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Examining the impact of driving factors of Carbon dioxide (CO_2) emissions using the STIRPAT model: The case of Ethiopia

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Abstract: This paper analyzes the impact of population growth, GDP per capita and technological improvement on Ethiopia's carbon dioxide emission in the period 1971-2011. Using a STIRPAT model and Auto Regressive Distributive Lag (ARDL) l to analyze this impact, the study found that the highly growing population of Ethiopia has the greatest impact on carbon dioxide emission. More specifically, 1% increase in population growth leads to 1.42% increase in CO_2 emission in the long run. In contrast to economic theory and literature, GDP per capita found to be statistically insignificant in impacting emission of CO_2 in the country. Moreover, the rapid decline in carbon intensity in the country has significantly reduced carbon emission levels. A reduction in carbon intensity by 1% reduces carbon emission by approximately 1.01%. This study also finds that the ongoing renewable energy transformation of the country's source towards hydropower energy production has contributed positively to the reduction in carbon emission. As the country has only exploited about 0.9% of its hydropower energy, further investment to this energy source not only contributes to fulfilling the energy need, but also ensure sustainability of its development.

Key Words: CO_2 emission, energy, population, efficiency, STIRPAT

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1. Introduction

1.1. Background of the Study

Concerns about sustainable development involve the need to achieve the highest economic growth possible with minimum possible impact on the environment. Carbon dioxide (CO_2) emission is one of the most serious factors affecting the environment. According to (Oliver et al, 2015), carbon dioxide emission has been moderate in the past few years at a global level. However, an emission level has increased at an average rate of 4, 5% in the period 2000-2010 while the global GDP growth was 4.5%. This, together with the fact that about 70% of world's global GDP growth is contributed by the non-energy intensive service sector, implies that emission is mostly attributed to energy consumption.

Carbon dioxide emission results from many economic activities. Data shows that the concentration of Carbon dioxide has been increasing globally since the 19th century. According to Oliver et al(2015), CO_2 emission from human activity arise from various sources such as the use of fossil fuels for power generation, industrial processes, transportation, residential and commercial buildings.

It is a fact that type of energy used in a given country determines the level of energy intensity, carbon intensity and emission level. For example, a county that mainly rely on hydropower energy will have lower emission of carbon than a country mainly dependent on coal energy. Oliver et al(2015) also indicates that Energy related economic activities has one of the most significant relevance on the release of carbon dioxide in the environment globally, with combustion of fossil fuels constitutes about 90 percent of total emissions.

When we see data on regional level, Africa's contribution to the global CO_2 emission trend is small, it is still important to investigate the region as non-fossil fuel sources contribution in the continent is significant. In his article, Canadell(2009), indicates that Africa was responsible 2.5 percent of the global cumulative CO_2 emissions for the period 1980 – 2005, and for about (500 Tg Cubic yards) emission of carbon dioxide between 2000 to 2005, of which about 260 was from the combustion of fossil fuels and the remaining from land use change, despite some variations at individual country level. Moreover, in this period, the share of Africa on global emission due to land use change was around 17%. As most of Africa is in the tropical region, it is understandable that emission from land use change is driven by activities such as deforestation which in turn is related with fast growing population in the continent and rapid growth in per capita GDP.

When we come to the case of Ethiopia, there have not been many studies undertaken to investigate the carbon dioxide emission and its main drivers, especially in recent decades where the population of the country is growing in a rapid rate and human activities have increased to a great extent. More importantly, the country has been making a transformation in the type of energy production and use, from the natural sources and fossil fuel to the production of hydroelectric energy. Therefore, it is important to understand the emission scenario of carbon dioxide in the country and its main drivers. This study seeks to investigate the drives of carbon dioxide emission in Ethiopia over the period 1971-2011. Using a "STIRPAT" model, we disentangle the effects of population, affluence and technology on carbon dioxide emission from energy consumption.

1.2. A very brief Profile of Ethiopia

Ethiopia is a landlocked country located the horn of Africa. The country is bordered by Eritrea to the north and north east, Kenya to the south, Sudan and South Sudan to the West and Somalia and Djibouti to the East. As of 2014, Ethiopia has a total population of almost 97 million, making it the most populous landlocked country in the world, and the second most populous country in Africa. (World Bank country statistics, 2016).

Ethiopia was a monarchy for most of its history. The country is regarded by most as the symbol for the independence of Africa since it was the only African country to defeat a colonial power during the scramble for Africa in the late 19th century. It is the origin of the coffee bean and a country with its own alphabet and calendars in use. Ethiopia was a monarchy for most of its history. (BBC, 2016)

Ethiopia is home to more than 80 ethnic groups. There are more than 88 languages spoken in the country, according to Ethnolongue.com, of these Amharic serves as the official language.

According to World Bank country profile, the GDP of Ethiopia reached its all-time record amount of 55.6 billion USD at current market prices in 2014 and Per capita GDP reached 573.6 USD. IMF's 2015 report also indicated that in terms of nominal GDP, Ethiopia is the 8th largest economy in Africa. Even though the economy of Ethiopia is recovering in recent years, it is still one of the poorest countries in the world and underwent a series of droughts and famines in the near past due to climatic changes and war.

Ethiopia has 1,126,829 square kilometers of land, making it the 27th largest country in the world. Its geography varies from the fertile west, rivers, lakes and jungles to hot and arid east. The climate of the country varies depending on the topographical regions. There are four main seasons, summer (the rainy season involving June, July and August), autumn(harvest season involving September, October and November), winter(dry season involving the months of December, January and February) and spring(Occasional showers including March, April and May). According to nationsencyclopedia.com (2016), the central part of the country is mostly a plateau and it has a minimal seasonal variation in temperature, ranging from 6 ^{o} C in the coldest season and 26^0C in the warm season. In the low lands especially in the eastern arid part temperature variation is much higher, with occasional high of 60 ^{o} C.

Ethiopia currently has a federal parliamentary form of government and the head of the government is the Prime Minister. Addis Ababa serves as the capital city and seat of the government. (BBC, 2016).

1.3. Statement of the Problem

As discussed earlier, the nature of economic activity and methods of energy generation have important impact on the emission level of carbon dioxide in a given economy. According to the National Meteorological agency of Ethiopia (2007), most emission profile of Ethiopia is from Energy use, mainly from agriculture, contributing about 90% of the total CO_2 emission in the country.

For years, Ethiopia's main energy source was from natural sources such as woods and charcoal burning. These sources of energy release high levels of carbon, but Ethiopia's total carbon emission have been very low due to its low level of energy consumption. In recent years, the country has made transformation into use of hydroelectric power to a large extent. More than 16 hydroelectric dams have been built in the last 50 years[1]. (Ministry of Water Resources of Ethiopia, 2016). It is believed that this transformation leads to improvements in energy efficiency and carbon efficiency due to lower level of Carbon dioxide emissions from hydroelectric energy production. With this in mind it is pertinent to see to what improvements energy and carbon intensity have reduced the growth of carbon emission from energy production such as hydroelectric power generation.

[1] This excludes the Grand Ethiopian Renaissance Dam of Ethiopia which will be the largest hydroelectric power plant in Africa. When finished, it will generate 6000MW of power and it is expected to be completed in 2018.

1.4. Aim and Scope of the Study

The main aim of the study is to investigate how anthropogenic factors have affected CO_2 emission in Ethiopia in the period 1971-2011. In addition to the impacts of growth in population and GDP per capita, this study aims to identify the impact of technology in the form of energy intensity and carbon intensity have affected the growth of CO_2 emission growth. More specifically, this study aims to see how the energy transformation of the country towards hydroelectric power generation has contributed (if any) to the reduction in carbon dioxide emission growth in the country for the same period. Moreover, this empirical research is also believed to provide a good starting point for further advanced research and input for environmental policy in the country.

1.5. Organization of the Paper

This paper is organized as follows. The first part is the introduction which includes brief profile of Ethiopia, statement of the problem, and aim and scope of the study. In the second part of this paper, we discussed the theoretical background and empirical literature regarding carbon dioxide emission and its main drivers on a global, regional and country level. Descriptive statistics regarding CO_2 emission and its drivers in Ethiopia is discussed in the third part of this paper. In the fourth part, we specify our model, data and statistical methodology adopted in the study. Based on statistical analysis of our model, the estimation results are discussed in the fifth part of the paper. Finally, a relevant conclusion is drawn based on the results obtained in the sixth part of the paper.

2. Theoretical Background and Literature

2.1. Theoretical background

For many years, scholars have tried to explain the human made factors behind the degradation of the environment. It can be said that the major driving forces of the major greenhouse gas emission involve a complex set of demographic, economical, resource, policy and technological factors. One of the most widely accepted theoretical attempts to analyze this set of forces, particularly in their impact on the greenhouse gas Carbon dioxide was developed in the 1970s is by several researchers which made a hypothesis that environmental impact was caused by the impacts of three main factors, namely population, Affluence and Technology. This hypothesis is what is normally known as the IPAT equation.

It is important to provide some insight about the so-called IPAT analysis since it laid the groundwork to investigate the main drivers of environmental impact that are of human nature. The IPAT framework was developed in the 1970s in the debate between Barry Commoner (1972), Paul R. Ehlrich and John Holdern (1971). Barry Commoner (1972) argued that human made factors were responsible for environmental damage in the United States after the end of the second world. According to him, the main factor for environmental damage during this time was mainly caused by changes in production technology. In more detail, he emphasized that, in the case of USA, activities such as the use of nitrogen fertilizer on less land (land displacement) intensified the environmental impact of agriculture, and the shift to more powered cars today compared to prewar cars had much more environmental impact and this impact is even more important than the impact of population on the environment. This argument by Barry was in contrast with the argument by Ehlrich and Holdern(1971) who argued that population growth has higher negative impact on the environment. They indicated that the overall negative impact of population on the environment can be expressed in a simple relation:

$$I = P * F \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.1)$$

Where P represents population and F represents a function to measure the per capita impact which can increase with per capita consumption, keeping technological change constant. However, they themselves pointed out that per capita impact can be offset if more benign technologies are introduced, and the fact that per capita impact and population size are not necessarily independent of each other. Therefore, they instead recognized that per capita consumption of energy and resources, and hence the associated per capita impact on the environment is functions of the size of population. Therefore they gave an even more recognition to the role of population size on environmental impact by modifying the simplest equation with the following:

$$I = f(P) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.2)$$

Where f(P) can both be an increasing and decreasing function of population size, depending on whether diminishing returns or economies of scale are dominant in their importance. Based on their arguments, it is possible to see that Ehlrich and Holdern(1971) have given importance to affluence and technology on having environmental impact but has given a particular importance on the role of human population growth. They indeed clearly mentioned the IPAT variables in their critique on the work of Barry Commoner.

The basic form of IPAT identity shows that environmental impacts due to human activities stems mainly from three core, not necessarily interdependent, factors, namely population, affluence and technology. Therefore, as it can be seen from its name, the IPAT identity can be put mathematically as:

$$I = P * A * T \text{...(2.3)}$$

Where I represent environmental impact, P stands for population, A represents affluence of change in consumption patterns, and T stands for technology. Here the main meaning of the equation is that to reduce the overall man related impact on the environment, we should stabilize population, limit our desire for greater affluence and innovate and adopt more efficient technologies. First, population increase has negative impacts on the environment in a number of ways including but not limited to increased use of land, increased use of resources and increased pollution.

