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Determinants of Energy-Based CO₂ Emissions in Ethiopia: A Decomposition Analysis from 1990 to 2017

Gideon Nkam Taka ^{1,2}, Ta Thi Huong ¹, Izhar Hussain Shah ³ and Hung-Suck Park ^{1,*}

¹ Department of Civil and Environmental Engineering, University of Ulsan, Daehak-ro 93, Nam-gu, Ulsan 44661, Korea; gideon taka@gmail.com (G.N.T.); tahuong.hus@gmail.com (T.T.H.)

² Department of Environmental Sciences, Faculty of Science, University of Buea, P.O. Box 63, Buea 12345, Cameroon

³ Institute of Environmental Sciences and Engineering, School of Civil and Environmental Engineering, National University of Sciences and Technology (NUST), Islamabad 44000, Pakistan; izhar88@hotmail.com

* Correspondence: parkhs@ulsan.ac.kr; Tel.: +82-52-259-1050; Fax: +82-52-221-0152

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Abstract: Ethiopia, among the fastest growing economies worldwide, is witnessing rapid urbanization and industrialization that is fueled by greater energy consumption and high levels of CO₂ emissions. Currently, Ethiopia is the third largest CO₂ emitter in East Africa, yet no comprehensive study has characterized the major drivers of economy-wide CO₂ emissions. This paper examines the energy-related CO₂ emissions in Ethiopia, and their driving forces between 1990 and 2017 using Kaya identity combined with Logarithmic Mean Divisia Index (LMDI) decomposition approach. Main findings reveal that energy-based CO₂ emissions have been strongly driven by the economic effect (52%), population effect (43%), and fossil fuel mix effect (40%) while the role of emission intensity effect (14%) was less pronounced during the study period. At the same time, energy intensity improvements have slowed down the growth of CO₂ emissions by 49% indicating significant progress towards reduced energy per unit of gross domestic product (GDP) during 1990–2017. Nonetheless, for Ethiopia to achieve its 2030 targets of low-carbon economy, further improvements through reduced emission intensity (in the industrial sector) and fossil fuel share (in the national energy mix) are recommended. Energy intensity could be further improved by technological innovation and promotion of energy-frugal industries.

Keywords: carbon emissions; low-carbon growth; developing countries; energy efficiency; decomposition analysis; industrial ecology; Ethiopia

1. Introduction

A hike in global warming, the accumulation of carbon dioxide (CO₂) emissions and greenhouse gas (GHG) emissions have attracted global attention. Most recently, an increasing number of countries have embarked on the road to promoting industrialization and economic restructuring and this has consequently led to higher levels of energy-related CO₂ emissions. In addition, rapid population growth and urbanization have been huge contributors to the changes in CO₂ levels around the globe [1]. Emissions of CO₂ are also a strong environmental consequence of economic development around the world [2]. Africa, with the lowest Human Development Index (HDI) in the world, has an obvious need to strive for economic posterity at all costs in the years ahead [3]. Around the globe, there is undeniable ample evidence of increasing CO₂ emissions, with Africa ranked the most susceptible to global warming. With the rising share of fossil fuels as an energy resource, two major challenges have emerged especially for the developing economies, namely: increasing CO₂ emissions and lowering efficiency of energy consumption [4]. This region has set sustainable development targets of reducing

CO₂ emissions by 80% from 1990 to 2050, with 1.44 global hectares (gha) per capita of development in ecological footprints and an increase in their HDI. Economic growth, high population and other factors have led to experience an increase in CO₂ emissions in Sub-Saharan Africa (SSA) countries [5]. The strong connection between energy use and economic growth has led to ever-increasing CO₂ emissions, and thus has directly affected the environment and local ecosystems [6,7]. In addition, a rapid depletion of non-renewable energy resources has also taken place worldwide [8] with huge implications for Africa's future economic development.

From a prospective viewpoint, Africa's future energy use is expected to be influenced by a fast-growing population and expanding economic activities, thus making the region more relevant from the global supply chain perspective [9]. Ethiopia is among the African countries that have achieved slow technological advancement, in the face of structural economic challenges, and have depended largely on rain-fed agriculture that is greatly damaged by droughts and witnessed overexploitation of natural resources [10,11]. Ethiopia is also among the five nations (Nigeria, South Africa, Angola, Kenya and Ethiopia) that make up 70% of the gross domestic product (GDP) of SSA and 40% of its population [3]. As far as energy consumption is concerned, the total primary energy supply (TPES) in Ethiopia is primarily from biofuels and waste (Figure 1). Although electricity generation is mainly hydroelectric (the country has a large hydropower infrastructure), yet the TPES comes from biofuels and waste followed by fossil fuels [12].

Figure 1. Total primary energy supply in Ethiopia measured as ktoe (1990–2017) [12]. (Note: biofuels and waste are shown in the secondary axis).

