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The Nexus among Globalization, Natural Resource Rent, and Energy Consumption for Environmental Sustainability in Ethiopia

Shemelis Kebede Hundie, Lamessa Tariku Abdisa, Habtamu Adane Legas and Arega Shumetie

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Shemelis Kebede Hundie[1], Lamessa Tariku Abdisa[2], Habtamu Adane Legas[3] and Arega Shumetie[2]

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[1] School of Policy Studies, Ethiopian Civil Service University, Addis Ababa, Ethiopia
[2] Ethiopian Economics Association, Addis Ababa, Ethiopia
[3] Department of Economics, Addis Ababa University, Addis Ababa, Ethiopia

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ARDL	Autoregressive Distributive Lag
EKC	Environmental Kuznets Curve
GFN	Global Footprint Network
MENA	Middle East and North Africa
OECD	Organisation for Economic Cooperation and Development

ABSTRACT

Nowadays the issue of environmental sustainability has gained paramount attention due to its threat to sustainable development. Understanding key factors determining environmental sustainability plays a crucial role in designing evidence-based environmental policies. The main objective of this study is to examine the effect of natural resource rents, political globalization, economic globalization, and renewable energy consumption on the ecological footprint in the presence of population growth, industrialization, urbanization, and economic growth using annual data spanning from 1971-2018. The study employed Autoregressive Distributed Lag (ARDL) bounds approach to testing for cointegration, and Bayer and Hanck combined cointegration test for the analysis. Besides, the novel dynamic ARDL simulation method was applied to estimate the counterfactual effect of shocks in each explanatory variable on the ecological footprint. The direction of Granger causality among variables under study was examined using the Toda-Yamamoto Granger causality and frequency-domain Granger causality tests. Results from the cointegration test reveal that the variables are cointegrated during the period under investigation. The Environmental Kuznets Curve (EKC) hypothesis is validated between economic growth and ecological footprint. Industrialization, urbanization, renewable energy consumption, political globalization, and natural resources rents deteriorate environmental sustainability by increasing ecological footprint. On the other hand, economic globalization reduces the ecological footprint. This study highlights that causality runs from economic growth, industrialization, political globalization, natural resources rents, and population growth to ecological footprint with feedback while renewable energy consumption causes ecological footprint with no feedback. Based on these findings, it is recommended that the government should develop a resource use plan and policy mainly for the non-renewable ones to ensure the optimal extraction of these resources. Though there are environmental safety standards that require companies engaged in the extraction of natural resources should be met, the level of monitoring and enforcement mechanism is not strong. Thus, the Environment Forest Climate Change Commission (EFCCC) should improve its monitoring mechanism to ensure the welfare of humans and the safety of the environment is not put in danger. Finally, the country should upgrade the technology and process for the production of renewable energy. This should be accompanied by the use of energy-efficient technology in the production and consumption of renewable energy sources to make the production and consumption of renewable energy sources more environmental-friendly.

Keywords: Ecological footprint, natural resources rents, renewable energy, Dynamic ARDL simulation, Globalization, Environmental sustainability

1. INTRODUCTION

1.1. Background of the Study

Currently, we are in a world where human populations are more crowded, more consuming, more connected, and, in many parts, more diverse than at any time in history. According to the projection by the United Nations, the world's population is expected to increase by 2 billion in the next 30 years and reach 9.7 billion in 2050 wherein the majority of the increment is expected from sub-Saharan Africa (SSA) (UN, 2019)[2]. Meeting the basic needs of the additional population means greater production and consumption of goods and services, increased demand for energy and materials, and intensified pressures on the environment and resources. The consistent increment in population growth results in a continuous increment in energy consumption, which could finally result in consistent pressure on the ecosystem and environment.

Alongside the global population increment, global energy consumption has dramatically increased in recent years and is projected to continue to increase. For example, consumption of renewable energy is expected to reach 161 exajoules by 2050. This is a significant increment since the total renewable energy consumption was only three exajoules in 2000. According to the US Energy Information Administration (EIA), world energy consumption is expected to grow by nearly 50% between 2018 and 2050, wherein the significant increment will be from non-OECD countries. Of the total increment in energy consumption worldwide, renewable energy is the fastest-growing source, with 3.1% growth per year between 2018 and 2050 (EIA, 2019[3]).

The continuous energy consumption increment necessitates the growth of capital expenditure, which creates a positive impact on the economy by creating more jobs and generating tax revenues for the government. The relationship between energy consumption and economic growth has been well documented in the literature (Ozurk, 2010; Hannesson, 2009; Lee and Lee, 2010; Belke *et al*., 2011; Farhani and Rejeb, 2012). However, a research frontier that is very crucial in recent times is the relationship between drivers of economic growth, energy consumption, and

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[2] UN DESA, 2019. Growing at a slower pace, world population is expected to reach 9.7 billion in 2050 and could peak at nearly 11 billion around 2100 | UN DESA | United Nations Department of Economic and Social Affairs

[3] EIA, 2019. Today in Energy, accessed online from https://www.eia.gov/todayinenergy/detail.php?id=41433#

environmental sustainability. For this, recent empirical studies have been geared toward examining the relationship between globalization, energy consumption, and environmental sustainability.

There are two strands of literature regarding the relationship between energy and the environment. The first group of literature focuses on overall energy consumption and examines the relationship between energy and the environment under the Environmental Kuznets Curve (EKC) framework (Yusu, 2014; Dogan & Seker, 2016; Franco *et al.*, 2017). Many of these studies have obtained the finding that energy consumption negatively affects environmental sustainability. The second strand of literature investigated the relationship between disaggregated energy consumption and environmental sustainability indicators (Destek & Sinha, 2020; Al-Mulali *et al.*, 2016; Al-Mulali & Ozturk, 2015; Ulucak & Khan, 2020). The results of these empirical studies vary depending on the type of environmental sustainability indicator and empirical model employed by the scholars. For example, Destek and Sinha (2020); Majeed and Luni (2019), and Ulucak and Khan (2020) have examined the relationship between consumption of renewable energy and the Ecological Footprint (EF) index and found that consumption of renewable energy reduces the ecological footprint, implying consumption of renewable energy improves the environmental quality. Similarly, Ulucak *et al.* (2020) investigated the relationship between disaggregated energy consumption and environmental sustainability in 26 OECD countries and found that non-renewable energy has a detrimental effect on the environment, while renewable energy reduces deterioration in environmental quality. Other studies have used carbon dioxide emissions (CO_2) as an indicator for environmental sustainability and examined the relationship between CO_2 and disaggregated energy consumption. Rasoulinezhad and Saboori (2018) investigated the long-run and causal relationship between CO_2 emissions and renewable and non-renewable (fossil fuels) energy consumption for commonwealth independent states and found a 1% increment in non-renewable energy consumption resulted in a 1% increase in CO_2 emissions. The study by Bekun, *et al.* (2019) shows that non-renewable energy consumption increases carbon emissions while renewable energy consumption decreases CO_2 emissions in 16-EU countries.

The discussion over the relationship between globalization and the environment started in the 1970s and is still a burning issue in the literature (Muradian & Martinez-Alier, 2001). Globalization, measured in the KOF globalization index[4] can promote environmental quality through the use of environment-friendly technologies and structural transformation, which in turn improve the environment. On the other hand, growing opportunities created through globalization may induce countries to export more, which would increase the production of goods at the expense of the environment (Ahmed *et al.,* 2019). Studies show that globalization has significant environmental consequences, which are difficult to specify (Managi *et al*., 2009; Shahbaz *et al*., 2018b). As a result, studies that attempted to examine the impact of globalization on environmental sustainability from a consensus perspective do not exist, and no conclusions can be derived from these empirical studies.

According to Copeland and Taylor (2013), the effect of globalization on the environment can be explained through three effects: scale, composition, and technique effect. The scale effect refers to the reaction of the production level to international trade. In other words, globalization triggers economic activity, for instance, by more transportation services and more production and consumption of goods and services (Le *et al*., 2016). Since these activities induce environmental costs, scholars argue that the scale effect of globalization worsens environmental quality by stimulating trade openness and other economic activities (Twerefou *et al*., 2017). On the other hand, globalization is expected to contribute to environmental quality through the technique and composition effects that underline the role of obtaining clean technologies and structural transformation of economies, respectively (Copeland and Taylor, 2013).

Similarly, other studies have examined the relationship between environmental sustainability and globalization using different measurement indexes. For instance, Al-Mulali and Ozturk (2015) examined the effect of trade openness on the ecological footprint for MENA countries using the EKC framework over the period 1996-2012 and found that trade openness and other co-variates increase environmental damage. Similarly, Mulai *et al*. (2016) have analyzed the impact of renewable energy, GDP, urbanization, and trade openness on the ecological footprint of 58 countries using time series data between 1980-2009 and found that trade openness has a positive impact on ecological footprint. A similar finding was obtained by Figge *et al*. (2017). On the other hand, Faik *et al*. (2019) found that trade openness reduces ecological footprint growth while Rudolph and Figge (2017) and

[4] See https://ethz.ch/content/dam/ethz/special-interest/dual/kof-dam/documents/Globalization/2021/KOFGI_2021_method.pdf for a detailed methodological procedures used in calculation of the KOF globalization index.

Ahmed *et al*. (2019) reported no significant relationship between ecological footprint and globalization. The study by Saud *et al.* (2020) concluded that globalization has a positive effect on the ecological footprint in some countries while it has a negative effect in other countries.

The relationship between natural resource abundance and environmental degradation has important environmental implications. However, this domain is insufficiently investigated, and the empirical findings are inconclusive. Significant economic growth, along with rapid urbanization and industrialization, has increased the extraction and consumption of natural resources in many developing countries. For instance, Bekun *et al.* (2019) found a positive significant relationship between natural resource rent and CO_2 emissions in the long run, implying that the overdependence on natural resource rent affects environmental sustainability if conservation and management options are ignored. Balsalobre-Lorente *et al*. (2018) also found that natural resource abundance, renewable electricity consumption, and energy innovation reduce environmental degradation in five EU countries. Likewise, Pao and Tsai (2010); Wu *et al.* (2017); and Kwakwa *et al*. (2018) found that natural resource depletion negatively affects the environment and has severe environmental concerns.

A review of all the above literature suggests that previous studies have analyzed different determinants of environmental sustainability, including globalization, energy consumption, and natural resources, but with different findings. Specifically, there is no consensus about the negative, positive, significant, or insignificant effects of globalization on the environment across countries. This calls for an in-depth country-specific study to infer proper policy implications regarding the relationship between globalization, energy consumption, natural resources, and the environment. Accordingly, this study explores the nexus between these variables in Ethiopia, which is the second-largest populous country and one of the fastest-growing economies in Africa. According to the Global Footprint Network (GFN)[5] data, Ethiopia is categorized among ecologically deficit countries with an ecological footprint of 1 against a biocapacity per capita of 0.6. In terms of globalization, Ethiopia's KOF has doubled from 1970 to 2018, which increased from 22.51 in 1970 to 45.06 in 2018.

[5] Global Footprint Network (GFN, 2021). Advancing the science of sustainability, accessed online on September 2, 2021, from https://data.footprintnetwork.org/?_ga=2.195158824.54630761.1630587454-598724089.1629450020#/

The population growth, coupled with economic growth and urbanization in Ethiopia, has created a huge energy demand. For example, the country has been thriving with great effort for a transition from non-renewable to renewable energy sources in the coming few decades. In this regard, the electricity demand is growing by 30% per year owing to rapid population growth and urbanization in the country (International Trade Administration, 2020)[6]. Though there is a huge demand for energy in the country owing to rapid population growth, economic growth, and urbanization, there are scanty empirical studies that investigate the relationship between globalization, energy consumption, natural resource extraction, and environmental sustainability. Earlier studies in the country have focused on the long-term evolution of energy and electricity demand forecasting (Gebremeskel *et al.*, 2021); energy demand analysis under different scenarios; and energy efficiency forecasting (Mondal *et al*., 2018). The only study that is close to the current one is the work of Usama *et al.* (2020), who examined the role of renewable energy and non-renewable energy in affecting CO_2 emissions under an augmented EKC framework. However, the environmental sustainability indicator used by the authors, CO_2 emission, is very narrow and is criticized in the literature because it is not a compressive indicator of environmental sustainability and it represents only a small proportion of environmental damage (Al-Mulali & Ozturk, 2015). This study employed a more comprehensive indicator of environmental sustainability that effectively captures environmental degradation, which is the ecological footprint.

In this regard, the contributions of the current study to the related stock of literature are based on the following three foundations: First, to the best of the authors' knowledge, there are no previous studies in Ethiopia that used ecological footprint as a proxy for environmental quality. The ecological footprint is a comprehensive indicator of environmental sustainability and effectively captures environmental degradation (Ahmed et al., 2021; Saqib & Benhmad, 2021). Previous empirical studies considered only one environmental quality indicator, mostly CO_2 emissions, and this produced misleading results since environmental quality is a multidimensional phenomenon. This necessitates using a comprehensive environmental quality indicator that takes into account all aspects of environmental degradation. Therefore, this study used the Ecological Footprint (EF henceforth) to fill the gap. Second, the study considered the role of economic and political globalization and natural resource rents as determinants of environmental

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[6] International Trade Administration (2020), accessed online from https://www.trade.gov/knowledge-product/ethiopia-energy

sustainability, which are rarely considered in the energy consumption-environmental sustainability nexus. Previous studies used partial indicators like trade openness and FDI as proxies for economic globalization, which could not show the full picture of its effect on environmental sustainability. Moreover, the effects of political globalization and natural resource rents on environmental sustainability have not been examined so far. Understanding the current energy scenario requires the inclusion of natural resource rents in the process of modeling environmental sustainability. Third, unlike previous related studies conducted in Ethiopia, the current study employed a novel estimation technique, that was the dynamic ARDL simulation model, to examine a dynamic relationship between globalization, energy consumption, natural resource extraction, and environmental sustainability.

1.2. Objectives of the Study

The main objective of the study was to investigate the nexus between globalization, energy consumption, natural resources, and the environment using time series data from 1971 to 2018. More specifically, the study had the following objectives:

- Investigate the patterns of energy consumption, natural resource rent, and sustainability issues in Ethiopia;
- Assess the status of energy consumption, natural resources rents, globalization, and ecological footprint in Ethiopia in the globalized economy;
- Examine the long- and short-run association between globalization, energy consumption, natural resource rent, and environmental sustainability in Ethiopia;
- Analyze the Granger causality between ecological footprint and variables of interest using the Toda-Yamamoto (TY) approach and frequency-domain techniques; and
- Predict the counterfactual responses of the ecological footprint to a shock in each explanatory variable under study using dynamic ARDL simulations.

2. LITERATURE REVIEW

The issue of climate change and its impact on human health remains the key focus and policy priority for the global agenda (Ulucak *et al*., 2019). According to the Intergovernmental Panel on Climate Change (IPCC, 2021), climate change has been spreading and intensifying due to rapidly increasing greenhouse gases (GHGs) and it is very likely that a warming level of 1.5°C in the coming decades if business as usual continues. The 2015 Paris Agreement called for reducing CO_2 emissions by 45% by 2030 from 2010 levels. However, the global average GHG concentrations reached a fraction of 414.24 parts per million of CO_2, which was a new record. This situation is a serious challenge for the sustainable development of the global economy.

The concept of sustainable development, with its three pillars such as social, economic, and environmental, has become ubiquitous (Purvis *et al*., 2019; Ulucak *et al*., 2019). Among them, environmental sustainability has become more relevant for sustainable development as a result of its direct correlation with climate change and poor ecological circumstances (Alvarado *et al*., 2021; Ulucak *et al*., 2019). In recent years, examining factors determining environmental sustainability has become the center of the debate. Different human actions such as consumption and production have the potential to drive \environmental sustainability. This section presents a review of related literature on the main drivers of environmental sustainability.