Affluence or consumption also assumed to have negative impact on the environment. The most common way to approximate patterns of consumption is GDP per capita. It is believed that an increase in GDP per capita increases demand for consumption and production which eventually leads to negative impact on the environment. The final term in IPAT identity, T or technology indicates how much resource intensive production affluence is. It measures environmental impact in creating, transporting and disposing of goods. It is easy to notice that an increase in efficiency reduces impacts on the environment. (Commoner, 1972).

The IPAT identity, in its particular form was redefined as an equation relating to driving forces that determine the impact of human on the environment in the form of greenhouse gas carbon dioxide emission. In relation to this, a new approach on the concept of energy intensity and CO_2 emissions is the widely known approach called Kaya Identity which was named after Yoichi Kaya. In his book titled 'Environment, Energy and Economy', co-authored with Keiichi Yokobori, Kaya (1997) developed a method to analyze and forecast Carbon dioxide emission scenarios. This approach has been a widely used and popular method in the area of environmental and energy economics. Major energy and emission forecasts including IPCC special report on emissions take advantage of this equation. The Kaya identity can be seen as the specific form of IPAT equation.

Perhaps it is important to give a brief discussion of a later modification to the IPAT analysis before discussing the more specific concept of Kaya identity. Since the IPAT takes the variable technology without any classification, Waggoner and Ausubel(2002) made a small reconceptualization named ImPACT by making a disaggregation of the technology variable in the conventional IPAT equation into consumption per unit GDP and environmental impact per unit of consumption. Hence, they stated the new equation as:

$$I = P * A * C * T \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.4)$$

In equation 2.4 above, C and T represent consumption per GDP and impact per unit of consumption, respectively. In contrast to the IPAT, the ImPACT model allows to predict impact as a product of population, Affluence (GDP per capita), consumption (such as energy) per GDP and impact per consumption. This is very similar with the Kaya identity which is expressed as:

$$CO_2 = Population * \left(\frac{Energy}{GDP}\right) * \left(\frac{GPD}{Population}\right) * \left(\frac{CO_2}{Energy}\right) \ldots\ldots\ldots\ldots (2.5)$$

In equation (2.5), the left-hand side of the equation represents emission levels of Carbon dioxide. The right-hand sides of the equations represent number of population, energy intensity, per capita income and carbon intensity, respectively. By projecting changes in the growth of the population, growth of the economy, intensity of energy and intensity of carbon use, it is possible to make a wise analysis and prediction of future emissions of carbon dioxide and other greenhouse gases. From the equation, it is possible to understand that population has a significant role because it has a multiplier effect. For example, when the population grows, it means more demand for energy, and it indirectly affects the emission level. In addition, the growth of the economy also implies a higher demand for energy. The role of technology here in the Kaya identity is that improvement in energy technology means it will take less energy to increase Gross domestic product by more extra dollar, i.e., and decline in energy intensity. The final term in the identity, carbon dioxide intensity, implies the need to switch to renewable and less fossil fuel dependent sources to lower the emission of carbon dioxide per unit of energy consumption. It is important to note that the four terms in the right-hand of the equation should be considered neither as independent of each other nor as fundamental driving forces. We can clearly see that tools for the analysis of driving forces of environmental impact have evolved in environmental economics, from the broad theoretical framework of sustainability such as IPAT and ImPACT to the specific analysis of CO_2 emission and energy(i.e. Kaya identity) (Mahony, 2013).

According to (Albrtecht, Francois and Schoors, 2002), for any two years the sum of percentage changes in each of the variables in equation 1 is approximately equal to the total percentage change in CO_2 emissions. We can see this by converting the Kaya into log and arthimetic form as:

$$\log CO2 = \log(Population) + \log\left(\frac{GDP}{Population}\right) \quad + \log\left(\frac{Energy}{GDP}\right) + \log(\frac{Carbon}{Energy}) \quad \ldots\ldots\ldots(2.6)$$

The above equation 2.6 implies that the growth rate of carbon dioxide emissions can be put as the sum of the growth rates of each of the right hand side variables, i.e., population growth rate, growth rate of energy intensity, growth rate of GDP per capita and growth rate of carbon intensity.

The IPAT identity and its specific form, Kaya identity, however, are not without criticism. Several authors pointed out that these identities are prone to some pitfalls. (Juan, Hubacek, Weber, Peters, Reiner, 2008) indicates that the identity doesn't allow identifying the sources of impact to specific industries and consumers since it is too aggregated equation in the analysis of environmental impacts. The other is the reason that it does only show the direct effects of the three driving factors of environmental impact (i.e. population, affluence and technology). Juan et al(2008).

Jordi (2002) criticized the original IPAT analysis on various grounds. First, he argued that the dependent variable in the equation, i.e. Impact on the environment, can incorporate various forms and use of a single index may not be sufficient. Moreover, he indicated that one indicator of environmental impact may worsen while the other improves at the same time. Therefore, reliance on one indicator cannot give the clear impact of the driving forces of environmental problems. Second, Jordi argued that the representation of the variable technology can be influence by several factors than one or two factors such as GDP or investment.

Moreover, (Detiz, as cited by Chertow(1998) indicated that the IPAT equation is too simple and it doesn't allow for the possibility of interaction among the variables. Alcott(2010), added to this by arguing that rather than putting the equation as an identity, it would be more correct to rewrite the equation as I = f(P,A,T). for instance, tripling technological efficiency which is equivalent to decrease the technological variable in the equation by 67% does not necessarily lead to reduction on impact by the same percentage as possible reductions in price induced by efficiency could lead to more consumption of a resource that could be conserved. This effect is knows as Jevons Paradox or rebound effect. Therefore, policies directed to reduce environmental impact via reduction of the variables in the equation are both very difficult to implement (such as population control) and are less likely to be effective as compared with Pigouvian taxation of resource use[2]. (Alcott(2010)

Schultz (2002, as cited by Jordi) argued that the IPAT equation misses an important variable that may have an impact on the environment, behavior. Accordingly, he modified the IPAT equation into IPBAT by incorporating human behavior into the equation. However, this was criticized by Jordi for making the equation more rigorous and for the difficulty of measuring this new variable. (Jordi, 2002).

In response to the limitations indicated above, a more advanced tool to analyze the effects of the impacts of environmental impacts has been developed by Dietz and Rosa (1998). Reformulating the IPAT equation, they came up with the so-called 'STIRPAT' or Stochastic Impacts by regression on Population, Affluence and Technology. They suggested that this new equation will allow for statistical tests and to investigate the complex relationship between the variables of interest. The STIRPAT equation is presented as:

$$I_{it} = \alpha P_{it}^{\beta} A_{it}^{\gamma} T_{it}^{\delta} \varepsilon \text{.................................. (2.7)}$$

Where the values α – ε are parameters or complex function that can be estimated using statistical tools. (Deitz and Rosa, 1994, as cited by Chertow). The subscripts indicate that original variables in the equation can vary across units of observation such as countries or regions. As indicated in the methodology part, Dietz and Roza suggested that this modified equation allows for estimation and testing of hypothesis. An additive regression model can be obtained by log linearizing the STIRPAT equation as follows:

$$\log(I_{it}) = \theta \log(P) + \gamma \log(A) + \delta \log(T) + \upsilon \text{..........(2.8)}$$

[2] When a tax on environmental impact is set to be equal to the marginal social damage created, it is said to internalize the externality as environmental quality has the property of public good. Such taxes are said to be Pigouvian taxes.

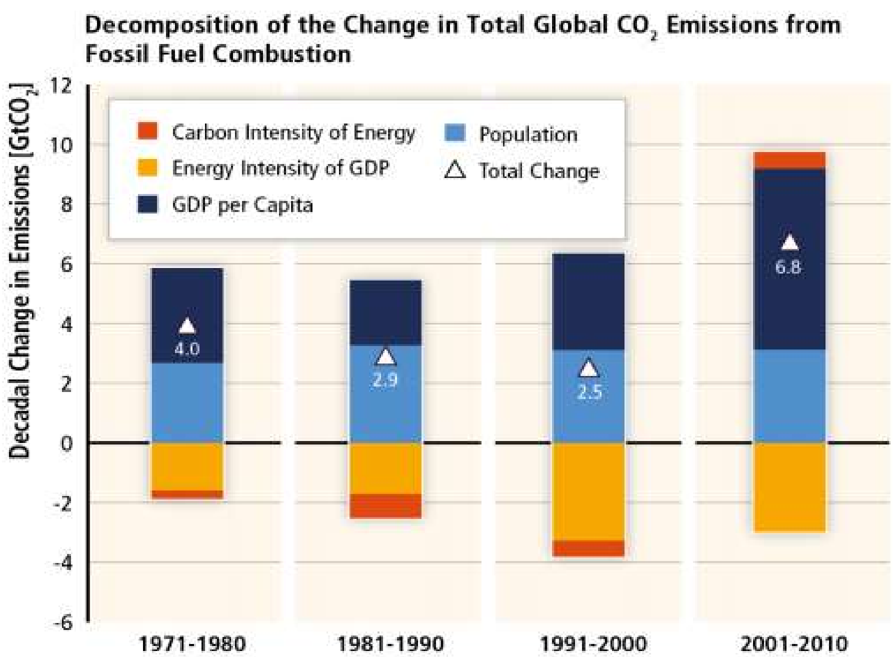
Where $\theta = \alpha * \beta$ and $\upsilon = \log(\varepsilon)$

The equation in 2.8 can be interpreted in terms of what is described by Dietz as ecological elasticity. Ecological elasticity is a quantitative measure the sensitivity of impact on the environment due to a change in the given anthropogenic driving forces. In other words, it measures the responsiveness, in proportional terms, of impact for one percent change in population or affluence. Therefore, population elasticity of impact measures the responsiveness impact to an increase or decrease in the size of population at a given macro level unit. Affluence elasticity of impact on the other hand measures the responsiveness of environmental impact to a change in the level of GDP per capita. Dietz, Rosa (1998). Since the measurement of technology is controversial, they indicate that the technology variable can be estimated by calculating the antilog of the residual term since it can be assumed that the leftover of the environmental impact caused by affluence and population can be described as the effect of technology. They also suggested that technology can be disaggregated by incorporating other factors in the model that are assumed to have influence per unit of production. In this case, T represents net of the effects of these additional factors which are now incorporated in the STIRPAT model.

2.2. Empirical literature review

Several authors tried to apply the IPAT, Kaya and its subsequent models empirically to identify the main driving forces of environmental impacts, at country, regional and global levels. One of the most important reports for carbon dioxide emissions is provided by the International Panel on Climate Change (IPCC) which is an international organization which assesses scenarios of climate change and its drivers at a global level. A working group contribution III to IPCC fifth assessment report(2015) indicates that total Greenhouse gas (GHG) emissions have continued to increase in the period 1970-2010 despite an increasing amount of mitigation policies put in place. More importantly, based on KAYA equation the report estimated that CO_2 emission from combustion of fossil fuel and industrial processes constitutes about 78% of the total GHG emissions rise for the same time period. Moreover, population and economic growth are found to be two of the most significant drivers of CO_2 emissions from combustion of fossil fuels, outpacing the reduction in emission due to improvements in energy intensity. Further forecasting of this scenario for the future also indicates that, without further mitigation policies to reduce emissions beyond those policies in place today, growth in emission is expected to persist driven by growth in world population and increase in economic activities. Figure 1 presents the main drivers of CO_2 emission from fossil fuel combustion.