Meanwhile, many studies have confirmed Kaya identity (extended IPAT approach, where “I” stands for environmental impact, “P” for population, “A” for affluence and “T” for technology) as a tool to assess a variety of determinants (population, economic growth, energy intensity, fossil fuel mix and emission intensity) with a flexibility of adding more factors to investigate drivers of environmental impacts. Previously, different variables have been introduced into this Kaya framework such as the labor input effect [13], industrial structure effect [14], and fuel mix component effect [15]. The application of Kaya identity has been quite global with several studies for China, Europe and United States [16], G20 countries [17], Cameroon [18], and other parts of Africa [19–22]. Among different variations of Kaya identity, some groups of researchers have used the Autoregressive Distributed Lag (ARDL) and the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) models in decomposition related studies. The STIRPAT model has been previously used for multi-country comparisons [23], and for different countries such as Ghana [24], Tunisia [25], the United States [26], China [27–29], and for several developing economies and economic sectors [30–32].

According to [33], within the global CO₂ emissions in 2018 as represented by 65.7 MtCO₂ in East Africa, Ethiopia accounts for only 15 MtCO₂. Although Ethiopia is ranked 94th in the world, it is very far from being one of the world's largest emitters of CO₂. It is currently the third largest emitter of CO₂ in East Africa, alongside Sudan (21 MtCO₂), Kenya (19 MtCO₂), Tanzania (13 MtCO₂),

Uganda (5.8 MtCO₂), Republic of South Sudan (1.9 MtCO₂), Rwanda (1.1 MtCO₂), Somalia and Eritrea (0.7 MtCO₂) each, and Burundi (0.5 MtCO₂). Following the Paris Agreement, Ethiopia is set to reduce its GHG emissions by 64% below the business-as-usual levels by 2030. To succeed with this high emission reduction target in a low-carbon growth economy, knowledge of changes in the country's CO₂ emissions and their determinants must be assessed quantitatively in order to devise informed policy decisions.

To quantitatively determine the drivers of environmental impact, such as energy-based CO₂ emissions, the Logarithm Mean Divisia Index (LMDI) is a well-regarded decomposition analysis approach [34]. The main strength of this method is that it can be applied to more than two factors and it would give a perfect decomposition; it creates a link between the multiplicative and additive decomposition, thereby giving estimates of an effect on the sub group level [35–38]. In recent years, this approach has been applied at various levels, both national and sub regional [27,39] such as in China [40,41], Latin America [42], the United States [30], Iran [43], India [44], Pakistan [45], Philippines [46], the European Union [47], Greece [48], Spain [49], Ireland [50], South Korea [51], United Kingdom [52], Brazil [53], and Turkey [54].

Until the present day, there has not been any single study on the decomposition of CO₂ emissions in Ethiopia, which considers all five determinants selected in this study (population, economy, energy intensity, fossil fuel mix, and emission intensity). As per the literature review, this is the first study to assess five factors using the Kaya identity and LMDI for CO₂ emissions in Ethiopia. The various determinants of carbon emissions studied can well provide more indicators that would expand the existing mitigative strategies in order to curb GHG emissions, and therefore help to attain the mitigation targets set by the country. Secondly, the data used in this study is the most recent available (including data for until 2017). In addition, the study of the determinants of CO₂ emissions in Ethiopia could help strengthen carbon mitigation practices in Ethiopia as well as at the African regional level. With this circumstance, this study aims to achieve following research objectives:

- (i) Examine the determinants for Ethiopia's CO₂ emissions from 1990–2017;
- (ii) Assess the effect of each determinant with its effect coefficient factor;
- (iii) Elaborate on policy implications for Ethiopia towards achieving low-carbon and sustainable economic development.

The study analyses the effect of five determinants on Ethiopia's CO₂ emissions from 1990–2017: population, economic growth, energy intensity, fossil fuel mix and emission intensity, together with their effect coefficient for the very first time. An extended Kaya identity and LMDI decomposition are used to explain the various determinants of Ethiopia's CO₂ emissions. Africa being most susceptible to global warming issues and Ethiopia among the top CO₂ emitters in East Africa makes this study very pertinent in curbing emissions in developing African countries. Additionally, Ethiopia is emerging as a manufacturing hub of Africa with increasing consumption of total primary energy, which requires huge attention as concerns CO₂ emission issues. The rest of the article is organized as follows: in the next Section 2, we present the materials and methods used in the study, followed by Section 3 which presents the results, while Section 4 presents the policy implications and recommendations. Finally, Section 5 presents the conclusion of the study.

2. Materials and Methods

The overall methodological framework applied in this study is illustrated in Figure 2. Firstly, the use of Kaya identity with LMDI approach was integrated to decompose changes in CO₂ emissions in Ethiopia from 1990–2017. As shown, extended Kaya identity and LMDI approach served as the basis of analysis in which activity effect was analyzed for five different drivers of CO₂ change. The extended Kaya identity and LMDI approach was used to analyze the population effect, economic growth effect, energy intensity effect, fossil fuel mix effect and emission intensity effect. The Kaya identity is a renewed version of the IPAT identity postulated previously [55,56].