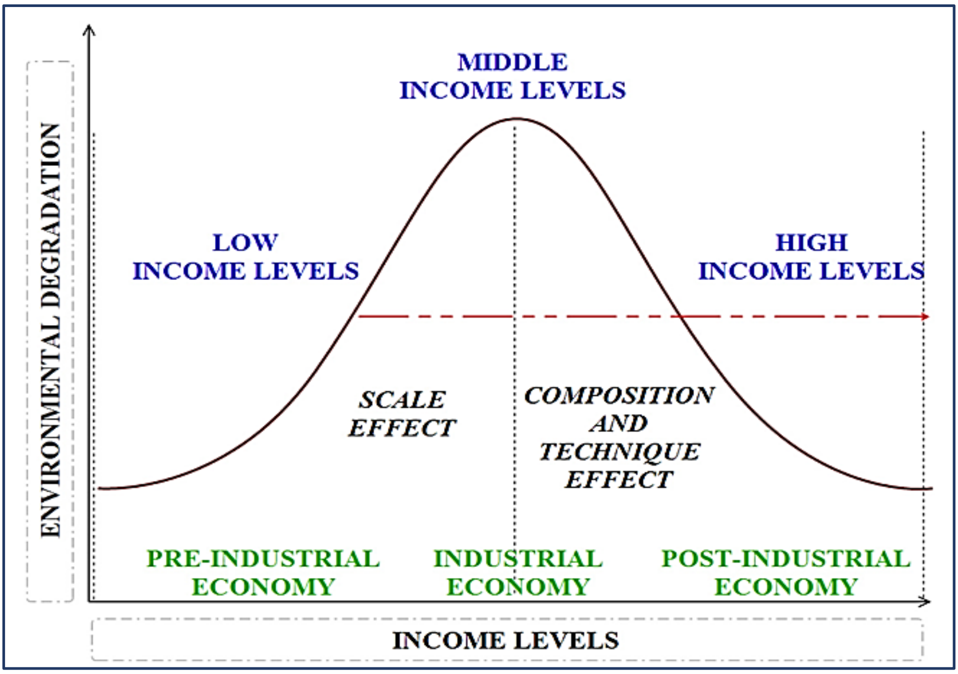
2.1. The Environmental Kuznets Curve (EKC)

Over the last three decades, empirical studies have been conducted to examine determinants of environmental sustainability. The effect of economic growth on environmental quality has been the most extensively investigated area in the energy and environmental economics literature. The existing related empirical studies investigated the relationship between economic growth and environmental quality using different environmental quality indicators like ecological footprint and CO_2 emissions. This section presents a review of selected literature on the relationship between economic growth and environmental quality.

Tremendous efforts have been made by scholars to examine and understand the effects of economic growth on environmental quality using different frameworks, but with inconclusive conclusions. The dominant framework under which the impact of economic growth on environmental quality has been investigated is the Environmental Kuznets Curve (EKC) hypothesis (Arnaut & Lidman, 2021; Haseeb, Xia, Danish, Baloch, & Abbaset al., 2018; Hundie, 2021; S. P. Nathaniel, Alam, Murshed, Mahmood, & Ahmad *et al*., 2021; Ulucak & Bilgili, 2018). The EKC concept emerged with the seminal work of Grossman and Krueger (1991), and it is named after Kuznets (1955), who conjectured that income inequality initially increases at an early stage of economic development and then falls after a certain economic development threshold is achieved. In this context, the EKC hypothesizes that the relationship between environmental degradation and economic growth can be captured by the inverted U-shaped function (Arnaut & Lidman, 2021; Maneejuk et al., 2020; Stern, 2004). The EKC hypothesis posits that economic growth harms the environment at an early stage of economic development, but it turns to improve environmental quality after a certain income threshold is achieved (Maneejuk *et al.,* 2020; Shahbaz & Sinha, 2019; Stern, 2004). Stern (2004) argued that the turning point at which the decoupling starts occurring depends on the environmental quality indicator used. The EKC hypothesis is graphically illustrated in Figure 1.

It is well-documented that several factors are responsible for the shape of the EKC. The common factors are scale, composition, and technical effect (M. A. Baloch et al., 2020; Grossman & Krueger, 1991; Sarkodie & Strezov, 2019). As can be seen from Figure 1, low-income countries should produce more goods and services to satisfy the increasing demand, and this requires more exploited resources, which aggravates environmental degradation. Besides, industrialization is promoted and consumption of non-renewable energy harms environmental quality (M. A. Baloch *et al*., 2020; Sarkodie & Strezov, 2019). When structural change has taken place in the economy, the negative effect of economic growth on environmental quality declines, and this is known as "the composition effect." According to the composition effect, environmental degradation rises when the agrarian economy shifts to energy-intensive and carbon-intensive industries. As the service sector takes over the industrial sector, environmental degradation improves (Sarkodie & Strezov, 2018). When countries reach a higher level of economic development, they start placing a greater value on environmental quality. Polluting and obsolete technologies are replaced by cleaner and more sophisticated ones, environmental regulations become stringent and industrial standards are set to improve environmental quality. This effect is known as the "technical effect" and it improves environmental quality through enhancing productivity and lowering emission levels, as argued by scholars (Sarkodie & Strezov, 2018, 2019; Stern, 2004).

Figure 1: The Relationship between Environmental Degradation and Income Levels



Source: Adopted from Sarkodie and Strezov (2019)

A plethora of empirical studies have been conducted to examine the validity of the EKC hypothesis both in developed and developing countries using different estimation techniques. The following table presents a summary of selected empirical studies conducted using the EKC framework.

Table 1: Summary of Selected Literature Review on EKC

Author (s)	Country(ies)	Period	Environmental Indicator (s)	Model	Results
Sarkodie and Strezov (2018)	Australia	1974 -2013	CO_2 and EF	FMOLS, DOLS, CCR	EKC is valid
Hundie (2021)	Ethiopia	1979–2014	CO_2	ARDL, DOLS	EKC is valid
Huang et al. (2021)	China	1995–2019	CO_2	CS-ARDL	EKC confirmed
Pata (2018)	Turkey	1974-2014	CO_2	ARDL, FMOLS, CCR	EKC confirmed
Hussain et al. (2021)	Thailand	1970-2018	EF	ARDL	EKC is valid
Sharif et al. (2019)	74 nations	1990-2015	CO_2	FMOLS	EKC is valid
Sharif et al. (2020)	Turkey	1965Q1-2017Q4	EF	QARDL	EKC is valid
Zoundi (2017)	25 African countries	1980-2012	CO_2	DOLS, System-GMM, DFE, MG, and PMG	Not confirmed
Tenaw and Beyene (2021)	20 SSA countries	1990-2015	EF	CCE-PMG and panel ARDL	EKC confirmed but it depends on the level of natural resources abundance
Baloch et al. (2020)	OECD countries	1990–2017	CO_2	PMG/ARDL	EKC is valid
Saqib and Benhmad (2021)	22 European countries	1995–2015	EF	DOLS and FMOLS	EKC is valid
Aziz et al. (2021)	Mexico, Indonesia, Nigeria, and Turkey	1995–2018	CO_2	MMQR	EKC is valid but depends on the quantile of income
Gill et al. (2018)	Malaysia	1970–2011	CO_2	ARDL	The relationship between economic growth and environmental

					degradation is linear and positive
Dogan and Ozturk (2017)	USA	1980–2014	CO_2	ARDL	U-shaped
Sohag et al. (2019)	OECD countries	1980–2017	CO_2	CS-ARDL	U-shaped
Dogan and Turkekul (2016)	USA	1960–2010	CO_2	ARDL	U-shaped
Allard et al. (2018)	74 countries	1994–2012	CO_2	Quantile regression	N-shaped except for high-income countries
Lorente and Alvarez-Herranz (2016)	25 OECD countries	1992–2010	CO_2	GLS	N-shaped
Dogan and Inglesi-Lotz (2020)	European countries	1980 –2014	CO_2	FMOLS	EKC is confirmed when aggregate GDP is used while U-shape exists when an industrial share of GDP is considered
Stern and van Dijk (2017)	151 countries	1990–2010	PM2.5	WLS	A positive relationship between environmental degradation and economic growth
Usama et al. (2020)	Ethiopia	1981–2015	CO_2	ARDL	EKC and N-shaped
Aşıcı and Acar (2018)	87 countries	2004–2010	Non-carbon EF	Panel data analysis	EKC not validated
Destek and Sinha (2020)	OECD countries	1980 –2014	EF	Group mean	U-shaped

Dogan et al. (2020)	BRICST	1980–2014	EF	FMOLS, DOLS, and AMG	U-shaped under FMOLS
Aydin et al. (2019)	26 EU member countries	1990–2013	EF	PSTR	EKC not valid
Mrabet and Alsamara (2017)	Qatar	1980–2011	CO_2 and EF	ARDL	EKC does not hold for CO_2 but is valid for EF
Sharma et al. (2021)	8 developing countries in Asia	1990–2015	EF	CS-ARDL	N-shaped

It may be logical and clear enough if you categorize the above literature based on their findings, U-shaped, inverted U-shaped, N-shaped…

A summary of some selected empirical reviews in Table 1 indicates that an irrefutable conclusion has not been reached yet regarding the validity of the EKC hypothesis. Empirical evidence is mixed regarding the impact of economic growth on environmental quality. Some evidence confirms the validity of the EKC hypothesis (Huang *et al*., 2021; Hundie, 2021; Hussain *et al*., 2021; Sharif *et al*., 2019, 2020), while others refute it (Aşıcı & Acar, 2018; Aydin et al., 2019; Destek & Sinha, 2020; Dogan et al., 2020; Stern & van Dijk, 2017). Empirical evidence that does not support the existence of the EKC hypothesis argues that the relationship between economic growth and environmental degradation follows positive and linear (A. R. Gill et al., 2018; Stern & van Dijk, 2017), U-shaped (Destek & Sinha, 2020; Dogan et al., 2020; Dogan & Turkekul, 2016; Sohag et al., 2019), N-shaped (Al-Mulali et al., 2020; Lorente & Alvarez-Herranz, 2016; Sharma et al., 2021a; J. Zhang, 2021), and M-shaped (Terrell, 2021; Zanin & Marra, 2012) relationships. Other scholars (Mikkelson, 2019) criticize the EKC hypothesis based on the fact that waiting for the EKC hypothesis to start improving environmental quality is not viable, particularly for developing countries. Mikkelson (2019) attributes his argument to two main factors; first, the current level of GDP of these countries is too far from the turning point of GPD and it requires a long time to reach there, and second, the world's ecological footprint has already overshot the global biocapacity. Mikkelson suggested calling for public policy to improve environmental quality rather than relying on the EKC hypothesis to do the job.

The validity of the EKC hypothesis depends on several factors, as revealed in Table 1. Soberon and D'Hers (2020) found that the EKC hypothesis exists when the ecological footprint is used as an indicator for environmental degradation while CO_2 emissions do not support it, which implies that the type of ecological indicators used to matter. Most of the previous studies investigating the relationship between economic growth and environmental quality have several limitations. First, they employed CO_2 emissions as a proxy for environmental degradation. However, this constitutes only a part of the total environmental damage caused by economic activities and therefore failed to provide a full insight *(Uddin et al*., 2017). Moreover, the ecological indicators like CO_2 emissions used in the previous studies fail to capture ecological sustainability since they take into account only a certain portion of the impacts of human activities on the environment (Destek & Sinha, 2020; Kirikkaleli et al., 2021). Recently, a strong inclination has been observed to use a comprehensive ecological indicator, ecological footprint, in analyzing the relationship between economic growth and environmental quality (Akadiri et al., 2019; Asici & Acar, 2018; Aşici & Acar, 2015; Aydin et al., 2019; Destek & Sinha, 2020; Dogan et al., 2020; Kirikkaleli et al., 2020; Uddin et al., 2017; Ulucak & Bilgili, 2018; Y. Wang et al., 2013). The ecological footprint is a strong and comprehensive ecological indicator (Al-Mulali et al., 2015; Danish & Wang, 2019; Destek & Sinha, 2020; Galli et al., 2012; Y. Wang et al., 2013) because it measures the biocapacity required for an economic system to function, i.e., the earth's biocapacity to supply natural resources to promote the required lifestyle and the amount of waste from consumption (demand side) and the capacity to absorb the waste produced by the economic system as well as how quickly new resources can be generated by nature (supply side) (Nathaniel, 2021a; Wackernagel & Monfreda, 2004). According to Ulucak and Bilgili (2018), the ecological footprint measures both direct and indirect effects of consumption and production activities on the environment. The ecological footprint covers CO_2 emissions, changes in land use, changes in fishing grounds, and deforestation (Bilgili & Ulucak, 2018). The ecological footprint indicator is constructed from six bio-productive land use categories, namely forest land, grazing land, cropland, carbon footprint, ocean, and built-up land (Nathaniel, 2021a).

Recently, a large body of economic growth-environment literature has emphasized the importance of using ecological footprint as a proxy for environmental sustainability (Danish, Hassan, *et al.*, 2019a, 2019b; Danish, Ulucak, *et al.*, 2019; Danish & Wang, 2019; Hassan *et al.*, 2019; Kirikkaleli *et al.*, 2020; Nathaniel, 2021a; Rudolph & Figge, 2017; Sabir & Gorus, 2019).

Second, the majority of the previous studies applied inappropriate econometric techniques (Narayan & Narayan, 2010; Saqib & Benhmad, 2021; Stern, 2004). More specifically, they applied the first-generation unit root, which results in biased and spurious results as it fails to take into account the presence of structural breaks. As the conventional cointegration and Granger causality tests depend on the order of integration of variables, they are susceptible to uncertainties posed by the pre-testing for unit root. Shreds of empirical studies show that the validity of the EKC hypothesis is sensitive to the technique of estimation employed. Barra and Zotti (2018) argued that the validity of the EKC hypothesis depends on treating stationarity. Panel data analysis dominates the economic growth-environmental quality relationship empirical studies (Saqib & Benhmad, 2021; Sharif et al., 2019; Sohag et al., 2019; Tenaw & Beyene, 2021; Zoundi, 2017). However, it is argued that a time series is more appropriate for the validity of the EKC hypothesis (Lieb, 2003).

Previous studies examined the validity of the EKC hypothesis in Ethiopia (Al-Mulali *et al.*, 2020; Hundie, 2018, 2021) CO_2 emissions as a proxy for environmental degradation.

2.2. Natural Resources Rents and Environmental Sustainability

The effect of natural resource rents on economic growth is a controversial topic and has received traction from scholars and policymakers. Some studies (Nawaz et al., 2019; Tiba & Frikha, 2019) confirm that natural resource rent plays a crucial role in improving the economic growth and consumption levels of nations as they provide fundamental factors of production with efficient allocation and institutional quality. Others (Erum & Hussain, 2019; Zallé, 2019) argued that the relationship between natural resource abundance and economic growth follows the resource curse hypothesis, which stated that countries endowed with natural resources grow at a slower rate than countries endowed with fewer natural resources (Tiba & Frikha, 2019). This implies that natural resources also affect environmental quality.

The causation between natural resource rents and environmental quality has become a debatable topic both theoretically and empirically (Nwani & Adams, 2021; Tiba & Frikha, 2019). Empirical studies reveal that the relationship between natural resource rents and environmental quality is mixed. Some scholars argue that natural resource rents improve environmental quality by reducing the import and consumption of fossil fuels (Balsalobre-Lorente *et al.*, 2018; Kongbuamai *et al.*, 2020; Kwakwa *et al.*, 2020) ; others (Ahmed, Asghar, et al., 2020; Bekun et al., 2019; Joshua & Bekun, 2020; Kwakwa et al., 2020; Nwani & Adams, 2021; Shittu et al., 2021; Ulucak, Danish, et al., 2020) suggest that natural resource rents detrimentally affect environmental quality. Natural resource endowments improve the innovative capacity of human beings, limiting human capacities to invest in technological advancement. Moreover, natural resource endowments encourage citizens to exploit these resources. Contrary to this, Danish, Baloch, *et al.* (2019) found that natural resource rents do not affect environmental quality, which supported the neutral hypothesis.

Some scholars argue that the relationship between natural resource rents and environmental quality depends on different factors. For instance, quality of governance (Nwani & Adams, 2021; Sinha & Sengupta, 2019) and institutional quality (Tiba & Frikha, 2019) are among the variables that moderate the link between natural resource rents and environmental quality. These scholars argue that obsolete technologies used to extract natural resources encourage inappropriate exploitation of natural resources at the expense of the environment. On the other hand, Ulucak *et al*. (2020) contended that the resource-environment link depends on the ecological indicator employed for the study. They found that natural resource extraction increases CO_2 emissions, but it does not affect the ecological footprint or carbon footprint. Though natural resource rents are key drivers of environmental quality with mixed results, to the best of the authors' knowledge, no study examined the effect of natural resource rents on environmental sustainability in Ethiopia.

2.3. Globalization and Environmental Sustainability

Globalization refers to the increasing interdependence of world economies as a result of the increasing scale of cross-border trade of commodities and services, the flow of international capital, and the wide and rapid spread of technologies, which has helped countries to earn significantly from the growing world economy. According to Gygli *et al*. (2019), globalization is the process that erodes national borders, integrates national economies, cultures, technologies, and governance, and creates complex interdependent relationships. Globalization has transformed the world by connecting nations socially, economically, and politically (Bilgili *et al*., 2020; Dreher, 2006; Gygli *et al*., 2019). These social, economic, and political connections have environmental consequences. Empirical evidence on the globalization-environment relationship is ambiguous and mixed (Shahbaz *et al*., 2018). Some empirical studies (Awan *et al.,* 2020; Islam *et al*., 2021; Shahbaz *et al*., 2017; Tang *et al*., 2020; Nathaniel, 2021b; Shahbaz et al., 2017) confirmed that globalization enhances environmental quality, whereas others (Ahmed *et al*., 2021; Awan *et al*., 2020; Kirikkaleli *et al*., 2021; Kwabena Twerefou et al., 2017; Le & Ozturk, 2020; Shahbaz *et al*., 2018; Tang *et al*., 2020; Zafar *et al*., 2019; Zaidi *et al*., 2019) found that it harms the natural environment. Other scholars, such as Jiang *et al.* (2021), contend that the globalization-environment relationship is not linear. They estimated the relationship between globalization and environmental quality and found an inverted U-shaped relationship. On the other hand, Rudolph and Figge (2017) argue that the effect of globalization on environmental quality depends on the components (production, consumption, exports, and imports) of the ecological footprint used in the analysis. According to Apaydin *et al.* (2021), globalization does not affect environmental quality.