Figure 1: Global CO2 emission from fossil fuel combustion



Source: Reprinted from *Climate Change 2014: mitigation of climate change* by IPCC (2015)

The fourth assessment report of the IPCC based on the KAYA model according to the refined Laspeyres index method also indicates that, globally, CO_2 emission had grown by an annual growth rate of 1.9% in the period 1970 - 2004. This, according to the IPCC is attributed to 1.6%, 1.8% and -0.5% annual growth rates in population, per capita GDP and energy intensity, respectively.

As indicated in the theoretical literature review part, Dietz and Rosa (1997) developed a modified form of the IPAT model called STIRPAT model and they estimated the effect of population and affluence on CO2 emissions using a multiple regression on 111 nations for the year 1989. They first estimated the general additive model which converts the basic STIRPAT model in logarithmic form. They also modified the model into a polynomial which included the quadratic form in the log of population and cubic form in the log of population form to allow for non linearities and provide adequate parametric match to the non-parametric characteristics of the variables. Their estimation result of their log-linearized model indicates that a 1.15% growth of population leads to one percent increase in CO_2 at a global level. Moreover, around 1.08% growth in affluence leads to a 1% growth in CO_2 emission levels. Affluence is represented by growth domestic product per capita.

Mukhopadhyay (2010) published a paper that identifies the major accelerators of CO_2 emissions using data from 114 countries around the world for the period between 1992 and 2004. They used LMDI decomposition analysis based on Kaya identity in their study. Their results suggest that, even though having a varying pattern, the effect of income on emissions is larger than the effect of population. Interestingly, they find that the effect of population on emission is found to be constant within the study period. Further decomposition to see a cross country and regional contribution to the global emission of CO_2 indicates that the middle-income countries, though having highest growth rates, substantially reduced their CO_2 emission levels for the given period of time. On the other hand, countries in North America, East Asia, Pacific and South Asia have shown an increase in emissions. Furthermore, the study revealed that emission efficiency improvement in the form of CO2 intensity has been attained by most countries in the study which contributed to the mitigation of CO2 worldwide while improvement in energy efficiency has not been remarkable.

Besides global level assessment of the main drivers of CO_2 emission, several authors also tried to estimate emission and its drivers at country and regional level. Some important reviews of literature at a country level are presented as follows:

Lise (2006) applied decomposition analysis and Kaya identity equation to identify energy intensity and drivers of carbon dioxide emissions for Turkey for the period between 1980 and 2003. Their results show that CO_2 emission per unit energy has increased for the period under their study. Further decomposition of carbon emission intensity in their study suggests that the emission intensity of CO_2 in Turkey had been mainly in the service sector. Even though energy intensity has dropped in Turkey, the observed increase in carbon intensity offsets the energy intensity effect leading to no significant reduction in carbon emission in all the sectors (agriculture, industry, services and transport) indicated in their study.

Xiangzhao and Ji (2008) investigated the episodes of CO_2 emissions in China starting from the fourth national plan (in the 1970s) to tenth national plan (2001-2005). To make their studies, they undertake decomposition analysis and the revised form of Kaya identity. Based on their empirical analysis, they concluded that most CO_2 emission in China for the whole period of study is driven by human activities (economic growth) which accounted about 86% of total CO_2 emission increment. Moreover, the facilitation of CO_2 mitigation was mainly due to improvement in energy use (energy efficiency). In quantitative terms, improvement in energy efficiency accounts for about 89% mitigation of CO_2. Optimization of primary energy, according to their study, is the second factor for the mitigation of CO_2 that accounts about 11% of the total mitigation for the given period. Finally, their study finds that population is the second most significant contributor of CO_2 emissions, next to economic growth, accounting for about 14% of the total emission for the period.

Mahony(2013) tries to investigate the main driving forces of CO_2 emissions in Ireland between 1990 and 2010. He used an extended version of Kaya identity and Log Mean Divisia Index (LMDI) method of decomposition as his method of analysis. Their empirical results suggest that scale effects have a more dominant effect on CO_2 emissions than energy intensity effect. More specifically, affluence and population growth has the major driving forces in CO_2 emission in Ireland for the period under their study. Though population has a positive effect on co2 emissions, its contribution is found to be dwarfed by affluence, making the total structural effect negative. The impact of energy intensity effect is found to be the most important factor limiting the growth of CO_2 emission. Generally, their study finds that the accumulated effects of reduced emissions were overweighed by accumulated effects of increasing emissions, leading to a significant increase in the overall energy-related carbon dioxide emissions.

Jung, An, Dodbida and Fujita(2012) investigated the main factors that affect emission of CO_2 in South Korea for the period between 2002 and 2009 they focused on five main regions of the country where carbon dioxide emission constitutes about 54% of the total carbon emissions in the country. These are also the regions where the major eco-industrial parks are located. They applied Kaya/IPAT analysis and decomposition analysis to investigate the effects of five factors of emission, i.e. production, population, energy intensity, emission and fuel mix effects using LMDI. Period wise analysis of their results indicates that production effect is the main factor contributing to CO_2 emission in all five regions considered. On the other hand, fuel mix effect and energy intensity effect contributed to the reduction in CO_2 emissions in a very small extent, while population effect has a varying effect across the five regions.

Gingrich, Kuskova and Steinberger (2011) applied decomposition analysis based on Kaya identity to investigate the main factors that determine the differences in CO_2 emissions in Austria and former Czechoslovakia for the period 1830-2000. More specifically, they tried to identify the population, income, energy intensity effects and energy composition contribution to the difference in CO_2 emissions between the two countries. They divided the whole period of study into five different periods. Based on their analysis, they find that Austria and Czechoslovakia had a similar trend in CO_2 emission in the period 1830 to 1920, when both were part of the Habsburg Empire. Also same trends had been seen in the period 1920-1938, and between after the Second World War and mid-1980s. They found increasing difference in CO_2 emissions between the two countries before they finally start to converge after the 1990s until 2000. They also find general similarities in CO_2 emissions in both countries. First, emission from fossil fuels increased after the start of the industrialization process. Second, a shift in fossil fuels was observed after from biomass to coal and from coal to crude and electricity.

Andreoni and Galmarini(2012) used decomposition analysis based on Kaya identity to identify the existence of decoupling between economic growth and CO_2 emissions between the period 1998- 2006 in Italy. They investigated four main variables, i.e. energy intensity, carbon intensity, economic growth and structural changes as the factors responsible for emission trend in CO_2. They also tried to see the sectoral dimension of CO_2 emission activity by dividing the economy into five main sectors, i.e. agriculture, industry, services, transport and electricity, heat, water and gas, and heat production sectors. The general results show that total decoupling did not happen in Italy during the study period in terms of CO2 emission and energy consumption. In addition, energy intensity and economic activity were found to be the major factors responsible for CO_2 emission. The structural effect also contributed to emission increase in most sectors of the economy considered. On the other hand, carbon intensity effect exhibited improvements and hence reduction in carbon emissions.

Despite a lot of empirical work on the major emission drivers across the world, a very few studies have been made to assess the impact on environment due to major driving forces in Africa and most importantly in Ethiopia. A study made by Yao, Feng(2014) to determine the main driving forces of CO_2 emission in the G20 countries(which includes South Africa)using the IPAT framework for the period 1971-1990 indicates that, unlike China, South Korea, Brazil, Turkey and Australia whose main driver for CO_2 emission was economic growth, South Africa's main driver of CO_2 emission was due to high population growth which was estimated to be around 25% for that period. Economic structure and energy intensity improvement was an important contributor for reduction in CO_2 emission for South Africa (7% reduction in emission) like the rest of the G20 countries for the same period of time. However the period 1990-2010 showed that the contribution of population growth became much smaller and further forecasts indicates that population growth's role as the major driving factor would be replaced by other drivers of emission in decades after 2010.

Duro and Padilla(2014) analyzed the sources of international inequalities in terms of per capita emission of CO_2 by applying the approach described by Kaya. More specifically, they divided their data into cross country levels and tried to investigate the international inequality, then extended the methodology to explore the within group and between group inequalities in emission levels and the main factors which contributes to this inequality for the period 1971-1999. Their full sample included 114 countries and nine groups of countries. Their analysis of emission inequality components for within Tropical Africa indicates that the increase in the within group inequality in the level of emission in the region is mainly caused by the increased contribution of income inequality and the large rise in the covariance between CO_2 intensity of energy and per capita consumption of energy. This outcome is in contrast to the other group of countries in the study such as the temperate zone group of countries whose inequality in per capita carbon emission declined during the period mainly due to smaller contribution of energy intensities on inequalities.

Another important study to empirically investigate the emission of anthropogenic emission was made by Canadell et al (2009). They analyzed the CO_2 emission from the combustion of fossil fuels for all countries in Africa for the period 1980-2005. Also, they further grouped the countries into separate groups, Northern Africa and Sub-Saharan Africa as separating groups, and Developing and Least Developed countries as separate group. South Africa was selected as an example of developing country and Ethiopia as an example of least developed country. For their analysis they used the simplified form of Kaya identity to identify the main drivers of CO_2 emissions. Their result on the trends of fossil fuel emission the drivers of those emissions indicates that emissions in Africa have grown at a faster speed than the world average and it is mainly attributed to rapid population growth. However, the study also indicates that the correlation between emission and population growth was strong for developing countries in the continent On the other hand, CO_2 emission outpaced population growth in least developed countries such as Ethiopia, mainly because of a simultaneous strong growth of GDP per capita.

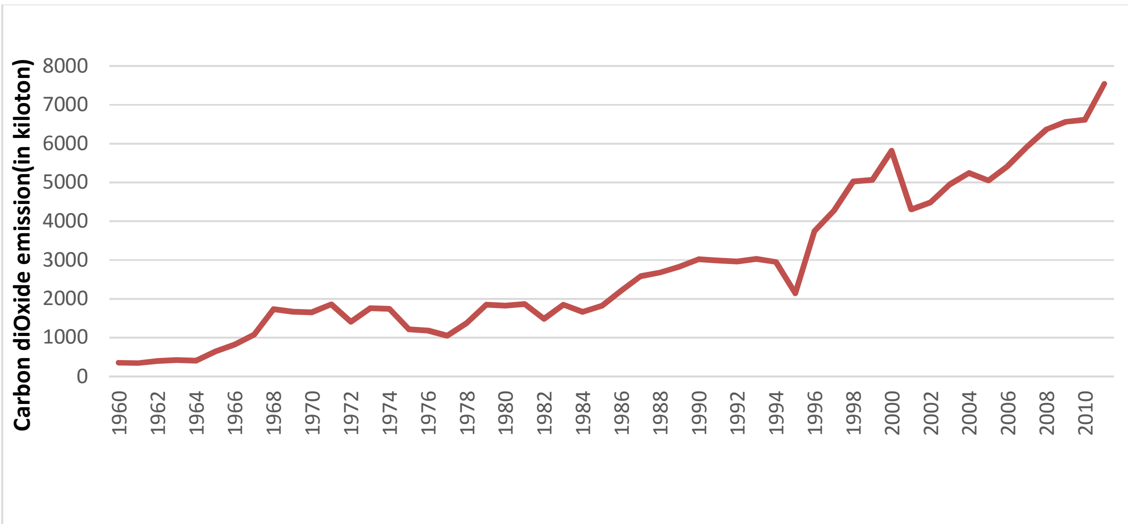
3. Carbon dioxide emission and its driving factors in the case of Ethiopia

3.1. Carbon dioxide emission

According to the World Bank's world development indicators database, CO_2 emission in Ethiopia has shown an increasing trend in the in the period 1960 – 2011. Roughly, emission levels in kiloton have increased by more than 2000% in the same period from about 352 Kilo ton in 1960 to more than 7542 Kilo ton in 2011. The total CO_2 emission trend from the fossil fuel burning and cement manufacture in Ethiopia for the period 1960 – 2011 is presented in figure 2 below.

