls for implementing strategies and interventions to reduce emissions (particularly road-based emissions) and guarantee climate-friendly and environmentally sustainable growth.

2. STUDY AREA

Ethiopia is located in Eastern Africa, with a land area of approximately 1,127,127 sq. km (World Bank, 2020). Kenya borders Ethiopia to the south, Sudan and South Sudan to the west, Eritrea to the north, and Djibouti and Somalia to the east, as shown in the map below - see Figure 1.

The country is also one of the least developed countries in the world and has a population of approximately 115 million, making it Africa's second most populous country after Nigeria (World Bank, 2020). Over the last decade, the country grew at an average economic growth rate of over 9% per annum (FDRE, 2021), which makes it one of the fastest-growing economies in the world. This resulted in increased economic activities and a positive outlook for the country. Agriculture is the main economic activity. It contributes 46% of the GDP and employs over 70% of the population (World Bank, 2020). However, despite the high dependence on agriculture, the country has continuously expanded its public infrastructure over the last 15 years to stimulate growth in other sectors of the economy. The investment in transport infrastructure like roads, industrial parks, railway infrastructure and the energy sector has been evident in this economic growth and transformation.

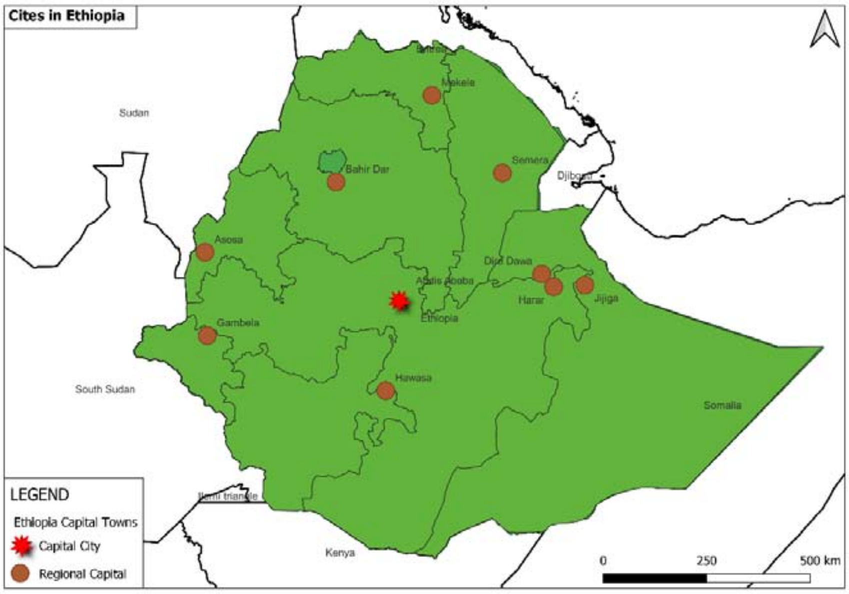


Figure 1: Map of Ethiopia (Adapted and modified from Open Street Maps)

Ethiopia has vast regional differences in terms of its topography, affecting the weather and climate (FDRE, 2021). The south and north-eastern parts of the country, which account for approximately 55% of its land mass, are low-lying with a tropical climate and average temperatures above 25° Celsius. In contrast, the country's central regions have elevations as high as 1,500 meters with cooler temperatures between 15° and 20° Celsius. The temperature varies from near freezing to 50° Celsius along the Red Sea. Like the topography and climate, there is also a noticeable variation in the precipitation between regions in the country. Mean annual rainfall collects to over 1,000 mm in the highlands, while the lowlands record a mean annual rainfall reading of 200 mm. In dry regions, the rainfall variability is higher. Due to this high latitudinal and altitudinal contrast, the region's climate is significant.

Regarding hydrology, Ethiopia's Nile basin forms a significant national surface water potential. The high variability in the altitudes hardly influences the hydrological processes due to the immense basins that hub the big rivers in the country. These basins include the Nile Basin, The Shebelli-Juba Basin, the rift valley basin, and the northeast coast near the Gulf of Aden. The county has famous rivers, such as the Blue Nile, that drain into the Mediterranean Sea together with the White Nile. The lake covers over 7000 km^2. The biggest lake is Lake Tana, located in the northwest of Ethiopia.

