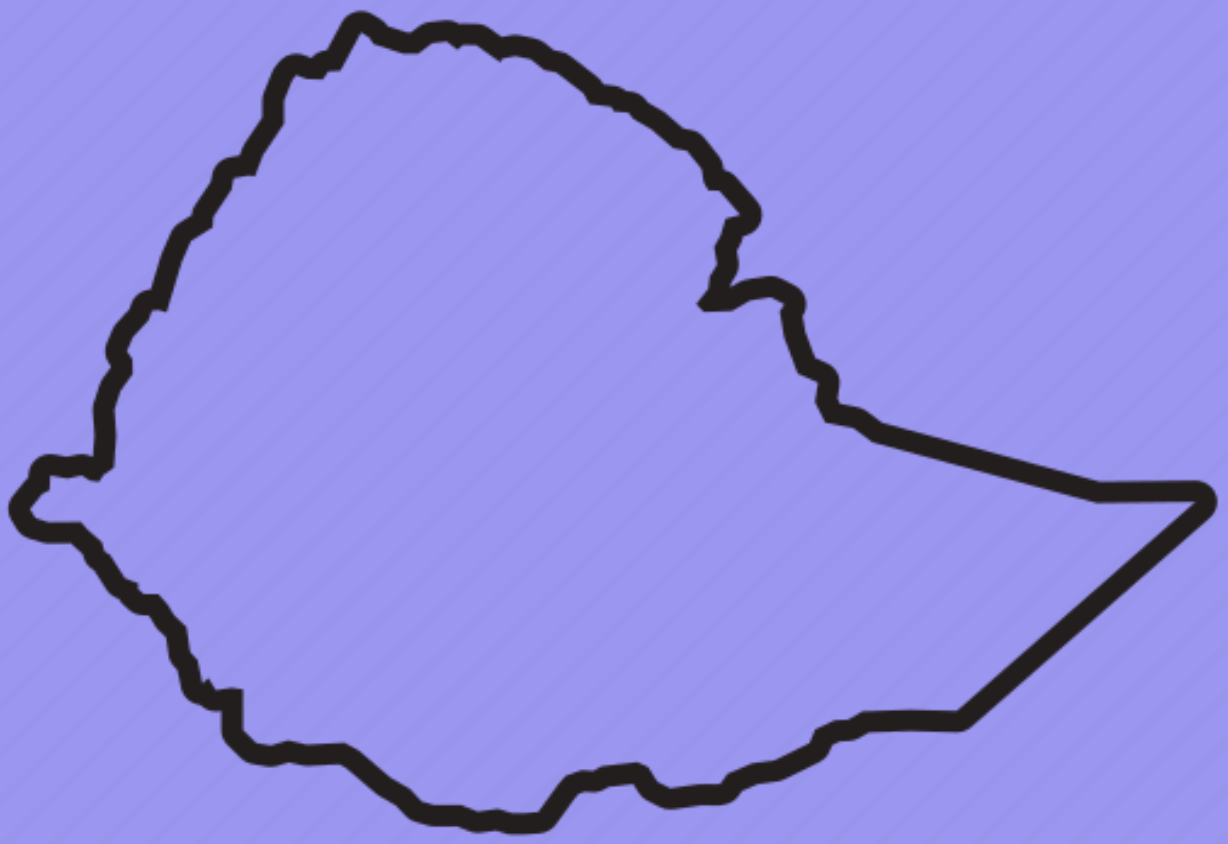
Applying GACMO to evaluate the mitigation options in the NDC Update in Ethiopia



Report on applying GACMO tool to evaluate mitigation options in the updated NDC in Ethiopia

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Contents

Abbreviation

BAU	Business as Usual
CO_2e	Carbon dioxide equivalent
CRGE	Climate-Resilient Green Economy Strategy
GACMO	Greenhouse Gas Abatement Cost Model
GEM	Green Economy Model
GHG	Greenhouse gas
GES	Global Environmental Solution
GWPs	Global warming potentials
ICAT	Initiative for Climate Action Transparency
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Process and Product Use
ktoe	Killo ton oil equivalent
LT-LEDS	Long term low emission development strategy
LUCF	Land use change and forestry
LPG	Liquified Petroleum gas
MRV	Measuring, Reporting and Verification
NDC	Nationally Determined Contributions

UNEP-CCC	UNEP Copenhagen Climate Centre
UNFCCC	United Nations Framework Convention on Climate Change
UNOPS	United Nations Organization for Procurement Services

Technical summary

The report highlights the application of Greenhouse Gas Abatement Cost Model (GACMO) to evaluate mitigation measure of the NDC in Ethiopia. The report aims to provide insights and guidance for integrating GACMO tools into the upcoming Nationally Determined Contribution (NDC) update, emphasizing the importance of informed decision-making in climate action. The potential impact of individual mitigation options on reducing greenhouse gas emissions was evaluated using the GACMO tool. The tool has quantified the emission reduction potential of each identified mitigation options and analyzed the extent of emission reduction across sectors, projecting future years. The tool has carried out comprehensive cost analysis for each mitigation option to assess the financial implications associated with implementation. Furthermore, the financial sustainability of each mitigation option was assessed by comparing projected costs with anticipated benefits in terms of emissions reduction. The findings from the emission reduction potential and cost analysis informed decision-making in the prioritization and selection of mitigation options for inclusion in the NDC update. Ethiopia's previous NDC submission in 2017 has focused on mitigating GHG emissions through various measures, including renewable energy expansion and energy-efficient technologies.