The rate of CO_2 emission has shown relatively higher pace between the years 1995 to 2000. Based on Kaya identity, we can explain the main reasons for this massive increase in CO_2 emissions. One explanation based on this identity can be a large increase in the population of the country during this time period. Moreover, data on population indicates that Ethiopia is one of the countries in the world with the highest levels of fertility rate which is around 3% per annum in recent years. The total population of the country increased from 35 million in 1980 to almost 97 million in 2014. This means the population has risen by more than 168% in just three decades. High population growth is associated with increased land use, increased resource use and hence a rise in the level of CO_2 and other Green House Gases (GHG) emission.

Figure 2: trend in CO_2 emission (in Kt) from burning of fossil fuels and cement manufacture in Ethiopia (1971-2011)



Source: own construction based on data from World Bank Database(2016)

The other explanation can be an increase in economic growth in the country. Recent data on the economy of the country shows that both GDP and per capita income has been increasing at a rate never seen before in the country. Most importantly, the country has achieved more than 10% annual GDP growth between the years 2004 till 2013 except the years 2009 and 2012 in which the country's GDP grew by 9 percent each. GDP has grown from 11 billion dollar (2005constant USD) in 2004 to almost 28 billion dollars in 2013 (World Bank, 2016). As a developing country, it this increase in economic activity will likely be another reason for the increase in the emission of CO2 in the country. In a similar context, this can be explained by the Environmental Kuznets Curve (EKC) hypothesis that at lower levels of income, environmental quality worsens when the economy grows (i.e. the relationship between economic growth and environmental quality follows an inverted 'U' shape.

Even though the general trend of CO_2 emission has shown an increasing trend, it is important to describe how the country's shift in the use of energy has impacted the CO_2 emission levels due to energy production. As indicated in the introduction part, in the last few decades the production and use of energy has made a significant shift to the carbon friendly hydroelectric electricity. This is the main purposes of this paper to see how this shift in energy production and use especially in terms of electricity has contributed to reduction in CO_2 emission from this source. Figure 3 presents CO_2 emission from electricity and heat production as percentage of total fuel combustion in the period 1971 – 2013.

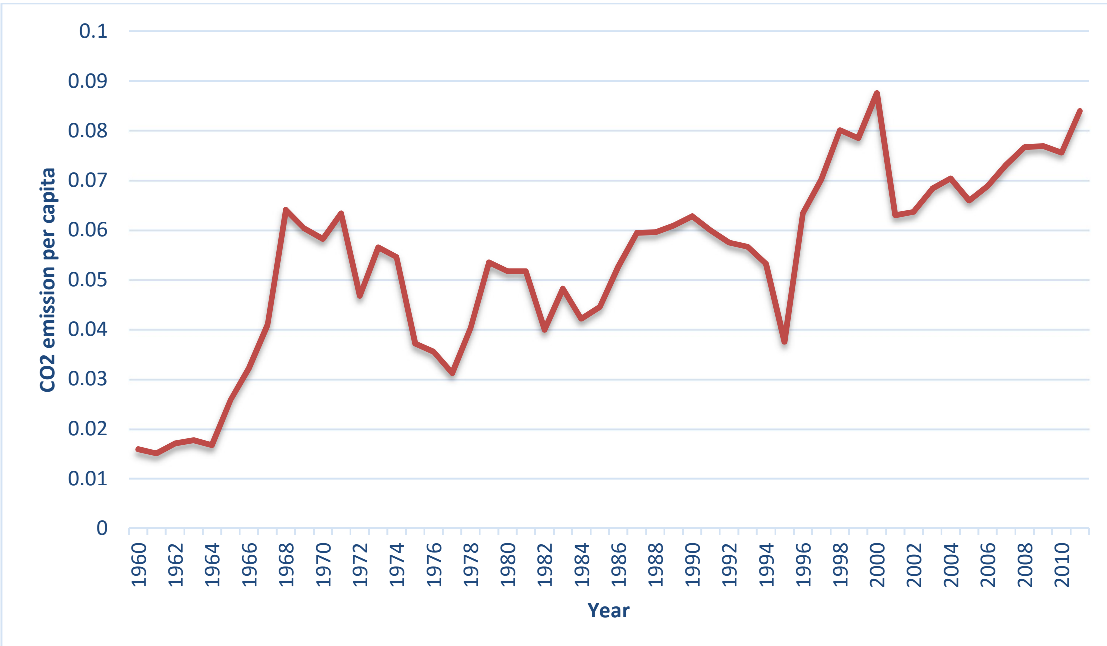
Figure 3: CO_2 emission (in Kt) from electricity and heat production (as % of total fuel combustion) in Ethiopia (1971-2013)

Source: own construction based on data from World Bank Databank (2016)

The above figure provides an important message regarding the effect of energy transformation in Ethiopia on the CO_2 emission trend scenario. It is easy to see that CO_2 emission from electricity production has shown a significant decline in the last three decades from roughly 31% in 1971 to only 0.11% in 2013. This implies that Ethiopia's move towards the Carbon free hydroelectric power production has significantly reduced CO_2 emissions from energy sector. A closer look at expansion of hydroelectric power generation in Ethiopia shows that the country has embarked on an ambitious hydroelectric dam construction program since 1960. More specifically, about 16 hydroelectric dams have been in use and under construction whose electricity generation varies from 36 mega Watt (MW) of electricity power to 2000 MW, according to the ministry of Water resources of Ethiopia. Further expansion of the hydroelectric power is expected in a couple of years from now as the country will be able to complete the largest hydroelectric power plant in Africa , the Grand renaissance dam, which will generate a maximum of 6000 MW of electricity. When completed in 2018, the dam will be the 11th largest plant in the world. This in turn implies that CO_2 emission from energy sector in the country is further expected to decrease significantly.

Now let's take a look at the trend of CO_2 emissions in per capita terms. The emission of CO_2 in metric ton per capita in the period 1960-2011 is presented in Figure 4. Even though total CO_2 emission levels have increased significantly in recent years, per capita emission of CO_2 has been volatile and small.

Figure 4: Carbon dioxide emission (Metric ton per capita) in Ethiopia 1960 - 2011



Source: Own construction based on data from World Bank databank (2016)

As it can be seen from figure 4 above, CO_2 emission per capita were 0.015 metric tons in 1960, and it has risen to 0.08 metric tons in 2011. This shows that the level of per capita CO_2 emission in Ethiopia is one of the lowest in the world. The trend shows a slight growth rage of per capita emissions in the last fifty years. One explanation for this slow rise can be that population growth has outpaced rise in emission levels and affluence. Meaning, even though CO_2 emission has shown an increasing trend, the increase in the number of population might lower the per capita emission of carbon dioxide.

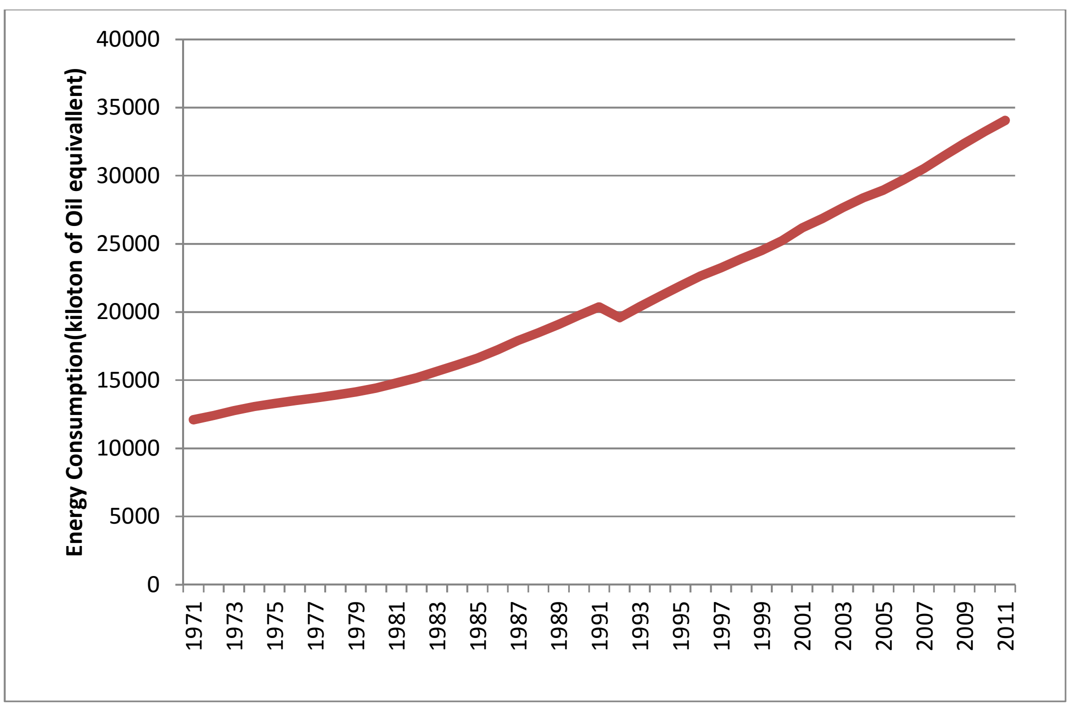
3.2. Drivers of Carbon dioxide emission

3.2.1. Energy and its Intensity

In today's world, there exists a huge disparity on the type, amount and efficiency of energy use. More specifically, developed countries mainly rely on modern sources of energy such as nuclear energy. On the other hand, developing countries mostly rely on traditional sources that are mainly from biomass.

According to the Ministry of Energy, Ethiopia has a significant potential for renewable source However, consumption of energy accounts for more than 50% of the total GHG emission in the country due to the significant dependence of transportation on petroleum fuels and unsustainable use of biomass energy. The pattern of energy consumption in Ethiopia is presented in Figure 5 below.