Most of the previous empirical studies that examined the globalization-environment relationship were criticized for employing a single dimension of globalization, such as FDI and trade openness (Dreher, 2006; Haelg, 2020). For instance, Grossman and Krueger (1991), Recently, a transition from using single proxies for globalization to a composite indicator of globalization has been observed (Ahmed *et al*., 2021; Aziz *et al*., 2021; Bu *et al*., 2016; Ibrahiem & Hanafy, 2020; Shahbaz et al., 2017; Yameogo *et al*., 2021). The KOF Globalization Index (KOFGI) has become the most popular and cited globalization index (Haelg, 2020). The KOFGI index assesses globalization on three levels: social, economic, and political dimensions (Dreher, 2006; Gygli *et al*., 2019).

Economic globalization has an ambiguous effect on the ecological footprint (Rudolph & Figge, 2017). In developing countries where there are weak environmental regulations, economic globalization promotes pollution-intensive industries, and this intensifies human ecological demands. According to Rudolph and Figge (2017), the negative relationship between economic globalization and ecological footprint is related to three factors: 1) Economic globalization encourages countries that have become more economically globalized to prioritize economic safeguards over environmental safeguards; 2) agricultural production intensification and energy use by developed countries increase the ecological footprint; and 3) there are no globally binding regulations to control land use and CO_2 emissions. Rudolph and Figge (2017) termed this negative economic globalization-ecological footprint link the "intensification" hypothesis. Khan and Ullah (2019) and Bilgili *et al*. (2020) studies reveal that economic globalization increases environmental degradation in Pakistan and Turkey, respectively. On the other hand, the "markets for the global environment" hypothesis postulates that economic globalization improves the ecological footprint. This hypothesis argues that economic globalization enhances technology transfer and diffusion of clean production technologies, leading developing countries to avoid less efficient technologies. For instance, Ulucak, Koçak, *et al.* (2020) found that a higher level of globalization decreases material consumption and so enhances environmental management in EU countries. Lv and Xu (2018) also confirmed that economic globalization improves environmental quality in 15 emerging countries.

Political globalization enables states to be connected through bilateral diplomatic contacts, international organizations, and transnational agreements. However, pieces of evidence on the effect of political globalization on the ecological footprint are inconclusive. The "global environmental governance failure" hypothesis states that political globalization increases ecological footprint. Wang *et al.* (2018) for example, used quantile regression to investigate the heterogeneous effects of democracy, political globalization, and urbanization on Particulate Matter

($PM_{2.5}$) concentrations in G20 countries. They found that political globalization harms environmental quality. Contrary to popular belief, political globalization has beneficial effects on the ecological footprint according to the “global environmental governance” hypothesis. This hypothesis argues that political globalization facilitates access to know-how, monitoring systems, and global institutions, which builds institutional capacity for environmental regulations and negotiations.

2.4. Renewable Energy Consumption and Environmental Sustainability

The current scenario of the ecosystem, particularly in developing nations, signifies the need for cleaner energy to improve environmental quality. However, because of these countries' emerging nature, economic goals may have pushed environmental issues to the back-burner. There is hot debate among scholars that renewable energy consumption is not a panacea for environmental sustainability (S. A. Abbasi & Abbasi, 2000; A. B. Gill, 2005; Saidur *et al.*, 2011). Therefore, it is necessary to consider renewable energy as a determinant of the ecological footprint to ascertain its environmental viability.

Several empirical studies have been conducted to examine the renewable energy consumption-environmental quality relationship. Some of the selected stock of studies in this line are Baloch *et al*. (2020), Aziz *et al*. (2021), Danish, Baloch, *et al*. (2019), Destek and Sarkodie (2019), Jiang *et al*. (2021), Nathaniel and Khan (2020), and Sarkodie *et al*. (2020). However, the empirical findings from these studies are inconclusive and mixed. It is reflected in studies like Sarkodie and Adams (2018), Sahoo (2021), and Jiang *et al*. (2021) which argue that renewable energy consumption improves environmental quality. Al-Mulali *et al.* (2020) investigated the role of renewable and non-renewable energy consumption in determining environmental quality in Ethiopia using an augmented EKC hypothesis for the period 1981-2015. They found that both renewable and non-renewable energy consumption inhibited environmental degradation in Ethiopia during the period under study. Other empirical studies (Alola et al., 2019; Bölük & Mert, 2014; Bulut, 2017; Farhani & Shahbaz, 2014) confirmed that renewable energy consumption leads to environmental degradation.

2.5. Literature Gap

The issue of environmental sustainability has received great attention in developing nations like Ethiopia. A plethora of empirical studies have been undertaken to examine factors affecting environmental sustainability, but conclusive results have not been reached yet. Most previous studies that attempted to investigate the determinants of environmental sustainability had limitations in terms of the econometric techniques used, the environmental sustainability indicators used, and the globalization indicators used for the analysis. No study has investigated the effects of globalization, renewable energy, and natural resource rents on environmental sustainability in Ethiopia using a composite ecological indicator (ecological footprint) and the KOF globalization index so far. To this end, the current study employs ecological footprint indicators as a proxy for environmental sustainability and the KOF globalization index to analyze the effects of globalization, renewable energy consumption, natural resource rents along with other control variables on environmental sustainability in Ethiopia. Moreover, this study is unique in that it applies the novel dynamic ARDL simulations to analyze the impact of changes in each explanatory variable on environmental sustainability. Hence, to the best of our knowledge, this is the first study to use ecological footprint as a proxy for environmental sustainability and can provide a comprehensive and robust understanding of environmental quality in Ethiopia.

3. METHODOLOGY OF THE STUDY

3.1. Data and Variable Description

This study aims to provide a comprehensive analysis of the effects of economic growth, globalization, natural resources rental, and renewable energy consumption on environmental sustainability in Ethiopia. Annual data for 1971-2018 was used for this analysis. The selection of time is based on the availability of reliable data. Data to undertake this study was collected from the Global Footprint Network (GFN), World Development Indicators (WDI), and the KOF index. Ecological footprint (EFP), economic growth (Y), economic growth squared (Y^2), renewable energy (RE), population growth (Pop), urbanization (Urb), industrialization (Ind), economic globalization (EG), political globalization (PG), and natural resource rent (NRR) were variables of interest considered in this study.

Table 2: Variables description and descriptive statistics

Variable	Definition	Source
EFP	Ecological footprint (Global hectares per capita)	Global Footprint Network
Y	Gross Domestic Product per Capita [constant US$ (2010)]	WDI
Y^2	Square of Gross Domes Product per Capita [constant US$ (2010)]	WDI
RE	Renewable energy [Electricity generated from renewable sources in Kwh]	WDI
Pop	Population growth	WDI
Urb	Urbanization	WDI
Ind	Industrialization	WDI
EG	Economic globalization	KOF index
NRR	Natural resources rent (a proxy for oil rents, natural gas rents, coal rents, mineral rents, and forest rents)	WDI
PG	Political globalization	KOF index

To get full insights on the effects of variables understudy on the environmental sustainability in Ethiopia, the secondary data sources was complemented through technical discussions with experts from different key organizations in the area. Accordingly, Key informant interviews were conducted with the following institutions.

- Ministry of Mines;
- Environment, Forest, and Climate Change Commission (EFCCC);
- Ministry of Water and Energy;
- Ethiopian Environment and Forest Research Institute;
- Ministry of Trade and Regional Integration; and
- UN Environment in Ethiopia

3.2. Method of Data Analysis

3.2.1. Descriptive Analysis

The first two specific objectives of this study are addressed through descriptive analysis. To assess the patterns of energy consumption, natural resource rents, and environmental sustainability in Ethiopia from 1971 to 2018, this study computed the mean, standard deviation, and the minimum and maximum value of each variable under study. Besides, time-series graphs were employed to assess trends and patterns of the variables under consideration during the study period. The study used descriptive analysis to assess the status of Ethiopia in terms of energy consumption, natural resource rents, globalization, and ecological footprint for the period under study. We calculated the mean, standard, maximum, and minimum values of the aforementioned variables for Ethiopia and compared them with their respective values for the globalized economy. Additionally, graphical illustrations were used to compare the patterns and trends of these variables for Ethiopia with those of the globalized economy.

3.2.2. Econometric Estimation Techniques

The study employed appropriate and relevant econometric models to examine the long-and short-run relationships, Granger causality, and the counterfactual responses of the ecological footprint to shock in each explanatory variable. Moreover, the exact U-test for the quadratic relationship and the stability test of the estimated model were used in this study.

3.2.2.1. Model Specification

To examine the validity of the EKC and the effects of globalization, natural resources rental, and renewable energy consumption on the ecological footprint in Ethiopia, this study employed the extended and modified Stochastic Impacts by Regression on Population (P), Affluence (A), and Technology (T) (STIRPAT) model formulated by Dietz and Rosa (1994) and modified by York *et al.* (2003). The basic STIRPAT model is specified in equation (1);

$$I_t = \beta_0 P_t^{\beta_1} A_t^{\beta_2} T_t^{\beta_3} \varepsilon_t \tag{1}$$

Transforming Equation (1) into a natural logarithm yields an equation of the following form:

$$\ln I_t = \beta_0 + \beta_1 P_t + \beta_2 A_t + \beta_3 T_t + \varepsilon_t \tag{2}$$

The core advantage of the STIRPAT approach is that it allows us to include other potential factors affecting environmental quality because P and A in Equation (2) are decomposable (Dietz & Rosa, 1994; York et al., 2003). For instance, previous empirical studies decomposed P into population size and urbanization (Hundie, 2021; Zhou & Liu, 2016) and used the level of industrialization and energy structure as a proxy T (S. Wang et al., 2017; Zhou & Liu, 2016). Regarding the affluence factor (A), GDP per capita is commonly used (Dogan et al., 2020; S. Wang et al., 2017; Zhou & Liu, 2016). Since the main objective of the current study is to investigate the effect of the variables on ecological footprint under the EKC hypothesis framework, the square of GDP per capita is included in the STIRPAT model.

Recent empirical studies reveal that different aspects of globalization, such as economic and political globalization, drive the ecological footprint (Ahmed *et al.*, 2021; Akadiri *et al.*, 2019; M. A. Baloch *et al.*, 2020; Bilgili *et al.*, 2020; Destek, 2020; Kirikkaleli *et al.*, 2021; Lv & Xu, 2018; Rudolph & Figge, 2017; Shahbaz *et al.*, 2017; J. Wang *et al.*, 2019; N. Wang *et al.*, 2018; Zafar *et al.*, 2019). This lends strong evidence that political and economic globalization needs to be included as determining factors of the ecological footprint in Ethiopia. Besides, the effect of natural resources on environmental quality is a hot issue of debate among scholars. Therefore, natural resource rent is another variable of interest included in the

STIRPAT model. Accordingly, the modified and extended SRITPAT model employed in the current study is given below:

$$\begin{aligned}\ln EFP_t = \beta_0 + \beta_1 \ln Y_t + \beta_2 \left(\ln Y_t\right)^2 + \beta_3 \ln Ind_t + \beta_4 \ln EG_t + \beta_5 \ln PG_t \\ + \beta_6 \ln NRR_t + \beta_7 \ln RE_t + \beta_8 Pop_t + \beta_9 \ln Urb_t + \varepsilon_t\end{aligned} \quad (3)$$

3.2.2.2. Unit Root Tests

The estimation techniques, ARDL, and dynamic ARDL approach to cointegration, and TY and frequency-domain methods to Granger causality, applied in this study are applicable regardless of the order of integration of variables under consideration. Still, conducting a unit root test serves three major purposes. First, the application of ARDL and dynamic ARDL requires checking that the dependent variable is strictly I(1) (Jordan & Philips, 2018; Sarkodie & Owusu, 2020). Second, to ensure that all the independent variables are not in a higher order of integration than I(1). Third, a unit root test is required to determine the maximal lag length to augment the VAR(p) to undertake the TY Granger causality test. For this purpose, the study applied the following unit root tests.

The study conducted a unit root test to differentiate appropriate econometric estimation techniques to obtain robust results. The conventional unit root tests are criticized because they produce biased and spurious results since they fail to consider structural breaks in the variables (Ahmed et al., 2021; Baum, 2005; Dogan & Ozturk, 2017; Shahbaz et al., 2013). To overcome this problem, this study employed the Clemente-Montanes-Reyes (CMR hereafter) developed by Clemente *et al.* (1998) and Zivot and Andrews (1992) (ZA hereafter). Detailed mathematical presentations of the CMR and ZA unit root tests can be obtained in Shahbaz, Loganathan, *et al.* (2015) and Hundie (2021).

The conventional unit root tests, which are based on the linear hypothesis, are spurious in capturing true macroeconomic variables' dynamics because they fail to consider any nonlinearity in the deterministic components (Liu & He, 2010). To overcome this problem, Kapetanios and Shin (2008) developed a GLS de-trending unit root test procedure against the alternative of a globally stationary exponential smooth transition autoregressive (ESTAR) process. For robustness check purposes, the study complements the unit root tests with Kapetanios and Shin's (2008) unit root tests. A detailed mathematical presentation of the Kapetanios and Shin (2008) unit root test is obtained in Otero and Smith (2017).

3.2.3. Cointegration Test

This section provides the econometric estimation techniques that enable us to examine the long-and short-run relationships between environmental sustainability and the explanatory variables under study. The study employed two different cointegration testing techniques, namely, ARDL bounds testing and Bayer and Hanck's combined technique for cointegration. The ARDL bounds test for cointegration enables the researchers to examine whether the variables in the model are cointegrated or not. If the cointegration is confirmed, the ARDL approach is estimated for both long- and short-run parameters. The Bayer and Hanck combined technique for co-integration was employed as a robustness check for testing the presence of cointegration. The details of the cointegration testing approaches and justifications for why these testing techniques were selected are discussed below.

3.2.3.1. ARDL Bounds Testing to Cointegration

The study used the Autoregressive Distributive Lag bounds test (hereafter, ARDL) to co-integration to investigate the long-run relationship among variables. The Unrestricted Error Correction Model (UECM) version of the ARDL model for Equation (3) is specified as follows:

$$\begin{aligned}\Delta \ln EFP_t &= \beta_0 + \sum_{i=1}^{p} \beta_{1i} \Delta \ln EFP_{t-i} + \sum_{i=0}^{q_1} \beta_{2i} \Delta \ln Y_{t-i} + \sum_{i=0}^{q_2} \beta_{3i} \Delta (\ln Y)^2_{t-i} + \sum_{i=0}^{q_3} \beta_{4i} \Delta \ln Ind_{t-i} + \sum_{i=0}^{q_4} \beta_{5i} \Delta \ln EG_{t-i} \\ &+ \sum_{i=0}^{q_5} \beta_{6i} \Delta \ln PG_{t-i} + \sum_{i=0}^{q_6} \beta_{7i} \Delta \ln NRR_{t-i} + \sum_{i=0}^{q_7} \beta_{8i} \Delta \ln RE_{t-i} + \sum_{i=0}^{q_8} \beta_{9i} \Delta \ln Pop_{t-i} + \sum_{i=0}^{q_9} \beta_{10i} \Delta \ln Urb_{t-i} \\ &+ \delta_1 \ln EFP_{t-1} + \delta_2 \ln Y_{t-1} + \delta_3 \left(\ln Y_{t-1}\right)^2 + \delta_4 \ln Ind_{t-1} + \delta_5 \ln EG_{t-1} + \delta_6 \ln PG_{t-1} + \delta_7 \ln NRR_{t-1} \\ &+ \delta_8 \ln RE_{t-1} + \delta_9 \ln Pop_{t-1} + \delta_{10} \ln Urb_{t-1} + \varepsilon_t\end{aligned} \tag{4}$$

The parameters δ_i $(i = 1, 2, ..., 10)$ are the corresponding long-run coefficients, while the parameters $\beta_{1i}, \beta_{2i}, ..., \beta_{10i}$ are the short-run dynamic coefficients of the UECM of the underlying ARDL model.

Examining the presence of cointegration among variables of interest stated in Equation (4) using the ARDL approach requires testing the following hypothesis:

$H_0 : \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = \delta_7 = \delta_8 = \delta_9 = \delta_{10} = 0$ against $H_1 : \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq \delta_6 \neq \delta_7 \neq \delta_8 \neq \delta_9 \neq \delta_{10} \neq 0$.

Since the F-statistic used in the above hypothesis testing is very sensitive to lag length, this study used the Akaike Information Criterion (AIC) to select the appropriate lag length for estimation of the UECM in Equation (4). If the calculated F-statistic is greater than the upper critical bound, the variables under study are co-integrated, while the F-statistic that falls below the lower critical bound indicates the absence of co-integration. The result is inconclusive if the calculated F-statistic lies between the lower and upper critical bounds.