Figure 2. Methodological approach followed in this study.

Next, a policy analysis was performed to better understand the energy policy developments in Ethiopia based on official reports and policy documents, in relation to changing carbon emissions in the country. This analysis carried out to overview the situation from a regional perspective.

2.1. Socio-Economic Status of Ethiopia

Ethiopia is located Northeast of Africa, at the horn of the continent, surrounded by Sudan to the East, Kenya to the North, Eritrea to the South, Djibouti to the West and Somalia to the Northeast [57]. In 2018, Ethiopia ranked second in SSA in terms of population (107.5 million) and fifth in economic status in Africa (2018) (GDP of 80.3 billion USD) [58]. During the last two decades, the country has undergone huge structural and economic changes, and experienced high economic growth, averaging 10.9% a year from 2005–2015, according to official data, and compared to its regional average of 5.4% [59,60]. As of 2018, the share of industries in national GDP was 28.1% which was considerably lower than that of services (40.0%) and agriculture (33.3%). But later, the Ethiopian economy recorded a 9% growth in 2018–2019, with a 12.6% growth by the industrial sector. With a shift from agriculture to manufacturing in recent years, Ethiopia is fast becoming the manufacturing hub of Africa with enormous progress made, especially following policies which include the Growth and Transformation Plan (GTP) [61]. Socio-economic statistics for Ethiopia from 1990–2017 are presented in Table 1.

Table 1. Socio-economic statistics for Ethiopia from 1990–2017 (The World Bank, 2018).

Year	1990	1995	2000	2005	2010	2015	2017 ^b
Population (Million)	47.9	57.0	66.2	76.3	87.6	100.8	106.4
GDP, Billion USD ^a	9.9	10.5	13.1	17.9	29.9	48.7	58.3
GDP per capita, USD	208.1	183.5	197.4	233.9	341.6	482.6	548.1
GDP Growth Rate (%)	2.7	6.1	6.1	11.8	12.6	10.4	9.5

^a based on constant US dollar prices of 2010. ^b Data are in intervals of 5 years with a last segment of two years to reflect the extent of the study period.

From a policy perspective, in response to global rising carbon emission levels, Ethiopia is a signatory to the United Nations Framework Convention on Climate change (UNFCCC), as ratified in 1994, followed by the Kyoto Protocol ratified in 2005, and the Paris Agreement ratified in 2017. These protocols set certain nationwide emission reduction targets. Ethiopia has made several policy efforts to fulfill carbon emission mitigation, such as the 1994 Environmental Policy, the Climate-Resilient Green Economy (CRGE) Strategy, GTP policy (2010–2015 and 2015–2020), etc. The GTPs as its development

framework, Ethiopia has registered GDP growth rates averaging slightly above 10% [62]. Poverty levels have been reduced substantially and Ethiopia is on track to meet most of the Millennium Development Goals (MDGs). Ethiopia is now embarking on GTP II, with the goal of moving towards a low-carbon growth economy, with middle-income status by 2025 [63]. The government of Ethiopia intends to curb its GHG emissions by 2030 to 145 MtCO₂e, in line with the 255 MtCO₂e reductions projected by business-as-usual emissions with the integration of CRGE and GTP II, with the GTP II aiming at achieving a carbon neutral economy. Currently at 1.8 tCO₂e, Ethiopia's per capita GHG emissions are not high compared to global average, but achieving its targets of reducing to 1.1 tCO₂e by 2030 is a priority concern [64].

2.2. Kaya Identity Approach

Kaya identity has been applied to many fields of energy, energy economics, environmental science, climate change, resource metabolism, etc.; examples include [50,65–67]. Here, assumptions of population growth, economic factors, and energy technology, as well as the carbon cycle itself play an important role in predicting the growth of CO₂ emissions. The conventional approach related to developing a series of emission scenarios depends on those factors and the use of those scenarios to manipulate mathematical models on how the atmospheric and climate systems will react with these inputs. At the therapeutic level given in the short section, we cannot begin to approach the complicated models. However, we can perform some simple calculations to at least give some meaning to some important factors. One way to establish some simple models of environmental problems is to start with the notion that the impacts are driven by the population, affluence and technology, also called the IPAT equation.

$$\text{Environmental Impacts} = (\text{Population}) \times (\text{Affluence}) \times (\text{Technology}) \quad (1)$$