Figure 5: Energy consumption (kiloton (kt) of oil equivalent) in Ethiopia (1971-2011)

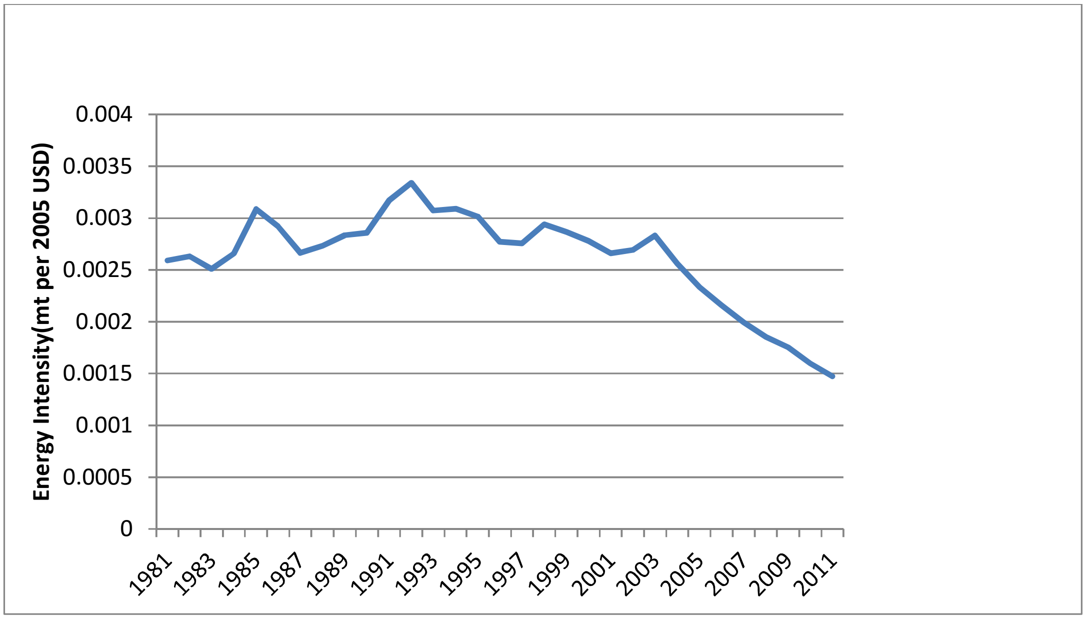


Source: Own construction based on data from World Bank Databank (2016)

We can observe from figure 5 that energy consumption in level terms (kt of oil equivalent) has shown an increasing trend over the last four decades since 1971. In 1971, the total Co2 consumption in the country was around 12 thousand kilo ton of oil equivalent. This figure has shown an increasing trend in the following years and by the end of 2011 the total use of energy has risen by more than 181% to become 34 thousand kiloton of oil equivalent.

Now let us look at the general trend of energy intensity. It can be seen in figure 6 below that energy intensity in the three decades from 1981 to 2011 has shown a varying trend. At the beginning of 1980s, energy intensity in Ethiopia was around 0.0025 metric ton of oil equivalent energy per one US dollar (at constant 2005$). In the following years, energy intensity has generally been volatile, increasing at some years and showing a decreasing trend in other years. The level of energy intensity in 2006 was similar to the level in 1983. Moreover, the level of energy intensity has shown a declining trend starting from 2002 till the end of the observation period, i.e. 2011. At 2011, the level of energy intensity declined to 0.0015. The main explanation for this decline in recent years can be the growing expansion of the economy as indicated by GDP of the country in the recent year. Another explanation can be the structural change in the economy towards the service sector and also an improvement in the level of energy efficiency which makes it feasible to produce one unit of economic output using lesser energy.

Figure 6: Energy intensity trend in Ethiopia (1981-2011)

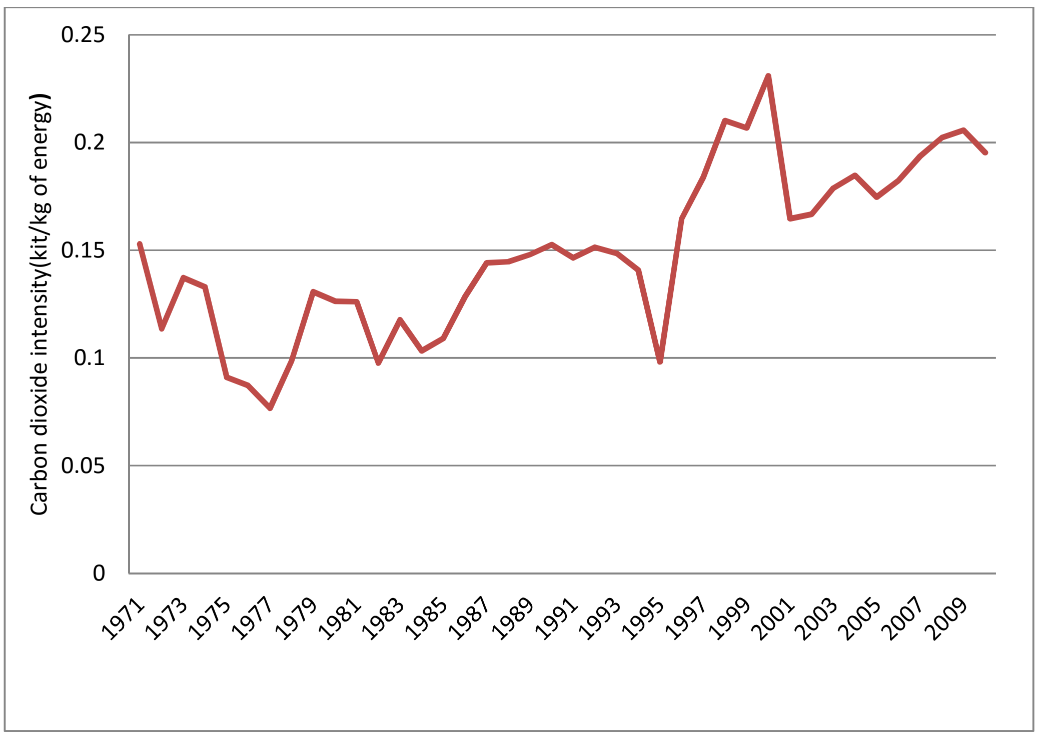


Source: Own construction based on data from World Bank Databank (2016)

3.2.2. Carbon dioxide Intensity

Another way to look at the trend of CO_2 emission is to look at the carbon intensity level of a given country. It measures the average emission rate of CO_2 per unit of energy produced. The intensity of carbon dioxide in Ethiopia, measured as the ratio of CO_2 emission in kiloton to energy use has also been volatile in the period 1971 to 2009. As we can see from figure 7 below, CO_2 intensity was around 0.15 in 1971, and it has dominantly shown a decreasing trend in the first few years of 1970s, reaching its lowest level in 1977. In the 1980s and 90s, CO_2 intensity has on average shown an increasing trend with the exception of 1995 and it has reached its peak in 2000(which is around 0.23). Finally, the level of CO_2 intensity lowered to the level of 0.19 in the year 2010. Here we can see that the intensity of CO2 hasn't increased by much in the four decades considered. One of the reasons is the increase in energy use during the time. As we will see in the next section, the energy use in the country increased significantly during this period and therefore increase in CO_2 emission was mostly due to increase in energy use that eventually led to volatile but not significant increase in CO2 intensity. We should note here that CO_2 intensity has shown higher volatility which is in contrast to emission levels due to electricity and heat production. The reason for this is that the term energy in the case of Carbon intensity mainly includes coal as the main source of energy, according to the definition provided by the World Bank while electricity and heat production includes an increasing proportion of renewable source of energy in the case of Ethiopia which mainly refers to hydroelectric energy.

Figure 7: Carbon dioxide emission intensity (kt of CO_2 per kg of energy use) from 1971 to 2009



Source: Own construction based on data from World Bank database (2016)

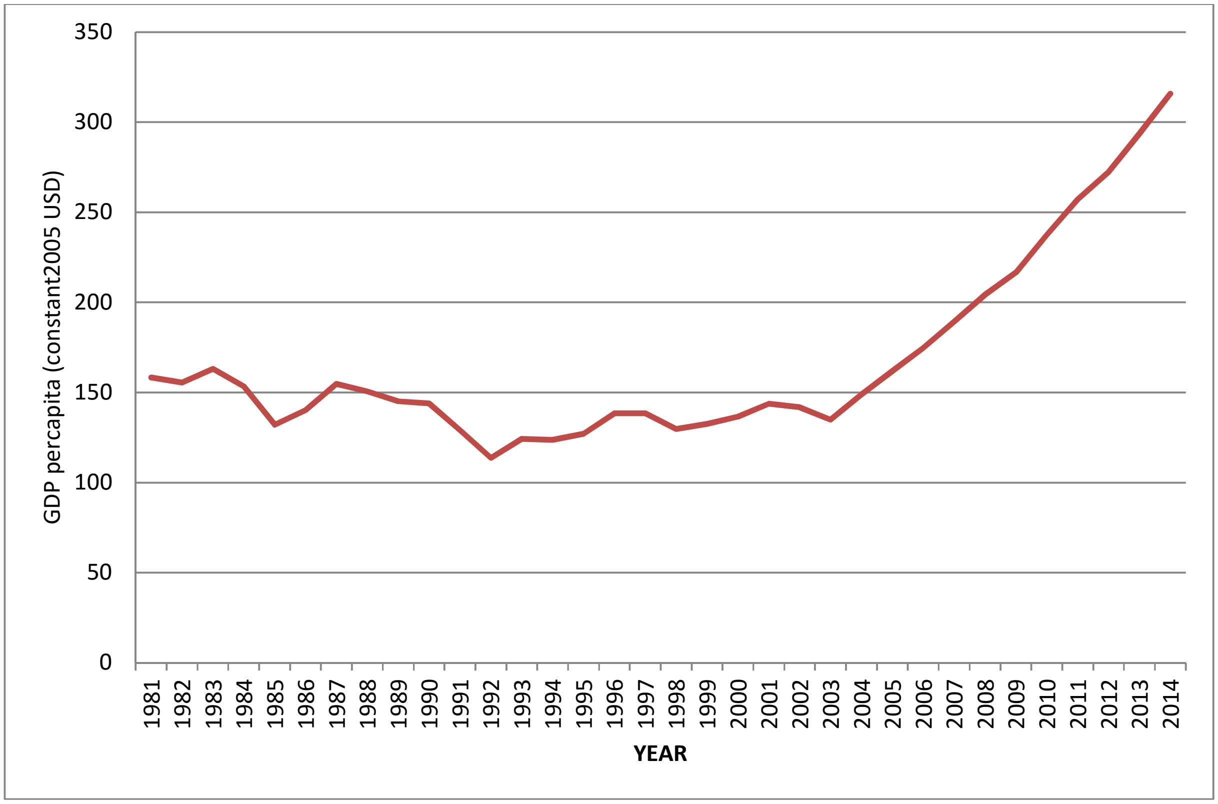
3.3. Population

Another major driving force of CO_2 emission is higher growth rate of population. The latest estimates on population by the United Nations indicates that as of May 2016, Ethiopia has a total population of just over 100 million which is equivalent to 1.35% of world's total population. This is more than four times compared to the number of population in 1960, which was around 22 million. The World Bank also indicates that the population of Ethiopia is growing by an average of 2.5% annually. This is well above the world average growth rate of population which is around 1.2%.

3.4. Affluence

As indicated in the previous part of this paper, affluence is one of the main driving forces of CO_2 emission. The word affluence represents the effect of average consumption of each person in the population. In other words, as the per capita level of consumption increases the overall impact on environment such as in form of CO_2 emission also increases. A widely used proxy to measure affluence is per capital level of gross domestic product (GDP). Therefore it is important to look at the GDP per capita trend in Ethiopia in order to investigate its effect on CO_2 emission. Figure 8 presents the scenario of income per capita in Ethiopia for the period 1981-2013.

Figure 8: Per capita GDP in Ethiopia (1981-2014)



Source: Own construction based on data from World Bank Databank(2016)

We can see that gross domestic product per capita reached USD 315 in 2014. This, according to World Bank data indicates that it is equivalent to only 3% of the average per capita GDP of the world. In the first two decades after 1981, growth of GDP per capita was almost stagnant and even decreasing for some years, the reason for which can be attributed to internal factors such as the Ethiopian Civil War (1974-1991), Ethio– Eritrean border war (1998-2000), and nationalization of the economy and elimination of the private sector by the previous socialist regime. Even though the GDP per capita in Ethiopia is very low, it has registered a significant growth in which the level of GDP per capita risen by more than 135% in the period 2003-2014. This made Ethiopia one of the fastest growing economies in the world. What can this tell us about CO_2 emission by human activities? Clearly, with reference to the IPAT equation and based on some empirical research discussed in the literature review part, this implies that the growth of GDP per capita can have a significant role in the emission trend in the country.