The next step in employing the ARDL bounds test approach to cointegration is estimating the following long-run and short-run models specified in Equations (5) and (6) respectively provided that cointegration is established among the variables.

$$\begin{aligned}\ln EFP = \beta_0 &+ \sum_{i=1}^{p}\beta_{1i}\ln EFP_{t-i} + \sum_{i=0}^{q_1}\beta_{2i}\ln Y_{t-i} + \sum_{i=0}^{q_2}\beta_{3i}\left(\ln Y_{t-i}\right)^2 + \sum_{i=0}^{q_3}\beta_{4i}\ln Ind_{t-i} \\ &+ \sum_{i=0}^{q4}\beta_{5i}\ln EG_{t-i} + \sum_{i=0}^{q_5}\beta_{6i}\ln PG_{1-i} + \sum_{i=0}^{q_6}\beta_{7i}\ln NRR_{t-i} + \sum_{i=0}^{q_7}\beta_{8i}\ln RE_{t-i} \\ &+ \sum_{i=0}^{q_8}\beta_{9i}\ln Pop_{t-i} + \sum_{i=0}^{q_9}\beta_{10i}\ln Urb_{t-i} + \nu_t\end{aligned} \tag{5}$$

$$\begin{aligned}\Delta\ln EFP_t = \alpha_0 &+ \sum_{i=1}^{p}\alpha_{1i}\Delta\ln EFP_{t-i} + \sum_{i=0}^{q_1}\alpha_{2i}\Delta\ln Y_{t-i} + \sum_{i=0}^{q_2}\alpha_{3i}\Delta\left(\ln Y_{t-i}\right)^2 + \sum_{i=0}^{q_3}\alpha_{4i}\Delta\ln Ind_{t-i} \\ &+ \sum_{i=0}^{q_4}\alpha_{5i}\Delta\ln EG_{t-i} + \sum_{i=0}^{q_5}\alpha_{6i}\Delta PG_{t-i} + \sum_{i=0}^{q_6}\alpha_{7i}\Delta\ln NRR_{t-i} + \sum_{i=0}^{q_7}\alpha_{8i}\Delta\ln RE_{t-i} \\ &+ \sum_{i=0}^{q_7}\alpha_{8i}\Delta\ln RE_{t-i} + \sum_{i=0}^{q_8}\alpha_{9i}\Delta\ln Pop_{t-i} + \sum_{i=0}^{q_9}\alpha_{10i}\Delta\ln Urb_{t-i} + \phi ECT_{t-1} + \upsilon_t\end{aligned} \tag{6}$$

Where ν_t and υ_t are error terms, ϕ is the speed of adjustment towards the long-run equilibrium and ECT_{t-1} is lagged error correction term calculated from the estimated cointegrated model.

3.2.3.2. Bayer and Hanck Combined Technique to Cointegration

To scrutinize and ascertain the long-run relationship among variables under study, the study used the Bayer and Hanck (2013) (B-H hereafter) co-integration approach combined with Engle and Granger (1987), Boswijk (1994), Banerjee *et al.* (1998), and Johansen (1988). This combined cointegration approach has several advantages over the single cointegration test techniques. Udi *et al.* (2020) argued that the B-H cointegration test is more powerful and robust and produces more reliable results. The B-H approach is a combination of individual test statistics, including Engle and Granger (EG), Johansen (JOH), Boswijk (BO), and Banerjee, Dolado, and

Mestre (BDM). The Fisher-type equation corresponding to the B-H cointegration test is presented as follows:

$$EG-JOH=-2\left[\ln(P_{EG})+\ln(P_{JOH})\right] \tag{7}$$

$$EG-JOH-BO-BDM=-2\left[\ln(P_{EG})+\ln(P_{JOH})+\ln(P_{BO})+\ln(P_{BDM})\right] \tag{8}$$

Where P_{EG}, P_{JOH}, P_{BO} and P_{BDM} are p-values of Engle and Granger (1987), Johansen (1988), Boswijk (1994), and Banerjee *et al.* (1998), respectively. No cointegration is the null hypothesis of the B-H cointegration test and rejection of the null hypothesis indicates the presence of cointegration.

3.2.3.3. Exact U-test for Quadratic Relationship

Because of the high degree of correlation between the quadratic and linear terms of economic growth, using conventional techniques to determine the presence of inverted U-shaped relations provides inaccurate results. Lind and Mehlum (2010) and Simonsohn (2018) criticized that the standard U-shaped relationship test does not provide sufficient conditions for a U-shaped relationship to be tested. The study employed the Sasabuchi-Lind-Mehlum (SML) exact U-test as a solution to this problem because it gives both necessary and sufficient conditions for testing the U-shaped relationship. Following Hundie (2021) and A. Baloch *et al*. (2018), the SLM U-test can be specified as below:

$$EF_t = a \ln Y_t + b\left(\ln Y\right)_t^2 + e_t \tag{9}$$

The U-shape hypothesis is given as:

$H_0 : \left(a + 2b \ln Y_{\min} \leq 0\right)$ and/or $\left(a + 2b \ln Y_{\max} \geq 0\right)$ against the inverse U-shaped hypothesis

$$H_1 : \left(a + 2b \ln GDP_{\min} \geq 0\right) \text{ and/or } \left(a + 2b \ln GDP_{\max} \leq 0\right)$$

3.2.3.4. Dynamic Simulations of ARDL

To scrutinize the counterfactual responses of the environmental sustainability to shock in each variable specified in Equation (3), this study applied the dynamic simulations of ARDL. A detailed presentation about the approach as well as the rationale for why the approach is selected is presented below.

Even though the ARDL bounds test for cointegration outperforms conventional cointegration testing techniques, the existence of lags, contemporaneous values, first differences, and lagged first differences of the independent and the dependent variable in the model specification makes interpretation of the ARDL results complex (Jordan & Philips, 2018). To overcome this difficulty, the study employed dynamic simulations of ARDL models developed by Jordan and Philips (2018) which helped the work to better interpret the practical significance (structural policy modeling) of the long-and short-run results estimated through the ARDL approach. The chief strength of this model is that it captures and automatically predicts the counterfactual responses of the dependent variable to shock in a single explanatory variable, keeping other things constant (K. R. Abbasi *et al.*, 2021; Jordan & Philips, 2018; Sarkodie *et al.*, 2020; Sarkodie & Owusu, 2020; Solarin *et al.*, 2021). The ARDL simulations are expressed as below:

$$\begin{aligned}\Delta\ln EFP_t = {} & \alpha + \phi_0 \ln EFP_{t-1} + \phi_1 \ln Y_{t-1} + \phi_2 (\ln Y)^2_{t-1} + \phi_3 \ln Ind_{t-1} + \phi_4 \ln EG_{t-1} + \phi_5 \ln PG_{t-1} \\ & + \phi_6 \ln NRR_{t-1} + \phi_7 \ln RE_{t-1} + \phi_8 \ln Pop_{t-1} + \phi_9 \ln Urb_{t-1} + \beta_1 \Delta \ln Y_t + \beta_2 \Delta(\ln Y)^2_t \\ & + \beta_3 \Delta \ln Ind_t + \beta_4 \Delta \ln EG_t + \beta_5 \Delta \ln PG_t + \beta_6 \Delta \ln NRR_t + \beta_7 \Delta \ln RE_t \\ & + \beta_8 \Delta \ln Pop_t + \beta_9 \Delta \ln Urb_t + \varepsilon_t\end{aligned} \tag{10}$$

3.2.4. Granger Causality Test

3.2.4.1. Toda-Yamamoto Granger Causality Test

To test the direction of the causal relationship between ecological footprint, economic growth, political globalization, economic globalization, natural resource rent, industrialization, population growth, renewable energy consumption, and urbanization, this study employed the Toda and Yamamoto (1995) Granger causality approach (TY hereafter). This approach was selected because it has several advantages compared to the conventional Granger causality techniques (Ahmed, Asghar, et al., 2020; Toda & Yamamoto, 1995; Uzar & Eyuboglu, 2019).

TY Granger causality approach estimates a $(k + d_{\max})^{th}$-order VAR where k is the appropriate lag length of the VAR model and $d_{\max}$ is the maximal order of integration. The TY Granger causality representation of EFP is given as follows:

$$
\begin{aligned}
\ln EFP_t = {} & \beta_{10} + \sum_{i=1}^{k} \theta_{1i} \ln EFP_{t-i} + \sum_{i=p+1}^{k+d_{\max}} \Omega_{1i} \ln EFP_{t-i} + \sum_{i=1}^{k} \delta_{1i} \ln Y_{t-i} + \sum_{i=p+1}^{k+d_{\max}} \phi_{1i} \ln Y_{t-i} + \sum_{i=1}^{k} \gamma_{1i} (\ln Y)^2_{t-i} \\
& + \sum_{i=p+1}^{k+d_{\max}} \psi_{1i} (\ln Y)^2_{t-i} + \sum_{i=1}^{k} \mu_{1i} \ln Ind_{t-i} + \sum_{i=p+1}^{k+d_{\max}} \eta_{1i} \ln Ind_{t-i} + \sum_{i=1}^{k} \vartheta_{1i} \ln EG_{t-i} + \sum_{i=p+1}^{k+d_{\max}} \omega_{1i} \ln EG_{t-i} \\
& + \sum_{i=1}^{k} \varphi_{1i} \ln PG_{t-i} + \sum_{i=p+1}^{k+d_{\max}} \mu_{1i} \ln PG_{t-i} + \sum_{i=1}^{k} \tau_{1i} \ln NRR_{t-i} + \sum_{i=p+1}^{k+d_{\max}} \tau_{1i} \ln NRR_{t-i} + \sum_{i=1}^{k} \varpi_{1i} \ln RE_{t-i} \varepsilon_{1t} \qquad (11) \\
& + \sum_{i=p+1}^{k+d_{\max}} \varpi_{1i} \ln RE_{t-i} + \sum_{i=1}^{k} \zeta_{1i} \ln Pop_{t-i} + \sum_{i=p+1}^{k+d_{\max}} \zeta_{1i} \ln Pop_{t-i} + \sum_{i=1}^{k} \varsigma_{1i} \ln Urb_{t-i} + \sum_{i=p+1}^{k+d_{\max}} \varsigma_{1i} \ln Urb_{t-i} + \varepsilon_{1t}
\end{aligned}
$$

TY equations for other series can be formulated in the same way. The TY approach uses the modified Wald test to ascertain the direction of the causal relationship among variables in an understudy.

3.2.4.2. Frequency-domain Granger Causality Test

To scrutinize the short-, medium-, and long-term causal effects of economic growth, industrialization, political globalization, economic globalization, natural resources rent, renewable energy consumption, population growth, and urbanization on the ecological footprint in Ethiopia at different frequencies, and this study applied a frequency-domain Granger causality test approach developed by Breitung and Candelon (2006). This technique was developed based on the TY causality testing approach; thus, it possesses all the advantages of the TY approach. However, the frequency-domain Granger causality testing approach has additional novel advantages. It eliminates seasonal variations since it allows small samples of data. Moreover, the approach distinguishes non-linearity and stages of causality in a time series (Adebayo *et al.*, 2021).

Following Breitung and Candelon (2006), an equation for a frequency-domain causality test in its cointegrating framework is given below:

$$\Delta y_t = \alpha_1 y_{t-1} + \alpha_2 y_{t-2} + \ldots + \alpha_p y_{t-p} + \beta_1 y_{t-1} + \beta_2 y_{t-2} + \ldots + \beta_p y_{t-p} + \varepsilon_t \qquad (12)$$

The null hypothesis that x is not caused y at frequency ω is denoted as $M_{x \to y}(\omega) = 0$ within a bivariate framework. This hypothesis is equivalent to the following linear restriction (Tastan, 2015).

$H_0 : R(\omega)\beta = 0,$ where $\beta = [\beta_1, ..., \beta_p]'$ and

$$R(\omega) = \begin{bmatrix} \cos(\omega) & \cos(2\omega) & ... & \cos(p\omega) \\ \sin(\omega) & \sin(2\omega) & ... & \sin(p\omega) \end{bmatrix}.$$

3.2.5. Stability of Estimated Model

Hansen (1992) argued that misspecification of the model in time series data may lead to biased results. This diminishes the explaining power of the empirical findings and puts the usefulness of the model for policy-making decisions in doubt. To this end, this study employed the cumulative sum (CUSUM) and cumulative sum squares (CUSUMSQ) of the recursive residuals to test for the structural stability of the estimated coefficient.

4. RESULTS AND DISCUSSIONS

4.1. Descriptive Results

4.1.1. Composition and Patterns of Ethiopia's Energy Supply

Energy demand in Ethiopia, like other SSA, is constrained by available supply, resulting in either not having any access or not being able to consume as much as economic agents demand. Such unmet demand is not captured in energy data and makes it difficult to measure energy demand more properly (IEA, 2014)[7]. Ethiopia has an electricity generation potential of more than 45 GW from hydropower, of which 30 GW is economically feasible. This is equivalent to a generation of 162 TWh of electricity. The country has also untapped potential in the areas of geothermal and wind, which have electricity generation potential of 5,000 MW and 10,000 MW, respectively (Ashebir & Desta, 2020). However, only a fraction of this potential has been harnessed so far. Table 3 summarizes the country's energy production potential from different sources and the amount currently exploited.

Table 3: Potential and exploited sources of energy in Ethiopia

No.	Source	Unit	Exploitable potential	Exploited amount	Percentage exploited (%)
1	Hydropower	GW	45	3.18	~17
2	Solar (day)	kWh/m^2	5.2	-	< 1
3	Wind	GW m/s	1350	0.324	< 1
4	Geothermal	GW	7	0.0073	< 1
5	Wood	Million Ton	1120	560	50
6	Agricultural waste	Million Ton	15–20	~6	30
7	Biogas	Household	1–3 million	17869	< 1

Source: Taken from Ashebir and Desta (2020)

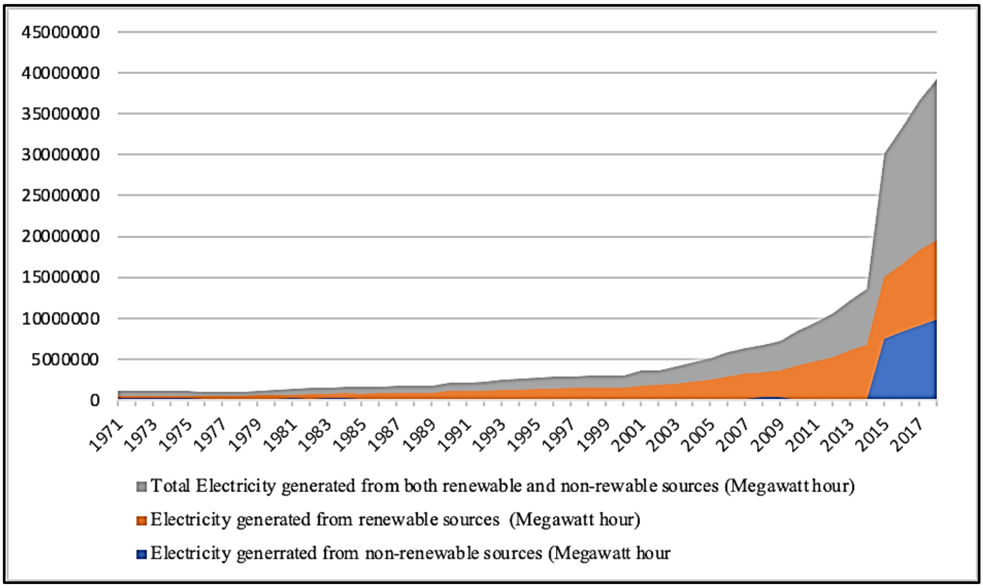
Ethiopia is poorly rated on different energy indicators. For example, the country was among the countries with the lowest score on the International Energy Agency's (IEA) energy development index with a score of 0.04 (IEA, 2014). Access

[7] See International Energy Agency, 2014. Africa Energy Outlook: A focus on Energy Prospects of in sub-Saharan Africa.

to electricity in the country has increased from 5% in 2000 to 45% in 2018, while the sub-Saharan average was 25.6 in 2000 and 46.8 in 2018, which is slightly better than the electricity coverage in Ethiopia (IEA, 2019). The energy intensity level of the country has declined from 28.63 MJ/GDP in 1990 to 14 MJ/GDP in 2015. The figure for SSA in 2012 was 7.9 MJ/GDP. Even though there is an improvement in the energy intensity of the country in recent years, the figure is still much higher than the SSA average. This implies that Ethiopia requires more energy to produce a unit of output or undertake a given economic activity compared to other average SSA countries (World Bank, 2016).

