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Determinants of Ecological Footprint: A Quantile Regression Approach

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Abstract: Through the examination of the ecological consequences of human actions, policymakers are able to distinguish certain areas in which resource use can be increased and the generation of waste diminished. This study examines the effects of foreign direct investment, gross domestic product, industrialization, renewable energy consumption, and urban population on the ecological footprints in 131 countries between 1997 and 2020. The objective of this study is to establish a thorough understanding of the relationship between these variables and ecological footprints while considering temporal changes from economic and environmental aspects. The analysis of a substantial dataset encompassing many countries aims to uncover recurring patterns and trends that can provide valuable information for the formulation of policies and strategies pertaining to sustainable development on a global level. The study fills a significant gap in the knowledge on the ecological impact of different variables, providing a nuanced understanding of the interdependencies among these factors, thus guiding sustainable development strategies, and promoting global sustainability. The study utilizes quantile regression analysis, a nonparametric estimator, to estimate consistent coefficients. The statistical analysis reveals that FDI, urbanization, and GDP have statistically significant and positive effects on ecological footprints. Industrialization and renewable energy consumption show significant and negative relationships with ecological footprints. The findings of this study contribute to the understanding of the relationships among these variables and provide insight to inform policy and decision-making efforts focused on reducing ecological consequences and advancing sustainable development goals.

Keywords: ecological footprint; sustainable development; urbanization; GDP; FDI; renewable energy

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Citation: Özcan, K.A. Determinants of Ecological Footprint: A Quantile Regression Approach. *Systems* **2024**, *12*, 59. https://doi.org/10.3390/systems12020059

Academic Editor: William T. Scherer

Received: 12 December 2023
Revised: 24 January 2024
Accepted: 9 February 2024
Published: 11 February 2024

1. Introduction

Industrialization, renewable energy, and urbanization significantly impact the Earth's resources. The Earth provides all of the resources needed to support urbanization, renewable energy, and industrialization and absorbs the subsequent waste. Zambrano-Monserrate et al. [1] suggest that human activities require approximately 1.75 Earths to sustainably provide ecological resources and absorb waste. This indicates that more resources are being used than Earth can produce and sustain within the same timeframe. The measure of the land and sea areas needed by human populations to sustain themselves underpins the global ecological footprint. Evidence from research studies shows that the global ecological footprint has increased significantly because of an increase in human activities over the last two centuries [2–4].

Within the scope of the research, the effects of variables (industrialization, urbanization, renewable energy consumption, FDI, and GDP), which are the possible determinants of the ecological footprint, were estimated from the sample for the period between 1997 and 2020 for 131 countries. This study aims to investigate the substantial influence of industrialization, renewable energy, urbanization, FDI, and GDP on the ecological footprint. The Earth's ability to supply resources and manage waste is being surpassed, resulting in a rise in the global ecological footprint. Industrialization has been recognized as a significant factor in the expansion of the ecological footprint, mostly attributable to its substantial need for energy and use of resources. Likewise, the process of urbanization is correlated with the occurrence of deforestation, soil erosion, and heightened demands for energy and water resources, hence intensifying the ecological impact. The study also highlights the possible positive or negative impacts of renewable energy on the ecological footprint, emphasizing the necessity of investigating its contribution to the mitigation of environmental degradation. The research questions that guide this study are as follows:

1. How does industrialization contribute to the increase in the global ecological footprint?
2. What is the impact of renewable energy consumption on the global ecological footprint?
3. How does urbanization affect the global ecological footprint?
4. What is the relationship between foreign direct investment, GDP per capita, and the global ecological footprint?

By addressing these research questions, the study aims to provide insight into the complex interactions between industrialization, renewable energy, urbanization, foreign direct investment, GDP per capita and the global ecological footprint. The findings will contribute to a better understanding of the environmental challenges posed by human activities and inform sustainable development strategies. Overall, the study aims to contribute to the understanding of the factors that contribute to the global ecological footprint. Therefore, it focuses on providing empirical evidence for the relationships between industrialization, renewable energy, urbanization, foreign direct investment, GDP per capita, and the ecological footprint. The findings of the study can inform policy and decision-making processes aimed at reducing the ecological footprint and promoting sustainable development.

