Trade, energy efficiency and low-carbon development in Kenya

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ABSTRACT

Greenhouse gases (GHG) emissions from the transport, energy and industrial sectors are on the rise in Kenya with projections indicating that energy production and consumption will be the leading contributors to emissions. This study examines the role of low carbon technologies in improving energy efficiency to transition the economy towards a low carbon development path. It assesses the implications of increased imports and domestic supply of energy efficiency improving machinery to reduce energy consumption to the macroeconomy (GDP, imports, exports) and to the environment (CO2 emissions) under domestic and international financing scenarios. The study applies a single-country computable general equilibrium (CGE) model calibrated to the 2020 social accounting matrix (SAM) for Kenya and targets the transport, energy, and industrial sectors. The low carbon technology needed to enhance energy efficiency in these sectors is embedded in imports of machinery and equipment as durable inputs. The low carbon technology machinery and fossil fuels are imperfectly substitutable under the CES production nest. Overall, the two financing options have positive impacts on GDP at factor cost, real GDP, exports, imports, domestic production, household consumption, domestic demand, and supply of low carbon technology machinery. The effects of international support are, however, more pronounced compared to those for financing through domestic resource mobilization. Both financing options translate into reduction in greenhouse gas emissions, with international resource support reducing greenhouse gas emissions by 3.99% while domestic resource mobilization reduces greenhouse gas emissions by 4.26%. The international community could commit to finance the supply of the low carbon technology commodities at lower world market prices. Kenya could commit to eliminate tariffs on imports of low carbon technology machinery. The government could target incentives at the transport, mining, and non-metallic minerals sectors which demonstrate a decline in value-added and output under the two financing options. Short-term subsidies could be implemented to cushion consumers against erosion in welfare emanating from rise in energy and transport prices. Incentives could target developing skills and knowledge needed to support domestic production of the low carbon technology commodities.

Keywords: Trade, Energy efficiency, low carbon technology

JEL Classification: L6, L7, O1, O2, O3, Q2, Q4, Q5

1. Introduction

Greenhouse gases (GHG) emissions from the transport, energy and industrial sectors are on the rise in Kenya with projections indicating that energy production and consumption will be a non-negligible contributor to emissions. Likewise, the consumption of fossil fuels in the process of generating electricity and in meeting transportation, household and industrial uses is increasing. GHG emissions from the transport and industrial sectors are mainly related to **energy consumption** and pertain use of fossil fuels especially oil, natural gas, and coal (in cement production) while GHG emissions from the energy sector pertain energy consumption in the process of **energy production**.

Improving the efficiency of energy in **consumption** and **production** activities is one of the measures stipulated by Kenya's Nationally Determined Contributions (NDCs) (Republic of Kenya, 2020) to mitigate GHG emissions and thereby move towards a low-carbon development in the country. Furthermore, Kenya's National Climate Change Framework Policy aspires to transition Kenya towards a cleaner, lower emission and less carbon intensive development with focus on sectors like transport and energy. The Climate Change Act and the Energy Transition and Investment Plan envision energy efficiency in the industrial, transport and energy sectors as key in achieving low carbon development.

Kenya's move towards a low carbon development is, however, hampered by financing and technological capacity constraints. Kenya currently does not have comparative advantage in production of low carbon technologies that would support energy efficiency especially in its transport, energy and industrial sectors. The low carbon technologies are usually embedded in commodities like machinery, electrical, and transport equipment and constitute the largest investment demand and are thus crucial in accumulating low carbon capital over time. As such, importing low carbon technologies becomes a likely scenario to improve energy efficiency and support transition of the economy towards a low carbon development path in Kenya. It then follows a question on how to finance the import of such low carbon technologies and products. Kenya's updated NDC envisages to mobilize 13% and 87% of the financial resources required to implement mitigation and adaptation measures through domestic and international sources respectively.

This study aims to examine the role of trade in low carbon technologies in improving energy efficiency to support Kenya's transition towards a low carbon economy. It specifically assesses the macroeconomic (e.g., GDP) and environmental (e.g., GHG emissions) implications of policies to increase imports and domestic supply of energy efficiency improving machinery and equipment products (and thus eventually reducing the use of fossil fuels). It employs a computable general equilibrium (CGE) model which integrates a GHG emission module.

2. Climate mitigation and low carbon development in Kenya

Despite its low contribution to total global GHG emissions of 0.19% between 1950-2023[1], Kenya's emissions are expected to continue rising (Powanga & Kwakwa, 2024). GHG emissions are mainly from activities like land-use and land-use change followed by fossil fuel combustion in industries. Unless Kenya's economy is transitioned to a low-carbon development path, meeting the needs of the growing population (for example, transportation needs, heating and lighting needs within residences, needs for more goods and services) will likely **be associated with more GHG emissions.** Population growth is associated with a rise in per capita energy consumption (Okcu,

[1] According to data from Our World in Data.

2019; Shefield, 2018; Kolawole et al., 2017; Singh & Vashishtha, 2020). Empirical evidence has shown that economies will have to produce more to meet demands of rapidly growing population (Goswein et al., 2017; Raihan et al., 2024; Jaime & Solleder, 2023) with expanding economies influencing emissions of greenhouse gases positively (Thi et al., 2024; Yu et al., 2022; Ochi & Saidi, 2024; Liobikiene & Butkus, 2019; Han & Chatterjee, 1997; Akinlo, 2008). As such, a low-carbon development pathway is paramount for emerging and industrializing economies like Kenya which are experiencing rapid growth in population and economic expansion.