Figure 2 presents a pattern of Ethiopia's electricity generation over time, from 1971-2018. The total electricity generation capacity of the country has significantly increased over the specified period. The share of electricity generated from non-renewable sources is very low, indicating that the majority of the country's electricity is coming from hydropower, solar, geothermal, and wind. Though the country has huge potential for producing energy from wind and solar, only a fraction has been harnessed so far. The lion's share of the country's renewable electricity is generated from hydropower, which accounts for about 87% of the total electricity produced in the country.

Figure 2: Patterns of Ethiopia's electricity generation by source, 19971-2018 (Megawatt hour)



4.1.2. Trends of Ethiopia in Globalization Index

Globalization is affecting the lives of every citizen both in developing and developed countries. However, it is still debatable how it affects the daily lives of citizens in various countries around the world. Many non-economists expect that the costs associated with globalization are exceeding its benefits, and there are fears of erosion in social and environmental standards, high poverty rates in less developed countries, and ever higher frequencies of financial crisis. On the other hand, most economists strongly believe that the net effect of globalization will be positive (Dreher, 2006).

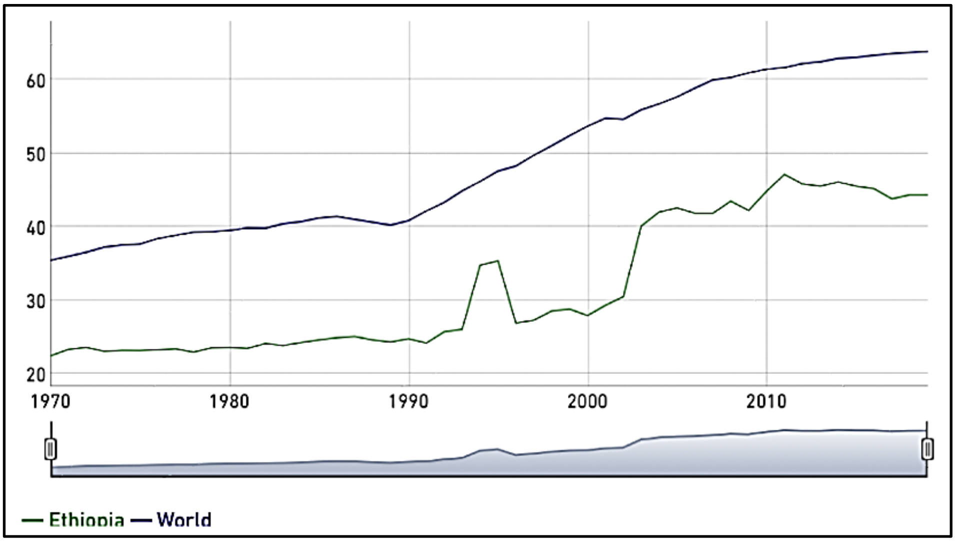
A proper measurement of globalization is required to examine the consequences and causes of globalization in more detail. Many previous empirical studies used proxies like trade and capital flows or openness to these flows (Boswell, 2001; Mah, 2002; Li and Reuveny, 2003; Heinemann, 2000; Vaubel, 1999; Chanda, 2001). Globalization is, however, a multifaceted concept that encompasses many more issues than openness to trade and capital flows. To understand this, scholars proposed composite indicators for measuring globalization, such as the KOF Globalization Index, introduced by Dreher (2006) and updated by Dreher *et al.* (2008). The KOF globalization index measures globalization along the economic, social, and political dimensions for almost every country in the world since 1970. It has become the most widely used globalization index in academic literature (Potrafke, 2015).

Globalization is defined differently by different scholars. In this study, the definition by Dreher (2006), which stems from Clark and Norris (2000), was used. In Dreher's (2006) framework, "*globalization is the process of creating networks of connections among actors at an intra or multi-continental distance, mediated through a variety of flows including people, information and ideas, capital, and goods.*" Globalization is a process that erodes national boundaries, integrates national economies, cultures, technologies, and governance, and creates complex relations of mutual interdependence.

In this context, globalization has three components: economic, social, and political globalization. Economic globalization includes trade and financial globalization, social globalization includes interpersonal, informational, and cultural globalization; while political globalization includes the number of foreign embassies and international NGOs in a country (Gygli *et al.*, 2019).

Figure 3 presents trends in the overall globalization index for Ethiopia and the rest of the world between 1970 -2019. As depicted in the figure, the globalization index of the country was slightly higher than 20 in 1970 and remained the same till 1990. This was low compared to the world average, which increased from about 35 in 1970 to more than 40 in 1990. This period overlaps with the period when the country was under the imperial and Derg regime, when the country's economic, social, and political integration into the rest of the world was limited. Starting from 1990 till 2000, the country's globalization index has shown fluctuations, but it has increased on average. After 2000, the country's globalization index increased significantly from about 30 in 2001/02 to about 45 in 2010/11. This was a period when the FDRE government introduced different policy reforms aimed at increasing the participation of the private sector both in the domestic and international markets, and reforms related to export and import market participation.

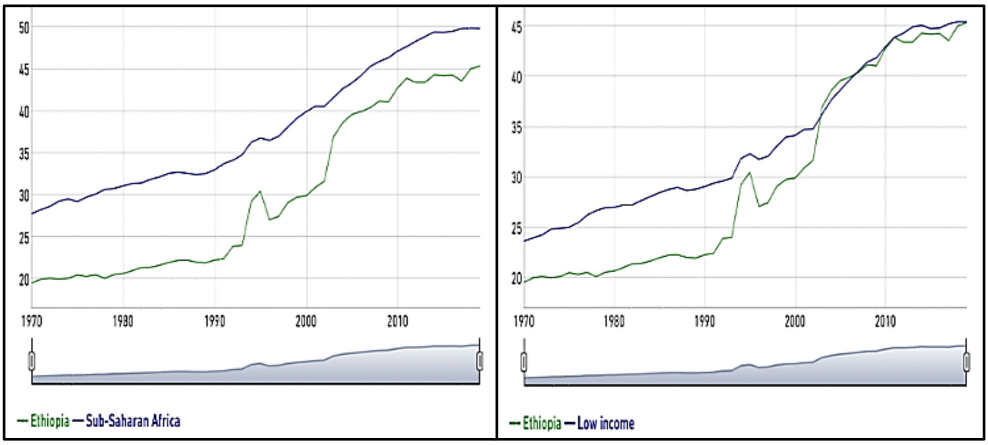
Figure 3: Trends of Globalization Index, Ethiopia vs rest of the world, 1970-2019 Source: KOF Globalization Database, 2021



The globalization index of Ethiopia is less than the average Sub-Saharan African countries' average throughout the period considered (see figure 4). The gap is, however, narrowing over time, mainly since 2000. This was the period when the FDRE government of Ethiopia undertook different policy reforms related to the socio-economic development of the country. A typical example is the structural adjustment program (SAP) that the government of Ethiopia adopted in 1996/97-2000/01. Following the policy recommendations of the IMF and the World Bank, the government of Ethiopia implemented different reforms, ranging from the liberalization of the external sector of the country's economy to the liberalization of exchange rates, with the aim of integrating Ethiopia into the global markets for goods and services. In pursuit of this objective, import tariffs have been progressively reduced, and the payment and exchange regulations for foreign trade in goods and services have been increasingly liberalized. The flow of foreign capital in the form of foreign direct investment and development aid has also significantly increased during this period.

The globalization index of Ethiopia increased significantly after 2000 compared to the low-income countries. This supports the above argument that the country's level of integration into the rest of the world has increased significantly after 2000 compared to both SSA and low-income countries' averages. On the other hand, before 2000, Ethiopia's globalization index was low compared to both SSA and low-income countries' averages.

Figure 4: Trends of Globalization Index, Ethiopia Vs sub-Saharan (left) and Ethiopia vs low-income countries (right)



Source: KOF Globalization Database, 2021

4.1.3. Ecological Footprint Index Trend of Ethiopia

The ecological footprint measures the demand made by a person or a group of people on global natural resources. It has become one of the most widely used measures of human impact on the environment and has been used to highlight both the apparent unsustainability of current practices and the inequality in resource consumption between and within countries. It tracks the use of productive surface areas, typically: cropland, grazing land, fishing grounds, built-up land, forest area, and carbon demand on land[8].

An ecological footprint has demand and supply sides in the sense that it measures a population's demand for the natural ecosystem's supply of resources and services. On the demand side, the ecological footprint measures an individual or a population's demand for plant-based food and fiber products, livestock and fish products, timber and other forest products, space for urban infrastructure, and forest to absorb its carbon dioxide emissions from fossil fuels. On the supply side, a city or nation's biocapacity represents its biological productive land and sea area, including forest, grazing, cropland, fishing grounds, and built-up lands (Rafferty, 2019).

The gap between ecological footprint and biocapacity is determined by several factors. The footprint is the product of how much people use and how efficiently this is being produced. The biocapacity per person is determined by how many hectares of productive areas there are, how productive each hectare is, and how many people (in a city, country, or the world) share this biocapacity (Rafferty, 2019).

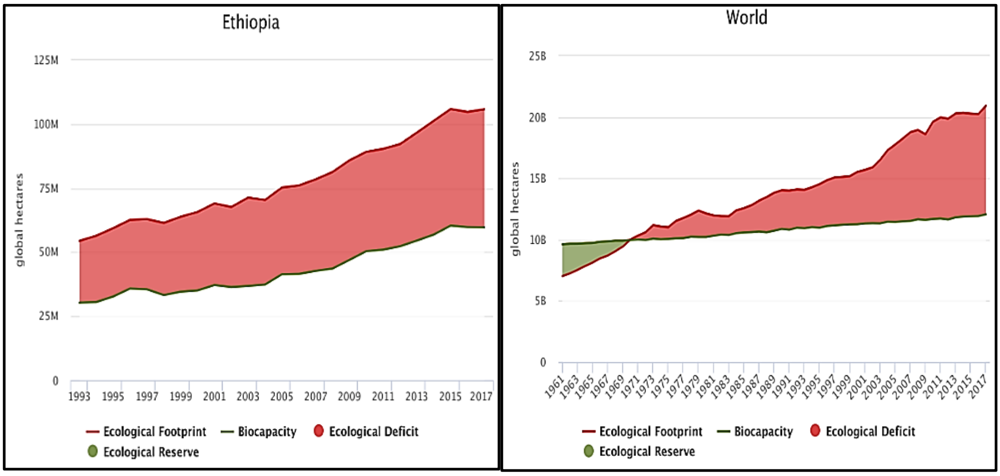
The value of the ecological footprint (EF) indicates whether a country is using its natural resources more than what its ecosystem can generate (biocapacity). If the country's EF is greater than its biocapacity, the country is running an ecological deficit. On the other hand, when a country's biocapacity is greater than its population's EF, the country boasts an "ecological reserve." Nations (also cities and states) can run ecological deficits by liquidating their resources, such as by overfishing; importing resources from other areas; and/or emitting more carbon dioxide into the atmosphere than their ecosystems can absorb.

Figure 5 shows the EF (red line), biocapacity (green line), ecological deficit (red area) and ecological reserve (green area) for both the world average and Ethiopia. Up to 1969/70, the world biocapacity was greater than its ecological footprint index, indicating ecological reserve. However, this was changed after 1970, when the world's ecological footprint became increasingly greater than the available biocapacity. The gap between biocapacity and the was continuously increasing after 1970, indicating a significant difference between the world population's demand and our planet's biocapacity. This indicates an ecological deficit and is represented by the red area in Figure 5 above. For Ethiopia, the data is available after 1993 and the country's EF is greater than the country's biocapacity throughout the period

[8] Global Ecological Footprint, accessed online on December 25, 2021, from https://www.footprintnetwork.org/our-work/ecological-footprint/

considered, indicating that the country is running an ecological deficit and the gap is also widening over time.

Figure 5: Ecological footprint vs Biocapacity for word average (left) and Ethiopia (right)



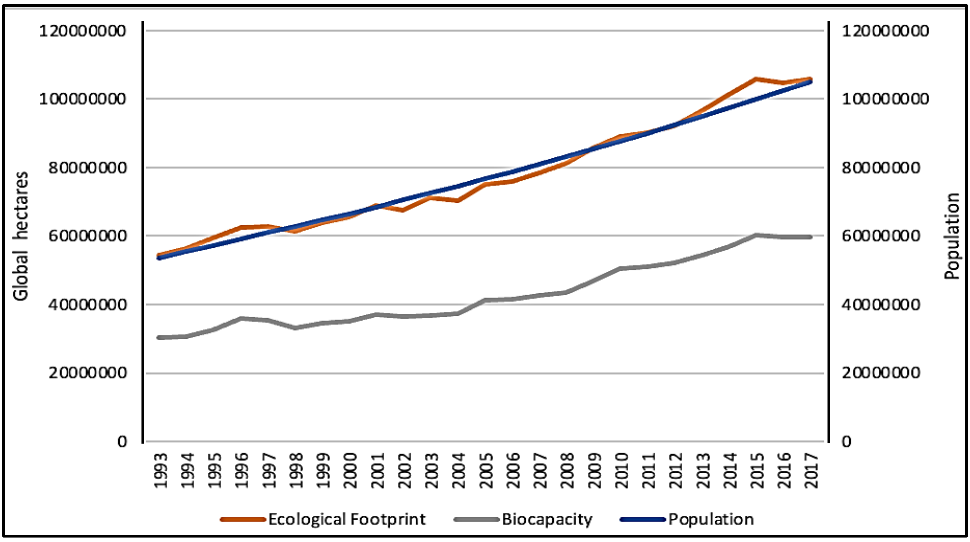
Source: Global Footprint Network, 2021

4.1.4. Correlation Between Ecological Footprint and Socio-economic Variables

Figure 6 shows trends in EF, biocapacity, and population growth for Ethiopia from 1993 to 2017. As can be seen from the figure, the EF for the country is greater than its biocapacity throughout the period considered. This implies that the country is running an ecological deficit and is consuming more than what it produces. The higher level of EF compared to the country's biocapacity may also show that the country's population cannot absorb its waste, particularly carbon emissions, so these are emitted into the atmosphere. According to the 2021 National Footprint and Biodiversity Account, in 2017, Ethiopia's biocapacity was 0.6 global hectares per person while its EF per person was 1.0, which means the country was running an ecological deficit of 0.4 global hectares per person.

The other important information presented in Figure 6 is the co-movement between the EF and the country's population growth. The two lines are moving closer in the same direction, implying that a high population drives up the country's EF.

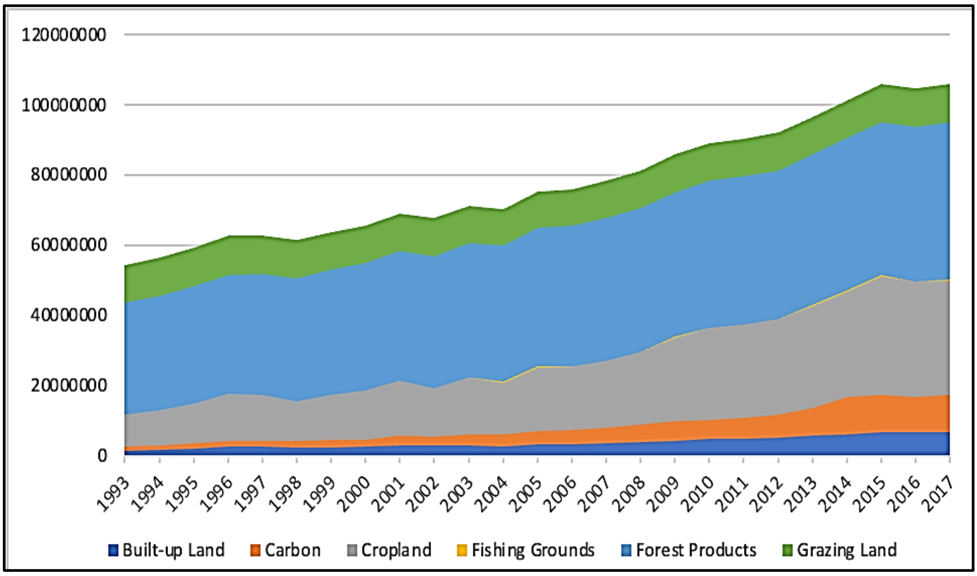
Figure 6: Trends of Ecological Footprint, Biocapacity, and Population growth for Ethiopia



Source: Computed based on Global Footprint Network, 2021

Looking at the country's EF by land type, the highest share was contributed by forest products, followed by croplands (see Figure 7). This implies the forest product footprint, which is calculated based on the amount of lumber, pulp, timber products, and fuelwood consumed by the country, is larger than the forest land area existing within the country needed to absorb emissions coming from such activities. The second-largest contributor to the country's EF is cropland, which consists of areas used to produce food and fiber for human consumption, feed for livestock, oil crops, and rubber, and it is the most bio-productive of all the land-use types. The cropland footprint includes crop products allocated to livestock and aquaculture feed mixes, and those used for fibers and materials, and it has been continuously increasing for Ethiopia. This is mainly due to the fact that new arable lands are brought in for crop production as a result of population pressure and crop demand in the country.