4. Model Specification, Data and Methodology

4.1. Model Specification

As stated in the introduction part, the main objective of this study is to investigate the role of anthropogenic factors having impact on the emission of CO_2 from energy in Ethiopia for the period 1971 to 2011. For this purpose, this paper primarily adopts the so called STIRPAT model. As indicated in the literature review part, the STIRPAT model is very popular methodology to investigate how important elements of a given country's economy, i.e., population, energy consumption, income per capita and carbon intensity, have impact on the general trend and amount of emission of this greenhouse gas. As indicated in the introduction and theoretical literature review part of this paper, the STIRPAT model provides a better investigation to analyze the effect of major driving forces affecting the environment as compared to the more basic and previous methods such as the IPAT equation and its specific form, the KAYA identity. Several authors applied the STIRPAT model to predict the future emission scenarios of carbon dioxide at a country, cross country, regional and global level.

To remind ourselves, we saw that the basic form of the Kaya Identity is presented as:

$$CO_2 = Population * GDP\ per\ capita * Energy\ Intensity * Carbon\ Intensity \ldots. (4.1)$$

It is easy to see that the KAYA identity itself is a specific version of the IPAT equation, i.e.,

$$Impact = Population * Affluence * Technology \ldots\ldots\ldots\ldots\ldots (4.2)$$

In equation (4.2), 'Impact' includes impacts on the environment, be it in the form of CO_2 emission or other kinds of damages. The variable 'Population' represents a similar variable in both Kaya and IPAT equations. 'Affluence' represents the magnitude of impact of human related activities on the environment such as CO_2 emissions. The most widely accepted proxy to represent this variable is gross domestic product per capita. Finally the Technology variable in the IPAT equation or technology is used to represent both abatements and impacts caused on the environment due to factors related to technology. A good proxy for this is the level of energy intensity, i.e. energy used per GDP, as stated in the KAYA identity. Another way is to see improvements in environmental impact realized due to efficiency in energy use and impact. For example, achieving technological efficiency can lead to lower energy requirement to produce one unit of output and lower level of emission per each unit of energy use in a given economy.

We also saw that both the Kaya identity and IPAT equations are too simple and doesn't allow for interaction among the variables. There are also some logical reasons why it is not plausible to use the basic form of the Kaya identity based on IPAT equation. The first reason is that the basic Kaya identity assumes that all the variables that have impact on emission of carbon dioxide are assumed to have the same (or proportional) impact with each other which is not the case in most situations. Second, both equations don't allow making statistical techniques such as regression to estimate the impact of each driving forces on the dependent variable. Therefore, a modification should be made on the original IPAT based Kaya identity. In this paper, we will employ the STIRPAT model proposed by Dietz and Rosa (1997) for reasons indicated in the theoretical literature review part regarding the demerits of basic Kaya equation. In their paper titled 'Effects of population and affluence on CO_2 emissions', Dietz and Rosa reformulated the original basic model slightly and applied the reformulation to the driving forces of CO2 emissions. To remind ourselves, The STIRPAT equation is presented as

$$I_i = \alpha P^{\beta} A^{\gamma} T^{\delta} \varepsilon \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.3)}$$

The coefficient 'α' is a constant that scales the model. The coefficientsβ, γ and δ then determine the net effect of each of the variables involved, i.e. population, affluence and technology on environmental impact and 'ε' is the residual term. Therefore, the coefficients can be estimated by applying the standard statistical techniques. We can convert the above equation into logarithmic form to make it convenient for regression analysis as follows:

$$\log I_i = \alpha\beta \log P + \gamma \log A + \delta \log T + \rho \dots\dots\dots\dots\dots\dots (4.2)$$

Where $\rho = \log \varepsilon$. This simple equation allows for simple calculation of the impact elasticity of each anthropogenic factor. Since we are interested the impact of population, GDP per capita, energy and carbon intensity on CO_2 emission, we can improve the STIRPAT basic model to incorporate the variables in the so called Kaya identity as:

$$\log CO_2 = \alpha\beta \log P + \gamma \log GDPPC + \delta \log CI + \delta \log EI + \rho \dots\dots\dots\dots\dots\dots (4.3)$$

In equation (4.3), the new terms, i.e. $'CO_2'$, 'GDPPC', 'CI' and 'EI' stand for carbon dioxide, gross domestic product per capita, carbon intensity and energy intensity. In order to grasp the effect of Ethiopia's energy transformation to hydroelectric based power generation, we will limit our definition of CO_2 emission, energy intensity and carbon intensity to only those resulted from electricity and heat.

The first coefficient on population (i.e. $\alpha\beta$) is expected to be positive because increase in population is likely to increase impact on the environment. The same applies to GDP per capita. According to the Environmental Kuznets Curve hypothesis, at lower levels of income, increased consumption and income per capita leads to higher demand for consumption goods which will eventually leads higher impact on the environment until a certain level after which it reverses and goes down. Technology in the form of efficiency in energy use and carbon intensity is expected to reduce the T multiplier; therefore it, in most cases, has a negative coefficient.

4.2. Data

In this paper, we will use data from the world development indicators of the World Bank which covers the time period 1971 to 2011 with the exception of GDP per capita. Data on GDP per capita is obtained from Penn World Table series. The data are available on an annual basis.

The direct definitions of the variables we are interested is provided by the World Bank and Energy Information Administration is defined as follows:

Carbon dioxide (CO_2) emissions[3] are emissions resulted from the burning of fossil fuels and manufacture of cement. It is the sum of three general categories carbon dioxide emission provided by International Energy Administration (IEA): (1). emission from electricity generation and combined heat and power generation. (2) Emission of generation of electricity and heat generation by auto producers and (3) other energy which include emissions from petroleum refineries, coal mining, gas and oil extraction and other energy producers (World Bank, 2016).

Population definition of the World Bank incorporates all residents of the country regardless of legal status or citizenship. This does not include refugees who don't permanently settle in the country of asylum. The estimate represents midyear values of the population. (World Bank, 2016).

[3] This paper only takes carbon dioxde emission from electricity and heat production one of the aim of this paper is to understand the effect of energy transformation towards hydroelectric power generation on the growth of carbon dioxde emission in the country.

The proxy for affluence, GDP per capita, is gross domestic product divided by midyear population. The World Bank (2016) defines GDP as the sum of gross value contributed by resident producers in the economy added with any product taxes and deducts any subsidies not included in the product values. It is calculated without taking into account the degradation on natural resources.

Carbon intensity is defined as CO_2 emissions from consumption of solid fuel which mainly refer to emissions caused by the use of coal as an energy source. (World Bank, 2016).

The Energy Information Administration (EIA) defines energy intensity[4] as a country's consumption of energy per one unit of GDP. Increased energy efficiency and structural transformation in the economy have reduced energy intensity in countries such as the United States, implying lesser energy is required to produce the same unit of gross domestic product.

4.3. Methodology

Considerable focus has been given to test the existence of long run interaction between variables in the recent years. The most conventional way used to analyze this relationship has mainly been the use of co-integration techniques has been the use of Engle-Granger two step procedures and Johansen's test for co-integration. These tools mainly apply for cases in which the variables to be estimated are difference stationary. They also involve pre and post estimation of the variables to check for stationarity, unbiasedness and efficiency. Pesaran et al 2001). On the other hand, the parameters obtained from ARDL are efficient and the estimated standard errors are no longer biased.

[4] Energy intensity in our case includes energy production and consumption from hydroelectric power source per one US dollar. This enables us to see how hydroelectric power transformation has actually increased energy efficiency of the country compared with the traditional sources of energy.

In this paper, we use the recently developed framework called Autoregressive Distributed Lag(ARDL) which was introduced by Pesaran et al(1998). This framework has advantages over its predecessors. The first is that it tests for the existence of short and long run relationship among variables of interest without the requirement that the underlying explanatory variables are purely integrated of order 0 (I(0)), integrated of order 1 (I(1)) or mutually co-integrated (Pesaran et at, 2001). In using this model, if computed Wald test and F statistic falls outside critical levels, it is possible to draw inference without the need to check the co-integrating relationship of the repressors using for example Johansen test.

Second, the ARDL approach allows different variables to have different levels of optimal lags which are not the case in the standard models indicated above. Moreover, the ARDL approach is more suitable for small sample size, usually for a time series data of below 80 years, if the data is available annually (Narayan, 2004).

The general ARDL (3, 3, 3) specification with three lags in relation to the variables involves the estimation of conditional error correction looks like the following:

$$\begin{pmatrix} CO2_t = \alpha_0 + \alpha_1 CO2_{t-1} + \alpha_2 CO2_{t-2} + \alpha 3 CO2_{t-3} + \beta_1 POP_{t-1} + \beta_2 \ POP_{t-2} + \beta_3 POP_{t-3} \\ + \phi_1 GDPPC_{t-1} + \phi_2 GDPPC_{t-2} + \phi 3 GDPPC_{t-3} + \varphi_1 EI_{t-1} + \varphi_2 EI_{t-2} + \varphi_3 EI_{t-3} + \psi CI_{t-1} + \psi CI_{t-2} + \psi CI_{t-3} + \varepsilon_t \end{pmatrix}$$

………………………… (4.4)

From equation 4.4, the long run co-integration relation can be obtained by removing time subscript and then by collecting terms as:

$$CO2_t * = \frac{\alpha_0}{1-\alpha_1-\alpha_2-\alpha_3} + \frac{\beta_1+\beta_2+\beta_3}{1-\alpha_1-\alpha_2-\alpha_3} POP_t * + \frac{\beta_0+\beta_1}{1-\alpha_1-\alpha_2-\alpha_3} GDPPC_t *$$
$$+ \frac{\phi_1+\phi_2+\phi_3}{1-\alpha_1-\alpha_2-\alpha_3} EI_t * + \frac{\varphi_1+\varphi_2+\varphi_3}{1-\alpha_1-\alpha_2-\alpha_3} CI_t *$$

………………………(4.5)

Similarly, the error correction mechanism can be obtained by rearranging the original equation as follows,

$$\Delta CO_{2_t} = \beta_1 \Delta POP_t + \beta_2 \Delta POP_{t-1} + \delta_1 \Delta GDPPC_{\ t} + \delta_2 \Delta GDPPC_{\ t-1} +$$
$$\phi_1 \Delta EI_{\ t} + \phi_2 \Delta EI_{\ t-2} + \varphi_1 \Delta CI_{\ t} + \varphi_2 \Delta CI_{\ t-2} +$$
$$\alpha_3 \Delta CO_{2_{t-1}} - (1 - \alpha_1 - \alpha_2 - \alpha_3) ECM_{\ t-1} + \varepsilon_t \text{.......... ....} \textbf{(4.6)}$$

In the above equation 4.6, ECM_{t-1} represents the error correction and its coefficient indicates the speed of adjustment whose value relies between 0 and -1 and the coefficients indicate the dynamics of the model in the short run.