The objective of this study is to examine the relationship between foreign direct investment (FDI), gross domestic product (GDP), industrialization, consumption of renewable energy, urban population, and ecological footprint while considering the temporal variations in economic and environmental factors. To discern recurring patterns and trends, the study utilizes an extensive dataset. Consequently, it provides valuable perspectives that may be applied in the creation of policies and strategies for worldwide sustainable development. This study seeks to gain a complete understanding of the interplay and influence of FDI, GDP, industrialization, renewable energy consumption, urban population, and ecological footprint on global sustainable development by evaluating their relationship over time. The research findings can provide valuable insight for policymakers and stakeholders to make well-informed decisions that support sustainable economic growth while mitigating environmental deterioration.

The research is divided into multiple sections. Section 1 includes an introduction. In Section 2, various factors affecting the ecological footprint, such as industrialization, renewable energy consumption, urbanization, FDI, and GDP, are comprehensively explained. Section 3 of this study provides a critical review of the relevant research undertaken within the existing corpus of the literature. In the next section, Section 4, the methodology of the study is presented. Following this, Section 5 provides the results of the analysis, and the interpretations of these results are discussed; the paper ends with a conclusion in which the results of the analysis of the variables affecting the ecological footprint are interpreted.

2. Determinants of Ecological Footprint

In 1992, William created the concept of the ecological footprint (EF) as a comprehensive tool for measuring resource consumption and the connection between the human utilization of natural resources and the ecological services offered by habitats in nature [5]. The EF quantifies the extent to which natural resources are utilized only for the production of resources consumed by a specific population and the absorption of the waste generated by it, employing the available technology [6]. The EF is a very efficient instrument for measuring the impact of human activities on natural resources [7]. Vaisi et al. [8] acknowledge that it serves as an accounting instrument for measuring sustainability principles and monitoring the consumption of natural resources. It offers guidance on how to decrease the human impact on the ecosystem. The main disadvantage lies in the challenge of acquiring precise and all-encompassing data, particularly in instances when environmental management systems are absent [9]. Although the ecological footprint provides a quantitative measure of the resources utilized by a population on land that is biologically productive, it fails to elucidate the fundamental mechanisms that generate these resources [10]. It also lacks explicit policy directives, except in advocating for reduced consumption and the expansion of agricultural land [11].

Industrialization is one of the main human activities with significant effects on the global ecological footprint. According to Yang et al. [12], even though industrialization is associated with economic growth, it is one of the leading contributors to an increased global ecological footprint. Industries require substantial energy and resources to sustain themselves within a specific timeframe. Wang et al. [13] noted that industrialization is accompanied by increased energy demand, which is predominantly sourced from fossil fuels. In addition to fossil fuels, other energy sources, such as coal and renewable energy, are needed to sustain the vast network of industries spanning major cities and urban centers globally. The energy consumption rate is higher than how nonrenewable energy sources are replenished [14–16]. In this regard, nonrenewable energy sources such as fossil fuels will be depleted after a specific timeframe. The above findings show a correlation between industrialization and an upsurge in the global ecological footprint in the context of energy use. The amount of energy being used is higher than the amount of energy being replenished, especially nonrenewable energy sources. Sources such as renewable energy require the extensive clearance of forests and land, for example, to pave the way for hydroelectric dams [17–19], and other sources of energy, such as fossil fuels and coal, require widespread mining, an outcome that leads to a reduction in biodiversity and an impaired ecological balance. Research studies show a correlation between deforestation and mining and a subsequent increase in the global ecological footprint. For instance, Gyamfi et al. [20,21] established that deforestation and mining reduces natural resources, such as forests, shedding light on how the above identified issues increase the global ecological footprint. Given that industries are ever-increasing, it is evident that natural resources such as forests, seas, and lands will continually be exploited to meet energy demands.