Urbanisation and rapid rural-urban migration significantly impact the demand for freight and passenger transport. The transport sector is dominated by public sector investments with road infrastructure development, the railway sector, maritime, logistics, and aviation sectors under government control. This transport infrastructure can be categorised as air, land, and water-based transport (See Table 1). Being landlocked, Ethiopia uses Djibouti port as its main gateway for international trade. Land-based transport modes comprise road and rail transport services and Off-road vehicles. Road transport has the most significant share of users on the urban, rural, and international corridors. In this study, Road transport is categorised into Light Duty Vehicles (LDV) and Heavy-Duty Vehicles (HDV). Rail transport is offered as the Addis Ababa Light Rail Transit (AALRT) system and the Ethiopia-Djibouti railway (EDR). The AALRT is mainly used for passenger transport, whereas the EDR is used for freight transport from the seaport in Djibouti. Air transport comprises passenger and freight, facilitating the long-distance movement of goods and services domestically, regionally, and internationally. The government is focused on growing the freight sector to support land freight logistics and integrated railway services. The government has also recently pushed for more aviation infrastructure, such as airports, airstrips, and helipads.

Table 1: Ethiopia's Transport Infrastructure

Land Use	Total
Road network	120,200 km
Rail network	700 km
Waterways	0 km
Commercial harbours	11
Airports	57

Source: https://www.worlddata.info/africa/ethiopia/transport.php

3. LONG TERM LOW ENERGY DEVELOPMENT STRATEGY

A major highlight in the development of the LEDS is the integration of mitigation and adaptation pathways. The introduction of mitigation and adaptation strategies and interventions in developing the low carbon pathway will guarantee climate resiliency in the transport sector both in the short and long term. The process starts with a review of relevant historical and current transport policy documents. See Table 2 for some of the relevant policy documents reviewed during the process.

Table 2: List of reviewed policy document

Document	Year
Climate Resilience and Green Economy strategy - CRGE	2010
Growth and Transformation plan (GTP I)	2013
Climate Resilience Transport Sector Strategy	2015
Growth and Transformation plan (GTP II)	2016
Transport Sector National Inventory GHG report	2018
National Transport policy	2020
National Motorised Transport Strategy	2020
National Project Ethiopia	2020
10-Year development plan	2021
Updated National Determined Contribution	2021

The review offers insights into existing trends in the transport sector. After the review activity, requisite historical sectoral activity data is collected to facilitate modelling a Business-As-Usual (BAU) scenario for the transport sector. Subsequently, a BAU scenario model was developed and refined for emissions and energy consumption within the sector.

The modelling exercise was done using the Low Energy Analysis Platform (LEAP). The next step involves identifying and reviewing sectoral policy priorities and mitigation intervention targets of the GOE. After that, mitigation scenarios are modelled and refined for the transport sector. The process then ends with documentation of the entire process. Climate resiliency is built into developing the low carbon development pathway at the stage of highlighting mitigation intervention policies and targets and modelling them. This is because due consideration is given to crucial adaptation initiatives like improving the process of transportation infrastructure delivery to reduce the impact of climate change. Furthermore, the mitigation interventions and modelled scenarios reflect low carbon trajectories that will support the development of the Ethiopian transport sector going forward. The main steps taken in developing the low-carbon pathway are highlighted in Figure 2.