Indeed, Kenya's Nationally Determined Contribution (NDC) (Republic of Kenya, 2020) sets out both ***adaptation and mitigation*** contribution based on conditional support. The ***mitigation*** contribution intended to abate greenhouse gas emissions by 30% by 2030 relative to the business-as-usual scenario. Although the first NDC was conditional on international support, most of the progress made in implementation up to 2020 was from domestic resources. Compared to the first NDC target of reducing greenhouse gas emissions by 30% from the 2015 baseline, Kenya's updated NDC commits to reduce greenhouse gas emissions by 32% by 2030 relative to the business-as-usual scenario of 143 MtC02eq; and in line with the country's sustainable development agenda and national circumstances with milestone targets are expected in 2025. Some of the planned policy actions within the updated NDC include adopting and adapting clean, efficient and sustainable energy technologies with an aim of reducing overreliance on fossil fuels and non-sustainable biomass fuels; **enhancing energy efficiency across different sectors especially energy, agriculture (livestock and crops), transport, industry, waste management, and land use land use change and forestry**; and increasing renewables in the electricity generation mix of the national grid.

Kenya has put up ambitious policies and measures to pursue a low carbon climate resilient development pathway to realize Vision 2030. Sustainable development is a guiding principle in the Constitution of Kenya (Republic of Kenya, 2010). The Kenya National Adaptation Plan (NAP) (2015-2030) (Republic of Kenya, 2016) has interventions that seek to enhance implementation of an energy generation mix plan that increases the resilience of the current and future energy systems to the impacts of future climate variability and change, support innovation and development of appropriate technologies and capacity that promote climate resilient development, and integrate climate change adaptation into the oil and mineral resources sector. There are ***financing***, ***technology***, and ***capacity building*** gaps to implementation of these proposed interventions. To achieve a low-carbon development, the National Climate Change Framework Policy (Republic of Kenya, 2016) targets key sectors like ***energy and transport*** for emissions reduction. The policy aspires to transition Kenya into a cleaner, lower emission and less carbon intensive development. The Climate Change Act (Republic of Kenya, 2016) further aspires to promote sustainable development through mitigation of greenhouse gas emissions. To achieve a low-carbon development path, the Act aims at **enhancing energy efficiency** in the **industrial, transport, and energy sectors** by encouraging adoption and adoption of efficient technologies.

The Kenya Energy Transition and Investment Plan (ETIP) 2023-2050 (Republic of Kenya, 2024) envisions the energy sector as contributing to net zero by 2050 with opportunities for ***financing and investment***. It aims to achieve this by ***attracting investments (USD 165 billion worth of additional investments with 90% of the investments targeted at the transport and energy (investment in energy technologies) sectors by 2050) and mobilizing funding both domestically and externally.*** On investments, the focus is on energy technologies that are low in carbon and capital intensive. Transport is expected to account for the largest share of capital investments (60%)

driven by growing demand for transportation as population and per capita incomes grow. Investments in energy (power and hydrogen) are expected to account for 30% of the capital investments. Industry and clean cooking are expected to account for 10% of the total capital investment needed. Main decarbonization technologies expected to **anchor the transition to net zero include electrification, energy efficiency and renewable energy; carbon capture and storage; low carbon hydrogen; battery electric technologies; clean cooking technologies; and negative emission solutions especially bioenergy with carbon capture and storage (Republic of Kenya, 2024).**

Table 1.1: Planned technology interventions and targeted sectors and accounts in Kenya's SAM

Sector	Activity	Technology intervention	Corresponding activity/commodity in Kenya's SAM
Industry	Iron and steel	Improve energy efficiency	▪ Machinery & other equipment ▪ Minerals
	Cement	Improve energy efficiency	▪ Non-metal minerals
	Chemicals	Improve energy efficiency	▪ Petroleum products ▪ Other chemicals
	Other manufacturing	Improve energy efficiency	▪ Other manufacturing
Transport	Cars & motorcycles	Improve energy efficiency	▪ Transportation & storage
	Freight trucks & buses	Improve energy efficiency	▪ Transportation & storage
	Aviation & shipping	Improve energy efficiency	▪ Transportation & storage
Buildings	Cooking/heating Lighting Cooling	Improve energy efficiency	▪ Construction ▪ Water supply & sewage
Energy	Energy	Improve energy efficiency Deployment of solar PV Onshore wind and geothermal	▪ Electricity, gas & steam ▪ Wood products
	Hydrogen	Production of green hydrogen	▪ Electricity, gas & steam

Source: Synthesis based on information from Energy Transition and Investment Plan (ETIP) and SAM

Kenya's share of CO_2 emissions from all activities (including land-use change) in global CO_2 emissions have been larger than the country's CO_2 emissions from activities other than land-use change. This means land-use changes have been a key source of the country's CO_2 emissions. Activities other than land-use change are mainly **energy production from fossil fuels with key components being electricity and heat production, transportation, industry, buildings including heating and cooking, industrial processes including cement production**, and landfills which emit methane (CH_4). Empirical evidence demonstrates that CO_2 is the main greenhouse gas followed by methane (CH_4) and nitrous oxide (N_2O) (Filonchyk et al., 2024; Fraccascia & Giannoccaro, 2019; Han & Chatterjee, 1997; Baiardi, 2023). The main source of CO_2 is combustion of fossil fuels, especially oil, natural gas, and coal (Filonchyk et al., 2024). Land use change including deforestation has compounded CO_2 emissions due to declining CO_2 sequestration (Raihan & Tuspekova, 2022). Methane is mainly emitted from anthropogenic activities especially extraction and transportation of natural gas, organic waste processing in landfills and livestock farming (Gong & Shi, 2021; Shahzad et al., 2021). Main activities emitting nitrous oxide are agriculture, fuel combustion, industrial processes, and fertilizer use (Smith, 2017). Empirical evidence demonstrates that main sectors emitting greenhouse gas emissions are the power industry (power plants—burning oil, coal, and gas for electricity generation), industrial combustion (chemical industry—synthesis of chemicals, steal and cement production), transport (road transport, aviation, maritime transport— burning gasoline, kerosene, and diesel), agriculture (crop and livestock farming), waste (waste disposal, garbage incineration, wastewater treatment, organic waste in landfills), buildings (energy consumption, heating), processes (cement production, iron and steel industry), and fuel exploitation (oil and gas extraction, mining) (Filonchyk et al., 2024; Hong et al., 2021).

