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# Emission accounting and drivers in East African countries

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## HIGHLIGHTS

- $CO_2$ emissions in East Africa are growing exponentially at 6.5% per year.
- The process of energy clean-up is slow with little emission reduction.
- Economic and population growth are the most significant emission drivers.
- Emission patterns and drivers vary significantly from country to country.
- Locally tailored emission reductions are needed.

## ARTICLE INFO

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## ABSTRACT

East Africa is typical of the less developed economies that have emerged since the 21st century, whose brilliant economic miracle has also triggered the rapid growth of energy consumption and carbon dioxide emissions. However, previous carbon accounting studies have never focused on the region. Based on multi-source data, this paper rebuilt the 45-sectors carbon emission inventories of eight East African countries from 2000 to 2017, and used index decomposition analysis to quantify the drivers of growth. Here we found that overall the $CO_2$ emissions show a 'two-stage exponential growth' pattern, with significant heterogeneity between countries. In terms of the energy mix, technical progress in hydro and geothermal energy was almost offset by a growing appetite for oil and coal, making it the weak and valuable factor driving emissions reduction (−1.4Mt). But it was far from enough to overcome the pressure of economic and population growth, which brought about a 13Mt and 11Mt emission growth respectively from 2000 to 2017. Increasing energy intensity due to industrialization and transport development also contributed to an increment of 6.4Mt. Low-carbon policies should be tailored to local conditions and targeted at the improvement of energy efficiency and use of renewable energy so as to achieve a win-win situation between sustainable economic growth and emission reduction.

## 1. Introduction

Climate change is a major common challenge for humanity in the 21st century. Anthropogenic factors, led by greenhouse gas (GHG) emissions, are the main cause of climate warming. On one hand, the major source of anthropogenic greenhouse gas emissions is carbon dioxide emissions from fossil energy consumption; on the other hand, fossil energy is also an indispensable part of economic development. How to reduce energy emissions while achieving the goal of sustainable economic development is a common challenge for countries around the

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world. Therefore, a scientific and detailed accounting of the evolution of $CO_2$ emissions and an exploration of the drivers of emissions growth is essential to decouple economic development from emissions.

International efforts to mitigate climate change have historically focused on reducing energy-related $CO_2$ emissions from countries with the largest economies, including the EU [1] and U.S. [2], or the largest populations, such as China [3,4] and India [5]. Numerous European countries have already reached the carbon peak through energy substitution from coal to oil, to natural gas and nuclear energy [6], and have further aggressively reduced their emissions by wider use of clean energy [7,8], improvements of energy efficiency [9] and industrial restructuring [10]. Outsourcing their polluting industries is also a reason, but the African countries cannot follow the previous track of EU countries (outsourcing, etc.) to reduce emissions, thus they need specific low-carbon roadmaps.

In an era with relatively mature technological pathways for reducing emissions, more and more developed countries have peaked or will soon peak emissions [1]. In the next generation, the main battleground for future emissions reductions will shift to developing countries and even less developed regions including East Africa [11]. On the one hand, biomass, which is badly in need of replacement by other advanced energy sources, dominates in East Africa; on the other hand, less developed countries are unable to improve energy efficiency and develop clean energy sources (wind and solar, etc.) in the short term, due to budget constraints and technological backwardness [12].

East Africa is one of the most economically and politically dynamic regions in the world today [13], with several countries having had economic growth rates among the top 10 in the world (e.g. Ethiopia and Rwanda). Since the 1990s, countries such as Ethiopia and Uganda have come to the end of their civil wars, stabilised their regimes and begun to build their economies. At the start of the 21st century, all the countries of East Africa were agrarian and actively exploring differentiated ways to revitalise their economies. Large economies such as Ethiopia, Kenya and Tanzania have set industrialisation as an important goal in their national economic development plans. Burundi and Eritrea, on the other hand, have small economies and are slow to develop. Poverty reduction based on agriculture is the primary goal, and industrial transformation has not yet taken place. Djibouti, with its unique geographical location, aims to become the transportation hub of East Africa and attaches importance to the development of international logistics. Rwanda, on the other hand, is focusing on the information industry and building a knowledge-based economy. Generally, East Africa is at the initial stage of industrialization and urbanization where economic growth and emissions are highly coupled. And the existing development model and the high growth rate of the economy are likely to be sustainable in the future [14]. On the one hand, the pursuit of rapid economic growth, as well as rising standard of living, will bring a huge energy gap. On the other hand, these less developed countries are unable to quickly improve energy efficiency and develop clean energy sources (wind and solar, etc.) in the short term, due to budget constraints and technological backwardness [12]. Therefore, strong mitigation measures, international attention and support are necessary.

East African countries have already taken active steps to mitigate climate change, which will pose significant risks to their agricultural economies. Since Ethiopia was the first to submit its INDC in 2015, seven other countries have followed. Countries have committed to GHG emission reductions ranging from 20 to 65% by 2030 (compared to the BAU scenario). Almost all of them emphasise on improving energy efficiency and the share of electricity generated from renewable sources. East African countries mainly rely on their geographical endowments to develop hydro, geothermal, wind and biomass energy. Countries such as Ethiopia and Kenya have taken full advantage of the Nile River and the East African Rift Valley to develop hydropower and geothermal energy. From 2007, Ethiopia started to promote the wide application of solar, wind, and small-scale hydro energy to meet decentralized electricity demands in rural areas [15,16]. The target is to upgrade the electricity generating capacity by 25 GW by 2030: 22 GW of hydro; 1 GW of geothermal; and 2 GW of wind [17]. While Kenya aims to be the leading geothermal power producer in Africa. According to Power Generation and Transmission Master Plan 2015–2035, geothermal capacity will be doubled to 1.6 GW by 2030, providing more than half of the annual generated electricity in 2035 [18]. Despite ambitious commitments to improve technological emission reductions, there has been no study to quantify the effectiveness of the policy. Is the energy mix of East African countries, and is production efficiency-optimised? If so, by how much have emissions been reduced? These are the questions that need to be studied urgently

Based on the above-mentioned socio-economic realities, East Africa is therefore one of the main battlegrounds for future world emissions reduction and needs accurate emission accounting and driver analysis.

However, due to poor data infrastructure and language barriers, few scholars have ventured into the accounting of carbon emission inventories in Africa. The few existing studies in this region use a particular country as a case study and are unable to explore the similarities and differences in emission patterns in the East African region [19]. In addition, data of the less developed countries in Africa often come from international institutions such as the World Bank, with limited statistical accuracy and lack of economic data of sub-industrial sectors. There is an urgent need for national statistics containing more accurate information to be used in carbon accounting than the single source of International Energy Agency (IEA) in existing studies [20,21]. Overall, there is a lack of carbon accounting and analysis of the East African region that is based on multi-source statistics with detailed sectoral mapping.

This paper rebuilds the $CO_2$ emission inventories and the temporal and spatial evolution patterns of eight East African countries from 2000 to 2017 based on multi-source data. The drivers of carbon emission changes are also analysed using the Index Decomposition Analysis – Logarithmic Mean Divisia Index method (LMDI). This paper fills a research gap targeting the drivers of long-term carbon emission changes in less developed regions and reveals several typical patterns of emission rise in East African countries (Sudan, South Sudan and Somalia were not included in this study due to the low availability of data due to war). The findings will help developing countries, especially low-income countries in East Africa, to formulate policies for energy efficiency improvement and energy mix transformation.