The following application of IPAT for carbon emissions from energy sources is often referred to as the Kaya identity, which is a more concrete form of IPAT in this case. Kaya identity, a modified/extended form of the IPAT equation, is often used to study carbon emissions related with energy resources [68]. In this study, we have used the Kaya identity framework to calculate the environmental impact of energy consumption for Ethiopia during 1990–2017, as given by Equations (2)–(4). The factors in Equation (2) represent ratios which are part of the Kaya identity and these factors showcase the relationship between anthropogenic CO₂ emissions and its determinants.

$$C = \text{Population} \times \frac{\text{GDP}}{\text{Population}} \times \frac{\text{TPES}}{\text{GDP}} \times \frac{\text{FFC}}{\text{TPES}} \times \frac{\text{CO}_2}{\text{FFC}} \quad (2)$$

Here the environmental impacts “C” are represented by carbon emissions, other factors include population “P”, affluence “A” expressed as GDP per person, technology “T” expressed as energy consumption per unit of GDP, and finally fossil fuel consumption “FFC” which is a fraction of TPES as fossil fuels. In this study, we have extended both the IPAT equation and Kaya identity as given by Equations (3) and (4). When incorporating the fossil fuel consumption (FFC) per unit of TPES (fossil fuel mix effect) we get Equation (3) or its simplified version in Equation (4)

$$I_t = P_t \times \frac{\text{GDP}_t}{P_t} \times \frac{\text{TPES}_t}{\text{GDP}_t} \times \frac{\text{FFC}_t}{\text{TPES}_t} \times \frac{\text{CO}_{2t}}{\text{FFC}_t} \quad (3)$$

and simplified as

$$I_t = P_t \times A_t \times E_t \times F_t \times C_t \quad (4)$$

where I = CO₂ emissions (Mt), P = national population, A = affluence considered in terms of GDP per capita measured in constant US dollar prices of 2010, and T = technology. In Equation (4), P_t and A_t are the population and affluence at time t , E_t represents energy intensity in terms of TPES per unit

of GDP measured in Mt per million USD, F_t represents fossil fuel mix effect, in terms of fossil fuel consumption (FFC) per unit of TPES, and C_t represents emission intensity in terms of CO₂ emissions per unit of FFC. All five impact categories in Equation (4) will be used to analyze their relative impacts on CO₂ emissions during 1990–2017 in Ethiopia.

2.3. Decomposition and Effect Coefficient Analysis

The LMDI decomposition analysis proposed in [34] is popular in evaluating the determinants of carbon emissions in various case scenarios. Based on the Kaya identity, the following equations illustrate the universal form of LMDI decomposition analysis. At the start year ($t = 0$) and end year ($t = 27$), using Equation (5), changes in the total environmental impact “ ΔI_t ” is calculated.

$$I_i(t) = P_i(t) \times A_i(t) \times E_i(t) \times F_i(t) \times C_i(t) \quad (5)$$

where ΔP_t represents the population effect, ΔA_t represents economy (or income) effect, ΔE_t represents the energy intensity effect, ΔF_t represents the fossil fuel mix (or substitution) effect, and ΔC_t represents the emission intensity effect. Each of the activity effect parameters will be calculated using Equations (6)–(10), respectively:

$$\Delta P_t = \sum \frac{P_{t_1} - P_{t_0}}{\ln P_{t_1} - \ln P_{t_0}} \times \ln \frac{P_{t_1}}{P_{t_0}} \quad (6)$$

$$\Delta A_t = \sum \frac{A_{t_1} - A_{t_0}}{\ln A_{t_1} - \ln A_{t_0}} \times \ln \frac{A_{t_1}}{A_{t_0}} \quad (7)$$

$$\Delta E_t = \sum \frac{E_{t_1} - E_{t_0}}{\ln E_{t_1} - \ln E_{t_0}} \times \ln \frac{E_{t_1}}{E_{t_0}} \quad (8)$$

$$\Delta F_t = \sum \frac{F_{t_1} - F_{t_0}}{\ln F_{t_1} - \ln F_{t_0}} \times \ln \frac{F_{t_1}}{F_{t_0}} \quad (9)$$

$$\Delta C_t = \sum \frac{C_{t_1} - C_{t_0}}{\ln C_{t_1} - \ln C_{t_0}} \times \ln \frac{C_{t_1}}{C_{t_0}} \quad (10)$$

Following the decomposition approach, we also used effect coefficient analysis to further study the changing impact of drivers of CO₂ emissions over time. The effect coefficient of each driving force (effect) was calculated using Equation (11):

$$e_P = \frac{\Delta P}{I_{Abs}}; e_A = \frac{\Delta A}{I_{Abs}}; e_E = \frac{\Delta E}{I_{Abs}}; e_F = \frac{\Delta F}{I_{Abs}}; e_C = \frac{\Delta C}{I_{Abs}} \quad (11)$$

where, $I_{Abs} = |\Delta P| + |\Delta A| + |\Delta E| + |\Delta F| + |\Delta C|$

2.4. Data Collection

The CO₂ emissions data for Ethiopia were compiled using national emission records for the years between 1990 and 2017 and were complemented by energy use data from the International Energy Agency (IEA) database [12], where required. Country population and GDP were acquired from national economic reports and global databases, such as the World Bank database. For the policy analysis, there were publicly available policy documents, such as the CRGE, GTP (2010–2015 and 2015–2020) as describe in Section 2.1. Some of the official reports by the Government of Ethiopia and IEA were also analyzed.