Among the key findings, hydro power connected to the main grid emerges as the most promising avenue for emission reduction in 2030, with a projected decrease of 42,307.44 kt/year. Additionally, the composting of Municipal Solid Waste proves to be the most cost-effective investment per ton of CO2 reduced, priced at $0.05/tonCO2. Notably, options such as Biogas from Municipal Solid Waste and Landfill gas flaring has exhibited a negative cost, indicating potential cost savings upon implementation. On the contrary, Wind turbines, off-shore, present the highest cost per ton of CO2 reduced at $126.07/tonCO2. Despite the significant emission reduction potential observed, options like shifting freight transport from road to rail and Electric rail were excluded from the MAC curve due to their higher costs compared to other alternatives. This evaluation underscores the critical importance of considering both emission reduction potential and cost-effectiveness in selecting mitigation options for inclusion in the Nationally Determined Contribution (NDC) update. There are also, mitigation options identified with an optimized cost of investment and implementation with raisable emission reduction that the country need to see critically. The finding has provided the valuable guidance for decision-makers to prioritize and

implement cost-effective mitigation measures that can effectively contribute to Ethiopia's climate action goals.

1. Introduction

The Initiative for Climate Action Transparency (ICAT) has been a crucial partner in supporting Ethiopia's environmental initiatives, particularly in facilitating the implementation of the Greenhouse Gas Abatement Cost Model (GACMO) during the period of 2023-2024. Through a comprehensive online and in-person training session, Ethiopia has received technical support to enhance its capacity in utilizing GACMO effectively. The primary aim of this report is to provide a comprehensive summary of how the country team has integrated this technical skill into the Ethiopian context, empowering them to make informed decisions and strategic choices concerning environmental conservation and sustainable development practices. Moreover, provide valuable insights and guidance tailored to the technical team entrusted with the upcoming NDC update, offering practical strategies and recommendations for integrating GACMO tools efficiently to support informed decision-making processes and drive sustainable climate action in Ethiopia.

With Ethiopia's last NDC submission dated 2021 and the upcoming update scheduled for 2026, there is a critical need for the country to assess the costs and benefits of different mitigation options to enhance its climate action commitments effectively. The application of the Greenhouse Gas Abatement Cost Model (GACMO) proves to be instrumental in meeting these needs, assisting Ethiopia in evaluating the financial implications and greenhouse gas mitigation potentials of diverse mitigation measures. The proactive engagement and follow-up mechanisms implemented by the ICAT Secretariat serve as a vital means to ensure that the tools and technical support provided are effectively utilized and have a tangible impact on Ethiopia's climate initiatives.

Ethiopia submitted its Intended National Determined Contribution (INDC) in 2015 which became Ethiopia’s Nationally Determined Contribution (NDC) in 2017. The NDC focused on mitigations of GHG emissions through improving crop and livestock production practices, protecting and re-establishing forests for their economic and ecosystem services, including as carbon stocks, expanding electricity generation from renewable sources and leapfrogging to modern and energy-efficient technologies in transport, industrial sectors, and buildings (FDRE, 2015). In addition, the Ethiopia’s NDC has identified many adaptation efforts to reduce vulnerability of livelihoods and landscapes to

climate impacts. Many of the initiatives offer positive returns on investments, thus directly promoting economic growth and creating high value additional jobs (CRGE, 2011).

The Climate Action Tracker's latest Ethiopian emissions projections are higher in 2030 when it is compared with the previous projections[1]. Ethiopia is set to overachieve its unconditional and conditional NDC targets in 2030 under its current policies. Ethiopia's own climate targets are within the range of what is considered a fair share of global effort. Currently, the country is actively working on its domestic processes for Article 6 implementation in Ethiopia. The country uses a 2016 IPCC guideline MRV methods to monitor the GHG emission and assess the reduction potentials of all mitigation options in a sector. As a requirement of Article 6 implementation, the country has identified a robust M&E and MRV techniques to monitor the emission reduction potentials of an individual mitigation option in a sector.

Under ICAT support, Ethiopia has adopted the Greenhouse Gas Abatement Cost Model (GACMO) as a tracking framework for assessing the contribution of each mitigation measures to achieving its global share of the carbon reduction. ICAT in collaboration with UNEP CCC, UNFCCC, ISPRA and GES has given an intensive capacity building on Article 6 (A6.2/A6.4/A6.8) to FDRE EPA and NDC Update implementing line ministries, and adopted GACMO tool to evaluate mitigations measures of the NDC Update. GACMO tool is a powerful tool crafted to assess and evaluate the costs and benefits associated with diverse mitigation options spanning across sectors. It also aids in analyzing and comparing various strategies identified as mitigation policies in the NDCs. When required, the decision-makers rely on GACMO to quantify the financial investments required and the potential benefits that can be derived from implementing different mitigation pathways. Finally, the findings of GACMO tool application to evaluate mitigation options of the NDC Update is reported.