## 2. Method

### 2.1. Emission accounting

Following the guidelines from the Intergovernmental Panel on Climate Change (IPCC) regarding the allocation of GHG emissions, we consider the administrative territorial scope for each country's $CO_2$ emissions accounting in this study. Administrative territorial emissions refer to the emissions that occur within administered territories and offshore areas over which one region has jurisdiction [22,23], including emissions from fossil fuel consumption produced by socioeconomic sectors directly within the region boundary. Emissions from transnational traffic are excluded in this scope, e.g. aircraft fuel emissions destined for East African countries. Biomass fuels are also not included in this scope. International agencies such as the IEA do not account for biomass emissions because it is carbon neutral from a full life cycle perspective [24]. The carbon released during burning is the carbon fixed during the growing process. Therefore, the consumption of the short-term biomass, such as crop waste should not be included in the total emissions. Firstly, we calculate the emissions from fossil fuel combustion. The emissions are calculated for four fossil fuels (i.e., coal and coal products, crude oil, oil products and natural gas) and 45 socioeconomic sectors (see table s1 in the supporting information). The 45 socioeconomic sectors are defined according to Shan et al (2017)'s accounting methodology, which includes all possible socioeconomic activities conducted in a developing country's administrative boundary.

$$CE_{energy} = \sum_{i}\sum_{j} CE_{ij} = \sum_{i}\sum_{j} AD_{ij} \times NCV_i \times EF_i \times O_{ij} \tag{1}$$

The time series of carbon emission inventories of eight East African countries (Ethiopia, Kenya, Tanzania, Uganda, Djibouti, Eritrea, Rwanda, Burundi) by energy varieties and sectors were rebuilt with multi-source data from the National Bureau of Statistics and international institutions.

### 2.2. LMDI decomposition

Kaya Identity and LMDI decomposition techniques [25] were used to analyze the driving factors of the changes. The change of carbon emissions is decomposed into five driving factors: population, economic aggregate, economic structure, energy intensity and energy structure (assuming constant emission factor) [21,26,27].

$$C = \sum_{ij} POP \times \frac{GDP}{POP} \times \frac{GDPi}{GDP} \times \frac{Ei}{GDPi} \times \frac{Eij}{Ei} \times \frac{Cij}{Eij} \tag{2}$$

Where C is the total amount of $CO_2$ emission; i represents the industrial sector; j represents energy type; $C_{ij}$ represents the $CO_2$ amount of j energy consumed by i industry; POP represents national population; GDP represents economic aggregate; $GDP_i$ represents the added value of i industry; $E_i$ represents the energy consumption of i industry; $E_{ij}$ represents the amount of energy j consumed in sector i; $C_{ij}$ represents the $CO_2$ emission of energy consumption j in i sector.

After addition decomposition, $CO_2$ emission growth can be decomposed into five factors in the question below:

$$\Delta C_{tot} = C^T - C^0 = \Delta C_{pop} + \Delta C_{econ} + \Delta C_{str} + \Delta C_{int} + \Delta C_{mix} \tag{3}$$

The subscripts pop, econ, str, int, and mix, respectively, denote the effects associated with population, economic activity, economic structure, sectoral energy intensity, and sectoral energy mix.

### 2.3. Data source

In this study, the economic and population data came from the World Bank [28] and African Development Bank [29]. Data on economic output by subsector are obtained from the statistical yearbooks of individual countries. All economic data are used at USD at constant prices in 2010.

The energy data are collected from the African Energy Commission [30], U.S. Energy Information Administration [31] and the Statistics Bureau of each country (Table 1). The energy types of all countries are integrated into six energy types: coal total; crude oil; oil total; natural gas; hydropower; and wind, geothermal and solar PV (photovoltaic), and each energy consumption is unified with kilotonnes of oil equivalent (ktoe) as the unit. The energy consumption of the power sector was obtained by the data of Energy Transformation of power generation after processing. This paper uses the emission factor coefficients given in the 2006 IPCC Guidelines for National Greenhouse Gas Inventory. Among them, the emission factors of oil products are obtained by weighting the consumption of petroleum subcategories in EIA.

**Table 1**
Data sources for selected countries.

| Country | Data type | Source |
|---|---|---|
| Kenya | Energy balance | AFREC energy database; Kenya National Bureau of Statistics; Energy Information Administration |
| | Emission factor | IPCC 2006 |
| | Sector-mapping indicator | Kenya census of industrial production and construction report 2018 |
| Tanzania | Energy balance | AFREC energy database; Energy Information Administration |
| | Emission factor | IPCC 2006 |
| | Sector-mapping indicator | Tanzania Annual Survey of Industrial Production Year 2008, 2013,2015,2016 |
| Ethiopia | Energy balance | AFREC energy database; Ethiopia Ministry of Water, Irrigation and Energy; Energy Information Administration |
| | Emission factor | IPCC 2006 |
| | Sector-mapping indicator | AFDB Socio economic database; Ethiopia CSA Manufacturing-Industry-Survey-Report |

## 3. Results

### 3.1. Emission patterns

#### 3.1.1. Aggregated trends

In terms of total emissions and evolutionary trends for the region as a whole, emissions in East Africa have been rising at an average annual rate of 6.03%, nearly tripling from 17.6Mt in 2000 to 47.6Mt in 2017, and showing a two-stage exponential growth pattern with 2010 as the turning point. At the same time, the region's rapid economic growth, with an average annual GDP growth rate of 6.45%, is highly consistent with emissions in terms of trends, with economic growth linked to emissions. Since 2010, the rate of increase in emissions has accelerated and gradually exceeded the rate of GDP growth, implying that without aggressive action on energy mix and energy efficiency, future growth per unit of GDP in East African countries will come at the cost of higher emissions.

In terms of emissions by country, Kenya emits the most, while Tanzania and Ethiopia have the fastest growth rates. Uganda's emissions are highly volatile, with a jump in emissions occurring between 2013 and 2015 due to large oil imports for the transport sector. The combined emissions of Kenya, Tanzania, Ethiopia and Uganda account for more than 80% of emissions in East Africa. The spatial distribution of emissions shows an agglomeration pattern. Kenya is the peak of emissions, while Ethiopia and Tanzania are the secondary peaks, as shown in Fig. 1. The emission trends of countries with large economies are relatively stable, with three large countries – Kenya, Tanzania and Ethiopia – showing a steady increase in emissions. The similarities and differences in the emission patterns are shown in Table 2. While the emissions of the other five countries, such as Djibouti and Eritrea, are more volatile.

#### 3.1.2. Case studies of key emitters

(1) Ethiopia

Ethiopia's economic and industrial structure has undergone dramatic changes over the past 20 years. Its emissions history is typical of East Africa's 'two-stage exponential growth'. From 2000 to 2010, agriculture and services were the pillars of the national economy, and Ethiopia's emissions grew slowly at an average annual rate of 6%. With the shift from agriculture to manufacturing after the implementation of the Growth and Transformation Plan (GTP) in 2010, Ethiopia has experienced an average annual GDP growth rate of 9.8% from 2010 to 2017. In this period, emissions grew at an average annual rate of 13%. This emission pattern confirms the pace of economic development and industrialization in Ethiopia and suggests a very high potential for future emissions.

In terms of the energy mix, the main sources of emissions in Ethiopia are oil and coal consumption, of which oil is the core source accounting for approximately 90% of emissions. Since 2006, coal has been consumed in Ethiopia and emissions have gradually increased to meet the needs of the growing non-metallic manufacturing and construction industries.