3. Results

This section presents the outcomes of this work based on the Kaya identity and LMDI decomposition. Activity effect and its coefficient analysis are also discussed in this section.

3.1. Kaya Identity Analysis

Results for the five parameters considered in the Kaya identity analysis such as the changes in population, economy, energy intensity, fossil fuel mix, and emission intensity, during the study period, are illustrated in Figure 3. As observed over the study period, most parameters have increased steadily over the study period (1990–2017) while only energy intensity was seen to be declining over the same period. As per the statistics for the period 1990–2017, the population grew by 122.1% (from 47.9 million in 1990 to 106.4 million in 2017), while the per capita GDP rose by 163.4% (from 208.1 USD in 1990 to 548.1 USD in 2017). This is indicative of large significant economic prosperity achieved by Ethiopia during the study period. The population is a strong factor for CO₂ emissions, as there is a linear relationship; as it grows, human consumption patterns also swell, creating the need for fuel increases and increasing anthropogenic contributions to global emissions [69]. With the implementation of the second phase GTP policy (2015–2020), several industrial parks are being developed throughout the national territory, which plays an important role in boosting economic growth in Ethiopia [70]. Economic growth, asset consumption and financial affluence do affect the CO₂ emissions and could cause high consumption of non-renewable energy resources [71]. Endowed with a higher economic growth rate, Ethiopia was able to rapidly develop urban and industrial infrastructures, transforming some of the industrial parks to eco-industrial parks, and thereby uplifting living standards of the growing population [20]. Considering the technological advancement and foreign direct investments in the industrial, agricultural and service sectors, a rising fuel mix share of 49.4% was observed (0.045 in 1990 to 0.89 in 2017). This indicated a high rate of consumption of fossil fuels in the country. The rising intensity of fuel mix was observed accompanied by rising economic growth and industrialization, indicating a rapid carbonization of the local economy. Similarly, emission intensity has also been on the rise in Ethiopia evidently by rising energy consumption. From 1990 to 2017, emission intensity increased from 2.46 to 3.22 (Mt CO₂ per ktoe of fossil fuels) indicating higher emissions being released. The country is, however, considered energy insecure because of rising emission intensity that is mainly due to changing industrial structures and rising CO₂ emissions from non-fossil fuel resources, such as biomass, wood, etc., as well as inefficient use of fossil fuel resources and the lack of high-efficiency energy conversion technologies, such as power plants, industrial boilers, steam generators, etc. [21]. Moreover, the early 1990s saw a drop in emission intensity mainly attributable to the industrial restructuring efforts in Ethiopia, whereas the years 2015–2017 have shown rising emission intensity as the industrial and GDP growth rates also increased sharply in those years.

Figure 3. Temporal changes in selected parameters used in this study.

The energy intensity of Ethiopia surprisingly is the only factor that decreased over the study period, that is from 1.81 (toe per 1000 USD) in 1990 to 0.72 (toe per 1000 USD) in 2017, indicative of a significant drop. As Ethiopia heavily relies on biomass and waste for energy, improved cook-stoves, universal electrification, and efficient lighting as measures put in place by Ethiopia, have gone a long way to improve emission intensity in recent years [22].

3.2. Decomposition Analysis

The five determinants of CO₂ emissions for Ethiopia are analyzed from 1990 to 2017. With an interval of five years and for 2016–2017, the determinants of carbon emissions and their relative contributions are presented in Table 2 (effect during the entire study period is also given in the last column). As shown, during the first half of the 1990s, CO₂ emissions were largely driven by emission intensity because the rising population growth was pushing for increasing use of fossil fuels. This was closely followed by higher population growth which also greatly affected the agricultural patterns and hence the carbon emissions in the country. It is well known that an increase in the population would put pressure on rising energy consumption patterns and hence cause higher impact on carbon emissions. The role of energy intensity in Ethiopia was less pronounced, yet it is important enough to be considered in national level policies. During the very same period, fossil fuel mix effect and affluence played a significant role in slowing down CO₂ emissions in Ethiopia. This can be attributed to the popular use of biomass, promotion of low-carbon energy sources, and improved methods of cooking (with environmentally friendly stoves) during that period. However, this was the only period when fossil fuel mix effect and economy effect were relatively low, and this helped to slow down the rate of carbon emissions significantly.

Table 2. Decomposition results for Ethiopia based on Kaya framework, %.