In the last two decades, however, Kenya's CO_2 emissions from land use change have decreased drastically with CO_2 emissions from other activities like cement production which is component of the country's industrial activities surpassing CO_2 emissions from land-use change while CO_2 emissions from oil as a source of energy are projected to surpass CO_2 emissions from land-use change. Projections indicate that by 2030, **energy** will be the leading contributor to emissions because of **increased consumption of fossil fuels in generating electricity, meeting domestic, commercial and industrial heating demands and for transportation (**Republic of Kenya, 2020). Kenya's carbon dioxide (CO_2) emissions from consumption, activities other than land-use change, oil, trade, cement production, and coal production are on the rise. For Kenya, policy priorities aiming to reduce greenhouse gas emissions while transitioning the economy to a low carbon development in line with the country's updated nationally determined contribution (NDC) by 2030 should target activities other than land use change **given their rising emissions.**

Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N2O) are also reported as the mandatory greenhouse gases in Kenya's Third Greenhouse Gas Inventory (Republic of Kenya, 2022). Of the three mandatory gases, CO_2 is the most dominant greenhouse gas (Republic of Kenya, 2022) contributing to 59% of greenhouse gas emissions and **manifesting sustained upward trend**. Carbon dioxide is mainly emitted from **burning fossil fuels, industrial production, and land-use change**. Given Kenya's emissions from land use change are declining, policy priorities could target to enhance energy efficiency in ***energy production and use*** as these would reduce emissions from burning of fossil fuels during ***energy generation*** and during ***energy use*** by industrial activities. Emissions from carbon dioxide are followed by methane emissions (37%) and nitrous oxide emissions (4%)[2]. With land-use and land-use-change and forestry (LULUCF) included in the analysis, methane (CH_4) emissions from enteric fermentation and Carbon Dioxide (CO_2) from forestry and other land use (FOLU) are the significant greenhouse gases contributing to over 48% of emissions. When land use, land use change, and forestry (LULUCF) is excluded, the significant greenhouse gas categories are methane (CH_4) from enteric fermentation and carbon dioxide (CO_2) from fuel combustion activities (including transport) and account for over 65% of greenhouse gas emissions. Kenya's emissions of methane and nitrous oxide are also on a sharp rise.

Greenhouse gases from the energy sector are categorized into three distinct activities— fuel combustion activities, fugitive emissions from fuels, carbon dioxide transport and storage. As per the third national greenhouse gas inventory, Kenya has estimated emissions emanating from **fuel combustion activities which include energy industries**, **manufacturing industries and construction, transport**, **and other sectors (combustion for generation of electricity and heat for own use by the activities**). Energy industries comprise of emissions from fuels combusted by the fuel extraction or energy-producing industries while manufacturing industries and construction capture combustion emissions from fuel use during the manufacture of secondary and tertiary products from solid fuels including the production of charcoal. Transport captures emissions from the combustion and evaporation of fuel for all transport activities excluding military transport. ***To***

[2] For Kenya, methane was the dominant greenhouse gas in the years preceding 2010 but carbon dioxide had become the dominant greenhouse gas from 2010 onwards.

transition the economy to a low carbon development pathway, Kenya is prioritizing energy efficiency as a mitigation strategy that would reduce greenhouse gas emissions for a sustained development. Empirical evidence shows that energy efficiency has potential to reduce greenhouse gas emissions (Liobikiene & Butkus, 2019; Altin, 2024; Schipper, 1993; Levine & Meyers, 1992). To achieve energy efficiency, access to modern technology by developing countries like Kenya through ***reduction of costs of importing the technology*** and ***financing of efficiency improvements*** is key in sustaining development in a low carbon path. Indeed, evidence shows assistance to facilitate energy efficiency in developing countries like Kenya is important in the achievement of sustainable development (Schipper & Meyers, 1983; Yalew et al., 2019).

In the last decade, Kenya carried out exploration activity for oil and gas, but its emissions are insignificant. Coal exploration activities were also carried out but despite the discovery of coal reserves, mining is yet to commence. Kenya, however, imports coal for use in cement production (Republic of Kenya, 2022). ***The country's gradual increase in greenhouse gas emissions is attributable to increasing fuel consumption driven by increasing demand for energy by the growing population and economy*** *(especially sectors like transport and industry)*. ***Energy efficiency could sustainably meet the rising demand for energy while minimizing greenhouse gas emissions and thus transitioning the economy to a low carbon development path.***