2. Objective of applying GACMO tool to evaluate Mitigations options

The primary objective of utilizing the Greenhouse Gas Abatement Cost Model (GACMO) tool to evaluate mitigation options in Ethiopia's updated Nationally Determined Contribution (NDC) is to facilitate informed decision-making and

[1] Ethiopia | Climate Action Tracker

strategic planning that effectively addresses climate change challenges while maximizing sustainability and cost-effectiveness.
The key objectives of applying GACMO tool for evaluating mitigation options of the Ethiopian NDC Update in this assignment are:

- To quantify Cost and Benefits associated with various mitigation options in Ethiopia.
- To evaluate Emission Reduction Potential of each mitigation option considered for inclusion in Ethiopia's NDC.
- To prioritize Effective Mitigation Strategies and select mitigation options that align with Ethiopia's climate goals, development priorities, and NDC targets.
- To enhance Transparency and Accountability in the decision-making process related to mitigation options.

3. Basics of the GACMO tool and potential benefits

Conceptually, GACMO has been developed to calculate the current and future greenhouse gas emissions abatement costs and enable countries to carry out a rapid and accurate evaluation of the GHG emission reduction impacts of different mitigation. It is utilized to calculate the GHG emission projections for the business-as-usual (BAU) and mitigation scenario based on a set of selected mitigation options. The first version of GACMO was adopted 25 years ago for Zimbabwe by Jorgen Fenhann and it has been widely used by various countries[2] in their climate change mitigation planning, implementation, tracking, and reporting. The tool used to evaluate the new mitigation options in terms of their abatement costs and mitigation potentials to find the mitigation actions appropriate for a country. Also, the tool helps to track the progress in achieving emissions reductions implemented climate change mitigation options.

Applying GACMO tool provides information to gain a deeper understanding of the economic implications, feasibility, and impact of mitigation measures across sectors such as energy, agriculture, transportation, and industry. The tool's ability to quantify costs and benefits empowers decision-makers to prioritize mitigation options that not only deliver environmental benefits but also align with the broader economic and development objectives. GACMO plays a pivotal role in guiding policymakers, researchers, and stakeholders in making informed choices regarding the most efficient and cost-effective approaches to

[2] New tab (unepccc.org)

combatting climate change. In essence, GACMO serves as a valuable instrument in the arsenal of tools available for climate action, offering a structured methodology to evaluate and compare different mitigation strategies and steer towards a more sustainable and low-carbon future. In Ethiopian, GACMO tool training was given to make all the GHG reporting sectors widely ready to prepare their national communications, biennial update reports (BURs), biennial transparency reports (BTRs), track and update their NDCs as per the required forms.

4. Readiness for applying GACMO tools in the NDCs

4.1 Steps to Utilize GACMO for Ethiopia's NDC Update

4.1.1 Data Collection and Baseline Establishment

Desk review of published articles, strategic documents, and online resources were conducted to gather secondary data from official sectoral databases, international organization portals, and websites. Additionally, primary data collection was carried out through key informant interviews, online surveys using Google Forms, and focus group discussions with sector experts from line ministries. Consultations were also held with stakeholders such as the Environmental Protection Authority and related line ministries responsible for emission reporting. The collected national information was provided to the international experts from UNEP-CCC for further analysis using the GACMO tool for NDC tracking. Subsequently, in collaboration with UNEP-CCC, the national team evaluated the mitigation measures of GACMO tool to evaluate its effectiveness in terms of cost of abatement and greenhouse gas reduction potentials.

4.2.2 Identifying Potential Mitigation Options

The Ethiopian NDC Update, Long term low emission development strategies (LE-LDS), GACMO tools mitigation sheet and other sectoral strategies were reviewed. The potentials of GHG reducing strategies were compiled accordingly. Through consultation with emission reporting sector ministries, implementable mitigation measures were identified. Then, an extensive list of potential mitigation strategies that could be adopted in Ethiopia NDC update to reduce the greenhouse gas emissions are prepared. As a preliminary evaluation, the feasibility of each mitigation option based on factors such as technological readiness, resource availability, policy support, and existing infrastructure with

its scalability and replicability of each strategy in the Ethiopian context are assessed.

4.1.3 Emission Reduction Potential and Cost Analysis

The potential impact of individual mitigation option on reducing greenhouse gas emissions was evaluated. The GACMO tool was utilized to quantify the emission reduction potential of each identified mitigation option. In addition, the extent of emission reduction of each mitigation policy including the projected future years is analyzed across sectors. Comprehensive cost analysis was done for each mitigation option to assess the financial implications associated with implementation. Moreover, factor in operational costs, maintenance expenses, technology investment, and any potential savings achieved through reduced emissions. Finally, the financial sustainability of each mitigation option was analyzed by comparing the projected costs with the anticipated benefits in terms of emissions reduction. The findings of the emission reduction potential and cost analysis were utilized to decision-making in the prioritization and selection of mitigation options for inclusion in the NDC update.