In terms of the sectoral composition of emissions, the exponential growth trend is mainly driven by the transport and construction sectors (Fig. 2). The transport sector is both the highest and the fastest growing emitter. According to World Trade Organization (WTO) and UN Comtrade trade data, transport equipment imports increased by 77.9% from 2010 to 2018, with aviation aircraft, rail tram locomotives imports

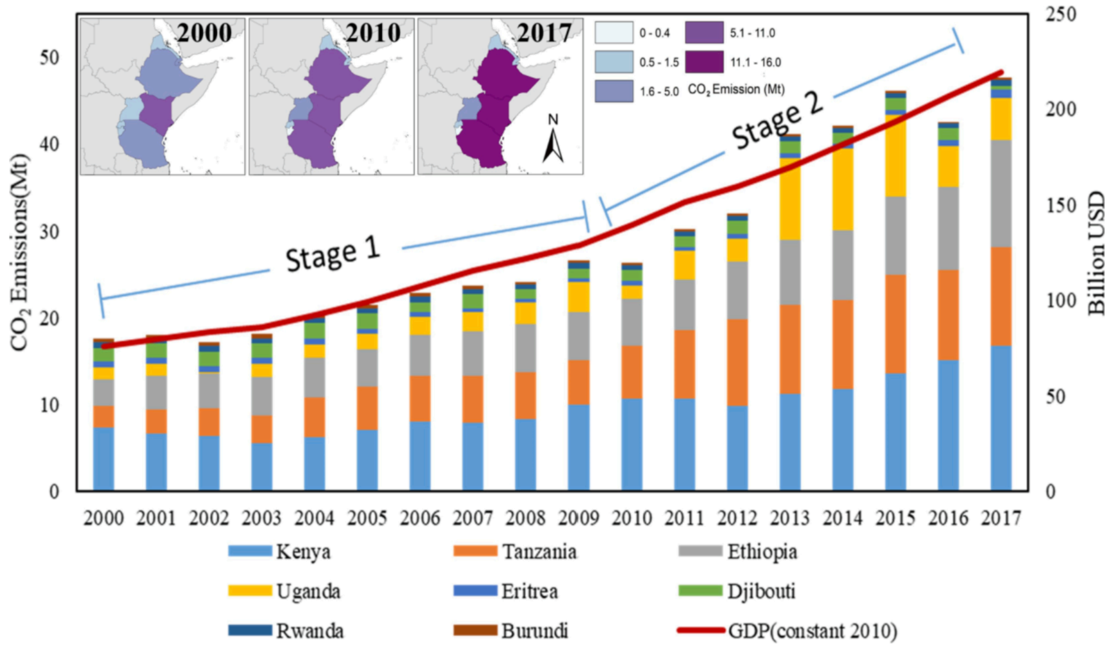


**Fig. 1.** Evolution of $CO_2$ emissions in eight countries in the East Africa region (The secondary axis corresponds to the total regional GDP).

**Table 2**
Similarities and differences in the emission patterns of the three countries.

| Country | Similarities | Growth patterns | Driving sectors |
|---|---|---|---|
| Ethiopia | 1. Overall emissions show a rapid upward trend with an average annual growth rate of about 10% | Exponential growth with year 2010 as the turning point | Significant decarbonization in the power sector; rapid rise in the construction sector |
| Kenya | 2. The transport sector is both the highest and the fastest growing emitter | Continued growth with minor fluctuations | Chemical manufacturing emissions are higher compared to other countries |
| Tanzania | 3. Higher emissions in transport, non-metal, construction, electricity, and food manufacturing sectors | Exponential growth with year 2010 as the turning point | High growth in mining and extraction sector after 2010; rapid rise in the construction sector |

increasing more than tenfold.

(2) Kenya

Kenya is the most industrialized country in East Africa and $CO_2$ emissions have been rising at a relatively steady rate, averaging 5.00% per annum, outpacing GDP growth of 4.79% per annum. The emissions have shown a fluctuating upward trend, with two troughs in 2003 and 2012 (mainly because of the political disruption and economic stagnation after the 2002 general elections).

By energy source, oil is also the core fossil fuel type, accounting for around 90% of emissions; coal emissions have been rising year by year from 2009 to 2014, but have stabilized since 2015 after the Kenyan government issued Intended Nationally Determined Contributions (INDC) to reduce emissions.

From the sectoral perspective, as in other countries, the transport sector is also the fastest growing emitter, accounting for over 60% of total emissions; The high growth trend in the electricity sector has been reversed since 2013 due to the rapid development of geothermal and hydro energy. The trend of "increase followed by decrease" reflects the

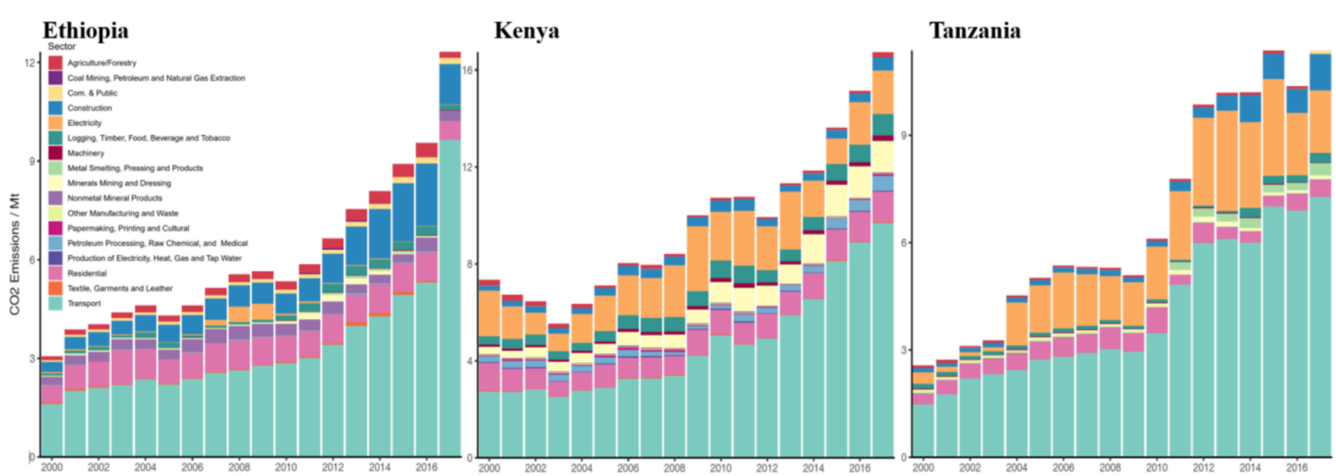


**Fig. 2.** Emission trends by sectors.

emissions life cycle of many less developed countries, including Kenya, where growth in energy demand is coupled with clean energy development. Within the industrial sector, emissions from non-metallic manufacturing are rising rapidly, reflecting growing demand from the national infrastructure. The Monel Railway, which began construction in 2014 and opened to traffic in 2017, has brought about an increase in emissions during this period. In addition, the chemical and food manufacturing industries are consistent high emitters.

(3) Tanzania

Similar to Ethiopia, Tanzania's emissions growth took a turnaround to a higher growth around 2010; the difference is that Tanzania's emissions growth trend has been somewhat effectively curbed due to several clean energy policies after 2015. The country's emissions evolution trend can be broadly divided into three phases: the eve of industrialization (2000–2010), high growth period (2010–2014), and slow growth period (2015–2017). In 2017 Tanzania's $CO_2$ emissions were 11.34 Mt, more than four times higher than emissions in 2000.

By energy type, oil is the core source of emissions and has been increasing significantly year on year. On the one hand, as the only natural gas producing country in East Africa, Tanzania has cleaner energy options than other countries. Natural gas account for 20% of emissions. On the other hand, coal is still widely used and its emissions have been increasing year on year since 2012, accounting for about 15% in 2017. The growing appetite for coal is like a shot in the arm in the course of economic development [32], effective in the short term but detrimental in the long term.