The energy sector is the second largest source of emissions in Kenya accounting for over 25% of total emissions with 21,503 Gg-CO_2e reported in 2022. The emissions are mainly from the ***transport sector*** which accounted for 57 percent of emissions in 2022 compared to 44 percent in 1990. Although there are signs of the transport sector in Kenya embracing e-mobility (Republic of Kenya, 2024), it is still heavily reliant on fossil fuels. ***Kenya is encouraging energy efficiency in the transport sector through the development of a national e-mobility policy*** *(Republic of Kenya, 2024).* ***E-mobility will lower greenhouse gas emissions from the transport sector by reducing reliance on fossil fuels.*** To ensure the transport sector is efficient and sustainable, the draft policy has ***statements on provision of fiscal and non-fiscal incentives targeting manufacturers and assemblers, infrastructure development, and electric vehicle consumers.*** Specific incentives include exemption of ***import duty, excise duty***, and ***value-added tax*** on imports of electric vehicle parts and completely built-up electric vehicles. Similar incentives are extended to local manufacturers and assemblers of electric vehicles. The policy also seeks to reduce ***stamp duty*** on electric vehicle infrastructure development, ***and review electricity tariffs*** for electric vehicle charging stations. This study targets ***the transport and storage activity "a_tran" in*** the 2020 Social Accounting Matrix (SAM) for Kenya for energy efficiency improvements.

The transport sector is followed by sectors ***undertaking combustion to generate electricity*** which accounted for 30 percent of emissions in 2022 compared to 29 percent in 1990. Possible sectors in the SAM include ***wood products (a_wood), non-metallic minerals (a_nmet)*** where combustion of coal to produce electricity would happen. ***Manufacturing industries and construction*** accounted for 9 percent of emissions in 2022 compared to 21% in 1990. Although the reduction in emissions from the manufacturing industries and construction may imply the sectors have remarkably transitioned towards cleaner production methods (processes), reducing the 2022 emissions further through enhanced energy efficiency could make the sectors cleaner for sustainable industrialization. Possible activities in the SAM that could be targeted for energy efficiency within the manufacturing industries and construction under the fuel combustion activities pillar would be construction (a_cons), mining (a_mine), other chemicals (a_chem), water supply and sewage (a_watr), machinery and other equipment (a_mach), and other manufacturing (a_oman).

Energy industries accounted for 4 percent of emissions in 2022 compared to 6 percent in 1990. Energy efficiency within the energy industries could further reduce emissions and make the sector cleaner for sustained development. Possible activities in the SAM that could be targeted for energy efficiency are ***petroleum products (a_petr),*** and ***electricity, gas and steam sector (a_elec***). Under energy industries, electricity generation has been the main source of greenhouse gas emissions. Petroleum refining was the second largest source of emissions though this activity has not been emitting greenhouse gases from 2013 after Kenya closed her oil refinery.

Table 1.2: Mapping sectors for energy efficiency in the greenhouse gas inventory into sectors in the SAM

Sector	Emissions (2022)	Emissions (1990)	Corresponding SAM account
Transport	57%	44%	▪ Transport and storage
Sectors undertaking combustion to generate electricity	30%	29%	▪ Wood products ▪ Non-metallic minerals
Manufacturing industries and construction	9%	21%	▪ Construction ▪ Mining ▪ Other chemicals ▪ Water supply and sewage ▪ Machinery and other equipment ▪ Other manufacturing
Energy industries	4%	5%	▪ Petroleum products ▪ Electricity, gas and steam sector

Source: Author compilation based on information from 2020 SAM and greenhouse gas inventory for Kenya

The total cost of implementing ***mitigation and adaptation actions*** in the updated NDC is estimated to be USD 62 billion. Compared to the first NDC, Kenya commits to mobilize resources to meet ***13% of the budget*** and requires international support for ***87% of the budget***.

3. Energy efficiency and GHG emissions, and the role of trade: a review

Energy efficiency bears potential to reduce greenhouse gas emissions and transition economies to a low-carbon development path (Bohringer & Rutherford, 2010). Energy efficiency could reduce energy consumption (Adetutu et al., 2016) and consequently GHG emissions.

Moreover, projections indicate that much of the world's energy demand will be happening in low- and medium-income developing countries (Fowlie & Meeks, 2021). However, developing countries experience constraints in accessing capital (Fowlie & Meeks, 2021) to enhance domestic capacity for energy efficiency. Developing countries like Kenya face domestic capacity constraints related to producing and consuming energy efficiently (Allcott & Greenstone, 2012). Studies have shown that enhancing productive capacities influences a country's energy efficiency (Demiral & Demiral, 2023). Encouraging investments that make energy consumption and production more efficient could reduce emissions of greenhouse gases thus transitioning economies to a low carbon development path (Alcorta et al., 2013; Bates & Moore, 1992). Previous research demonstrates that investment gaps could hinder realization of efficiency in energy consumption and production (Bremer et al., 2024; Allcott & Greenstone, 2012; Jaffe & Stavins, 1994).

For Kenya, investments in energy-efficiency enhancing technologies have been low mainly due to financial constraints (DeCanio & Watkins, 1998; Bremer et al., 2024). Like any other developing countries, trade is a channel through which Kenya can access energy efficiency improving technology, intermediate inputs and capital equipment (Coe et al., 1997; Henry et al., 2009). Trade could support developing economies transition to cleaner and more efficient production technologies (Akerman et al., 2024; Copeland & Taylor, 1994; Cherniwchan, 2017). Studies exemplify that technology could be capital-augmenting, energy-augmenting, or labour-augmenting (Otojanov et al., 2023; Jacobs, 2023; Lucas, 1967). Although technological change is labour-augmenting in the long-run, it is capital-augmenting in the short-run (Acemoglu, 2010) and this is key in supporting capacity of developing countries like Kenya to produce low carbon technology commodities. When technology is embodied in capital, especially machinery, the vintage investment is viewed in terms of efficiency units (Hulten, 1992; Fisher, 1965). Since technology embodied in capital in this manner constitutes efficiency units, this study views low carbon technology machinery as key in supporting energy efficiency within Kenya's transport, energy, and industrial sectors. Innovations will also be needed to ensure continuous improvements in the capital (Popp et al., 2024) embodying low carbon technology.