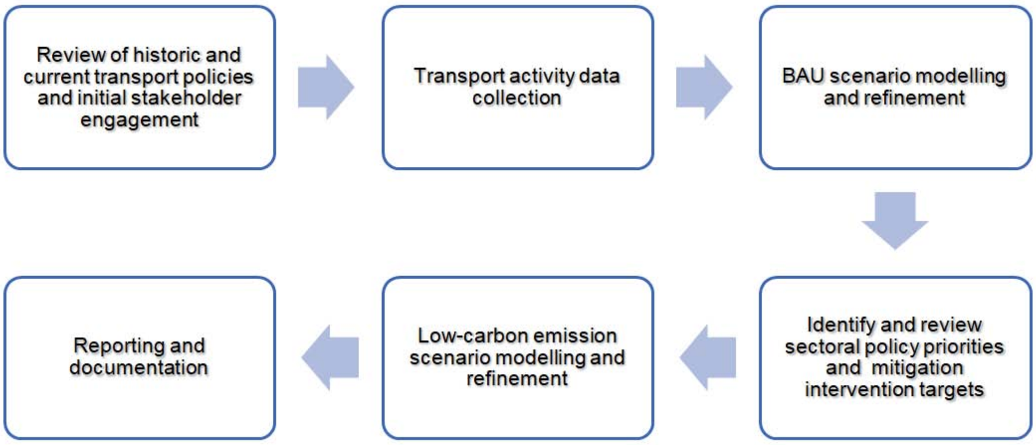


Figure 2: Workflow for the LT-LEDS

4. MODELLING

As stated earlier, LEAP, developed by the Stockholm Environment Institute (SEI), is used to develop the BAU and mitigation scenarios. It is an end-use driven tool that allows for extensive scenario analysis. Leap contains a full energy system accounting framework, which allows for the consideration of both demand and supply-side technologies and accounts for total system impacts. The model can also track pollution resulting from the main stages of the fuel chain, like extraction, processing, distribution, and combustion. Furthermore, LEAP is linked to environmental databases and resources which allow the developed scenarios to meet up with the IPCC guidelines. It is highly flexible regarding its data requirements and the degree of customisation it can support. It also determines the optimal level of investments in power generation, storage technologies, and transmission capacity using another open-source tool known as the Next Energy Modelling system for Optimisation (NEMO) (Heaps, 2020). Two approaches can be used for modelling in LEAP: a top-down and a bottom-up approach. The top-down approach is based on total or final energy consumption estimation using aggregate base year parameters such as total Vehicle-Kilometers (VKT). This approach can be used to develop strategic and aggregate models that give an overview of energy demand and its attendant emissions.

Conversely, the bottom-up approach allows for the development of more detailed models using disaggregate data of the different sub-sectors and branches of the transport sector. The essential advantage of the latter is that it allows for the development analysis of more detailed mitigation scenarios. Furthermore, there are two variants used in the bottom-up approaches. The first is based on estimating VKT as the significant unit of analysis, while the other involves converting the VKT to Passenger-Kilometer (P-km). The latter approach is more flexible as it allows the modelling of passenger modes such as public transport and can capture behavioural aspects of transport such as mode shift. The P-km approach is used for this work. Table 3 summarises three modelling approaches possible in LEAP. The different components of the modelling activity are in the remainder of the section.

Table 3: Modelling approaches in LEAP

Approach	Comment
Top down	Does not allow future scenario analysis
Bottom up – VKT	Allows for limited scenario modelling and analysis
Bottom up – P-km	Allows for extensive scenario modelling and analysis including behavioural responses, such as modal shifts

4.1 Data Requirement

All the transport activity data used for developing and analysing the BAU and low-carbon scenarios and other mitigation scenarios are supplied by officials at the Ministry of Transport in Ethiopia. Data used for the analysis can be seen in Table 4.

Table 4: Data used for the modelling exercise

Data	Description	Unit
Vehicle categories	Category or class of vehicles used for the analysis	-
Vehicle types	The types of vehicles operated on roads and highways within the national(regional)	-
Vehicle number	Number of each stated vehicle type	-
Average vehicle-kilometres travelled per year	Number of kilometres travelled by each vehicle class annually	veh-km
Fuel type	Types of fuel used to power vehicle types	-
Fuel economy	Average fuel economy for each vehicle type	km/l
Average annual Fuel consumption	Average fuel consumed by each vehicle type annually, the total consumption is obtained as a product of multiplying by the total number of vehicles	l/veh/yr

4.2 Data Structure

The data structure used to develop the models are in line with that prescribed in (Eggleston et al., 2006) and is shown in Figure 3. The first level of the hierarchy is the transport sector itself. Next, the transport sector is classified into passenger, freight, and off-road transport sub-sectors. Specific modes of transport such as road, rail, air, and water further classify these. The fourth level of the hierarchy is a categorisation based on vehicle classes and transport services followed by the specific vehicles in the lowest level. Depending on the available data, this structure is modified for the regional models by adding or removing a mode of transport or vehicle type at the appropriate data structure level.