Effect (%)	5-Year Intervals					Full Period
	1990–1996	1996–2001	2001–2005	2006–2011	2011–2017	1990–2017
Population	50.98	50.85	63.24	41.13	26.79	42.65
Economy Effect	−9.86	13.35	86.90	113.26	63.83	51.75
Energy Intensity	8.38	−6.14	−86.01	−108.58	−61.17	−49.13
Fossil Fuel Mix	−0.97	51.70	10.15	47.82	68.68	40.26
Emission Intensity	51.47	−9.77	25.72	6.37	1.87	14.48

During the latter part of 1990's, change in CO₂ was mainly driven by the fossil fuel mix effect and population growth. Meanwhile, energy intensity and emission intensity played the smallest role in changing the carbon emissions. As the years went by, the economy effect, population factor and emission intensity caused a rise in CO₂ emissions from this point onwards. During 2001–2005, CO₂ emissions more than doubled from previous periods and thus indicated a rise in carbonization from national economic development, and the impacts that played a positive role were economy effect, population increase, and emission intensity. The period from 2006 to 2011 also saw a substantial increase in carbon emissions driven by economy effect, fossil fuel mix effect, and population effect. Thus, this period was highly responsible for increased CO₂ emissions in Ethiopia and apparently no effective effort was made towards carbon emission mitigation. This is usually the case with developing countries that always consider improvement in energy efficiency with the aim of reducing energy consumption patterns to output [19]. However, between 2011 and 2017, emission intensity was improved, and the population factor was greatly improved, both resulting in slowing down the rising CO₂ emissions. On the whole, during the entire study period, the major driver of CO₂ emissions was found to be affluence (promoting higher consumption patterns), followed by population influx (higher resource demand per capita); also followed closely was fossil fuel mix effect (rising fossil fuel shares), emission intensity (higher CO₂ emissions per unit of FFC). The only negative driver of CO₂ emissions during 1990–2017 was found to be energy intensity (more economic output per unit of TPES).

Thus, in order to promote a low-carbon growth, energy intensity could be focused in the future to further slowdown the growth in carbon emissions [72].

3.2.1. Population Effect and Its Coefficient

As shown in Table 2, population played a significant role in increasing carbon emissions during the study period (1990–2017). This is a clear indication that population growth is directly proportionate to CO₂ emissions and in future, population growth and urban demographic patterns will directly increase carbon emissions. Rising population is also an indication of increase in household size, high levels of urbanization, emerging infrastructure, increased transport facilities, increase in levels of energy consumption, change in lifestyle patterns and an ever-increasing exploitation of natural resources. Results for population effect and its coefficient for CO₂ emissions in Ethiopia from 1990–2017 are shown in Figure 4.

Figure 4. Population effect and its coefficient effect for CO₂ emissions.

As shown in Figure 4, population effect (colored red) has been fluctuating upward. Within the study period from 1995 to early 2000, the population was relatively stagnant, but with a rather high coefficient effect, the share of population effect is somehow at a standstill and other determinants in the study are relatively becoming stronger drivers of CO₂ emissions. For the entire study period, the coefficient population effect was reduced from 0.15 in 1990 to 0.10 in 2016, which is a 33% drop implying an overall drop with the impact share. Studies have proven that population growth contributes enormously to CO₂ emissions in both developed and developing countries [69] and with a steady rise in both populations and with CO₂ emissions in Ethiopia, much attention is needed to reduce the CO₂ emissions per capita. In this regard, some efforts made by the government of Ethiopia to promote low-carbon economic development should be appreciated. However, more efforts are required to protect their population from adverse effects of climate change such as extreme droughts through responsive action against climate change.

3.2.2. Economic Growth Effect and Its Coefficient

Economic growth is synonymous to affluence, standards of living and the socio-economic performance of a country. As Ethiopia has made a good economic progress during the study period, it has heavily impacted its CO₂ emissions as well. So far, Ethiopia has witnessed relatively fast growth in per capita GDP levels, higher consumption of finished goods, material intensive living patterns, and increased overall energy consumption. As given in Table 2, rising affluence was the major driver of carbon emissions in the country during 1990–2017. This can be seen at its peak between 2006–2011. Results for the economy effect and its coefficient for CO₂ emissions in Ethiopia from 1990–2017 are shown in Figure 5.

Figure 5. Economic growth effect and its coefficient for CO₂ emissions.

As seen in Figure 5, the economic growth effect was fluctuating in the early and late 1990s but assumed a sharp rise from the year 2000 onwards. Especially in the year 2003, the Ethiopian economy experienced an economic boom, and this had a bearing on economic growth, and by extension, on the standards of living. This did not come without a spinoff in CO₂ emission levels. However, the economic growth somehow experienced another fluctuation between 2004 till 2011 before having a dramatic increase until date. This also strongly accounted for the changes in CO₂ emissions. For the period 1990 to 2017, economic growth effect coefficient increased from -0.44 in 1990 to 0.26 in 2017, indicating a large rise in its overall impact share. This highlights the fact that desirable economic prosperity will invite unwanted environmental implications along the way. As a way forward, Ethiopia, and the countries alike, could achieve sustainable economic growth by promoting clean energy technologies, and by incorporating the concepts of material circularity in their urban, regional, and industrial development as part of their sustainable development strategy.