Figure 7: Ethiopia Ecological Footprint by Land type



Source: Computed based on Global Footprint Network, 2021

4.2. Econometrics Results

4.2.1. Unit Root Test Results

It is vital to check for the unit root properties of the variables before conducting a long-run relationship and Granger causality tests among them. Table 3 presents results from the CMR and ZA unit root tests. The result reveals that some of the variables (Pop, lnUrb, and lnNRR) are stationary at level [I(0)] both under the CMR and ZA unit root tests. Political globalization (lnPG) and renewable energy consumption (lnREE) variables are I(0) under CMR and ZA, respectively. The remaining variables (lnEFP, lnY, $\ln Y^2$, lnInd, and lnEG) are I(1). The result affirms that the dependent variable (lnEFP) is I(1) while there is no I(2) variable in the model. Therefore, the ARDL estimation technique is appropriate for the model. Moreover, the result shows a clear presence of at least one structural break in the variables.

Table 4: Unit root tests with structural breaks

	Clemente-Montanes-Reyes Unit-Root Test with Double Mean Shifts						ZAUR test allowing for a single break in intercept and/or trend	
At levels	Innovative outliers			Additive outliers			t-statistic	Break date
	t-statistic	TB1	TB2	t-statistic	TB1	TB2		
lnEFP	-2.595 (3)	1996***	2007***	-5.359 (2)	1999***	2008***	-3.26 (2)	2005
lnY	-3.869 (2)	2001**	2005	-3.026 (2)	1986**	2004**	-4.34 (2)	2010
lnY^2	-1.532 (11)	2002***	2005**	-2.739 (4)	2002***	2004	-4.35 (2)	2010
lnREE	-1.745 (11)	1995	2008	-0.552 (10)	1996***	2012***	-5.13 (0)**	2012
Pop	-31.066 (1)**	2005***	2009***	-14.278 (1)	2005***	2009***	-9.04(0)***	2007
lnUrb	-8.836 (12)**	1995***	2006	-3.099 (0)	1983***	1996***	-15.06(0)***	2007
lnInd	1.643 (11)	2000	2005***	-2.159 (8)	1998***	2004	-3.49(2)	2007
lnEG	-5.138 (0)	1992***	2000**	-3.950(4)	1991***	1999***	-4.24(0)	1994
lnNRR	-11.850 (0)**	1979	2001***	-5.045 (11)	1978	2002***	-8.07(0)***	1982
lnPG	-6.770 (2)**	1992***	2001***	-5.895 (1)**	1991***	2004***	-4.54 (2)	2003
First Difference								
lnEFP	-7.066 (2)**	1995**	2003***	-5.857 (2)**	1994	2002	-7.35(2)***	2008
lnY	-7.538(0)**	2005***	2009***	-3.362(2)	2004**	2010***	-8.06(0)***	2007
LnY^2	-8.122 (0)**	2005***	2009***	-8.122 (0)**	2005**	2009***	-8.95 (0)***	2007
lnREE	-5.997(5)**	2005***	2008	-4.372 (9)**	2012**			
Pop				-5.888 (2)**	2005	2008		
lnUrb				-14.04 (1)**	2004***	2007***	-9.28 (0)***	2007
lnInd	-12.557 (0)**	1979***	2006	-7.171 (1)	1980	2005	-8.96 (0)***	2007
lnEG	-6.518 (5)**	1993***	2004***	-7.171 (1)**	1980	2005	-6.90 (0)***	2006
lnNRR				-5.438 (2)	1978			
lnPG							-8.08 (1)***	2003

*** and ** refer to the rejection of the null hypothesis at 1% and 5% levels of significance respectively. The figures in parentheses are lag lengths; ZAUR= Zivot-Andrews Unit Root.

Results in Table 5 also confirm that the variables under study have mixed unit root properties (I(0) or I(1)). This implies that the conventional cointegration and Granger causality tests are not appropriate for the analysis. Moreover, the dependent variable being I(1) and the absence of an exploding independent variable make the application of both ARDL and dynamic ARDL approaches more appropriate.

Table 5: Kapetanios and Shin unit root test

Variables	KS Stat.	Variables	KS Stat.
Levels		**First Differences**	
lnEFP	-1.852 (3)	lnEFP	-2.879 (4)**
lnY	-4.261 (2)***	lnY	-3.755 (0)***
LnY^2	-4.468 (2)***	LnY^2	-3.919 (0)***
lnREE	-4.395 (1)***	lnREE	-5.221(0)**
Pop	-5.693 (0)***	Pop	-6.899 (1)***
lnUrb	-3.377 (2)***	lnUrb	-4.266 (0)
lnInd	-3.261 (2)**	lnInd	-4.844 (0)***
lnEG	-0.659 (0)	lnEG	-2.835 (0)**
lnNRR	-16.308 (0)***	lnNRR	-1.483 (3)
lnPG	0.420 (0)	lnPG	-2.770 (2)**

Note: KS stat. stands for Kapetanios & Shin statistic. *** and ** refer to the rejection of the null hypothesis at 1% and 5% levels of significance respectively. The figures in parentheses are lag lengths.

4.2.2. Cointegration Test Results

The first step in conducting the ARDL bounds cointegration test is determining the optimal lag length because the result is lag length sensitive. The study used Akaike Information Criteria (AIC) to select the lag length used in estimating the ARDL bounds cointegration test. The model was estimated under unrestricted constant and unrestricted trend deterministic components.

The result in Table 6 shows that the variables under consideration are cointegrated because the calculated F-statistic (5.59) is greater than the upper bound critical value (3.56) at a 5% level of significance. Similarly, the novel Bayer and Hanck (2013) combined cointegration test shows that the null hypothesis of no cointegration is rejected at a 5% level of significance, confirming that the variables are cointegrated.

Table 6: ARDL bounds Cointegration, and Bayer and Hanck Cointegration Tests

Model Specification	Selected Model	F-Stat.	Result
$F_{\ln EFP}(\ln EFP \mid \ln Y, (\ln Y)^2, \ln Ind, \ln NRR, \ln REE, \ln Urb, Pop, \ln EG, \ln PG)$	(3, 3, 3, 2, 3, 3, 3, 2, 2, 3)	5.59**	Cointegration
Bounds Test Critical Values	CV	I(0)	I(1)
	1%	2.97	4.24
	5%	2.43	3.56

Bayer and Hanck Cointegration

Estimated Model	EG-JOH	EG-JOH-BO-BDM	Cointegration
$F_{\ln EFP}(\ln EFP \mid \ln y, (\ln Y)^2, \ln NRR, \ln NREE, \ln URB, \ln EG, \ln PG, \ln Ind, Pop)$	56.82***	113.88***	Yes

Note: *** and ** refer to the rejection of the null hypothesis at 1% and 5% levels of significance.

4.2.3. Long- and Short-run Parameter Estimation

The long-run relationship between ecological footprint and the independent variables is presented in Table 7. Moreover, the visual presentation of the results is depicted in Figure 2. The results from the ARDL estimates disclose that economic growth (lnY) has a statistically significant positive effect on the ecological footprint (lnEFP). A 1% increment in economic growth increases the ecological footprint by 1.87% in Ethiopia during the study period, keeping other things constant. This implies that economic growth is one of the major factors that adversely affect environmental sustainability in the country. This finding is in line with Hundie (2021) and Taka *et al*. (2020). According to Taka *et al*. (2020), economic activity is the leading factor that contributed about 52% of the total CO_2 emissions in Ethiopia from 1970-2017.

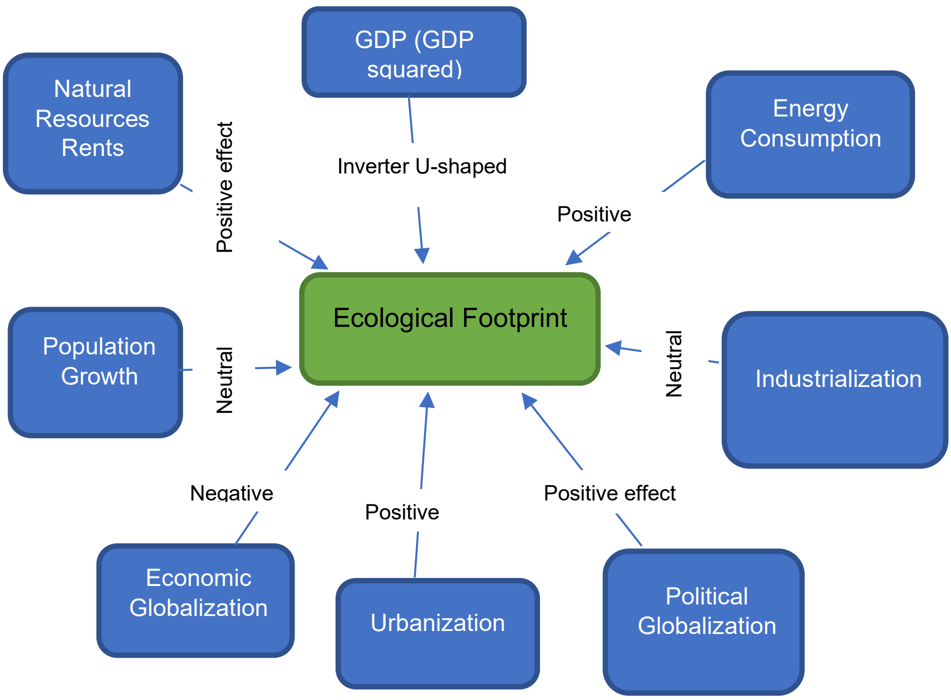
Scholars (Al-Mulali *et al*., 2020; Mondal *et al*., 2018; Oqubay, 2018; Taka *et al*., 2020) claim that the Ethiopian economy is the fastest-growing in Africa. The upsurge in ecological footprint is implausible with the fastest growing economy. Following the scale effect, economic activity increases with the growing economy. Production and consumption levels have increased, which has stimulated resource consumption like energy in every sector of the economy. These activities have increased the level of ecological footprint in Ethiopia. The positive relationship between economic growth and ecological footprint is also attributed to the lax environmental regulations and commitment in countries like Ethiopia. At an early stage of development, economic growth takes place at the cost of environmental sustainability.

Table 7: Long-run coefficients

Variable	Coefficient	Std. Error	t-Statistic	Prob.
lnY	1.8713	0.3502	5.3440	0.0018
$(\ln Y)^2$	-0.3977	0.0793	-5.0188	0.0024
lnInd	0.03387	0.0214	1.5852	0.1640
lnNRR	9.50E-12	2.93E-12	3.2444	0.0176
lnRE	0.00958	0.0028	3.3888	0.0147
lnUrb	0.7204	0.1536	4.6894	0.0034
Pop	0.0067	0.0047	1.4436	0.1990
lnEG	-0.2597	0.0542	-4.7874	0.0030
lnPG	0.6466	0.1214	5.3263	0.0018

The relationship between economic growth and ecological footprint is negative and statistically significant. Specifically, a 1% upsurge in economic growth resulted in about a 0.4% reduction in ecological footprint in Ethiopia during the study period, keeping other things constant. The positive relationship between economic growth and ecological footprint and the negative relationship between economic growth squared and ecological footprint confirms the validity of the EKC hypothesis in Ethiopia. Our finding is in line with many studies done before (Ahmad *et al.*, 2020; Ahmed *et al.*, 2021; Balsalobre-Lorente *et al.*, 2019; Hassan, Xia, Huang, *et al.*, 2019; Hundie, 2021; Khan & Ullah, 2019; L. Zhang *et al.*, 2021); while it contradicts some studies (Aydin et al., 2019; Destek & Sinha, 2020; Dogan *et al.*, 2020). The inverted U-shaped relationship between economic growth and EF implies that economic growth starts to be a panacea for environmental sustainability once a certain income level is attained, and countries could start paying due attention to environmental sustainability. Countries make their environmental regulations more stringent and the enforcement of environmental regulations is effective at this stage of development. When this income level is achieved, the composition effect and technical effects start dominating the scale effect, so that economic growth improves environmental sustainability. More specifically, the economy started shifting from energy-intensive industrial products to services (composition effect) and promoting energy-efficient techniques of production (technical effect).

Figure 8: Estimation Results from ARDL Methods



Results from the long-run coefficients reveal that economic globalization and EF have a negative relationship, which this is in line with the "markets for the global environment" hypothesis. Our finding is consistent with Shahbaz *et al.* (2017) for China but contradicts Ahmed, Zafar, *et al.* (2020) in the case of Japan; Ahmed *et al.* (2021b); Lv and Xu (2018); Xiaoman *et al.* (2021) and Yameogo *et al.* (2021) in SSA. The negative effect of economic globalization on EF is that it promotes technology transfer and diffuses clean production technologies, as argued by Rudolph and Figge (2017). The technology transfer and diffusion instigated by economic globalization encourage developing countries to leapfrog less efficient production processes.

Moreover, economic globalization ignites structural transformation (Ahmed *et al*., 2021) in a way that ensures environmental sustainability.

Political globalization has a positive and statistically significant coefficient, indicating that it increases EF in Ethiopia during the study period. The finding corroborates the "global environmental governance failure" hypothesis, which argues that weak political integration and the absence of efficient institutions fail to govern global ecological issues. Besides, Rudolph and Figge (2017) argued that a lack of transparency, democracy, and accountability results in global governance failure. All these factors make investment goals outweigh environmentally sustainable consumption, production, and trade. Therefore, political globalization intensifies the EF. Our finding is in line with Wang *et al.* (2018) but in contradiction with Destek (2020), who found a negative relationship between political globalization and EF for Central and Eastern European countries.

Natural resource rents have a positive and statistically significant effect on the EF in Ethiopia for the period under study. This finding agrees with the findings of Ahmad *et al*. (2020) and Ahmed, Asghar, *et al*. (2020) for China, Bekun *et al*., (2019) for 16-EU countries, (Danish, 2020), and Hassan, Xia, Huang, *et al*. (2019) for Pakistan, Ulucak, Danish, *et al*. (2020) for OECD, and (Nathaniel, Yalçiner, *et al*., 2021) for BRICS but contradicts with findings of Tufail *et al*. (2021) for developed countries, Danish *et al*. (2020) and L. Zhang *et al*. (2021) for Pakistan, and Xiaoman *et al*. (2021). This means that higher natural resource rents encourage countries to overuse natural resources, which deteriorates environmental quality.

The positive effect of natural resource rents on the EF in Ethiopia is also attributed to the growing economic activities that stimulate industrialization, urbanization, and agricultural expansion. Wassie (2020) contended that factors like population growth, agricultural expansion, resettlement, industrialization, and urbanization have been putting huge pressure on sustainable natural resources in Ethiopia. Alvarado *et al*. (2021) claimed that income dependence on natural resources, which is common in developing countries, is detrimental to the environment. The rate of natural resource depletion increases due to increasing economic activities like agriculture, deforestation, and mining, which generate harmful waste. Natural resource consumption through agriculture, deforestation, and mining influences the environment because it degrades biocapacity. Natural resource exploitation directly triggers economic growth, which accelerates CO_2 emissions. Unsustainable natural resource consumption increases dependency on imported fossil fuel, which is hazardous to the environment. Besides this, the poor resource management system and defective ownership structure in Ethiopia might be the reasons for unsustainable natural resource use.

Results from the long-run coefficients show that renewable energy consumption increases EF. Our findings corroborate with the findings of Alola *et al.* (2019), Bölük and Mert (2014), Bulut (2017), Farhani and Shahbaz (2014), and Kongbuamai *et al.* (2021). The positive effect of renewable energy consumption on the EF in Ethiopia might be attributed to different factors. First, for renewable energy consumption to improve environmental sustainability, its share of the total energy consumption of the country should be large (Danish, Baloch, *et al.*, 2019), which is not the case in Ethiopia, wherein biomass dominates the energy consumption mix. According to Mondal *et al.* (2018), biomass constituted about 87.7% of the total energy consumption of Ethiopia in 2020. A report by MoTI and IDPC (2019) showed that fossil fuels constituted more than 80% of the Ethiopian industry' energy consumption. Second, renewable energy consumption does not guarantee improvement in environmental sustainability. According to Nguyen and Kakinaka (2019), the effect of renewable energy consumption depends on the country's development stage. For low-income countries like Ethiopia, renewable energy consumption detrimentally affects EF as renewable energy policies are not strong. Third, energy efficiency in Ethiopia is low.

In the long-run, urbanization has a statistically significant positive effect on the EF in Ethiopia over the study period, in which a 1% rise in urbanization leads to a 0.72% upsurge in EF if other things remain constant. This is attributed to the fact that urbanization stimulates economic activity, which in turn increases energy consumption. As the energy consumption mix of Ethiopia is dominated by non-renewable sources and low energy efficiency, higher energy consumption inevitably creates ecological pressure that increases the EF. Moreover, urbanization increases the demand for transportation, food, infrastructure, water, and other resources that generate waste. Our finding is consistent with Ahmed, Asghar, *et al.* (2020), Nathaniel *et al.* (2020), and Danish Wang (2019), but in contradiction with the finding of Danish *et al.* (2020), who found a negative effect of urbanization on the EF in BRICS countries.