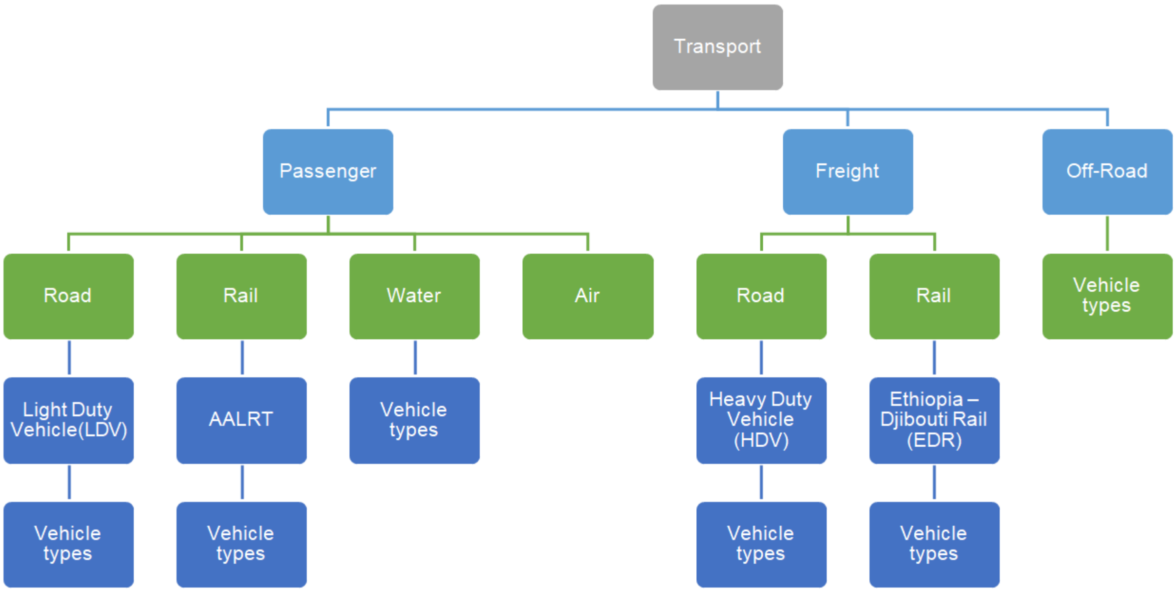


Figure 3: Custom data structure for Ethiopia's transport sector in LEAP

4.3 Emission Factors

Three levels or tiers (Tier 1, Tier 2, and Tier 3) are discussed in the (Eggleston et al., 2006) guidelines for estimating emissions from fossil fuel combustion. Each tier represents a level of methodological complexity. The Tier 1 method used in this paper is fuel-based since emissions from all combustion sources can be estimated based on the quantities of fuel combusted (average emission factors). Since Ethiopia has no country-specific emission factors, we use the default values in the Tier 1 approach of the IPCC guideline for the transport sector. This tier has three emission-factor options (default, lower and upper value). The default values for these emission factors are used. The use of Tier 1 guidelines implies either overestimates or underestimates the total emission since the actual country-specific factors may be higher or lower when ultimately established. Therefore, a periodic review of the current estimates is recommended to align them with the most current realities. The emission factors used in this work are captured in Table 5.

Table 5: 2006 IPCC Emission factors for different transport subsectors

Sector	Fuel type	CO_2 (Kg/TJ)	CH_4 (Kg/TJ)	N_2O (Kg/TJ)
Road transport	Motor Gasoline	69,300	33	3.2
	Gas/Diesel Oil	74,100	3.9	3.9
Water transport	Motor Gasoline	69,300	7	2
	Gas/Diesel Oil	74,100	7	2
Air transport	Jet Kerosene	71, 500	0.5	2
Off Road	Gas/Diesel Oil	74, 100	4.15	28.6

4.4 Modelling Assumptions

The following assumptions shown in Table 6 were used to guide the modelling exercise.