4.2 Considerations for Mitigation Option Evaluation

Alignment of the chosen mitigation strategies with Ethiopia's national development objectives, climate goals, financial capacities, NDC targets and commitments was checked. The impact on how each mitigation option contributes to achieving the specific emission reduction goals set forth in the Ethiopia NDC Update was assessed.

4.3 Stakeholder Consultation

A diverse group of stakeholders from universities, privates, various government sectors were consulted throughout the assessment process. Valuable insights, perspectives, and expertise on the feasibility, impact, and challenges associated with implementing different mitigation options were collected from the consultation dialogue. Besides, the stakeholder consultation input was considered in the preliminary and GACMO tool output-based mitigation strategy evaluation process.

5. Application of GACMO Tool to Ethiopian NDC Updates

About 119 mitigation option are found in the default GACMO tool. Countries might use selected mitigation measures and contextualize to their NDC

conditions. About thirty-one (31) mitigation actions of the GACMO tool have been discovered as relevant for Ethiopian NDC Update. About eighteen (18) of them have already been included as a greenhouse gas emission reduction option in Ethiopia NDC update. While the others thirteen (13) mitigation options have been found in GACMO tool and but were not included in the NDC Update in 2021. These new mitigation actions (13 mitigation actions) are commonly implemented in various sector ministries. Up on evaluation result of all actions based on the GACMO tool producing marginal cost Vs GHG reduction potentials, they will be included as mitigation measures of the NDC Update (Table 1).

In the capacity building workshop, experts from the GHG reporting sector ministries have approved the relevance of all the mitigation measures and checked them against set of their NDC targets. Hence, the experts of the sector ministries have approved the compiled data and organize it in an appropriate unit format found in the GACMO tool. Then, the activity data of all possible mitigation actions and the recent MRV (GHG inventory) data of Ethiopia were inserted into GACMO tool. Then, they analyze and use the finding for report preparation. Finaly, they have produced a MARC curve and interpreted the data accordingly.

Currently, to see the cost of investment in the marginal cost abatement curve and associated GHG reduction potential, all the identified mitigation measures are evaluated by GACMO tool. The list of mitigation options that are evaluated by GACMO Tool are summered in Table 1. The yellow color-coded mitigation actions are found in GACMO tool, whereas the red color-coded mitigation options are not directly found on the tool.

Table 1 GHG Reduction Options in the Ethiopian NDC Update (yellow: new mitigations from GACMO to be utilized for the NDC Update, Green: common mitigation actions in both NDC Update and GACMO)

Type	Reduction option	Sub-type unit	[3]Remarks
Agriculture	Zero tillage	1000 ha	
EE households	Efficient lighting with CFLs	1000 Bulbs	
	Efficient lighting with LEDs replacing CFL	1000 Bulbs	
	Efficient wood stoves	1000 stoves	

[3] Green: Mitigation measures which are found both in the NDC Update and GACMO Tool; Yellow: A mitigation measure found in GACMO tool but it was not included in the NDC Update and practically implemented mitigation measures in the Ethiopian context.

Type	Reduction option	Sub-type unit	[3]Remarks
	Efficient charcoal stoves	1000 stoves	
	LPG stoves replacing wood stoves	1000 stoves	
	Efficient electric stoves	1000 stoves	
EE service	Efficient office lighting with CFLs	1000 lights	
	Efficient office lighting with LEDs	1000 lights	
	Efficient water pumping	4 Million m3 water	
Energy distribution	Connection of isolated grid to central grid	1 GWh consumption	
Forestry	Reforestation	Reforestation of 1000 ha	
	REDD: Avoided deforestation	No deforestation for 1000 ha	
Geothermal	Geothermal power	1 MW	
Hydro	Landfill gas flaring	1 t/day plant	
	Incineration plant	200 t/day plant	
	Recycling of plastics	1000 t MSW/year plant	
	Biogas from Municipal Solid Waste	1000 t/year plant	
	Composting of Municipal Solid Waste	1000 t/day plant	
Solar	Solar PVs, large grid	1 MW	
Transport	Bus Rapid Transit (BRT)	1 km BRT line	
	Electric cars	1000 cars	
	Electric 18m buses	1000 buses	
	Electric 12m buses	1000 buses	
	Electric rail	1 Million train. km /year	
	Shifting passengers from car to rail	1 Million person.km/day	
	Shifting freight transport from road to rail	1000 ton. km /day	
	Restriction on import of used cars	1000 cars	

Type	Reduction option	Sub-type unit	[3]Remarks
	New bicycle lanes	1 km bicycle lane	
	Electric three-wheelers	1000 three-wheelers	
	Electric two-wheelers	1000 two-wheelers	
Wind	Wind turbines, off-shore	1 MW	
# GHG reduction options: 31			

5. Input information

5.1 Assumption

Basic country information such as existing USD exchange rate to local currency and discount rate was considered to 55.5 ETB and 7.0%, respectively. Baseline data of the country was taken from a 2020 GC country emission and other supplementary information (Table 2).