Further, given the bulk of the technology is concentrated in advanced economies, the study views trade as the channel through which Kenya as a developing economy could access it. The outcome of accessing the energy efficiency capital (machinery) would be observed in reduction of greenhouse gas emissions as an indicator of transitioning towards net zero emissions. Indeed, empirical evidence demonstrates that energy efficiency is a channel through which developing countries can sustainably grow in a low carbon environment (Kats, 1990). Developed economies also recognize energy efficiency as a channel through which the net zero transition could be actualized (Morao, 2025; Kokosalakis et al., 2021).

The low carbon development path driven by energy efficiency is, however, highly dependent on mobilization of financial resources (Kats, 1990; Lee, 2014). MacKillop (1980) extends the argument that advanced economies in the global north should transfer technology to the developing economies in the global south to support sustainable energy development. Among others, liberalization of custom duties, coupled with reduction of world import prices on low carbon technology machinery could reduce the financial restrictions hindering access to energy-efficiency improving technology. Much of the literature has, however, focused on tariff liberalization as the intervention through which access to foreign knowledge and technology embedded in capital could be accessed (Cherniwchan et al., 2017; Hwang et al., 2016; Amiti, 2007) with few focusing on reduction of world import prices through support by the international community. Indeed, the latter is well stipulated in the Paris Agreement to support climate mitigation and adaptation actions in low-income countries such as Kenya. The interventions would encourage access to technology embodied in imports, especially low carbon technology machinery and other manufacturing equipment. Studies demonstrate that imports embody technology which could support diffusion of innovation and knowledge (Ayerst et al., 2023). Given the bulk of innovation and R&D activity is concentrated in advanced economies (Buera & Oberfield, 2020; Cai et al., 2022; Sampson, 2023), trade could support diffusion of the technology embodied in imports from advanced to developing economies like Kenya.

Different methodologies have been deployed in the literature in studying linkages between trade and the environment. Prominent methodologies include ex-ante simulations in general equilibrium and partial equilibrium contexts, and econometrics (Griffin & Gregort, 1976). The firm, industry, plant, product, and economy have been used as units of analysis (Cherniwchan et al., 2017; Akerman et al., 2024; Barrows & Ollivier, 2018). Popular production functions considered in the literature include CES, Translog, Cobb-Douglas, and Leontief (Griffin & Gregort, 1976; Cobb & Douglas, 1927; Christensen et al., 1973; Eaton & Kortum, 2002; Leontief, 1947).

Broadly, low carbon technology products include consumer goods[3], industrial supplies, capital goods, and transport equipment. To build local capacity that would transition the dirty (inefficient)[4] sectors into a low carbon development path, low carbon technology products in the form of **industrial supplies**, **capital goods** and **transport equipment** would be needed. Obtaining the technology embedded in these low carbon products (industrial supplies, capital goods, and transport equipment) could transition Kenya's economy into a low carbon development path. Financing is, however, needed to access the products. Existing research has demonstrated that low carbon technology could be deployed to developing countries through technology development and transfer collaboration and capacity development across the innovation value chain (Khosla et al., 2017). **Since production of the low carbon technologies (LCTs) is mainly concentrated in the advanced economies, trade is a channel through which these technologies can be accessed[5] by developing countries such as Kenya (Cobbold et al., 2024; Eaton & Kortum, 2002).** Empirical evidence demonstrates that importing low carbon technologies from advanced economies to developing economies stimulates innovation through cost-reducing knowledge spillovers (Zhiyuan et al., 2017; Fracasso et al., 2015; Lu & Travis, 2012).

As per Kenya's updated NDC, the cost of implementing mitigation and adaptation measures that would support transitioning the economy to a low carbon development path is estimated at USD 62 billion. The country plans to mobilize resources to meet 13% of the cost with international support financing the deficit (87%). One of the ways through which Kenya could achieve its commitment to mobilize resources to meet the 13% of the projected mitigation and adaptation budget is through further liberalization of imports of low carbon technology commodities especially ***capital goods***, ***transport equipment***, and ***industrial supplies*** to support realization of energy efficiency in the ***transport***, ***energy***, and ***industrial[6] sectors***. Practically, this could be achieved through reduction of import costs (**import tariffs**, **value-added tax (VAT),** and **excise duty**) on imports of capital goods, transport equipment, and industrial supplies. These measures are already incorporated in the draft e-mobility policy for Kenya (Republic of Kenya, 2024). These commodities can be seen as constituting capital. Together with the embedded technology, the commodities would encompass effective capital[7] (Romer, 2018) and would enhance energy efficiency in the **transport, energy, and industrial** sectors for a low carbon development. According to Romer (2018), technology is just knowledge, and this means effective capital is capital with embedded knowledge which can spur efficiency through learning. Studies have demonstrated that liberalization enhances access to inputs[8] (Topalova & Khandelwal, 2011; Amiti & Konings, 2007; Halpern et al., 2015).

Developing countries like Kenya could also access low carbon technology through the **international community supplying the technology at lower prices.** This channel would play a

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[3] These are final consumer goods which have been produced using low carbon technology.
[4] In this case, transport, energy, and industry including constructing (buildings).
[5] Other channels could be through investments in developing countries by multinational corporations (MNCs) which possess higher advanced technology and capital stock; government incentives including subsidies to local firms undertaking energy production (subsidies for development of low carbon technologies, subsidies for green manufacturing (e.g solar PV, e-vehicle manufacturing), and subsidies for development of green hydrogen).
[6] Including construction (buildings)
[7] The technology in this case is referred to as capital augmenting (Romer, 2018).
[8] Capital in this case.

role in the achievement of 87% in mitigation and adaptation costs within the updated NDC. Empirical evidence reveals that funding by the international community for low carbon development in developing countries is still low (Afful-Koomson, 2014; Treichel et al., 2024; Mohan, 2025) and thus the need for its upscaling.