Table 6: Modelling Assumptions

Variable	Model Assumptions	Comment
Fuel standards	Default IPCC Tier 1 values were used	Country specific fuel standards do not exist
Modelling	Bottom-up approach	Combined modelling of VKT, P-km for passenger transport and tonnes-km for freight transport
Travel demand growth	Growth rate used are based on the analysis of transport as a sub-sector of the energy sector	This approach results in the alignment of the transport sector with the energy sector and the (FDRE, 2021) based on IPCC recommendation
Activity data	Based on provided data	Data supplied by the MOT

4.5 Sectoral Policy Interventions and Development Objectives for the Low Emissions Pathways

The intended climate mitigation interventions and developmental objective of the GOE for the transport sector is shown in Table 7. The validated targeted level for each intervention is also shown in the table based on goals already stated in various policy documents. These interventions are aimed at making the transport sector easily accessible, affordable, sustainable and climate resilient. Currently the government has set its 10-year targets with objectives of the MoT, (2020).

Table 7: Transport sector Low-carbon policy intervention and targets

High level Intervention		2022	2030	2050	Source
Shift from petroleum to hybrid and electric vehicles		0%	15%	75%	10 Year development plan
Enhancing Non-motorized Transport (NMT) - bicycle, walking		5%	60%	100%	NMT strategy and 10 YDP
Improve mass transport (BRT, rail, trolley bus)		34%	70%	100%	10 Year development plan
Fuel quality and efficiency		0%	16%	18%	Ministry of water and energy
Increase share of rail transport	Freight	7%	20%	50%	10 Year development plan
	passenger	2%	10%	50%	10 Year development plan

5. RESULTS

The baseline result projects the growth of energy demand and emissions in the transport sector if the existing policies remain as they are. The emission results of the modelling exercise are presented in Figures 4a to 6b for 2010 through 2050, being the base year through the target year, respectively. The results are presented in terms of the 100-Year

Global Warming Potential (GWP). It is estimated that the total emissions from the Ethiopian transport sector is 2.87 million tons of CO2e in the base year and is expected to increase to approximately 15.63 million tons of CO2e by 2050, see Figure 4a. In terms of energy consumption, the results of the national aggregation model obtained from the LEAP tool shows that the energy consumption in the transport sector in 2010 is just over 39.48 Petajoules (PJ). This is expected to increase to 214.63 PJ in 2050 See Figure 4b.