By sector, the transport sector is the core source of emissions which are rising rapidly; the electricity sector is consistent with the pattern of increasing and then decreasing emissions described above. It is worth noting that Tanzania suffers from a 'manufacturing deficit' relative to its ambitious plans to achieve middle-income status [33]. The manufacturing sector is nearly absent from Tanzania's highly growing emission accounts. A number of policy initiatives had been undertaken to strengthen the industrial sector's dynamism, resulting in slow growth in emissions from construction, non-ferrous metal extraction, as well as the food and non-metal mineral manufacturing sector.

## 3.2. Driving factors

### 3.2.1. Aggregated trends

The results of the three-period LMDI decomposition show that economic and population growth in East Africa are responsible for 13Mt and 11Mt of emission growth from the year 2000 to 2017, respectively. In this period, the population of most countries in the East African region grew at a high average rate of over 2.4% per annum, with the highest average annual growth rate of 3.3% in Tanzania. In 2017, the population of the East African region reached 280 million, with an annual growth rate of 2.87%, a trend that is still not slowing down. To control the natural population growth rate will be effective in curbing the trend of emission growth.

Energy intensity factors contributed 3.4Mt of emission reductions in the period up to 2010, but became a significant driver of emission growth between 2010 and 2017, resulting in 9.8Mt of emission growth. This is due to the fact that economic growth in East Africa between 2000 and 2010 was relatively slow and not driven by energy consumption; however, after 2010 the region's economic development process became significantly more energy intensive, with energy consumption growing at a much higher rate than GDP growth. While the energy mix is generally improving, the potential for emission reductions from hydro and geothermal energy development is almost offset by the growing demand for oil and coal, leaving the energy mix as a weak driver of emission reductions (1.44Mt). Improvements in the energy mix are far from sufficient to remove the pressure on total energy consumption from economic activity and population growth in East Africa.

In terms of economic structure, although countries such as Ethiopia, Kenya and Tanzania have undergone a period of industrialization and built a range of large infrastructure, the economic structure effect has not led to increased emissions due to the low energy intensity of industry and high dependence on agriculture in the region as a whole. Agriculture is the economic lifeblood of most East African countries, with close to 60% of the population employed in agriculture, and the development of sustainable agriculture is key to achieving the SDGs [34]. Agricultural revitalization strategies in countries such as Kenya, and priority of tertiary sector in countries such as Rwanda, have resulted in a net emission reduction effect for the economic structure factor from 2010 to 2017. Through country-specific analysis, we find that the emissions growth pattern in East Africa can be divided into two types of energy intensive and energy decoupled.

### 3.2.2. Energy-intensive economies

The energy-intensive type includes countries such as Ethiopia and Tanzania. They are characterized by a high dependence of economic growth on energy consumption and emissions. The rapid economic growth in recent years has been accompanied by a significant increase in emissions growth, with the transport and infrastructure sectors developing rapidly. Capital and energy are gradually replacing the labour factor, which had been dominant in previous development history. These factors have led to a significant increase in energy intensity in these countries (Fig. 3).

(1) Ethiopia: High-speed industrialization and ambitious transport development goals

From 2010, Ethiopia implemented its Growth and Transformation Plan (GTP), which encouraged large-scale foreign investment in agriculture, industry and infrastructure towards a goal of achieving rapid industrialization. The growing GDP per capita was the largest driver of emissions growth (5.3 Mt increment). Extraction of minerals (gold, salt, precious stones, fuels, etc.), infrastructure development, increasing manufacturing industry lead to 2.7Mt increment in economic structure factor. The expanded use of oil in transport and the higher use of coal in manufacture contributed 3.7Mt emissions. Population growth of 2.7% per annum was also an important contributor.

In terms of energy mix, Ethiopia has seen rapid growth in hydroelectric power generation since 2010, with 930.71 ktoe of hydroelectric power generation in 2017 (six times compared to 2000); wind and solar production rose from 4.3 ktoe in 2000 to 71.48 ktoe in 2017, completing the technical breakthrough from zero to one. However, although the share of renewable energy has increased slightly (from 15% to 20%), its emission reduction effect is offset by the expanded use of oil in transport and the higher use of coal in manufacture. This demonstrates the role that new technologies and shifts away from carbon intensive sources of energy can play in offsetting increases in emissions that inevitably result from strong economic growth in poor countries.

(2) Tanzania: Catching-up industrialization and growing appetite for fossil fuels

Economic and population growth has steadily contributed to the growth of carbon emissions. The driving effects show a progressive increase between the two stages. In particular, economic growth of 6.5% per year has led to emissions of up to 2.70Mt, while high population growth of 2.9% per year has led to emissions of 2.33Mt from the year 2000 to 2017.

Similar to Ethiopia, the Tanzanian government is actively increasing the share of the industrial sector, particularly the manufacturing sector, in the national economy. However, Tanzania's manufacturing industries such as food processing were rarely dependent on fossil energy (mainly use biomass such as charcoal), had low emissions intensity and contributed little to carbon emissions. The rise in industrial GDP

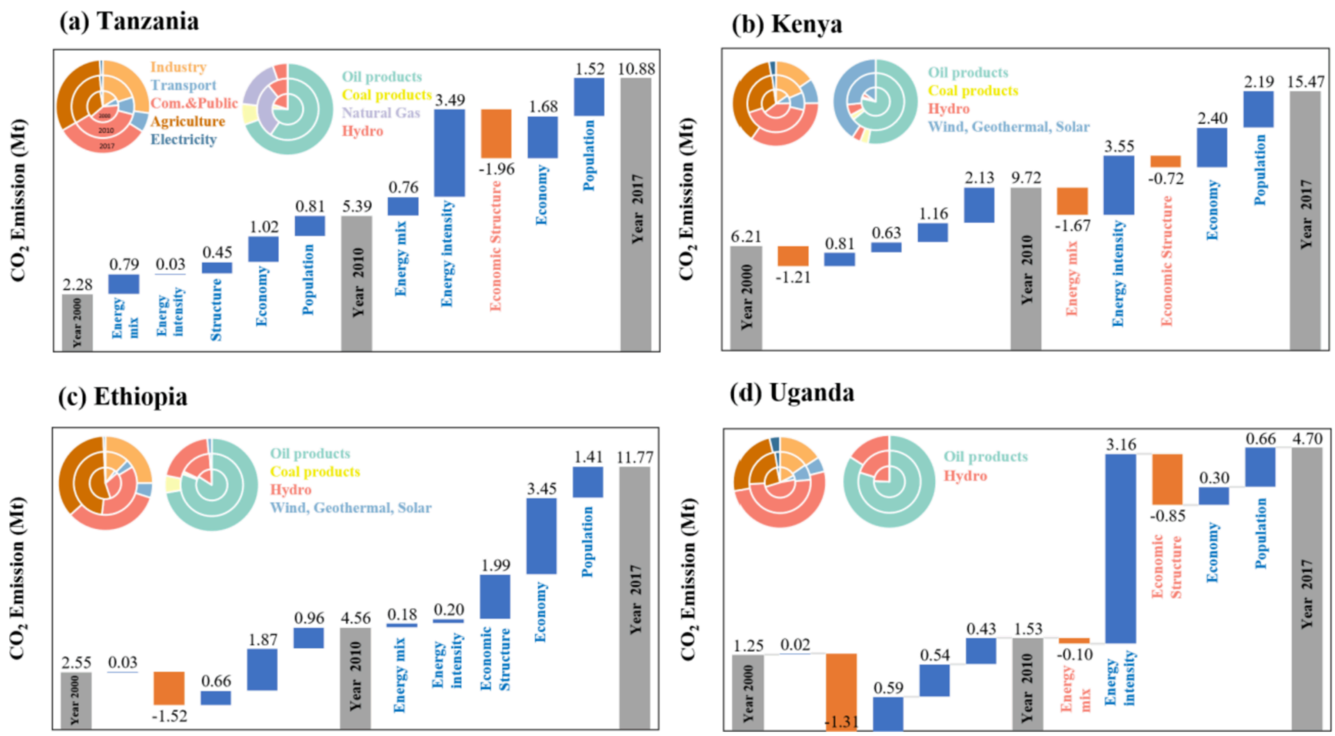


**Fig. 3.** Drivers of emissions growth in energy-dependent economies. The two doughnut charts represent the evolution trend of economic structure and energy structure from 2000 to 2010 to 2017 (from the inner ring to the outer ring) respectively.

therefore did not create an emissions burden and indirectly makes the economy less dependent on the transport sector. Reduced reliance on the emission-intensive transport sector (GDP share fell from 8.99% to 6.71%) had freed up 1.97Mt of emission space for Tanzania.