This study therefore examines how enhancing international funding and importation of low carbon capital goods would place the Kenyan economy on a low carbon development path. Development is about change and progress that improves the economic and social wellbeing of people and has metric (for example GDP, output, incomes) and non-metric dimensions (for example health, living standards) (Myrdal, 1974; Slim, 1995). Since this implies development is about continuity, it should be sustainable. Indeed, reducing greenhouse gas emissions from the ***transport***, ***energy***, and ***industrial sectors*** through enhanced energy efficiency would transition the Kenyan economy towards a low carbon development. Access to low carbon technologies would enhance Kenya's energy efficiency in these sectors and this would transition the economy towards a low carbon development path.

4. Data and Methodology

The study applies a single-country computable general equilibrium (CGE) model, DEMETRA (JRC, 2020)[9] calibrated to the 2020 Kenya's Social Accounting Matrix (SAM). Advances in modelling climate change and sustainable development are expected to fill an important methodological and policy analysis gap in the literature (Giglio et al., 2021).

4.1.The DEMETRA model

It is an economy-wide model suitable for ex-ante policy analysis[10] in small-open economies, like Kenya. It has strengths in analysis of policy issues relevant to agriculture, resources, and economic development including international trade modelled through a two-level Armington specification that allows for consideration of multiple trade partners. It has a flexible CES production function with a production technology and energy nest that allows for imperfect substitution between machinery and equipment and petroleum fuels in production activities. For the current study, the composite energy input is substitutable with capital as a factor of production, and this is a key channel for achieving energy efficiency. It has currently been extended to incorporate a greenhouse gas emissions module which makes the model suitable in analyzing the interface between trade, energy efficiency, and low carbon development in Kenya under the current study.

4.2.Kenya's SAM

The policy simulations are anchored on the 2020 Social Accounting Matrix (SAM) for Kenya. The SAM is an economy-wide square matrix with columns and rows. Columns represent expenditures while rows represent incomes. It has accounts on commodities, activities (sectors), factors of production (labour, capital, land), households, enterprises, government, taxes, savings and investments, and the rest of the world. The activities account has 51 activities while the commodities account has 71 commodities. The sectors examined are represented as activities in the SAM.

Since the study considers technology to be capital augmenting (effective capital), machinery and equipment as a low carbon technology commodity is identified in the SAM. Trade is the channel

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[9] Dynamic Equilibrium Model for Economic Development, Resources, Environment & Agriculture.

[10] Details here https://datam.jrc.ec.europa.eu/datam/model/DEMETRA/index.html

through which Kenya would need to access the low carbon technology machinery and equipment. In the SAM, machinery and equipment account for 38.74% of investment demand in imports, 1.20% of marketed output (gross output), 57.00% import penetration and 24.50% export intensity. Indirect taxes levied on machinery and equipment in Kenya include import tariffs and sales taxes and constitute tax revenue for the government. Of the indirect tax revenue collected from machinery and equipment, 51.54% is from import tariffs and 48.46% is from sales tax.

Gross supply of machinery and equipment in the SAM is 3.5%, which is relatively low. The Kenyan government intends to increase supply of low carbon technology machinery and equipment to support energy efficiency and transition the economy towards a low carbon development path. Despite supply of machinery and equipment being low and focus being directed towards increasing their supply, no specific target for supply of machinery and equipment has been set.

4.3.GHG module

Each type of fossil fuel (e.g., coal, oil, natural gas) has a specific emission factor, which represents the amount of CO2 emitted per unit of energy consumed. These emission factors are crucial for calculating total emissions. The quantity of energy commodities used in various activities, such as electricity generation, industrial processes, and household consumption, is measured to determine the overall emissions. The CO2 emissions resulting from the combustion of fossil fuels are linear function of the quantity of energy commodities used. In case of Kenya, based on the SAM, 'mining' and "petroleum products" are classified as fossil fuel products. The base dataset on emissions is based on the GTAP11-e database, 2017 (Aguiar et al., 2022).

Based on the GTAP classification, DEMETRA also considers non-combustion emissions. The non-combustion GHG emissions also include non-combustion CO2, and are linked to five sets of emission drivers: (1) Output-linked non-combustion emissions, (2) non-combustion process emissions linked to intermediate consumption, (3) non-combustion process emissions linked to fossil fuel combustion in production, (4) endowment-linked non-combustion emissions, and (5) household-based non-combustion emissions (Chepeliev, 2020). Table 4.1 presents the base emissions as per the GHG module of the model.