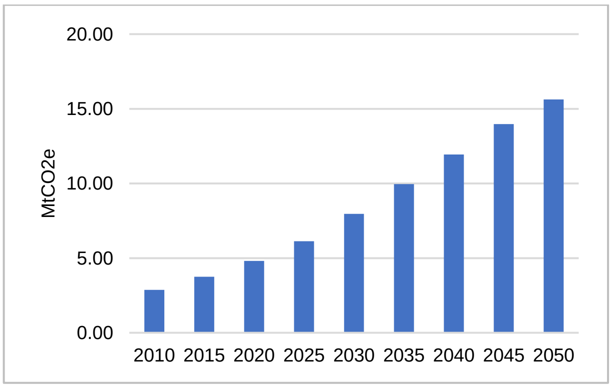


Figure 4a: Total transport sector emissions

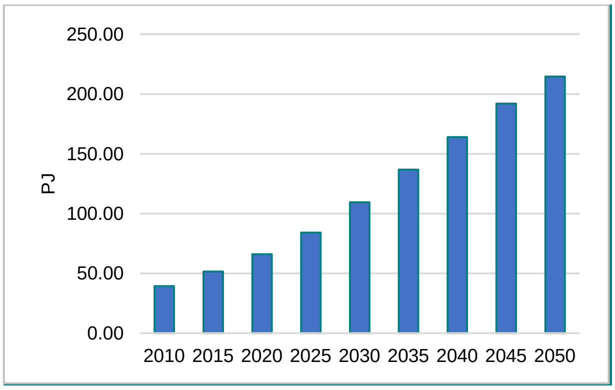


Figure 4b: Total transport sector energy use

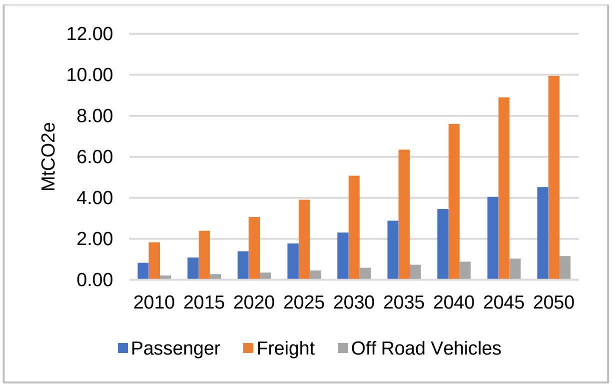


Figure 5a: Transport sub-sector emissions

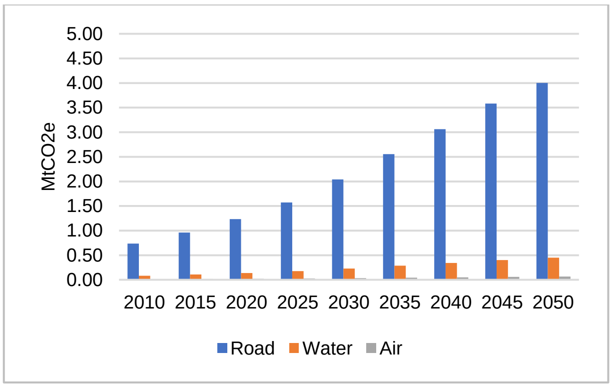


Figure 5b: Passenger transport sector emissions

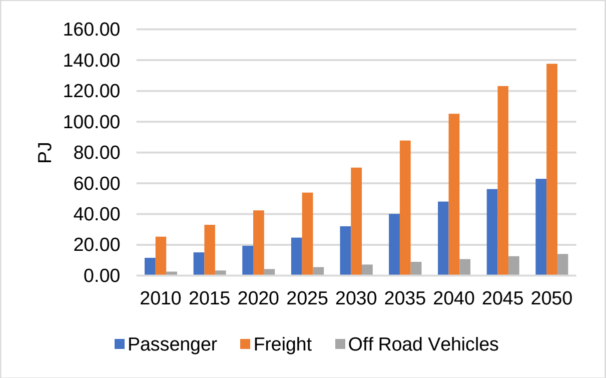


Figure 6a: Transport sub-sector energy

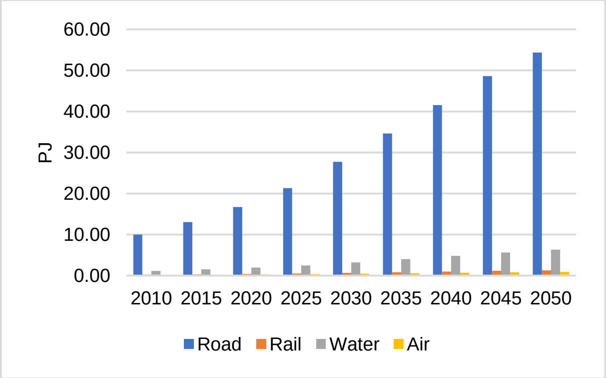
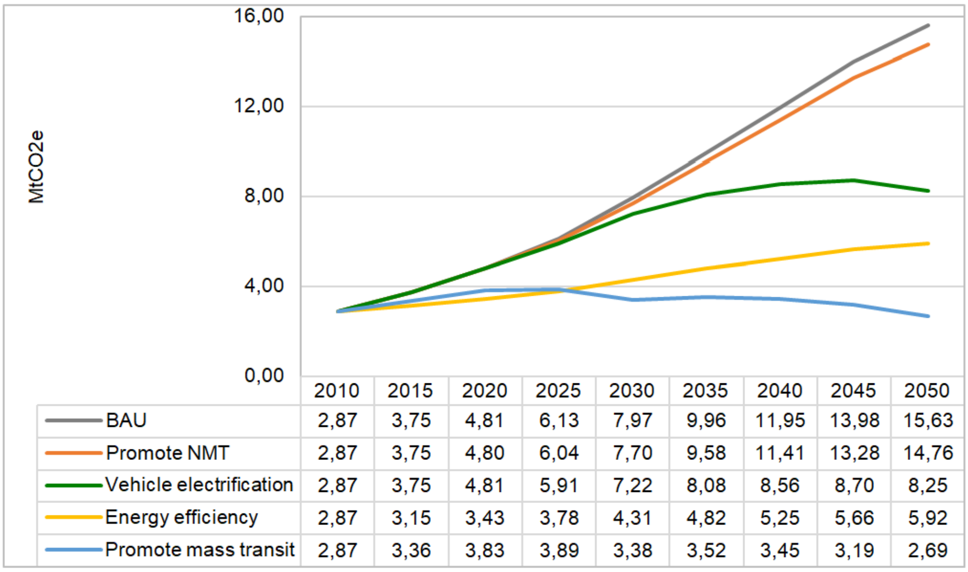


Figure 6b: Passenger transport sector energy

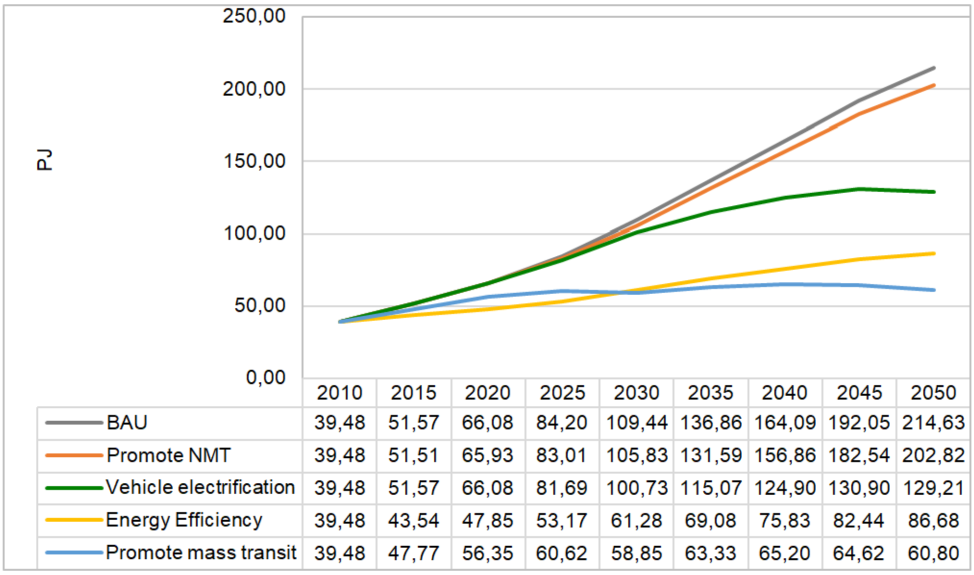
The total estimated emissions were obtained from a combination of the road, water, air, and off-road modes of transport, as seen in Figure 5a. The road sub-sector comprising Light-duty passenger vehicles and Heavy-duty freight vehicles accounts for over 90% of emissions. Domestic water and air passenger transport contribute less to the net emissions; see Figure 5b. Neither passenger nor freight rail transport contributes to the net emissions as they are powered by electricity. This indication could be used to set emissions reduction goals within the transport sector. Additionally, it would allow focusing efforts on those sub-sectors with higher emissions per capita. Similar trends are also observable in the energy consumption within the sector, as seen in Figure 6a and Figure 6b.