3.2.3. Energy Intensity Effect and Its Coefficient

In this study, energy intensity was represented by TPES per unit of GDP. It expresses the energy requirement of an economy with increasing values indicating higher energy demand from the economic processes. Moreover, as energy intensity rises, carbon emission intensity also rises indicating a direct relationship and a recoil effect of economic growth and higher energy demand. As shown in Table 2, energy intensity was the only driver of carbon emissions with the most negative values (apart from 1990–1991) and it helped slow down rising CO₂ emissions in Ethiopia. The trend for energy intensity in Ethiopia was a downward slope, indicating an improvement of the efficiency of energy use. The results for energy intensity effect and its coefficient for CO₂ emissions in Ethiopia during 1990–2017 are shown in Figure 6.

As shown in Figure 6, energy intensity effect has dwindled over the last few decades. Especially during 2004–2005 and 2014–2015 when energy intensity effect decreased significantly, indicating its slowing effect on CO₂ emissions during these periods. Moreover, the energy intensity effect coefficient has been coincidental with the energy intensity effect, indicating its fluctuating relative impact on net carbon emissions has remained somehow similar. This means the share of energy intensity in 1990 has not changed much in 2017 as well. For the entire study period, the energy intensity effect coefficient decreased from 0.32 in 1990 to -0.26 in 2017, a substantial change in its overall impact share. With heavy reliance on biomass and waste for energy, and the lack of up-to-date energy technologies, Ethiopia needs to further improve its energy intensity to curb rising carbon emissions. To this end, hydropower is could be an important source of clean renewable energy in Ethiopia. Acknowledgement is made of

the improved cook-stove initiative, efficient lighting systems and the universal electrification, which are promising efforts in Ethiopia to improve energy intensity [22]. Other measures to further improve energy intensity in Ethiopia could be to change the light bulbs to those with lower voltage (use of LED bulbs in lightening), consumption and minimization of energy waste, capacity building and public awareness towards energy savings.

Figure 6. Energy intensity effect and its coefficient for CO₂ emissions.

3.2.4. Fossil Fuel Mix Effect and Its Coefficient

Fossil fuel mix effect refers to the proportion of fossil fuels in TPES, which is an important factor in determining the changing impact of fossil fuels and non-fossil resources on carbon emissions. For the study period, Ethiopia's share of fossil fuels has been unsteadily rising, as seen in Figure 7. Presented in Table 2, the impact of fossil fuel mix effect has been second (after population effect) in rising CO₂ emissions. Results for the fossil fuel mix effect and its coefficient for CO₂ emissions in Ethiopia for 1990–2017 are shown in Figure 7.

Figure 7. Fossil fuel mix effect and its coefficient for CO₂ emissions.

As shown above (Figure 7), the fossil fuel mix effect has mostly fluctuated during the study period with a peak shown for the year 2014. This indicates that the fossil fuel mix effect has been a uniform driver of carbon emissions in the country, and extraordinarily little structural change has occurred to

minimize the fossil fuel mix effects. Although there have been periods when the fossil fuel mix effect helped in slowing down CO₂ emissions, its overall impact has been positive. Moreover, the fossil fuel mix effect coefficient has followed a similar trajectory to the energy intensity effect, indicating a strong coupling of the two factors. In the near future, alternate energy resources such as the wind energy, solar, bioenergy, and geothermal could be developed to support the existing hydroelectric resources. Short-term measures could include the use of fuel-efficient on-road vehicles, reduced travelling per person per car (e.g., carpooling and sharing) in order to minimize country's CO₂ emissions coming from fossil fuel combustion.

3.2.5. Emission Intensity Effect and Its Coefficient

Emission intensity effect refers to the emissions of CO₂ per unit fossil fuels that are consumed, and this can clearly predict the changing energy mix and technological advancement. With increasing demand for fossil fuels in Ethiopia, as the population grows with time, CO₂ emissions per unit fossil fuels consumed has increased, indicating higher emissions now as compared to the previous years. This can be partly attributed to the increased use of coal and petroleum fuels, as compared to natural gas. Moreover, ageing energy infrastructure and mobile sources (such as vehicles) also have a negative effect on Ethiopia's emission intensity. As shown in Table 2, the impact of emission intensity effect on CO₂ emissions has been negative during the late 1990s and positive during the rest of the period. Results for emission intensity effect and its coefficient for CO₂ emissions in Ethiopia during 1990–2017 are shown in Figure 8.

Figure 8. Emission intensity effect and its coefficient for CO₂ emissions.