Table 4.1: Base emissions— metric tons equivalent of CO2 emissions

Sector	Metric tonnes equivalent of CO2 emissions
Transport	0.033
Energy	0.116
Industry	
Construction	0.033
Chemicals	0.013
Mining	0.013
Non-metallic minerals	0.013
Petroleum	0.025
Other manufacturing	0.013

4.4.Simulation scenarios

We then assume and model such that these machinery and equipment increase energy efficiency that eventually reduces the demand for fossil fuels. We explored the implications of two alternative options to finance the increasing imports of machinery and equipment. The first financing option (financing through domestic resources—***SIM1***) assumes a reduction of custom tariffs on imports of energy efficiency improving machinery and equipment. In this scenario, the direct cost is borne by the Government of Kenya. Accordingly, we reduce imports tariffs on machinery and equipment by 100%. The second financing option (international support—***SIM2***) assumes the imports of energy efficiency improving machinery and equipment are supplied at lower world import prices as part of developed countries' commitment to support developing countries' transition towards net zero. Accordingly, we reduce world market prices for machinery and equipment by 7.74%. Both *SIM1* and *SIM2* lead to a 32.57% increment in the supply of machinery and equipment. *SIM1* and *SIM2* are respectively associated with a 6.84% and a 6.66% reduction in supply of petroleum as fossil fuel and source of greenhouse gas emissions. Although Kenya has committed to enhance supply of low carbon technology and machinery to substitute petroleum fossil fuel and reduce greenhouse gas emissions, there have been no official pronouncement by how much the supply of low carbon technology machinery and equipment should be increased. The 32.57% increment in supply of machinery and equipment considered in this study converges with the 100% removal of custom tariffs on imports and 7.74% reduction in world market prices for machinery and equipment.

5. Results

The results are reported in percentage changes relative to the baseline. At the macro-level, the preliminary results presented encompass greenhouse gas emissions, GDP at factor cost, real GDP, exports, imports, domestic production and supply, household consumption, government income, total investment demand, domestic demand, petroleum prices, and machinery prices.

The presentation of the results further focuses on sector adjustments to demonstrate what happens to greenhouse gas emissions, petroleum demand, machinery demand, commodity output, commodity prices, quantity of intermediate inputs, and price of intermediate inputs by sector.

5.1 Macroeconomic

Overall, the two options for financing Kenya's transition to low carbon development have positive impacts on *GDP at factor cost*, *real GDP*, *exports*, *imports*, *domestic production*, *household consumption*, *domestic demand*, and supply of *low carbon technology machinery* (Table 5.1). For the 32.57% increment in supply of low carbon technology machinery and equipment, the macroeconomic effects of the international support where developed countries commit to support developing countries' transition towards net zero are, however, largely more pronounced than those for financing through domestic resource mobilization. Both financing options translate into reduction in greenhouse gas emissions, with international resource support reducing greenhouse gas emissions by 3.99% while domestic resource mobilization reduces greenhouse gas emissions by 4.26%.

Supply of petroleum reduces in both financing options as supply of low carbon technology machinery and equipment increases. This demonstrates substitution between petroleum as a fossil fuel with low carbon technology machinery which is key in enhancing energy efficiency. In both cases, machinery and petroleum prices fall, with machinery prices falling more than petroleum prices. The option of international support is associated with improvements in government income and total investment expenditure, while the optional of domestic resource mobilization is associated with a decrease in government income and total investment expenditure. The decline in government income for the domestic resource mobilization scenario reveals that the government foregoes revenue with tariff elimination. The international resource support would, therefore, be more preferred and this in line with Kenya's policy position of attracting much of the financing to achieve her nationally determined contribution (87%) through international support and 13% through domestic resource mobilization.

Table 5.1: Results at macro level (percentage changes from base)

Indicator	SIM1	SIM2
GDP at factor cost	0.14	0.23
Real GDP	0.09	0.18
Exports	6.12	3.93
Imports	2.89	3.36
Domestic production	0.85	0.96
Household consumption	0.27	0.37
Government income	-1.59	0.62
Total investment expenditure	-0.84	1.41
Domestic demand	0.14	0.53
Petroleum prices	-1.32	-1.37
Machinery prices	-5.39	-5.54
Machinery supply	**32.57**	**32.57**
Petroleum supply	-6.84	-6.66
Greenhouse gas emissions (CO2)	-4.26	-3.99

5.2 Results by sector

At the sector level, the two interventions are associated with notable reductions in greenhouse gas emissions (Table 5.2) and (Table 5.3) and increment in demand for low carbon technology machinery. For the two financing options, much of the reduction in greenhouse gas emissions is observed in the **petroleum**, **construction, chemicals**, and **mining** sectors. These are essentially industrial sectors, and the implication is that much of the reduction in greenhouse gas emissions would be witnessed in the industrial sector.

For the domestic resource mobilization option, **value added** increases in **energy**, **chemicals**, **petroleum**, and **other manufacturing sectors**, but decreases in the other sectors. **Petroleum demand** decreases in all sectors except in **mining**, **non-metallic minerals**, and **petroleum**. In contrast, **demand for low carbon technology machinery increases in all sectors**. **Commodity output increases in all sectors** except **transport**, **construction**, **mining**, and **non-metallic minerals**. **Commodity prices decrease in all sectors** except in **transport**, **energy**, **mining**, and **non-metallic minerals**. **Quantity of intermediate inputs increases** in all sectors except **transport**, **mining**, and **non-metallic minerals**. Price of intermediate input decreases in all sectors except in the transport sector (Table 5.2). For the transport sector, the increase in prices of intermediate input and the decline in quantity of intermediate inputs used could explain the observed decline in output in the sector.