The energy intensity factor is the main cause of the increase in emissions in Tanzania, and there is heterogeneity in the temporal pattern of its effect. Around 2000, Tanzania's economy was dependent on agriculture and raw material exports and economic growth was relatively slow. Energy intensity was not a driver of emissions growth until 2010. However, between 2010 and 2014, the boosting demand in the transport and electricity sectors led to an increase in energy consumption per unit of sectoral GDP (from 0.39 ktoe per million USD in 2010 to 0.73 in 2017), which significantly drove the growth in carbon emissions.

In terms of energy mix, the newly generated energy demand is mainly satisfied by natural gas and coal. Although consumption of hydro and solar energy is slowly increasing, the share is gradually decreasing. The energy mix as a whole is moving towards a higher carbon footprint, causing emissions of 0.82Mt and 0.85Mt in the two phases respectively. Tanzania's INDC includes the development of various renewable energy sources such as geothermal, wind, solar and renewable biomass [35]. Since 2008, the Tanzanian government has promoted solar energy through investment (TEDAP), engineering [36] and subsidies [37,38]. 2.28 ktoe (less than 0.1%) of energy in 2017 was supplied by wind PV and geothermal energy. While achieving a valuable start from zero to one, the promotion of renewable energy is a long way off compared to the high growth in fossil energy consumption.

(3) Kenya: At the Crossroads of the East African Continent's Energy Transformation

Kenya's average annual economic growth of 4.79% and population growth of 2.7% are also steady drivers of emissions growth. Similar to Ethiopia and Tanzania, Kenya is also undergoing massive infrastructure development such as the 'Monegasque Railway', but the construction sector's GDP share rose by only 1% from 2010 to 2017. The core driver of the country's economic growth is agriculture. Export-led agriculture is Kenya's key industry, accounting for 65% of export earnings and providing livelihoods (employment, income and food security needs) for over 80% of the country's population [34]. The share of agricultural GDP increased significantly from 27.9% in 2010 to 37.7% in 2017. The national policy to revitalize agriculture as a low-emissions intensity sector led to an emission reduction effect of 0.72 Mt in the post-2010 economic structure factor. Similar to Tanzania, the contribution of energy intensity to emissions jumped, contributing 3.55 Mt of $CO_2$ emissions from 2010 to 2017. Major construction projects and increased demand for electricity have led to a rapid increase in the country's energy intensity.

Kenya has an abundance of clean energy in the ground. The country is actively pursuing a range of energy development initiatives to tap into the vast geothermal reserves of the East African Rift Valley and to develop geothermal energy in a localized manner. The government plans to generate 27% of the country's electricity from geothermal energy by 2031. The country is the only country in East Africa to have achieved significant emissions reductions from renewable energy sources, with improvements in the energy mix freeing up nearly 3Mt of emissions between 2000 and 2017, absorbing 80% of the emissions from economic growth (3.56Mt).

### 3.2.3. Energy decoupled economies

Compared to infrastructure-driven economies, countries such as Djibouti and Rwanda developed tertiary sectors such as transport, finance, tourism and communication industries during the study period, with an alternative pattern of emissions. Their industrial structures have low energy dependency and declining energy intensity. These countries feature relative smaller economies, volatile emissions and modest growth, and some of them have even experienced significant declines in emissions (Fig. 4).

(1) Djibouti

Djibouti's economic growth has suffered due to the unstable

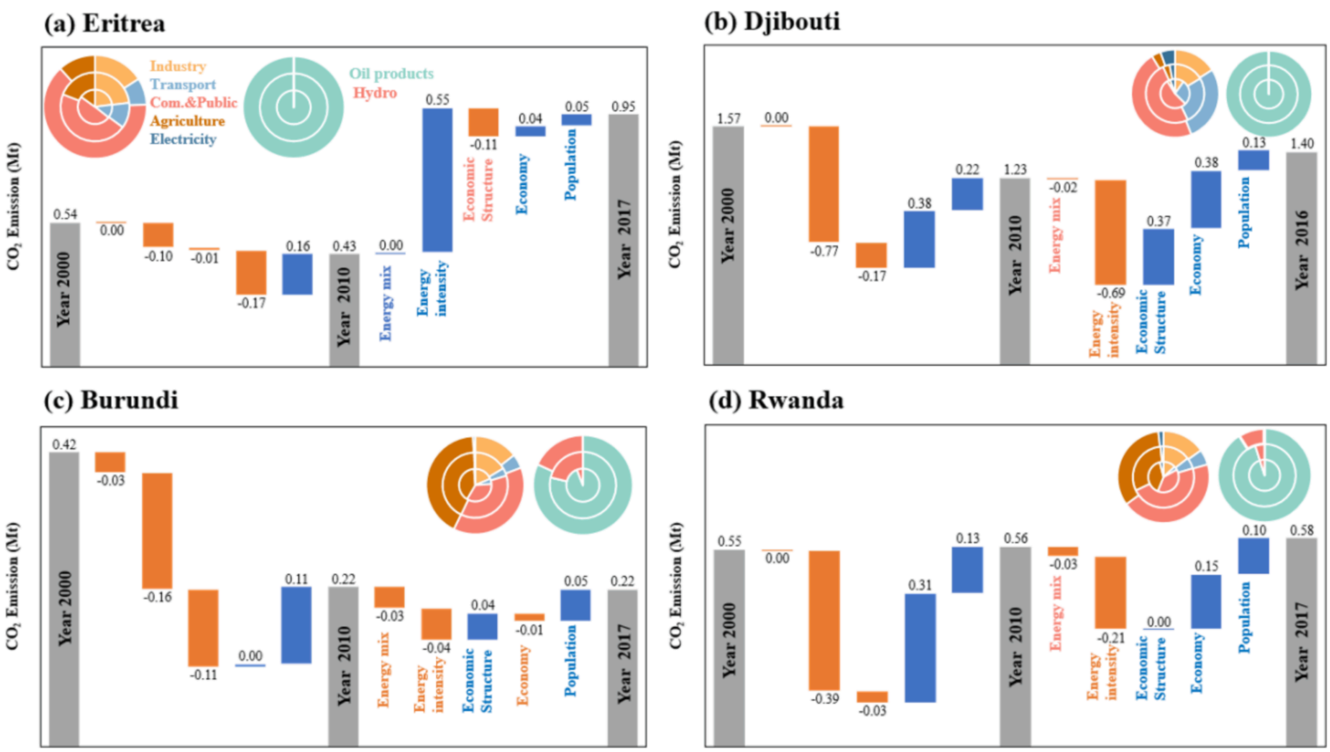


**Fig. 4.** Drivers of emissions growth in energy-decoupled economies. The two doughnut charts represent the evolution trend of economic structure and energy structure from 2000 to 2010 to 2017 (from the inner ring to the outer ring) respectively.

international and domestic political situation and has been gradually recovering since 2000. Economic growth resulted in 0.76Mt of carbon emissions. Located at the entrance to the Red Sea linking Europe, Africa, the Middle East and Asia, Djibouti's economy is commanded by the services sector, providing services as both a transit port for the region and as an international transshipment and refueling centre. This makes Djibouti's economy less energy-dependent, with energy intensity gradually decreasing as the economy grows, bringing up to 1.5Mt of emission reduction benefits. The services-centred economic development model is also driving investment in transport infrastructure (mainly ports) and power sector. The increase in the power sector's GDP share from 2010 to 2017 resulted in 0.37Mt of emissions due to the fact that more than 99% of electricity generation originated from the burning of imported oil. Djibouti urgently needs to make efforts to clean up its electricity, otherwise it will suffer from the huge emissions footprint of electricity demand from the service sector.