Table 2 Fuel prices for the entire period - GACMO tool output

	LPG	Gasoline	Bioethanol	Jet Fuel	Diesel oil	Biodiesel	Heavy Fuel Oil	Kerosene	Coal	Coke	Petroleum coke	Lignite	Natural Gas
Distillate price/crude oil price (litre/litre)	0.90	1.40		1.40	1.20		0.80	1.40					
Fuel price (US$/litter)	0.44	0.69	0.83	0.69	0.59	1.20	0.39	0.69					
Fuel price (US$/GJ)	17.3	20.4		19.2	16.2		10.0	19.2	5.9	5.9	5.9		3.1
Fuel density (t/m3)	0.54	0.75	0.76	0.80	0.84	0.88	0.98	0.80					
Fuel Calorific value (GJ/t)	47.3	44.8	26.8	44.6	43.3	26.8	40.2	44.8	25.0	28.0	31.0	18.3	39.0

5.2 Baseline (2020) and projected (2030) energy balance for Ethiopia

In Table 3 outlining Ethiopia's Fossil Fuel Energy Balance in TJ for the year 2020 (baseline), the data shows the energy consumption across different sectors. In the Industry-miscellaneous sector, the consumption of various fossil fuels includes 2,135 TJ of LPG, 9,211 TJ of gasoline, 2,512 TJ of jet fuel, 13,858 TJ of diesel, and 138,583 TJ of HFO, totaling 152,441 TJ for total oil products. The Transport sector, specifically road transport, consumed 28,135 TJ, while domestic air transport used 35,504 TJ. Households consumed 377 TJ of LPG and 3,266 TJ of kerosene and other fuels, totaling 3,643 TJ. The total energy consumption across all sectors amounted to 328,789 TJ.

Table 3 Ethiopia's Fossil fuel energy balance in TJ, 2020.

Fossil fuel energy balance in TJ	LPG	Gasoline	Jet Fuel	Diesel	HFO	Kerosene and other	Total oil products	Coal	Total energy (fossil)
Unit	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ
Fossil power plants	-	-	-	-	-	-	-	-	-
Industry - miscellaneous		2,135		9,211	2,512		13,858	138,583	152,441
Transport - road		28,135			109,066		137,201		137,201
Transport - domestic air		35,504					35,504		35,504
Households	377	3,266					3,643		3,643
Total all energy consumption									328,789

In Table 4, provided, the energy consumption in kilotons of oil equivalent (ktoe) for different sectors in Ethiopia is outlined. In the industry-miscellaneous sector, the total consumption is 15,382.94 ktoe. For road transport, the consumption is 9,473.77 ktoe, while domestic air transport consumes 2,451.56 ktoe. Households use 127.57 ktoe of energy. The final consumption of energy sources includes LPG at 13.20 ktoe, gasoline at 4,724.10 ktoe, diesel at 929.49 ktoe, fuel oil at 7,784.53 ktoe, and coal at 13,984.52 ktoe. The total energy consumption across all sectors is 27,435.84 ktoe.

Table 4 BAU projected Fossil fuel energy balance - 2030

ktoe units	Industry - miscellaneous	Transport - road	Transport domestic air	Households	Final Consumption
LPG	-	-	-	13.20	13.20
Gasoline	215.44	1,942.73	2,451.56	114.36	4,724.10

Diesel	929.49	-	-	-	929.49
Fueloil	253.49	7,531.04	-	-	7,784.53
Total oil products	1,398.42	9,473.77	2,451.56	127.57	13,451.32
Coal	13,984.52	-	-	-	13,984.52
Total	15,382.94	9,473.77	2,451.56	127.57	27,435.84

5.3 GHG balances (Baseline, inventory year 2020)

Table 4 provides a detailed breakdown of Ethiopia's Baseline Greenhouse Gas (GHG) balance in kilotons of CO_2-equivalents for the year 2020, focusing on emitting energy options across different sectors. The table showcases the emissions associated with various fossil fuels such as LPG, gasoline, jet fuel, diesel, HFO, coal, lignite, natural gas, coke, and petro-coke. In the Industry-miscellaneous sector, significant emissions are attributed to diesel and HFO, while in the Transport sector, road transport accounts for a substantial portion of emissions.