5. Empirical Results and Discussion

5.1. Unit Root Test and Lag Selection

For our observation, a stationarity test has been used to determine the order of integration of each variable. The Phillip Perron (PP) test for stationarity has been applied as it corrects for serial correlation and heteroscedasticity in errors by modifying the Dicky Fuller test statics. (Philips and Perron, 1988)

The test results for unit root using Phillip Perron stationarity test indicates that at 95% confidence level, all of our dependent and independent variables (all in logarithmic form) are not stationary in level form, but they are found to be stationary after first difference. Hence, we found that all our variables are integrated of order 1, I (1). The test result is present in table 1 as follows:

Table 1: Phillp Perron Test for unit root

Variable	t-statistic(intercept only)		5% Critical level	Order of integration
	Level	First Diff.		
Log(CO_2 emission)	-1.68	-7.81	-2.94	I(1)
Log(Population)	0.75	-3.74	-2.94	I(1)
Log(GDP per capita)	-1.02	-6.09	-2.94	I(1)
Log(carbon intensity)	-1.22	-8.01	-2.94	I(1)

As we have a small observation, Venus (2004) suggested that Akakie Information Criteria (AIC) and Final Prediction Error (FPE) are better than other lag selection criterion in the case of small sample as they minimize the possibility of underestimation while maximizing the chance of recovering the true lag length.

Hence, our ARDL model estimation indicated that the optimal lag level both for our dependent and independent variables to be three. This makes our model to be ARDL (3,3,3,3). Note that higher lag length can reduce the degree of freedom of our estimates. On the other hand, choosing too small length can cause serial correlation. Therefore, post estimation diagnostic test for serial correlation is necessary[5].

5.2. Test for Cointegration

To test for the existence of long run relationship among our variables, we use the F statistic. An F statistic higher than upper bound critical values indicates that there exists long run relationship among the variables. On the other hand, F statistic lower than lower bound critical value indicates no long run relationship among the variables. However, if the F statistics is below the upper bond critical value but above the lower bound critical value, the results are inconclusive and other types of test, such as Johansen Co-integration test should be used.

The result of F-statistics test to check for the existence of cointegration is presented in table 2 below:

[5] See appendix for post estimation test results

Table 2: ARDL Bounds Test

Sample: 1974- 2011

Included observations: 38

Test Statistic	Value	k
F-statistic	8.723282	3
Critical Value Bounds		
Significance	I0 Bound	I1 Bound
10%	2.37	3.2
5%	2.79	3.67
2.5%	3.15	4.08
1%	3.65	4.66

The results clearly show that the F statistic is higher than the upper bound at all levels of significance which led us to not reject the null hypothesis of no co-integration among our valuables. Hence, we can conclude that there exists long run relationship among our variables.

5.3. Estimation results of Long run relationship

The empirical results of long run relationships showing the interaction between Carbon dioxide emission from electricity and heat production and population, GDP per capita, and Carbon intensity, as produced by the ARDL model is presented in the following summarized table. Energy intensity variable has been omitted due to the problem of perfect multicollinearity with one or more of the other variables.

Table 3: Long run relationship between Carbon dioxide emission and Anthropogenic driving forces

Long Run Coefficients

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Population	1.417051	0.097776	14.492779	0.0000
GDP per capita	0.001091	0.111487	0.009788	0.9923
Carbon intensity	1.018972	0.024275	41.976735	0.0000
Constant	-8.654040	1.371255	-6.311038	0.0000

The empirical results in table 3 show that CO_2 emission from electricity and heat production is positively affected by population growth in the long run. This result is similar with both the theoretical literature indicated in KAYA identity and most empirical literatures reviewed in the previous sections of this paper. More specifically, 1% increase in population leads to 1.42% increase CO_2 emission from electricity and heat production and this result is statistically significant. Similarly, in the long run, CO_2 emission reacts positively to growth rate of CO2 intensity. Meaning the results imply that 1% improvement in carbon efficiency in terms of carbon intensity leads to 1.02% decline in the growth of Carbon dioxide emission from energy. This result is in consistency with many empirical research that technological improvements can reduce.

In contrast, growth rate of GDP per capita is found to be insignificant in affecting the growth of Carbon dioxide emission in the long run. This result is not consistent with empirical research done with respect to least developed countries, such as Candell (2009) who in their research found that per capita income plays a significant and big role in the future emission of LDCs such as Ethiopia due to the higher growth rate of these countries in the catching up process in terms of income. Finally, we cannot see the exact impact of energy efficiency in terms of energy intensity in affecting the growth rate of CO_2 emission due to the existence of perfect collinearity problem encountered during the estimation process. Also, we cannot compare the effect of energy intensity with some empirical research such as Duro(2014), who predicts that in the case of selected tropical African countries CO_2 emission would decline in the long run mainly due to improvements in energy intensity.

5.4. Error correction Using ARDL Methodology

The results of the error correction model indicate the impact of the independent variables on CO_2 emission in the short run. These results also show whether the outcomes are in consistent with equilibrium in the long run. Table 4presents the results of Error correction using ARDL model.

Table 4: ARDL error correction model estimates

ARDL Cointegrating And Long Run Form
Dependent Variable: CO2
Selected Model: ARDL(3, 3, 3, 3)
Sample: 1971 2011
Included observations: 38

Cointegrating Form				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(CO_2(-1))	-0.231977	0.106189	-2.184565	0.0399
D(CO_2(-2))	-0.409725	0.100596	-4.072958	0.0005
D(Population)	22.880386	3.908319	5.854279	0.0000
D(Population(-1))	-40.618288	7.126847	-5.699335	0.0000
D(Population(-2))	22.799161	3.737296	6.100444	0.0000
D(GDP per capita)	-0.051415	0.033800	-1.521148	0.1425
D(GDP per capita(-1))	0.052711	0.033346	1.580709	0.1282
D(GDP per capita(-2))	0.104252	0.036459	2.859454	0.0091
D(Carbon intensity)	0.974700	0.003799	256.558505	0.0000
D(Carbon intensity(-1))	0.202727	0.102188	1.983861	0.0599
D(Carbon intensity(-2))	0.387283	0.098195	3.944026	0.0007
Cointegrating Eq(-1)	-0.383543	0.053421	-7.179601	0.0000

We can see from the above table that the effect of population growth on CO_2 emission is significant short run. This result is similar with the long run effect of population but the short run impact of population is very strong. It led us to the conclusion, for the period 1971-2011 in Ethiopia; population plays the biggest role in emission of CO_2 in the short run. This is obvious when we see that the growth rate of population in Ethiopia currently is one of the highest in the world, making the demand for consumption higher which is directly related to emission levels. In contrast, GDP per capita is found to be insignificant in affecting CO_2 emission in the short run. This result is consistent with the long run results we saw earlier.

The technological coefficient indicating the relationship between CO_2 emission carbon intensity shows statistically significant results. Similar with the long run effects, carbon intensity has almost the same impact in CO_2 emission decline in the short run. The coefficient of the error correction term (Cointegrating Eq(-1)) represents the short run dynamics of the relationship between our variables. Since its value (-0.38) is negative and statistically significant, the magnitude implies that nearly 38% of any disequilibrium between the dependent variable and the independent variables is corrected within one year. This result allows us to expect that there exists cointegration among our variables.

6. Conclusions

Through a statistical analysis of the effects population, affluence and technology on the emission of Carbon dioxide in Ethiopia in the period 1971-2011, we find that the impact of population growth on carbon dioxide emission growth is strong, at least in the period of time considered in this study. As Ethiopia's population is currently increasing at an alarming rate, it is expected that this will have a negative impact on the environment. More specifically, with regard to CO_2 emission from energy consumption, high population growth in Ethiopia implies that the demand for energy and exploitation of resources will be higher, leading to higher emission levels. Therefore, policies directed at the mitigation of CO_2 emission in Ethiopia should also be consistent with the population policy of the country. Even though the country has adopted a clear population policy and achieved a significant improvement in mitigating the growth rate of population and fertility rate, still more needs to be done to prevent its negative impact on the environment.

Unlike the assumptions of the STIRPAT model and its predecessors, i.e. IPAT and Kaya identity, the impact of GDP per capita is found to insignificant in affecting CO_2 emission from electricity and heat production both in the short run and in the long run. This result is also inconsistent with the so called Environmental Kuznets Curve (EKC) hypothesis which assumes a curvilinear relationship between GDP per capita and environment. According to this hypothesis, environmental degradation worsens as an economy grows from levels until some threshold income is reached, after which the environmental impact starts to decrease.

Carbon intensity has reduced carbon emission from energy production in the form of electricity generation in the country in the time period considered in this study. As carbon emission per kg of energy has declined from about 0.008 to 0.0001from 1971 to 2011, it is obvious to see that this has contributed significantly to the reduction of CO_2 emission from this technological efficiency. More importantly, this is the result of the country's ambition to transform its energy source towards hydroelectric power generation in the past 50 years. The country has exploited only 0.9% of its hydropower potential. Hence, more investment in hydropower plants to fulfill the energy need in the country not only contributes to the energy need of Ethiopia at this important stage of the development process, but also ensures its sustainability.

We couldn't find evidence of the effect of energy intensity to the reduction in Carbon dioxide emission from energy in the country due to the problem of collinearity. This study resolved some important questions regarding carbon dioxide emissions and its driving forces in Ethiopia. The author believes that further studies are required in this area with a different time scope, data and methodology to fully understand the impacts of energy intensity on carbon dioxide emissions in Ethiopia.

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Appendix A

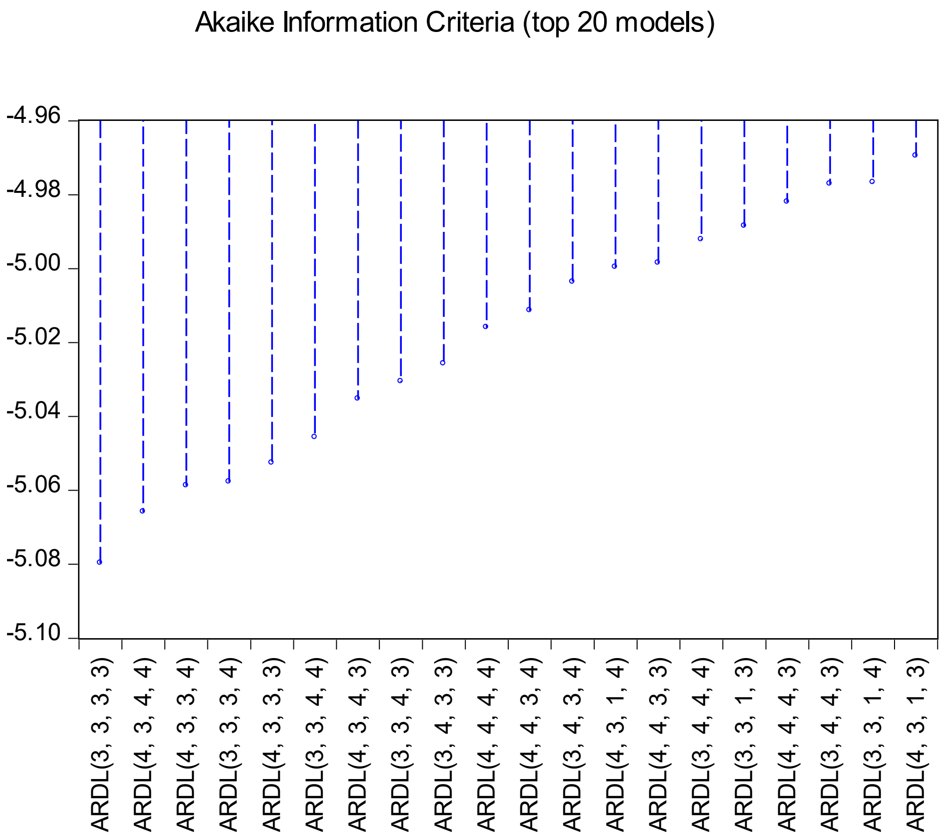
A. Lag Selection based on Akakie Information Criteria