As shown above (Figure 8), the emission intensity effect has been fluctuating during the study period 1990–2017. The emission intensity effect had the value of 14.48 during 1990–2017 (Table 2) which indicates less prominent impact on rising carbon emissions in comparison with other positive drivers. This means that current emission intensity levels are less harmful to the levels of CO₂ emissions when compared with economy effect, population effect, and fuel mix effect. Nonetheless, attention must be paid to minimizing emission intensity through innovative structural changes. With increasing carbon emissions from fossil fuels, the emission intensity effect coefficient has dropped slightly during 1990–2017 indicating a diminishing impact share for this determinant.

4. Policy Implications and Recommendations

In view of the present results and Ethiopia's target on limiting its net GHG emissions by 2030 to 145 Mt CO₂e, it is pertinent to draw up some policy insights based on this study and make key

recommendations for the future. At the country level, rising CO₂ emissions and air pollution issues have made it necessary for Ethiopia to draw up strategies to combat these environmental adversities. In addition, as the Government of Ethiopia has put in place a number of strategies and programs aimed at enhancing the adaptive capacity against climate change, reducing the vulnerability of the country to CO₂ emissions still remains a great challenge. Policy initiatives such as CRGE and GTP are now greatly focusing agriculture, forestry, renewable energy and advanced technologies to develop a green economy. In addition, issues related to the environment, forests and climate change are being actively discussed at the national level. During the last two decades, emissions have been shifting their major sources; formerly the emissions were mainly from the agricultural sector (including livestock, soils, forestry etc.), but currently a huge portion of the emissions are coming from the industrial sector (including manufacturing and building construction). Some of the important policy implications based on the results of the study are outlined below.

- From the population standpoint, organization of trainings and capacity building programs could be implemented regarding green issues and the issues of carbon emissions. These can be complemented by increasing public awareness on energy savings and conservation to curb rising carbon emissions and poor air quality issues currently faced by the country.
- Economic growth must be sustainable in nature. This means that renewable energy resources should be promoted at the national level and low-carbon economic growth should be part of the national economic development agenda.
- The use of clean and renewable energy needs to be encouraged at all levels of society. For example, the use of efficient cook-stoves as against the use of wood for fuels could be a good initiative specially for the regional communities and sub-urban populations.
- Leapfrogging to modern and energy-efficient technologies in transport and industrial sectors could support the achievement of their 2030 carbon mitigation targets if adequate policy decisions are taken.
- From the energy intensity viewpoint, more efforts could be directed to enhance higher GDP generation per unit energy consumed. This could be done by eliminating energy intensive sectors and promoting high-end production of finished goods and services. This, however, could involve multinational and regional cooperation with industrialized economies so that the transfer of technology is materialized.
- From a fossil fuel mix effect perspective, energy efficient strategies in industries (such as industrial symbiosis and waste-to-energy), housing (such as LED lighting, smart lighting, green construction), transportation (such as clean fuels, emission control systems in vehicles), and agriculture (such as solar powered grids, rain water harvesting) could be encouraged from a policy perspective. In addition, alternative sources of energy (such as geothermal, wind, solar) could also greatly help curb GHG emissions at the national level.
- From an emission intensity perspective, improvements could be achieved in all sectors of economy. For instance, in the agricultural sector, best farm practices for improving crop yield and livestock production could create co-benefits such as higher food security and reduced carbon emissions.

5. Conclusions

With a fast-growing economy such as that of Ethiopia, there are bound to be some adverse effects to the environment. Ethiopia has so far achieved a plausible economic growth especially in the last two decades. The environmental cost of economic progress is also quite high. This study examined major drivers, based on Kaya identity, in rising CO₂ emissions from fossil fuel consumption in Ethiopia from 1990 till 2017. Important outcomes of this study are presented below.

- From an analysis of the results obtained, the population of Ethiopia grew by 122% from 1990–2017, its GDP grew by 385% while CO₂ emissions increased by 450% portraying a true picture of economic buoyancy at the cost of massive carbonization.

- Based on the decomposition analysis, major influencers of rising CO₂ emissions in Ethiopia included economy effect (49.1%) followed by population effect (42.7%) and fossil fuel mix effect (40.3%). However, emission intensity effect (14.5%) was four times less harmful than economy effect.
- The only negative driver of CO₂ emissions was energy intensity effect which played the greatest role in mitigating rising carbon emissions in the country during 1990–2017.
- Based on the effect coefficient analysis, the shares of energy intensity effect and emission intensity effect have been declining in recent years, while the impact shares of population effect, economy effect, and fossil fuel mix effect have been on the rise meaning they could further cause carbon emissions to increase unless mitigation strategies are adopted.

These results, and policy implications discussed in this article, could very well be used as an instrument to promote low-carbon and sustainable economic growth in Ethiopia and other emerging countries of the world.

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