(2) Rwanda

Rwanda has embarked on a low-carbon development path, revitalized by service industries such as banking and finance, wholesale and retail trade, and tourism. High economic growth has been accompanied by very stable emissions, its economic growth is not energy driven and carbon emissions are decoupled from GDP. Rwanda's small but emerging economy has seen strong foreign investment and has been ranked by the United Nations Conference on Trade and Development as the top information and communications technology (ICT) country in East Africa [39], attracting large investments from leading international companies including Microsoft and Nokia. Driven by sufficient Foreign Direct Investment (FDI), the tertiary sector has grown rapidly and accounted for an increasing share of the national economy, reaching 47% in 2010, making it the largest sector of the national economy. This low carbon economic growth has resulted in small energy consumption per unit of GDP growth, and the energy intensity effect has significantly reduced Rwanda's emissions (0.6 Mt decrement).

## 4. Conclusions and policy implications

### 4.1. Summary

This paper rebuilds the $CO_2$ emission inventories and spatial and temporal evolution patterns of eight East African countries from 2000 to 2017 based on multi-source data. The drivers of carbon emission changes are also analyzed using the LMDI method. This paper fills a research gap targeting the drivers of long-term carbon emission changes in less developed regions and reveals several typical patterns of emission rise in East African countries. The conclusions drawn are as follows:

(1) The $CO_2$ emission pattern of East Africa shows a two-stage exponential growth with 2010 as the cut-off point. After 2010, along with large-scale foreign investment and the rapid development of the transport and infrastructure sectors, the growth rate of carbon emissions increased significantly. The emissions reached 47.6Mt in 2017, with a significant potential for future growth.
(2) From sectoral perspective, transport, electricity, construction and non-metal manufacturing are the top four emitters in order, accounting for more than 80% of total emissions. Emissions from the electricity sector show an increase followed by a decrease due to both rising demand and a higher proportion of clean energy, with a reduction of 0.95Mt in sum.
(3) From 2000 to 2017, the core drivers of $CO_2$ emissions growth are economic and population growth, resulting in 13Mt and 11Mt of emissions respectively, accounting for 27% and 23% of total emissions in 2017. While the driving effects of economic structure, energy intensity and energy mix are regionally heterogeneous.
(4) While the energy intensity of manufacturing is declining in countries such as Ethiopia and Tanzania, the overall energy intensity of East African countries is trending upwards due to the high expansion of energy demand in the transport and power

sectors. The increase in energy intensity led to a 9.82Mt increase in emissions between 2010 and 2017, which could lead to higher $CO_2$ emissions per unit of GDP in the future.

(5) East African countries are actively using their geographical resources to develop renewable energy sources such as geothermal energy and hydro energy according to local conditions, which is a strong driver for emission reduction. However, the emission reduction effect of clean energy development is offset by the rapid rise in demand for coal and oil, and the overall energy mix effect is only 1.44Mt emission reduction.

Compared to major emitters such as the United States, China and India, developing countries in regions such as Africa and South America have smaller individual emissions, but overall emissions are on par with those of the major emitters and have great potential to dominate global emissions in the future. These countries face multiple daunting challenges on their socio-economic development paths, such as poverty eradication and emissions reduction. Controlling population growth could be effective for reducing emissions since the huge population generates a huge demand for household energy and consumption of products and services (transportation, buildings, food, etc.). A reduction in the total fertility rate (TFR) would also significantly reduce the burden women are under and improve living conditions. Rwanda, Kenya and Uganda have policies for encouraging the uptake of modern contraception and reducing TFR, which have been effective over the last 15–20 years. However, the total population in East Africa are still growing rapidly (the regional average population growth rate in 2017 was 2.87%) because mortality rates are falling at a faster rate, which is their basic situation. So on one hand, we encourage policies for promoting the uptake of modern contraception to reduce TFR in countries that are in a position to do so. On the other hand, it is also important to note that the benefits of controlling population growth are limited considering their large population base, and that more emphasis on efficiency optimisation is needed to offset the emissions of population growth. While previous studies have shown that emerging economies (e.g. BRICS) can effectively reduce emissions by improving their energy mix and efficiency [40], low-income countries face significant challenges in both areas. East African countries therefore need targeted technology reforms for high emission intensity sectors in conjunction with international help to achieve a win-win balance between sustainable economic growth (poverty eradication goal) and energy reduction (international responsibility). Our analysis provides a full analysis of the characteristics of economic development and energy structures in the East African region, as well as the heterogeneity of specific development paths and strategies in individual countries. Based on our results, we suggest that:

(1) Increase the proportion of foreign investment in new clean energy development expenditure. On the one hand, low-income countries have not been able to effectively improve their energy mix and promote energy transition due to their economic base and lagging technology; on the other hand, East African countries are mostly dependent on foreign imports for oil and coal consumption. They have not yet formed a path dependence on certain high-carbon energy sources compared to major coal-producing countries such as China and India, making the leap from biomass to hydro, geothermal, wind and photovoltaic energy difficult but with greater potential. The East African region is rich in renewable energy endowment (geothermal energy endowment in the East African Rift Valley in Kenya, hydro energy in the Abbey and Omo river basins in Ethiopia, solar photovoltaic endowment in Tanzania, etc.). Currently, while wind and solar energy have made a breakthrough from zero to one, but there is limited scope for emission reductions and further investment is needed with the help of FDI. Therefore, all countries in the East African region need to make rational use of foreign investment and focus more on the development of clean energy, rather than take FDI as 'a shot in the arm' to catalyze the economy at the cost of high emissions. This will not only contribute to sustainable development but will also win more foreign investment (from WDB etc.).

(2) Decarbonization pathways in the industrial and transport sectors should focus on reducing energy intensity. As energy-intensive sectors, the development of industry and transport will inevitably result in high emissions. However, the industrial and transport sectors have a very high coefficient of influence in national economies and are the "lifeblood" of the rising economies of developing countries. While a structural shift from industry to agriculture and services may be consistent with energy efficiency and low-carbon development goals, it is not consistent with sustainable economic development goals. Industry and transport decarbonization should focus on reducing energy intensity and improving energy efficiency, rather than give up development opportunities. Governments should promote sustainable economic development by structurally transforming the manufacturing sector through high value-added techniques and product diversification, as well as improve the energy efficiency of transport and develop public transport.

(3) Each country should develop a decarbonisation path that is tailored to its own circumstances. Although the eight countries in East Africa share a degree of similarity in economic and emissions patterns, studies have shown that the drivers of economic growth and emissions growth are significantly heterogeneous across countries. It is important to consider national circumstances and adapt to local circumstances, avoiding the 'instrumental thinking' of arbitrarily applying a policy that has worked in another country to the decarbonization process in that country. For example, for countries such as Ethiopia and Tanzania, where FDI and infrastructure development are progressing rapidly, it is important to introduce FDI into technology-intensive, high value-added sectors, to fully absorb the spillover effects of technology diffusion, and to avoid the country becoming a "haven" for the transfer of pollution from low value-added industries in developed countries. For countries such as Kenya that aim to revitalize their agriculture, they should actively develop the technological practice of converting agricultural waste into biomass energy, develop renewable energy sources such as starch fuel and plant alcohol fuel, and realize the green agriculture. Kenya should also take full advantage of the development of hydropower and geothermal energy and be a leader in the clean energy transition in East Africa.