Method: ARDL
Date: 05/17/16 Time: 22:45
Sample (adjusted): 1974 2011
Included observations: 38 after adjustments
Maximum dependent lags: 4 (Automatic selection)
Model selection method: Akaike info criterion (AIC)
Dynamic regressors (4 lags, automatic): POP GDPPC CARBONI
Fixed regressors: C
Number of models evalulated: 500
Selected Model: ARDL(3, 3, 3, 3)
Note: final equation sample is larger than selection sample

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
CO2(-1)	0.384478	0.174628	2.201701	0.0385
CO2(-2)	-0.177748	0.163078	-1.089955	0.2875
CO2(-3)	0.409725	0.127052	3.224868	0.0039
POP	22.88047	9.545300	2.397040	0.0255
POP(-1)	-62.95540	24.74758	-2.543901	0.0185
POP(-2)	63.41767	23.05673	2.750506	0.0117
POP(-3)	-22.79924	7.700731	-2.960659	0.0072
GDPPC	-0.051415	0.043195	-1.190309	0.2466
GDPPC(-1)	0.104544	0.051441	2.032310	0.0544
GDPPC(-2)	0.051541	0.053445	0.964378	0.3453
GDPPC(-3)	-0.104252	0.050725	-2.055220	0.0519
CARBONI	0.974700	0.005158	188.9606	0.0000
CARBONI(-1)	-0.381151	0.170109	-2.240628	0.0355
CARBONI(-2)	0.184556	0.161160	1.145173	0.2644
CARBONI(-3)	-0.387284	0.125788	-3.078869	0.0055
C	-3.319206	1.213005	-2.736350	0.0121

R-squared	0.999899	Mean dependent var	18.74228
Adjusted R-squared	0.999830	S.D. dependent var	1.259214
S.E. of regression	0.016437	Akaike info criterion	-5.082958
Sum squared resid	0.005944	Schwarz criterion	-4.393448
Log likelihood	112.5762	Hannan-Quinn criter.	-4.837635
F-statistic	14474.41	Durbin-Watson stat	2.047798
Prob(F-statistic)	0.000000		

*Note: p-values and any subsequent tests do not account for model selection



Appendix A shows the results of Akakie's Information Criterion (AIC) for selecting lag structure of our ARDL model. We can see that AIC chosen our lag structure for our ARDL model to be ARDL (3, 3, 3, 3).

B. Estimates of long run model ARDL(3,3,3,3)

ARDL Cointegrating And Long Run Form

Dependent Variable: CO2

Selected Model: ARDL(3, 3, 3, 3)

Date: 05/17/16 Time: 22:56

Sample: 1971 2011

Included observations: 38

Cointegrating Form

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(CO2(-1))	-0.231977	0.106189	-2.184565	0.0399
D(CO2(-2))	-0.409725	0.100596	-4.072958	0.0005
D(POP)	22.880386	3.908319	5.854279	0.0000
D(POP(-1))	-40.618288	7.126847	-5.699335	0.0000
D(POP(-2))	22.799161	3.737296	6.100444	0.0000
D(GDPPC)	-0.051415	0.033800	-1.521148	0.1425
D(GDPPC(-1))	0.052711	0.033346	1.580709	0.1282
D(GDPPC(-2))	0.104252	0.036459	2.859454	0.0091
D(CARBONI)	0.974700	0.003799	256.558505	0.0000
D(CARBONI(-1))	0.202727	0.102188	1.983861	0.0599
D(CARBONI(-2))	0.387283	0.098195	3.944026	0.0007
CointEq(-1)	-0.383543	0.053421	-7.179601	0.0000

Cointeq = CO2 - (1.4171*POP + 0.0011*GDPPC + 1.0190*CARBONI -8.6540)

Long Run Coefficients

Variable	Coefficient	Std. Error	t-Statistic	Prob.
POP	1.417051	0.097776	14.492779	0.0000
GDPPC	0.001091	0.111487	0.009788	0.9923
CARBONI	1.018972	0.024275	41.976735	0.0000
C	-8.654040	1.371255	-6.311038	0.0000

C. Test for Hetroskedasticity

Heteroskedasticity Test: Breusch-Pagan-Godfrey

F-statistic	0.354130	Prob. F(15,22)	0.9786
Obs*R-squared	7.390682	Prob. Chi-Square(15)	0.9459
Scaled explained SS	1.659825	Prob. Chi-Square(15)	1.0000

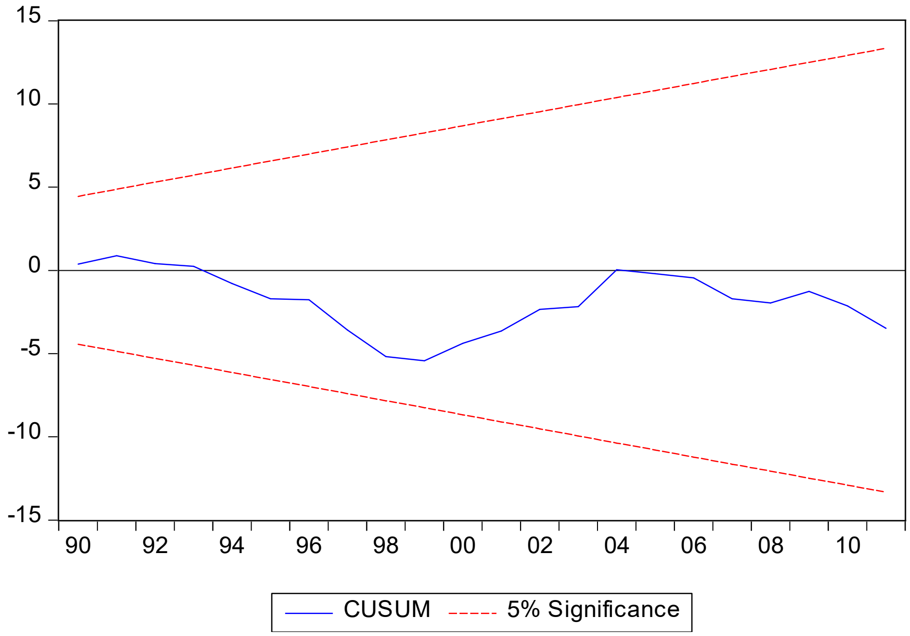
Test Equation:
Dependent Variable: RESID^2
Method: Least Squares
Date: 05/17/16 Time: 23:44
Sample: 1974 2011
Included observations: 38

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.021102	0.015762	1.338786	0.1943
CO2(-1)	0.002594	0.002269	1.143267	0.2652
CO2(-2)	-0.001946	0.002119	-0.918294	0.3684
CO2(-3)	0.001078	0.001651	0.652976	0.5205
POP	-0.070400	0.124034	-0.567586	0.5761
POP(-1)	0.177034	0.321576	0.550519	0.5875
POP(-2)	-0.161862	0.299605	-0.540253	0.5944
POP(-3)	0.052414	0.100065	0.523800	0.6057
GDPPC	-0.000426	0.000561	-0.758255	0.4563
GDPPC(-1)	0.000146	0.000668	0.217783	0.8296
GDPPC(-2)	0.000303	0.000694	0.436850	0.6665
GDPPC(-3)	7.32E-05	0.000659	0.111018	0.9126
CARBONI	1.85E-05	6.70E-05	0.276266	0.7849
CARBONI(-1)	-0.002614	0.002210	-1.182703	0.2496
CARBONI(-2)	0.002029	0.002094	0.968665	0.3432
CARBONI(-3)	-0.001215	0.001635	-0.743150	0.4653

R-squared	0.194492	Mean dependent var	0.000156
Adjusted R-squared	-0.354719	S.D. dependent var	0.000184
F-statistic	0.354130	Durbin-Watson stat	2.211757
Prob(F-statistic)	0.978587		

Then null hypothesis of Breusch-Pagan-Godfrey test is homoscedasticity and the alternative hypothesis is heteroscedasticity. As we see from our table above the chi squared value is not significant with p-value above 5%. Therefore we can't reject the null hypothesis of homoscedasticity.

D. CUSUM Stability Test



It can be seen from the above figure that the plot of CUSUM lies within the critical 5% bounds which shows evidence of long run relationship among our variables. Hence, it confirms that our coefficient is stable.

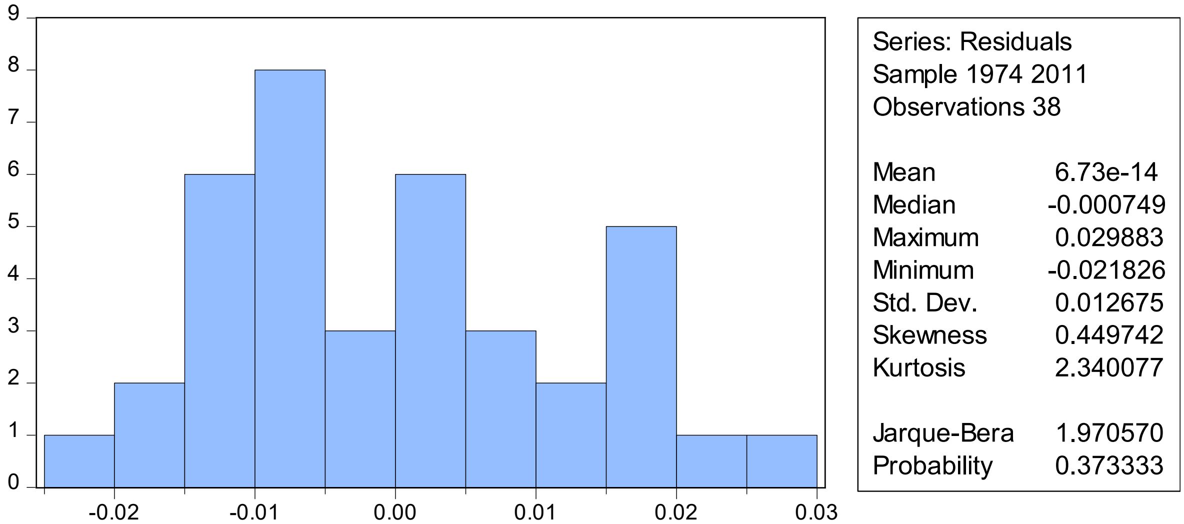
E. Test for Serial Correlation(Breusch-Godfrey LM test)

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	1.986237	Prob. F(3,19)	0.1502
Obs*R-squared	9.072224	Prob. Chi-Square(3)	0.0683

The Breusch-Godfrey test is a test for the existence of autocorrelation in the residuals. The null hypothesis is no serial correlation of any order and the alternative hypothesis is serial correlation at the given lag order. Our test result for serial correlation has a probability value of greater than 5% (0.068). This led us not to reject the null hypothesis of no serial correlation.

F. Jarque-Bera test for normality of residuals



Jarque-Bera test is a test for goodness of fit to see whether the data has a normal distribution by observing its skewness and kurtosis. The null hypothesis is that skewness and excess kurtosis are zero and hence the data are from a normal distribution. As we can see from the above figure, the probability value for our Jarque-Bera value is greater than 5% which is insignificant. This led us to not to reject the null hypothesis of normal distribution.