The results of the mitigation scenarios are aggregated into four primary policy considerations seen in Figure 7 and Figure 8 for emissions and energy consumption. The policy on NMT offers the least projected emission reduction while promoting mass transit which comprises two interventions, namely improving mass transit and increasing passenger and freight rail, offers the highest projected emission reduction by 2050. This analysis identifies which policy combinations to prioritize in its goal to decarbonize the transport sector. One limitation of this study is that it does not fully account for all the reduction in transport related emissions during the COVID-19 pandemic owning to the limited access to available data for the period. However, for the purpose of this study an exact forecast is not needed as its looks at the transport function that can bring the most benefits to emission reduction.



	2010	2015	2020	2025	2030	2035	2040	2045	2050
BAU	2,87	3,75	4,81	6,13	7,97	9,96	11,95	13,98	15,63
Promote NMT	2,87	3,75	4,80	6,04	7,70	9,58	11,41	13,28	14,76
Vehicle electrification	2,87	3,75	4,81	5,91	7,22	8,08	8,56	8,70	8,25
Energy efficiency	2,87	3,15	3,43	3,78	4,31	4,82	5,25	5,66	5,92
Promote mass transit	2,87	3,36	3,83	3,89	3,38	3,52	3,45	3,19	2,69

Figure 7: Transport sector mitigation policies for emissions



	2010	2015	2020	2025	2030	2035	2040	2045	2050
BAU	39,48	51,57	66,08	84,20	109,44	136,86	164,09	192,05	214,63
Promote NMT	39,48	51,51	65,93	83,01	105,83	131,59	156,86	182,54	202,82
Vehicle electrification	39,48	51,57	66,08	81,69	100,73	115,07	124,90	130,90	129,21
Energy Efficiency	39,48	43,54	47,85	53,17	61,28	69,08	75,83	82,44	86,68
Promote mass transit	39,48	47,77	56,35	60,62	58,85	63,33	65,20	64,62	60,80

Figure 8: Transport sector mitigation policies for energy consumption

6. CONCLUSION

The government of Ethiopia has set out to develop a low-emission development strategy. The transport sector features prominently in this effort as it is a significant contributor to GHG emissions that harm the climate. However, there are co-benefits accrued as transport is still very useful in the country's economic growth. Therefore, following the development of a sectoral baseline for emissions and energy consumption, this document highlights the development of a low-carbon emission pathway for the future expansion of the sector. The primary approach adopted in the low carbon pathway development is described, followed by the identification of key policy priorities (mitigation interventions) and implementation targets for the priorities that can aid the reduction of emissions and lead the sector towards carbon neutrality by 2050. Lastly, the actual pathways are developed by modelling the earlier-mentioned policy interventions. The results show that prioritizing interventions in the road freight sector and expansions of mass transits will aid the attainment of the objective of decarbonizing Ethiopia's transport sector, thereby supporting green growth.

7. ACKNOWLEDGEMENT

The authors hereby acknowledge the Agence Française de Développement (AFD) for funding this work. We also wish to thank the working groups at the various Government ministries that supported the work by providing access to relevant data and sharing their insights at the working group meetings. Lastly, we acknowledge the Green Global Growth Institute (GGGI) and the other members of the LEDS team for facilitating the LEDS project and supporting it respectively.

8. REFERENCES

Eggleston, HS, Buendia, L, Miwa, K, Ngara, T & Tanabe, K. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Available at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html

FDRE. 2021. *Updated Nationally Determined Contribution Of Federal Democratic Republic Ethiopia*.

Heaps, CG. 2020. *LEAP: The Low Emissions Analysis Platform.[Software version: 2020.1. 19] Stockholm Environment Institute. Somerville, MA, USA*.

MoT. 2018. *Ethiopia: Transport Sector National GHG Inventory*.

MoT. 2020. *National Transport Policy*.

Pachauri, RK, Allen, MR, Barros, VR, Broome, J, Cramer, W, Christ, R, Church, JA, Clarke, L, Dahe, Q, Dasgupta, P, et al. 2014. *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change*. Ipcc.

World Bank. 2020. *The World Bank in Ethiopia*. Available at: https://www.worldbank.org/en/country/ethiopia