(4) Develop agriculture and forestry in accordance with national circumstances to achieve synergy effects of employment, emission reduction and economic growth. Industrialisation is not the only way to revitalise the economies of all low-income countries, especially the poorest ones with a weak industrial base [41]. In fact, most countries in East Africa have a relatively good agricultural base which provides most of the jobs. The development of agriculture and forestry in accordance with national circumstances can be an effective way to balance economic development with emissions reduction [41]. Firstly, the agriculture, forestry and fishing industry itself has low energy requirements and low emission intensity, even carbon-negative. In our research Kenya's structural shift to commercial agriculture has reduced $CO_2$ emissions by 0.72 Mt. Afforestation is also a suitable way to increase carbon sinks in the East African context. This will significantly reduce costs for their emissions reduction commitments. Secondly, commercial agriculture can simultaneously increase employment and GDP if supported by technology and finance, bringing considerable potential synergies. East African countries should create special industries when they do not all have to be industrialised, such as livestock in the Netherlands. Coffee from Ethiopia and Kenya, bananas and drinks from Burundi all have the potential to become speciality products. Thirdly, agricultural and forestry crop waste is a low-cost renewable energy source compared to solar and wind power. International organizations such as the FAO are promoting prosopis biomass as a sustainable energy source in places such as Djibouti [42]. Renewable biomass fuels for distributed power generation in East Africa is promising and considerable in the future [43].

### 4.2. Discussion

In this paper, carbon emissions are accounted on a territorial basis according to the 2006 IPCC guidelines methodology. This approach has limitations when applied to the East African region. The accounting scope does not incorporate biomass fuels, which play an important role in East Africa and Africa as a whole. Over 80% of the primary energy supply in the countries in this study comes from biomass [44]. International agencies such as the IEA do not calculate biomass emissions because it is carbon neutral from a full life cycle perspective. The carbon they release when burned is the very carbon that is fixed during the growth process. Therefore the consumption of fallen branches, crop waste and forests of recycled fuel crops should not be included in the total emissions. Emissions of fuel woods from deforestation, which is very common before 2010, should be accounted for in the country's overall emissions, but the relevant data for emission accounting (e.g., quantity of wood used for burning, species of wood and emission factors) is difficult to collect. However, such emissions from biomass are becoming less and less, as countries including Kenya, Tanzania and Ethiopia have put strict restrictions on natural forest harvesting and charcoal trading since 2010 [45–47]. Our study also estimates the maximum potential biomass emissions using Ethiopia and Kenya as examples. Assuming that all firewood and charcoal are unsustainable, the biomass carbon emissions in 2017 for the two countries in 2017 are around 140 Mt and 45 Mt respectively (using the emission factors for firewood from the IPCC 2006 guidelines).

Our policy proposals for attracting green foreign investment appear idealistic in the current economic climate in East Africa. FDI plays an important role in improving the local energy and economic structures of developing countries, guided by scientific policies [48–50]. FDI can achieve economic growth and energy efficiency at the same time, i.e. investment in green technologies that bring profits. So this study suggests that it is important to consider not only the quantity but also the quality of investment when formulating policies. The foreign capital invested in high-tech and green industries could be increased. However, this policy proposal is in certain ways idealistic and limited in East Africa, because we have only considered the climate change perspective. When making an investment, it is necessary to consider a variety of factors, more in terms of economic costs and benefits. Investors mainly tend to take advantage of cheap labour and the available natural resources to increase their profits. This caused the conflict between economic development and climate change mitigation objectives. So we should place greater emphasis on improving production and energy efficiency, as well as on the development of renewable energy sources according to local conditions. More attention needs to be paid to the trade-off between economic development and climate governance in the future.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apenergy.2022.118805.

## References


[1] Le Quéré C, Korsbakken JI, Wilson C, Tosun J, Andrew R, Andres RJ, et al. Drivers of Declining CO2 Emissions in 18 Developed Economies. Nat Clim Change 2019;9 (3):213–7. https://doi.org/10.1038/s41558-019-0419-7.

[2] Dai H-C, Zhang H-B, Wang W-T. The Impacts of U.S. Withdrawal from the Paris Agreement on the Carbon Emission Space and Mitigation Cost of China, EU, and Japan under the Constraints of the Global Carbon Emission Space. Adv Clim Change Res 2017;8(4):226–34. 10/ggfzmc.

[3] Guan D, Meng J, Reiner DM, Zhang N, Shan Y, Mi Z, et al. Structural Decline in China's CO2 Emissions through Transitions in Industry and Energy Systems. Nat Geosci 2018;11(8):551–5. https://doi.org/10.1038/s41561-018-0161-1.

[4] Shan Y, Guan D, Hubacek K, Zheng Bo, Davis SJ, Jia L, et al. City-level climate change mitigation in China. Sci Adv 2018;4(6). https://doi.org/10.1126/sciadv.aaq0390.

[5] Pappas D, Chalvatzis KJ, Guan D, Ioannidis A. Energy and Carbon Intensity: A Study on the Cross-Country Industrial Shift from China to India and SE Asia. Appl Energy 2018;225:183–94. 10/gdxq4d.

[6] Sims REH, Rogner H-H, Gregory K. Carbon Emission and Mitigation Cost Comparisons between Fossil Fuel, Nuclear and Renewable Energy Resources for Electricity Generation. Energy Policy 2003;31(13):1315–26. 10/dsg6hx.

[7] Healey S, Jaccard M. Abundant Low-Cost Natural Gas and Deep GHG Emissions Reductions for the United States. Energy Policy 2016;98:241–53. 10/f9bk5m.

[8] Zhang M, Lv T, Zhao Y, Pan J. Effectiveness of Clean Development Policies on Coal-Fired Power Generation: An Empirical Study in China. Environ Sci Pollut Res 2020; 27(13):14654–67. 10/gh2krt.

[9] Oduro MA, Gyamfi S, Sarkodie SA, Kemausuor F. Evaluating the Success of Renewable Energy and Energy Efficiency Policies in Ghana: Matching the Policy Objectives against Policy Instruments and Outcomes. Renew Energy – Resources, Challenges Appl 2020. 10/gh24h9.

[10] Copic S, Djordjevica J, Lukic T, Stojanovic V, Djukicin S, Besermenji S, et al. Transformation of Industrial Heritage: An Example of Tourism Industry Development in the Ruhr Area (Germany). Geographica Pannonica 2014;18(2): 43–50.

[11] Jackson R, Quéré C, Andrew R, Canadell J, Korsbakken J, Zhu Liu, et al. Global Energy Growth Is Outpacing Decarbonization; 2018. doi: 10/gf66st.

[12] Pueyo A. What Constrains Renewable Energy Investment in Sub-Saharan Africa? A Comparison of Kenya and Ghana. World Dev 2018;109:85–100. 10/ghzdrc.

[13] Sarkodie SA, Adom PK. Determinants of Energy Consumption in Kenya: A NIPALS Approach. Energy 2018;159:696–705.

[14] UNECA. Macroeconomic and Social Developments in Eastern Africa 2020: Benchmarking Performance Towards National, Regional and International Goals; 2020.

[15] Abebe Tadege. Climate Change National Adaptation Program of Action (NAPA) of Ethiopia; 2007. Retrieved https://unfccc.int/resource/docs/napa/eth01.pdf.

[16] Ministry of Environment and Forest of Ethiopia. Intended Nationally Determined Contribution (INDC) of the Federal Democratic Republic of Ethiopia; 2015.