Table 5.2: Results by sector for SIM1 (Percentage from base)

Indicator	Transport	Energy	Industry					
			Construction	Chemicals	Mining	Non-metallic minerals	Petroleum	Other manufacturing
Value added	**-0.04**	1.21	**-0.10**	5.38	**-0.40**	**-0.37**	3.01	2.46
Petroleum demand	-1.18	-3.64	-10.90	-12.10	-7.61	-1.27	-16.08	-11.36
Machinery demand		29.96	20.16	18.54	24.60	33.15	13.18	19.55
Commodity output	**-0.75**	0.38	**-0.33**	5.57	**-0.99**	**-1.29**	1.76	2.39
Commodity prices	**0.61**	**0.42**	-0.25	-1.02	0.17	0.64	-1.32	-0.41
Quantity of intermediate inputs	-0.65	0.86	0.04	6.24	-0.71	-1.09	2.08	2.91
Price of intermediate inputs	0.31	-0.99	-0.65	-1.94	-0.61	-0.09	-1.98	-1.24
Greenhouse gas emissions	-1.18	-3.64	-10.90	-12.10	-7.61	-1.27	-16.08	-11.36

For the second financing option, value added increases in all the sectors. Demand for petroleum decreases in all sectors while demand for low carbon technology machinery increases in all sectors. **Output increases** in **energy, construction, chemicals, petroleum,** and **other manufacturing sectors** but decreases in all other sectors. **Commodity prices decrease** in the **construction, chemicals, petroleum**, and **other manufacturing** sectors but increase in all other sectors. The **quantity of intermediate inputs increases** in the **energy**, construction, chemicals, petroleum, and other manufacturing sectors but decreases in the other sectors. The price of intermediate input decreases in all sectors except for transport (Table 5.3). In the transport sector, the increase in price of intermediate inputs, coupled with a decrease in quantity of intermediate inputs used, could explain the observed decline in the transport sector's output.

Table 5.3: Results by sector for SIM2 (Percentage from base)

Indicator	Transport	Energy	Industry					
			Construction	Chemicals	Mining	Non-metallic minerals	Petroleum	Other manufacturing
Value added	0	1.29	2.16	4.76	0.46	0.58	2.72	2.22
Petroleum demand	-1.38	-3.79	-9.13	-12.89	-7.06	-0.50	-16.65	-11.83
Machinery demand	-	30.21	22.98	17.89	25.78	34.66	12.8	19.33
Commodity output	**-0.87**	0.28	1.87	4.83	**-0.29**	**-0.54**	1.27	2.06
Commodity prices	**0.74**	**0.53**	-0.07	-1.05	0.24	0.75	-1.37	-0.42
Quantity of intermediate inputs	-0.74	0.80	2.22	5.52	0	-0.27	1.6	2.61

Price of intermediate inputs	0.38	-1.12	-0.69	-2.03	-0.63	-0.19	-2.07	-1.34
Greenhouse gas emissions	-1.38	-3.79	-9.13	-12.89	-7.06	-0.61	-16.65	-11.83

6. Conclusions and Recommendations

In this paper, we attempted to show how international technological support in the form of enhancing energy efficiency could help to reduce GHG emissions in developing countries such as Kenya.

Overall, there is a clear substitution away from fossil fuels as a source of energy in Kenya towards energy efficient low carbon technology machinery and equipment for the two options of financing the transition towards a low carbon development in Kenya. The interventions are associated with notable reduction in greenhouse gas emissions both at macro and sector levels. This demonstrates a transition of the Kenyan sectors examined from being *"dirty"* to being *"clean"*. For the two financing options, industrial sectors reveal the largest reduction in greenhouse gas emissions.

The financing options considered have potential to transition the Kenyan economy towards a low carbon development path in that they simultaneously reduce greenhouse gas emissions and support development as measured by GDP at factor cost, real GDP, exports, and domestic production. Low carbon technology machinery substitutes the high carbon emitting fossil fuels as manifested in the increased supply of machinery at lower market prices while supply of petroleum decreases despite petroleum prices decreasing. International financing options have relatively larger effects on development compared to domestic resource mobilization.

Domestic resource mobilization leads to increased value added in energy, chemicals, petroleum, and some manufacturing sectors, while other sectors experience a decline. Petroleum demand generally decreases, except in a few sectors—mining, non-metallic minerals, and petroleum which remain reliant on it. Demand for low carbon technology machinery increases across all sectors, indicating the sectors become clear. Commodity output rises across most sectors, except for transport, construction, mining, and non-metallic minerals. Commodity prices generally fall, except for transport, energy, mining, and non-metallic minerals, where prices increase. Quantity of intermediate inputs increases in most sectors except transport, mining, and non-metallic minerals. Prices of intermediate inputs decrease across the board, except in the transport sector.

International resource mobilization leads to increased value added in all sectors. Demand for petroleum decreases in all sectors while demand for low carbon technology machinery increases in all sectors. Output increases in energy, construction, chemicals, petroleum, and other manufacturing sectors but decreases in all other sectors. Commodity prices decrease in the construction, chemicals, petroleum, and other manufacturing sectors but increase in all other sectors. The quantity of intermediate inputs increases in the energy, construction, chemicals, petroleum, and other manufacturing sectors but decreases in the other sectors. The price of intermediate input decreases in all sectors except for transport. In the transport sector, the increase in the price of intermediate input, coupled with a decrease in the quantity of intermediate inputs used, could explain the observed decline in the transport sector's output.

To fully actualize the transition of the economy towards a low carbon development, the international community could commit to finance the supply of the low carbon technology commodities at lower world prices. This is in line with Kenya's updated nationally determined contribution which seeks to mobilize 87% of the needed resources through international support and 13% through domestic resource mobilization. To address the heterogenous effects of the financing options across sectors, Kenya could design incentives targeted to the transport, mining, and non-metallic minerals sectors which demonstrate a decline in value-added and output for the two financing scenarios, and the construction sector which demonstrates and decline in value-added and output for the domestic resource mobilization scenario. Since the two interventions for transitioning Kenya's economy to low development path are associated with increment in energy and transport prices, short-term subsidies could be implemented to cushion consumers against welfare erosion as the country builds domestic capacity for energy efficiency. Policy incentives could target to develop skills and knowledge needed to support domestic production of low carbon technologies.

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