Table 7 presents the error-correction representation of the selected ARDL model. The result shows that except $\Delta \ln Ind$, $\Delta \ln Ind_{t-2}$, $\Delta \ln REE_{t-1}$, $\Delta \ln Urb$, and, all variables in their lagged difference determine the dynamics of the ecological footprint in Ethiopia during the study period. The coefficient of the lagged error term (ECT_{t-1}) is negative and statistically significant at a 1% level, which confirms the presence of a long-run relationship among variables in the model. However, adjustment towards the long-run equilibrium does not happen in a monotone path since the coefficient ECT_{t-1} is less than -1 (-1.88) rather an adjustment process fluctuates around the long-run value. As argued in different studies (Danish, Hassan, *et al.*, 2019; Hundie, 2021; Hundie & Daksa, 2019; Loayza & Ranciere, 2005; Narayan & Smyth, 2006; Uzar & Eyuboglu, 2019). Once the process is completed, the adjustment towards the long-run value is rapid.

Table 8: Error correction representation for the selected ARDL model

ECM Regression Case 5: Unrestricted Constant and Unrestricted Trend				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**P-value**
Constant	-10.97417	1.155398	-9.498174	0.0001
Trend	-0.029842	0.003219	-9.270249	0.0001
$\Delta \ln EFP_{t-1}$	0.205443	0.084277	2.437722	0.0506
$\Delta \ln EFP_{t-2}$	-0.406633	0.094112	-4.320748	0.0050
$\Delta \ln Y$	1.742789	0.214139	8.138597	0.0002
$\Delta \ln Y_{t-1}$	-2.258727	0.304049	-7.428828	0.0003
$\Delta \ln Y_{t-2}$	-1.911569	0.272834	-7.006347	0.0004
$\Delta(\ln Y)^2$	-0.367915	0.041149	-8.941013	0.0001
$\Delta(\ln Y)^2_{t-1}$	0.454335	0.061769	7.355439	0.0003
$\Delta(\ln Y)^2_{t-2}$	0.434770	0.053120	8.184713	0.0002
$\Delta \ln Ind$	-0.037512	0.038201	-0.981949	0.3640
$\Delta \ln Ind_{t-1}$	0.080448	0.031156	2.582085	0.0417
$\Delta \ln Ind_{t-2}$	-0.073842	0.035949	-2.054071	0.0858
$\Delta \ln NRR$	4.61E-12	8.57E-13	5.380557	0.0017
$\Delta \ln NRR_{t-1}$	-1.09E-11	1.81E-12	-6.032421	0.0009
$\Delta \ln NRR_{t-2}$	-8.37E-12	1.11E-12	-7.508240	0.0003
$\Delta \ln REE$	0.010907	0.001162	9.382599	0.0001
$\Delta \ln REE_{t-1}$	0.000919	0.001175	0.782252	0.4638
$\Delta \ln REE_{t-2}$	-0.004716	0.001121	-4.206149	0.0056
$\Delta \ln Urb$	0.504275	0.294996	1.709431	0.1382

Variable	Coefficient	Std. Error	t-Statistic	P-value
$\Delta \ln Urb_{t-1}$	-1.649298	0.247205	-6.671794	0.0005
$\Delta \ln Urb_{t-2}$	-1.775527	0.231493	-7.669889	0.0003
ΔPop	0.004068	0.001040	3.911253	0.0079
ΔPop_{t-1}	-0.003718	0.000807	-4.606456	0.0037
$\Delta \ln EG$	-0.022008	0.023833	-0.923423	0.3914
$\Delta \ln EG_{t-1}$	0.217937	0.048700	4.475050	0.0042
$\Delta \ln PG$	0.129551	0.029154	4.443718	0.0044
$\Delta \ln PG_{t-1}$	-0.725727	0.108231	-6.705322	0.0005
$\Delta \ln PG_{t-2}$	-0.337474	0.065537	-5.149347	0.0021
ECT_{t-1}	-1.884259	0.199030	-9.467199	0.0001

4.2.4 Stability of Estimated Model

Hansen (1992) argued that misspecification of the model in time series data may lead to biased results. This diminishes the explaining power of the empirical findings and puts the usefulness of the model for policy-making decisions in doubt. To this end, we employ the cumulative sum (CUSUM) and cumulative sum squares (CUSUMSQ) of the recursive residuals to test for the structural stability of the estimated coefficients.

Figure 9: Plot of the cumulative sum of recursive residuals

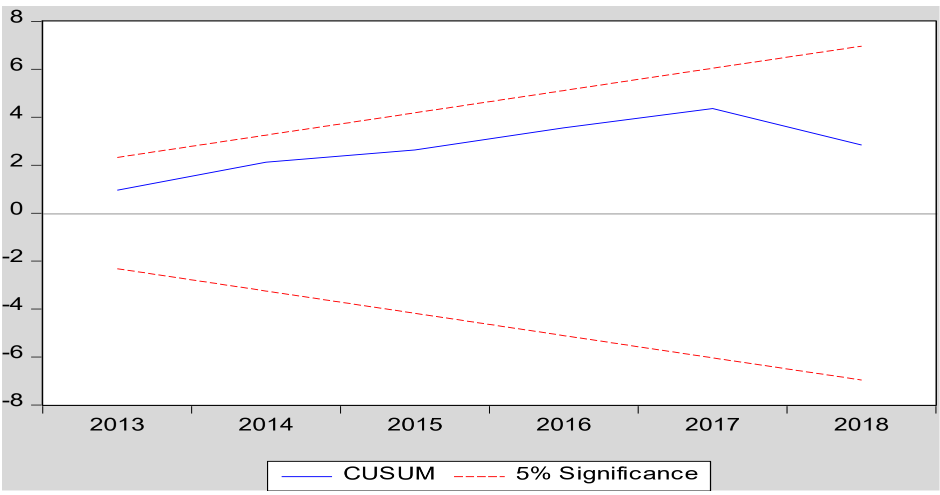
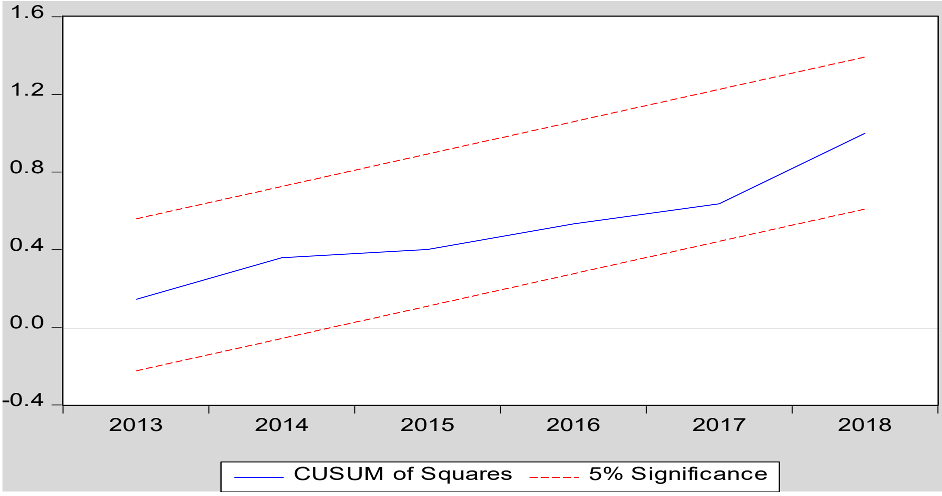


Figure 10: Plot of the cumulative sum of squares of recursive residuals



Results in Figure 1 and Figure 2 show that both CUSUM and CUSUMSQ fall within the critical bounds at a 5% significance level, which confirms the stability of the estimated model over the studied period. Therefore, the model is appropriate for econometric analysis, policy formulation, and recommendation in Ethiopia.

4.2.5. Granger Causality Test Results

The TY approach to Granger causality requires determining the appropriate VAR lag length using different lag selection criteria. However, Liew (2004) and Lütkepohl (2006) suggest that Akaike's information criteria (AIC) outperform other criteria because they have super properties in a small sample. Besides, results from the AIC are efficient and consistent, as argued by Shahbaz et al. (2015). Therefore, the lang length determined by the AIC is used to determine the appropriate VAR lag length for estimating the TY approach to Granger causality if results across different criteria differ.

Table 9 VAR Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-928.8455	NA	1617031.	42.67479	43.08029	42.82517
1	-538.6593	585.2793	3.366921	29.48451	33.94499	31.13867
2	-434.2491	109.1561	5.747449	29.28405	37.79950	32.44199
3	-151.0767	167.3291*	0.018569*	20.95803*	33.52846*	25.61975*

Table 10 Toda-Yamamoto Granger causality test results

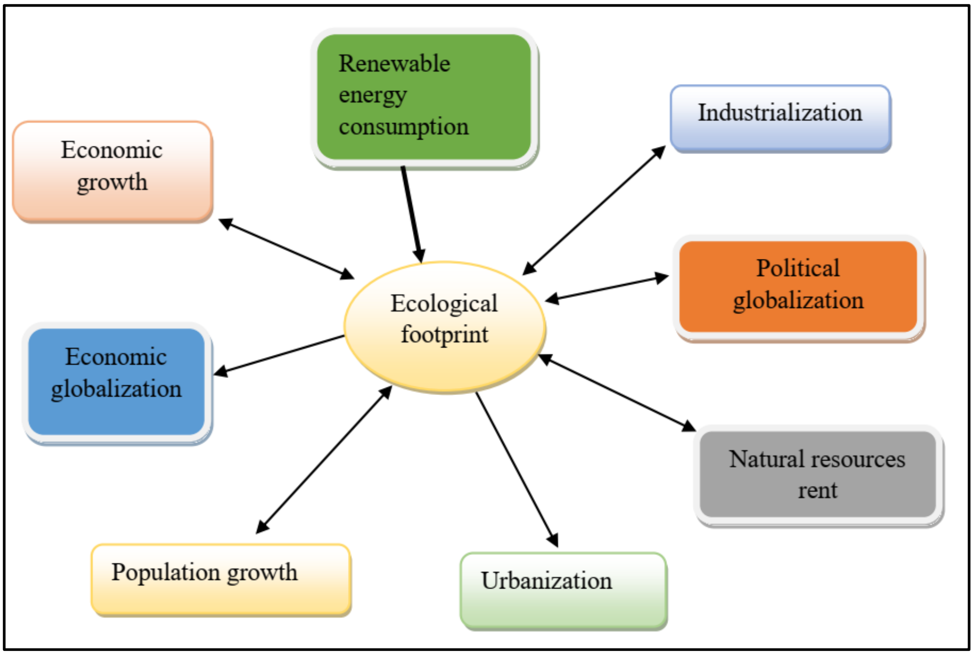
Dependent variables	Sources of Causation									
	lnEFP	lnY	$(\ln Y)^2$	lnInd	lnEG	lnPG	lnNRR	lnRE	lnPop	lnUrb
	$\chi^2(3)$	$\chi^2(3)$	$\chi^2(3)$	$\chi^2(3)$	$\chi^2(3)$	$\chi^2(3)$	$\chi^2(3)$	$\chi^2(3)$	$\chi^2(3)$	$\chi^2(3)$
lnEFP	-	7.375*	7.832**	7.870**	4.033	8.266**	15.232***	10.799**	10.154**	2.535
lnY	29.408***	-	59.912***	37.728***	22.672***	11.556***	15.986***	28.824***	10.221**	24.067***
$(\ln Y)^2$	5.115	18.601	-	5.750	4.154	11.026**	16.079***	5.552	9.098**	24.846***
lnInd	24.552***	164.017***	138.143***	-	29.689***	95.145***	258.880***	34.855***	80.0456***	224.001***
lnEG	13.881***	4.504	2.280	22.029***	0.571	2.559	0.254	11.557***	6.886	1.188
lnPG	12.326***	0.182	0.505	2.511	4.234	3.734	0.618	1.374	0.669	0.169
lnNRR	9.724**	8.960**	10.957**	0.590	3.346	11.878***	-	5.304	7.603	6.001
lnRE	4.912	1.556	1.830	1.259	2.959	2.519	1.354	-	0.958	0.604
lnPop	8.915**	51.257***	36.539***	3.768	4.152	3.587584	64.742***	12.346***	-	29.796***
lnUrb	177.186***	3359.483***	2564.118***	258.410***	169.835***	153.178***	3422.611***	728.976***	251.545***	-

*Note: ***, **, and * refer to the rejection of the null hypothesis at 1%, 5%, and 10% levels of significance. * indicates lag order selected by the criterion; LR: sequentially modified LR test statistic (each test at 5% level); FPE: Final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion*

As indicated in Table 8 the optimal VAR lag length selected by all criteria is 3. From the unit root test rest, it is confirmed that the variables under consideration are a mixture of I(0) and I(1) the maximum order of integration is 1. Therefore, an augmented VAR (4) is estimated under the TY approach. Following Zellner (1962), this study estimated the VAR (4) system using seemingly unrelated regression (SURE) as it yields more efficient coefficients. Then, the joint statistical significance of the first three coefficients of each lagged independent variable in the VAR(4) system is tested.

Table 9 reports the TY approach Granger causality test results. The result shows a bidirectional causality between economic growth and EF, which is consistent with the finding of Danish *et al.* (2020). Bidirectional causality is also observed between industrialization and EF, political globalization and EF, natural resource rents and EF, and population growth and EF. Granger causality runs from renewable energy consumption to EF without feedback. The causality results are illustrated in Figure 11.

Figure 11: Representation of causality results among variables



To scrutinize the causal relationship between lnY and $(\ln Y)^2$, lnInd, lnEG, lnPG, lnNRR, lnREE, and lnEFP in Ethiopia, this study employed a frequency-domain causality test. Unlike the TY approach to Granger causality, it discriminates against granger causality between variables in the long-, medium- and short-term. The frequency-domain causality test result is tabulated in Table 10. The result reveals that variables like lnY, lnInd, lnEG, lnNRR, and Pop Granger cause lnEFP only in the long run while lnPG, lnREE, and lnUrb Granger cause EF in the long-, medium-, and short-run.

Table 11: Frequency Domain Causality Test

Direction of causality	Long-term	Medium-term	Short-term
	$\omega_i = 0.05$	$\omega_i = 1.5$	$\omega_i = 2.5$
lnY $\Rightarrow$ lnEFP	4.9748*	0.1592	1.3494
$(\ln Y)^2 \Rightarrow$ lnEFP	5.4232*	0.7692	4.6488*
lnInd $\Rightarrow$ lnEFP	6.1958 **	0.7270	1.8898
lnEG $\Rightarrow$ lnEFP	0.0560*	2.7609	1.5509
lnPG $\Rightarrow$ lnEFP	4.7835 *	7.1217 **	7.0373 **
lnNRR $\Rightarrow$ lnEFP	5.4772*	4.0631	1.7956
lnREE $\Rightarrow$ lnEFP	6.0056**	6.9078**	9.0724**
lnPop $\Rightarrow$ lnEFP	7.5021 **	1.9582	2.0462
lnUrb $\Rightarrow$ lnEFP	7.5986 **	7.3935**	7.4636**

Note: ** and * indicates rejection of the null hypothesis at 5% and 10% respectively.

The empirical result indicated in Table 8 shows that lnPG, lnREE, and lnUrb Granger cause lnEFP in the short-, medium-, and long-run. This implies that lnPG, lnEG, and lnUrb are key indicators of short-, medium-, and long-term lnEFP in Ethiopia. According to Table 8, lnY, lnInd, lnEG, lnNRR, and Pop Granger cause lnEFP only in the long-run.

4.2.6. Exact U-test for Quadratic Relationship

The exact U-test for the quadratic relationship between ecological footprint and economic growth is shown in Table 9. The result reveals that the lower bound slope of economic growth (lnY) is positive (0.068) and statistically significant at a 5% level of significance. The upper bound slope is negative (-0.091) and statistically significant at 1% of significance.