[17] IEA. Ethiopia Energy Outlook – Analysis; 2019. Retrieved January 23, 2021 https://www.iea.org/articles/ethiopia-energy-outlook.

[18] Kenya Energy and Petroleum Regulatory Authority. Power Generation and Transmission Master Plan, Kenya Long Term Plan 2015 - 2035 Vol I – Main Report. *Energy and Petroleum Regulatory Authority*; 2018. Retrieved February 5, 2021 https://www.epra.go.ke/download/power-generation-and-transmission-master-plan-kenya-long-term-plan-2015-2035-vol-i-main-report/.

[19] Mose NG. Renewable Energy and Nonrenewable Energy Consumption, $CO_2$ Emissions and Economic Expansion Nexus: Further Evidence from Kenya. Energy Econ Lett 2017;4(4):36–48. https://doi.org/10.18488/journal.82.2017.44.36.48.

[20] Alam MM, Hossain EB, Ringler C, Mekonnen D, Rosegrant M. Ethiopian Energy Status and Demand Scenarios: Prospects to Improve Energy Efficiency and Mitigate GHG Emissions. Energy 2018;149:161–72. https://doi.org/10.1016/j.energy.2018.02.067.

[21] Taka GN, Huong TT, Shah IH, Park H-S. Determinants of Energy-Based CO2 Emissions in Ethiopia: A Decomposition Analysis from 1990 to 2017. Sustainability 2020;12(10):4175. https://doi.org/10.3390/su12104175.

[22] Eggleston HS, Leandro Buendia, Kyoko Miwa, Todd Ngara, Kiyoto Tanabe. 2006 IPCC Guidelines for National Greenhouse Gas Inventories; 2006.

[23] Shan Y, Guan D, Zheng H, Ou J, Li Y, Meng J, et al. China $CO_2$ Emission Accounts 1997–2015. Sci Data 2018;5(1). https://doi.org/10.1038/sdata.2017.201.

[24] IEA. CO2 Emissions From Fuel Combustion 2020 Edition; 2020. Retrieved January 5, 2022 https://iea.blob.core.windows.net/assets/474cf91a-636b-4fde-b416-56064e0c7042/WorldCO2_Documentation.pdf.

[25] Ang BW. LMDI Decomposition Approach: A Guide for Implementation. Energy Policy 2015;86:233–8. 10/f7x569.

[26] Ang BW. The LMDI Approach to Decomposition Analysis: A Practical Guide. Energy Policy 2005;33(7):867–71. 10/dk94m7.

[27] Yang X, Wang S, Zhang W, Li J, Zou Y. Impacts of Energy Consumption, Energy Structure, and Treatment Technology on SO2 Emissions: A Multi-Scale LMDI Decomposition Analysis in China. Appl Energy 2016;184:714–26. 10/ghqfzp.

[28] WDB. World Bank Group – International Development, Poverty, & Sustainability. *World Bank*; 2021. Retrieved August 11, 2021 https://www.worldbank.org/en/home.

[29] AFDB. Home - Africa Information Highway Portal; 2021. Retrieved August 12, 2021 https://dataportal.opendataforafrica.org/.

[30] AFREC. AFREC | The African Energy Commission; 2019. Retrieved January 28, 2021 https://au-afrec.org/.

[31] EIA. International - U.S. Energy Information Administration (EIA); 2020. Retrieved May 13, 2021 https://www.eia.gov/international/overview/world.

[32] Rosen Jonathan W. As the World Cuts Back on Coal, a Growing Appetite in Africa. Science 2017. Retrieved March 16, 2021 https://www.nationalgeographic.com/science/article/lamu-island-coal-plant-kenya-africa-climate.

[33] Page John. Industry in Tanzania: Performance, Prospects, and Public Policy. 5th ed. UNU-WIDER; 2016.

[34] FAO. Kenya at a Glance | FAO in Kenya | Food and Agriculture Organization of the United Nations; 2020. Retrieved May 16, 2021 http://www.fao.org/kenya/fao-in-kenya/kenya-at-a-glance/en/.

[35] United Republic of Tanzania. Intended Nationally Determined Contributions of the United Republic of Tanzania; 2015. Retrieved January 15, 2021 (https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/United%20Republic%20of%20Tanzania%20First%20NDC/The%20United%20Republic%20of%20Tanzania%20First%20NDC.pdf).

[36] Bellini Emiliano. Tanzania Launches 150 MW Solar Tender. Pv Mag Int 2018; September 24.

[37] Meza Edgar. Tanzania Announces One Million Solar Homes Initiative. Pv Mag Int 2015;February 18.

[38] IEA. Tanzanian Energy Development Access Programme (TEDAP) – IEA/IRENA Renewables Policies Database. *IEA;* 2014. Retrieved January 24, 2021 (https://www.iea.org/policies/4963-tanzanian-energy-development-access-programme-tedap).

[39] UNCTAD. Services Policy Review: Rwanda; 2013. Retrieved August 14, 2021 (https://unctad.org/system/files/official-document/ditctncd2013d6_en.pdf).

[40] Wang Q, Jiang R. Is Carbon Emission Growth Decoupled from Economic Growth in Emerging Countries? New Insights from Labor and Investment Effects. J Cleaner Prod 2020;248:119188. https://doi.org/10.1016/j.jclepro.2019.119188.

[41] Newfarmer RS, Tarp F, Page J, editors. Industries without Smokestacks: Industrialization in Africa Reconsidered. Oxford, United Kingdom: Oxford University Press; 2018.

[42] FAO. FAO, Partners Explore Prosopis Biomass as Energy Source in Djibouti. Food and Agriculture Organization of the United Nations; 2017. Retrieved September 17, 2021 http://www.fao.org/africa/news/detail-news/en/c/903653/.

[43] Nzotcha U, Kenfack J. Contribution of the Wood-Processing Industry for Sustainable Power Generation: Viability of Biomass-Fuelled Cogeneration in Sub-Saharan Africa. Biomass Bioenergy 2019;120:324–31. 10/gn2tts.

[44] Bailis R, Drigo R, Ghilardi A, Masera O. The Carbon Footprint of Traditional Woodfuels. Nat Clim Change 2015;5(3):266–72. 10/f6455n.

[45] Doggart N, Ruhinduka R, Meshack CK, Ishengoma RC, Morgan-Brown T, Abdallah JM, et al. The Influence of Energy Policy on Charcoal Consumption in Urban Households in Tanzania. Energy Sustain Develop 2020;57:200–13.

[46] Njoroge P, Ambole A, Githira D, Outa G. Steering Energy Transitions through Landscape Governance: Case of Mathare Informal Settlement, Nairobi, Kenya. Land 2020;9(6):206. 10/gnx2x9.

[47] Rarieya Y. Tanzania to Ban Use of Charcoal to Save Forests. *CGTN Africa*; 2018. Retrieved March 15, 2021 https://africa.cgtn.com/2018/01/11/tanzania-to-ban-use-of-charcoal-to-save-forests/.

[48] Demena BA, Afesorgbor SK. The Effect of FDI on Environmental Emissions: Evidence from a Meta-Analysis. Energy Policy 2020;138:111192. https://doi.org/10.1016/j.enpol.2019.111192.

[49] Romano AA, Scandurra G, Carfora A, Fodor M. Renewable Investments: The Impact of Green Policies in Developing and Developed Countries. Renew Sustain Energy Rev 2017;68:738–47. 10/gn2ntk.

[50] Song M, Tao J, Wang S. FDI, Technology Spillovers and Green Innovation in China: Analysis Based on Data Envelopment Analysis. Ann Oper Res 2015;228(1):47–64. 10/f69hmz.