Table 4 Baseline GHG balance (ktCO2-equivalents), Inventory Year: 2020

Emitting energy options	**Ton CO_2/Toe (IPCC):**	**Industry - miscellaneous**	**Transport - road**	**Transport - domestic air**	**Households**	**FINAL emission**
LPG	2.64	0	0	0	23.78	23.78
Gasoline	2.90	147.96	1,949.76	2,460.43	226.33	4,784.47
Jet Fuel	2.99	0	0	0	0	0
Diesel	3.10	682.23	0	0	0	682.23
HFO	3.24	194.35	8,438.07	-	-	8,632.42
Kerosene and other	3.01	0	0	0	0	0
Total oil products	-	1,024.53	10,387.83	2,460.43	250.11	14,122.89
Coal	3.96	13,109.95	-	-	-	13,109.95
Lignite	4.24	0	0	0	0	0
Natural Gas	2.35	0	0	0	0	0
Coke	4.53	0	0	0	0	0
Petro-coke	4.20	0	0	0	0	0
Total		14,134.48	10,387.83	2,460.43	250.11	27,232.85

Table 5 presents the non-CO_2 emissions from non-fuel combustion sources in

kilotons of CO_2-equivalents for the year 2020 in Ethiopia. The data indicates significant methane (CH_4) emissions from energy combustion, totaling 10,691 $ktCO_2e$, and nitrous oxide (N_2O) emissions from energy combustion amounting to 2,207 $ktCO_2e$. Agriculture, including other land-related activities, contributes substantially to non-CO_2 emissions with a total of 294,487 $ktCO_2e$. Fugitive methane emissions are minimal at 1 $ktCO_2e$, while forestry shows a negative value of -50,155 ktCO2e, indicating a carbon sink. Solid waste and liquid waste sectors account for 6,387 $ktCO_2e$ and 3,949 $ktCO_2e$, respectively. Industrial processes contribute 4,527 $ktCO_2e$ to non-CO_2 emissions. The total non-CO_2 emissions from non-fuel combustion sectors in Ethiopia amount to 272,094 $ktCO_2e$, emphasizing the importance of addressing these sources to effectively reduce the country's overall greenhouse gas emissions and combat climate change.

Table 5 non-CO_2 – non fuel combustion source of emission in $ktCO_2e$

Non-CO_2 emissions, non-fuel combustion sectors	**ktCO2e**
CH_4 from energy combustion	10,691
N_2O from energy combustion	2,207
Total Agriculture (including other land)	294,487
Fugitive (CH_4)	1
Forestry	-50,155
Waste - solid	6,387
Waste - liquid	3,949
Industrial processes	4,527
Total non-CO_2 emissions, non-fuel combustion sectors	272,094

5.4 Growth factors

Ethiopia is also one of the Least Developed Countries in the world and is the second-most populous country in Africa with a population of more than 100 million (CSA, 2013). The country has endorsed a climate resilient green economic path since 2010 and has registered dramatic economic growth, with a growth rate averaging 9.2% a year from 2010/11 to 2019/20. This growth rate is high when compared to a regional average of 5.4% (PDC, 2021). The high growth rates have been also accompanied by structural transformation. This is

evidenced by the fact the share of the agricultural sector to GDP decreased to 32.7% in 2019/20 from 45.7 in 2010/11 while the construction and services sectors made up the majority of the growth. The share of the constructions and the service sectors from the total GDP reached as high as 21.1 and 39.5, respectively, in 2019/20. All this while, the rate of poverty has declined from 29.6% in 2010/11 to 23.5% in 2019/20 (PDC, 2021).

6. Evaluation result

6.1 BAU projected GHG balance

Table 6 presents the Business-As-Usual (BAU) projected greenhouse gas (GHG) emission balances from the fuel combustion sector in Ethiopia for various fuel types. The data shows that the industry sector emits 59,717.24 $ktCO_2e$, with miscellaneous activities contributing to this total. Transport, particularly road transport, accounts for 30,031.20 $ktCO_2e$ emissions, while domestic air transport contributes 7,113.09 $ktCO_2e$. Households emit 366.68 $ktCO_2e$ from fuel combustion. Among the different fuel types, coal combustion stands out with 55,388.67 $ktCO_2e$ emissions. Overall, the total GHG emissions from the fuel combustion sector under the BAU scenario are projected to reach 97,228.20 $ktCO_2e$, highlighting the significant contribution of this sector to Ethiopia's total emissions and the importance of implementing mitigation measures to reduce these emissions and combat climate change.

Table 61 BAU projected GHG emission balances from fuel combustion sector

$ktCO_2$	Industry - miscellaneous	Transport - road	Transport - domestic air	Households	Total emission
LPG	-	-	-	34.86	34.86
Gasoline	625.10	5,636.74	7,113.09	331.82	13,706.76
Jet Fuel	-	-	-	-	-
Diesel	2,882.37	-	-	-	2,882.37
Fuel oil	821.09	24,394.46	-	-	25,215.55
Kerosene and other	-	-	-	-	-
Total oil products	4,328.56	30,031.20	7,113.09	366.68	41,839.53
Coal	55,388.67	-	-	-	55,388.67

$ktCO_2$	Industry - miscellaneous	Transport - road	Transport - domestic air	Households	Total emission
Total	**59,717.24**	**30,031.20**	**7,113.09**	**366.68**	**97,228.20**