Table 12: Exact U-test for a quadratic relationship

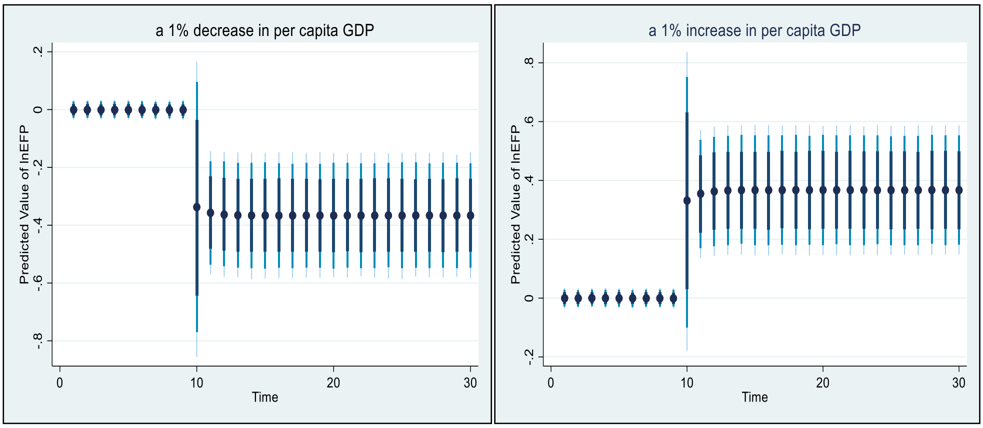
	Lower bound	Upper bound
Interval	1.807	3.307
Slope	0.068	-0.091
t-value	1.869	-3.024
$P>\|t\|$	0.034	0.002
Extreme point	2.447728	
Overall test of the presence of an Inverse U shape:		
t-value	1.87	
$P>\|t\|$	.0341	
95% Fieller interval for extreme point: [1.572; 2.622]		
Test: H_1: Inverse U shape vs. H_0: Monotone or U shape		

This confirms the rejection of the null hypothesis (monotone or U-shape) in favor of the alternative (inverse U-shape). This implies that the relationship between ecological footprint and economic growth follows the EKC hypothesis, is corroborated by the results of the ARDL.

4.2.7. Dynamic ARDL Simulations Results

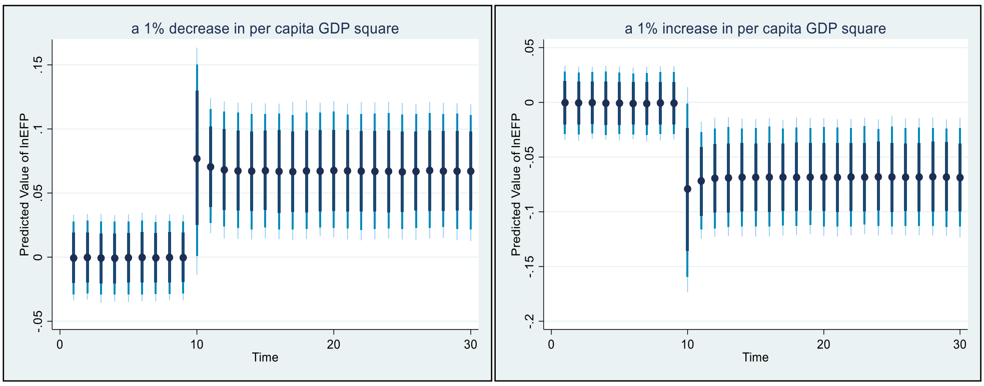
After testing the long-run equilibrium, the study estimated the response of the ecological footprint to a counterfactual change in each independent variable while keeping other regressors constant. Plots of the dynamic ARDL simulations are depicted in Figures 12-18. The plots of the dynamic ARDL simulations show a response from the ecological footprint and are based on ±1% shock to the individual regressors in 10 scenario times and over a range of 30 to determine the length of the simulation scenario. The average predicted values are represented by dots, while the dark blue to light blue line specifies 75%, 90%, and 95% confidence intervals, respectively. In all plots of the dynamic ARDL simulations (Figures 12-18) the average predicted values due to a counterfactual shock in each independent variable lie within the 95% confidence interval. This implies that the estimated models are statistically significant and stable, and therefore, sufficient for making unbiased inferences.

Figure 12: Economic growth and ecological footprint



The dynamic ARDL simulation plot in Figure 12 reveals that a -1% shock to economic growth improves the ecological footprint and contributes to environmental sustainability. On the contrary, a 1% shock to economic growth hampers environmental sustainability by increasing the ecological footprint.

Figure 13: Economic growth squared and ecological footprint



As depicted in Figure 13, a 1% increase in per capita GDP square decreases ecological footprint, while a -1% shock in per capita GDP square aggravates ecological footprint. Results in Figures 12-13 confirm the validity of the EKC hypothesis between economic growth and ecological footprint in Ethiopia during the period studied. Moreover, a counterfactual shock to economic growth has a long-lasting effect on the ecological footprint.

Figure 14: Economic globalization and ecological footprint

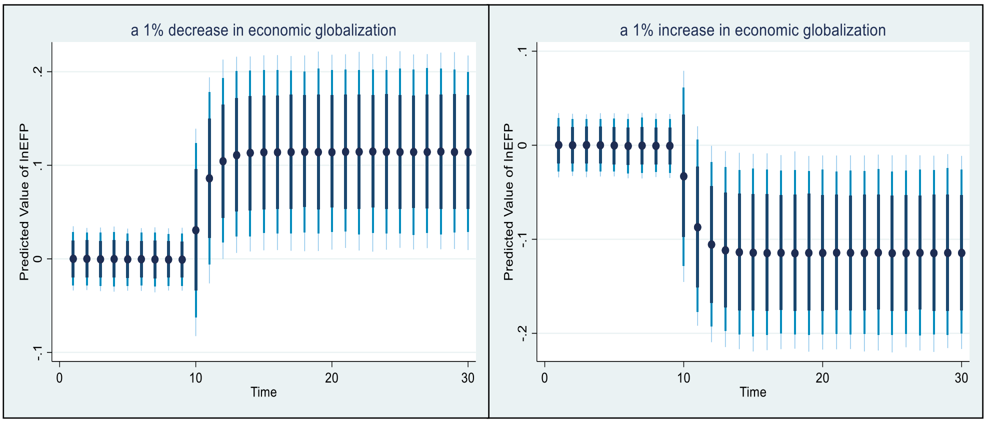
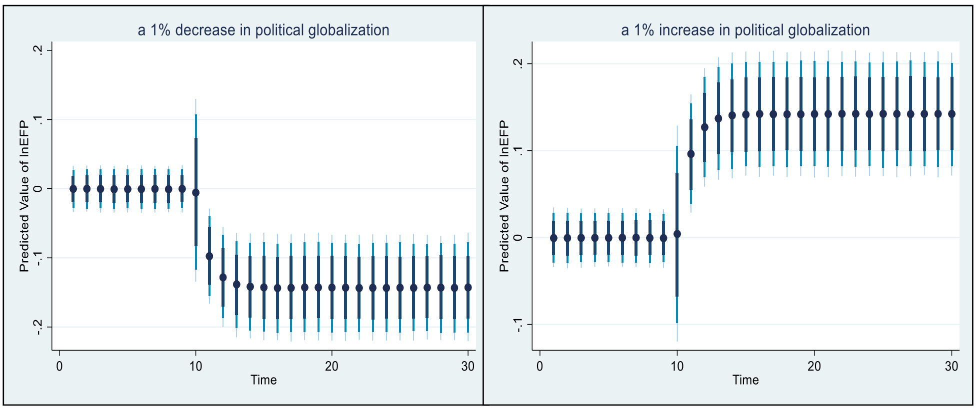


Figure 14 plots the effect of ±1% a counterfactual shock to economic globalization on the predicted values of the ecological footprint. The result reveals that a -1% shock to economic globalization deteriorates environmental sustainability by increasing the ecological footprint, while a 1% shock to the same variable has the opposite effect, and the effects of both cases are long-lasting. This finding is in line with the long-run results obtained from the ARDL approach.

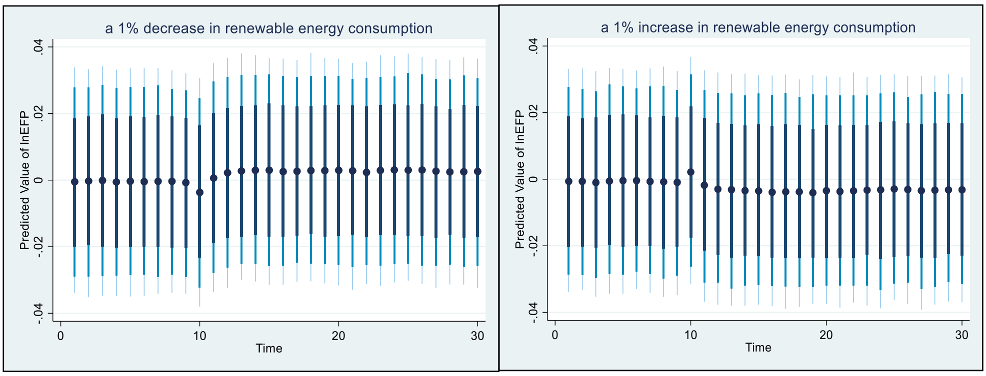
Figure 15: Political globalization and ecological footprint



The dynamic ARDL simulations plotted in Figure 15 show that a -1% shock to political globalization improves the ecological footprint and, therefore, can contribute to environmental sustainability. On the other hand, a 1% upsurge in political globalization increases our ecological footprint. A counterfactual shock to political globalization has a long-lasting effect on the ecological footprint in Ethiopia.

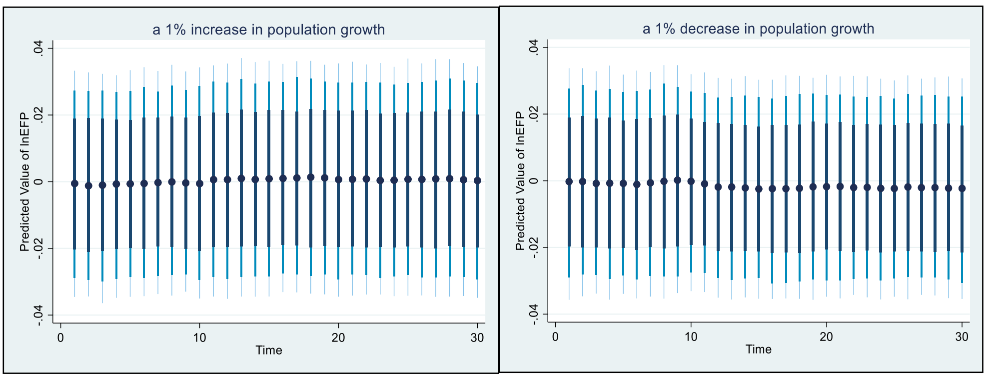
As depicted in Figure 16, a -1% shock in the predicted value of renewable energy consumption may decrease ecological footprint in the first period, but ecological footprint slightly increases thereafter. A 1% shock in the predicted value of renewable energy consumption increases the ecological footprint only in the first period but the ecological footprint starts decreasing thereafter. This implies that a shock in renewable energy consumption has no long-lasting effect on its ecological footprint.

Figure 16: Renewable energy consumption and ecological footprint



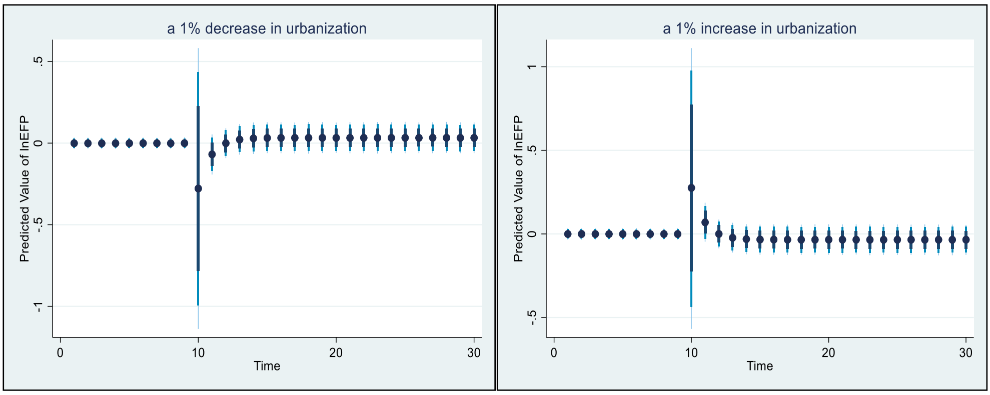
A plot of dynamic ARDL simulations in Figure 17 indicates that shock in population growth does not affect ecological footprint.

Figure 17: Population growth and ecological footprint



The visual presentation of the dynamic ARDL simulations regarding the response of the ecological footprint to a $\pm1\%$ counterfactual shock in urbanization is plotted in Figure 18. The result reveals that a -1% shock in predicted urbanization decreases ecological footprint during the first time but ecological footprint increases thereafter. A 1% shock in predicted urbanization leads to an increase in ecological footprint in the first period, but ecological footprint decreases thereafter, which implies that a shock in urbanization has no long-lasting effect on ecological footprint.

Figure 18: Urbanization and ecological footprint



5. CONCLUSIONS AND POLICY IMPLICATIONS

This study examined the effects of renewable energy consumption, natural resource rents, and economic and political globalization on environmental sustainability in Ethiopia using annual data spanning from 1971-2018. The augmented STIRPAT model under the EKC framework was used to specify the econometric model applied to scrutinize the effect of explanatory variables on the dependent variable. For the sake of robustness, this study employed different second-generation unit root test techniques, namely Clementes, Montanes, and Reyes (1998), and Zivot and Andrews (1992) unit root tests to account for structural breaks and the Kapetaneous and Shin (2008) unit root tests to deal with nonlinearity in the deterministic components. A cointegration test was conducted using the ARDL bounds test and the Bayer and Hanck combined test for cointegration. The effect of a counterfactual shock in each explanatory variable on the EF was analyzed using the dynamic ARDL simulation technique. The current study employed Toda-Yamamoto granger causality and frequency-domain granger causality tests.

Results from both ARDL and Bayer and Hanck approaches to cointegration revealed that there is a cointegrated, stable, and vigorous long-run relationship between EF and its determinants in Ethiopia in the specified study period. The long-run results show that the effect of economic growth on EF follows an inverted U-shaped relationship, confirming that the EKC hypothesis is valid for Ethiopia. This implies that economic growth deteriorates environmental sustainability in Ethiopia in the early stages while economic growth itself will become a panacea for environmental sustainability in the later stages once a certain income level is attained. In the long-run, natural resource rents, renewable energy consumption, urbanization, and political globalization have a deleterious effect on the EF; therefore, harming environmental sustainability in Ethiopia.

The long-run effect of economic globalization on EF is negative, which implies that it decreases the EF and positively contributes to environmental sustainability in Ethiopia. The empirical results from the dynamic ARDL simulations support the long-run results obtained from the ARDL approach.

The TY Granger causality test result revealed that causality runs from economic growth, natural resource rents, political globalization, industrialization, and population growth to EF with feedback effects. It was found that there is a unidirectional Granger causality running from renewable energy consumption to EF, indicating the consumption of renewable energy affects environmental sustainability but not vice versa.

Based on the findings of the study, the following recommendations are derived. Ethiopia should create a balance between promoting economic growth and EF if the country needs to ensure environmental sustainability. The effective policy to keep a balance between maintaining high levels of economic growth and EF is to make the environmental rules and regulations more stringent, promote a fossil-fuel-free economy, and increase energy efficiency. Since energy is a key driver for economic activities, the manufacturing, and industrialization processes of the country should upgrade the clean technology and processes for the production of goods and services.

The causality running from natural resource rent to the environmental sustainability indicator shows that the extraction of natural resources, mainly non-renewable ones, could have a significant environmental effect. This impact is especially pronounced if there is no strong policy safeguarding proper utilization of natural resources. Ethiopia, however, has no mining policy that safeguards the optimal extraction of natural resources. The information obtained from the Ministry of Mines shows that the country has no mining policy. The proclamation number No.1213/2020, which talks about mining operations in the country, including the licensing, process is also silent on the resource use plan and extraction policy. Though the sector has only recently been getting attention from both the government and private sector, it is imperative to put in place the necessary policy that safeguards the optimal extraction of these resources. On the positive side, there are environmental standards that the country sets that companies engaged in the extraction of natural resources should meet and follow, including the level of mitigation that the Environment Forest Climate Change Commission (EFCCC) expects. However, the level of monitoring and enforcement is weak in this regard, calling for the EFCC to improve its environmental monitoring and enforcement mechanisms.

It was found that there is a unidirectional Granger causality running from renewable energy consumption to EF. More specifically, the use of renewable energy improves the environmental sustainability of the country. The heavy dependency of the country on hydropower adds to the explanation that the use of renewable energy improves the environmental sustainability of the country. Thus, the country should take this opportunity to upgrade the technology and processes for the production of renewable energy. This should be accompanied by the use of energy-efficient technology in the production and consumption of renewable energy sources to make the production and consumption of renewable energy sources more environmentally friendly.

Given the population pressure in the country, it is imperative to utilize the country's energy sources based on the country's overall development strategy. In this regard, developing the culture of renewable energy entrepreneurship in higher institutions in the country is helpful in the efficient utilization of energy resources. These have two-fold advantages. First, it could stimulate demand for renewable technologies, which would have a positive impact on environmental sustainability. Second, it would create job opportunities for the youth in the country. Thus, the government, through the ministry of education and the ministry of water and energy, should give due emphasis to this.

The government of Ethiopia should enhance economic globalization by increasing the number of agreements like FDI and enhancing market integration with its regional trading partners to improve environmental sustainability. The detrimental effect of political globalization on the EF in Ethiopia can be abated by ensuring that political globalization helps to access knowledge, monitoring systems, and global institutions that build institutional capacity for environmental regulations and negotiations.

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