Table 7 displays the Business-As-Usual (BAU) projected greenhouse gas (GHG) emission balances from the non-CO2, non-fuel combustion sector in Ethiopia. The data reveals that methane (CH4) emissions from energy combustion are estimated at 38,169.6 ktCO2e, while nitrous oxide (N2O) emissions from energy combustion amount to 7,879.553 ktCO2e. Agriculture is a significant contributor to non-CO2 emissions, with a total of 415,328.2 ktCO2e, primarily from enteric fermentation. Forestry shows a negative balance of -36,985.7 ktCO2e, indicating carbon sequestration. Industrial processes contribute 19,126.27 ktCO2e to non-CO2 emissions. Overall, the total non-CO2 emissions from the non-fuel combustion sector under the BAU scenario are projected to reach 461,032.1 ktCO2e, with the total GHG emissions amounting to 558,260.3 ktCO2e. This data underscores the importance of addressing non-CO2 emissions in addition to fuel combustion to effectively mitigate climate change impacts in Ethiopia.

Table 7 BAU projected GHG emission balances from non-CO2 - non- fuel combustion sector

Non-CO_2 emissions, non-fuel combustion sectors	$ktCO_2e$
CH4 from energy combustion	38169.6
N_2O from energy combustion	7879.553
Total Agriculture	415328.2
Enteric fermentation	415328.2
Manure management	0
Rice cultivation	0
N_2O from agricultural soils	0
Burning of agricultural residues	0
Fugitive (CH_4)	0
Forestry	-36985.7
Waste - solid	10704.42
Waste - liquid	6809.67
Industrial processes	19126.27
Total non-CO2 emissions, non-fuel combustion sectors	461032.1
Total GHG emission	558260.3

6. 2 Mitigation (emission reduction) options

In table 8 the reduction potentials of mitigation actions from different sectors are summarized. The total emission reduction potential increases from 29,344

ktCO2e in 2025 to 63,553 $ktCO_2e$ in 2030. Sector wise, the biggest reduction potentials are observed power sector rating from 8,999 to 43,143 $ktCO_2e$. Energy or power sectors have employed green energy sources such as hydropower, solar and wind so that it has reduced highest number of emissions from the sources. Whereas household sector's emission reduction projections are smaller than those of the other mitigation actions. The waste sector implements methane collection, flaring, and incineration activities to reduce GHG emissions and has the second biggest annual GHG emission reductions among all sectors.

Table 8 Sectorial split of GHG reduction potential

GHG reduction ($ktCO_2e$/year)	2020	2025	2030	2035	2050
Total	0	29,344	66,553	63,487	63,487
Power	0	8,999	46,209	43,143	43,143
Industry	0	0	0	0	0
Transport	0	4,318	4,317	4,317	4,317
Households	0	1,383	1,383	1,383	1,383
Services	0	0	0	0	0
Agriculture & Fishery	0	0	0	0	0
Forestry	0	4,253	4,253	4,253	4,253
Waste	0	10,390	10,390	10,390	10,390

6.3 MAR Curve mitigation options

As it is summarized on Table 9 and MARC Curve annex (Figure 1), the GACMO tools output has shown that several mitigation options have been characterized at different investment cost of reduction and various levels of emission reduction potentials. New bicycle three wheelers mitigation option in Ethiopian Mitigation option has required highest cost of investment but relatively lowest reduction potential. The RED: avoided deforestation, Efficient lighting with CFLs and Composting of municipal solid waste have shown relatively smaller cost of investment and lower reduction potentials. While, mitigation options such as Reforestation, Hydro power connected to main grid, Incineration plant, Solar PVs, large grid, Geothermal power and Wind turbines, off-shore have shown the highest emission reduction potentials with the lowest cost of investments. These mitigation actions have shown promising emission reduction potentials for Ethiopia to be implemented with lowest investment cost. The Biogas recovery actions from Municipal Solid Waste and Landfill gas flaring have shown relatively low investment cost but have given the highest reduction potentials. Moreover, mitigation measures such as Bus Rapid Transit (BRT) and LPG stoves replacing wood stoves have shown little emission reduction potentials at the expense of

lowest cost of investment.

Table 9 Mitigation options included in the MAR Curve

Reduction option	US$/ton$CO_2$	Emission reduction in 2030 per option kt/year
Electric three-wheelers	296.90	181.83
New bicycle lanes	229.53	13.73
REDD: Avoided deforestation	10.38	2420.00
Efficient lighting with CFLs	9.22	13.33
Composting of Municipal Solid Waste	0.05	1472.05
Biogas from Municipal Solid Waste	-0.19	6358.32
Landfill gas flaring	-0.94	1572.58
Reforestation	-15.45	1833.33
Hydro power connected to main grid	-24.91	42307.44
Efficient electric stoves	-38.04	10.08
Incineration plant	-56.41	979.66
Solar PVs, large grid	-65.42	303.44
Bus Rapid Transit (BRT)	-89.46	63.47
LPG stoves replacing wood stoves	-113.57	10.27
Geothermal power	-123.88	3065.93
Wind turbines, off-shore	-126.07	532.06
Shifting freight transport from road to rail	1612.93	927.50
Efficient wood stoves	933.25	1338.33
Electric cars	878.44	15.51
Recycling of plastics	248.65	7.78
Efficient charcoal stoves	62.01	4.11
Electric two-wheelers	-812.98	0.33
Electric rail	-3489.24	3114.89

7. Conclusion

The integration of the Greenhouse Gas Abatement Cost Model (GACMO) into decision-making processes is a significant step towards informed climate action. As Ethiopia prepares to update its Nationally Determined Contribution (NDC), utilizing tools like GACMO and robust Monitoring, Evaluation, and Reporting mechanisms helps for assessing suitable mitigation options, effectively. The evaluation has indicated significant contributions of diesel and HFO in the industry-miscellaneous sector. The high emissions from road transport were also observed. The total GHG emissions from fuel combustion are projected to reach 97,228.20 ktCO_2e under the Business-As-Usual (BAU) scenario, highlighting the urgent need for mitigation measures in these sectors. Non-CO_2 emissions from non-fuel combustion sources, including methane and nitrous oxide from

energy combustion, agriculture, and other land-related activities, are substantial, totaling 272,094 ktCO2e. Addressing these sources is crucial for effectively reducing overall GHG emissions. Furthermore, the evaluation of individual mitigation measures indicates shows a high cost of Electric three-wheelers, Shifting freight transport from road to rail, Efficient wood stoves and Electric cars with highest emission reduction potentials. Whereas, mitigation options such as Electric three-wheelers, New bicycle lanes, Shifting freight transport from road to rail, Efficient wood stoves and Electric cars have shown the relatively lowest cost of investment but highest potentials of GHG reduction in general. Moreover, there are many mitigation measures with optimum cost of investment at reasonable green house gas reduction. In general, the Ethiopian emission regulatory and reporting sector needs to utilize GACMO tool to prioritize and select the best optimized tool for the upcoming NDC Update stock take.

Annex 1: MARC Curve of Mitigation actions of the Ethiopian NDC Updates, March 2024

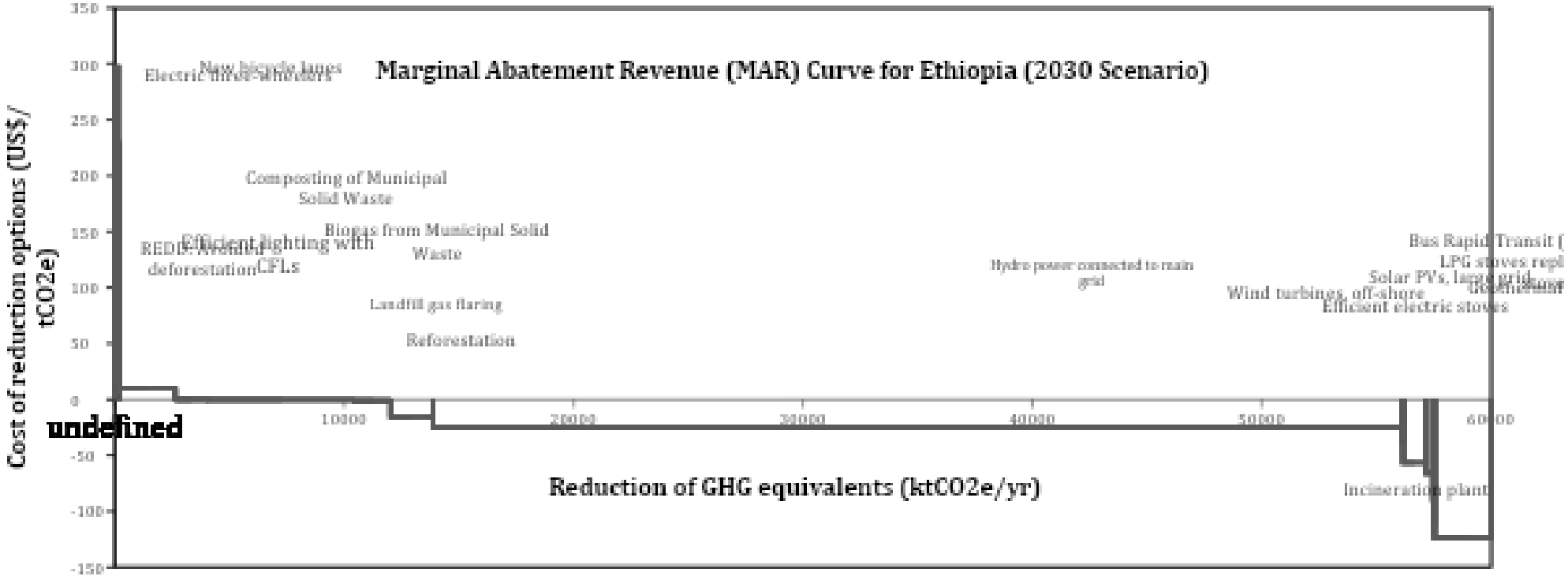

Figure 1 MARC Curve of Mitigation measures of the Ethiopian NDC Update 2022