Industrialization also demands significant resources to produce the desired output, such as automobiles, wooden products, electronic appliances, papers, and plastic products. All resources, such as iron ore and copper, are sourced from the Earth mainly through mining and deforestation [22–24]. For example, minerals such as copper, iron core, platinum, and lithium are extensively mined, leading to environmental degradation and impaired biodiversity. Mining also involves the destruction of land and forest, leading to extensive ecological footprints [25,26]. The rate at which minerals are being depleted through mining to support industrialization is higher, indicating that industrialization is increasing the global ecological footprint. In addition, industrialization also needs more land to continue to grow, reducing the amount of land that could otherwise support life [27]. The utilization of industrial land resources is often wasted because of irrational land use structures and low utilization efficiency, resulting in environmental degradation and additional land use for industry [28]. In addition, industrialization also produces substantial amounts of environmentally harmful waste [29]. Industrialization is a vast organization of systems that involves the transportation, mining, manufacturing, and management of industrial wastes [30,31]. The amount of waste produced because of human activities associated with industrialization has been increasing over the last two centuries. Some of the wastes include chemicals, gaseous wastes from automobiles and manufacturing processes, and solid wastes. Because the measure of the global ecological footprint also includes the amount of waste produced within a particular timeframe, industrial wastes have led to an increased ecological footprint [32]. According to Proshad et al. [33] and Mahmood et al. [34], industrialization demands vast environmental resources with which to operate and sustain itself, producing waste and leading to an increased global ecological footprint.

Extensive research has been conducted on the environmental consequences of industrialization, including examining industrial concentration, environmental policies, historical data analysis, and economic effectiveness. In their study, Zhu and Xia [35] examined the impact of industrial agglomeration on environmental pollution in China and concluded that industrial agglomeration has indeed played a role in contributing to environmental pollution. A study by Li et al. [36] demonstrated a nonlinear correlation between environmental regulations and the transfer of pollution-intensive companies. Regulations both restrict and encourage these industries, with the encouraging effect increasing and diminishing in response to improved regulations. Elliott and Frickel [37] employed historical data to investigate the aggregation of perilous parcels in connection with shifting patterns of industrial land utilization, neighborhood composition, new residential development, and environmental legislation in the United States. In their study, van Berkel et al. [38] examined the correlation between cleaner production and industrial ecology, emphasizing the capacity of proactive environmental measures to promote industrial sustainability.

Economic expansion and the increase in organically farmed land both contribute to a reduction in the carbon footprint in the European region. On the contrary, agricultural expansion, investments in road infrastructure, fertilizer usage, and aquaculture production all contribute to growth in the carbon footprint [39]. The manufacturing industry contributes significantly to greenhouse gas emissions, primarily as a result of the ecological effects associated with its infrastructure, processes, and products [40]. The production of tourism-related goods and services, specifically those that heavily rely on fossil fuels, leads to the emission of significant amounts of greenhouse gases [41]. The digital industry has the potential to decrease carbon emissions by increasing industrial production efficiency and modifying consumption and production patterns in other industries [42]. The supply chain is the principal contributor to carbon emissions within the construction industry [43]. The electricity production and ferrous metals sectors exhibit the highest potential for reducing carbon emissions [44]. Smart-grid technologies are acknowledged for their ability to mitigate carbon emissions in the energy and transportation sectors, and they have the potential to do the same in the manufacturing industry [45].

On the other hand, urbanization, which encompasses the growth in towns and cities, is associated with an increased global ecological footprint. Urbanization involves removing green spaces and building commercial, industrial, and residential buildings. Oppong et al. [46] and Useni Sikuzani et al. [47] noted that urbanization involves deforestation, the removal of soil, and the destruction of green spaces to pave the way for buildings. Soil, green spaces, and forests are critical components that sustain biodiversity and ecological balance [48]. However, research studies show that a significant amount of soil is excavated during urbanization, which occurs concurrently with the removal of green spaces and forests, to clear land for construction projects [49–51]. Such activities leave significant landmarks in place of natural resources, such as forests and land. By depleting environmental resources, urbanization contributes to an increased global ecological footprint.

Urbanization is also associated with consolidation and growth in urban populations. Populations require significant resources, such as food, water, and energy [52,53]. Evidence from research shows an inverse relationship between population growth and global ecological balance. For example, a growth in population needs a significant amount of food, which must be sourced, for example, from large-scale farming and fishing. Large-scale farming leads to environmental degradation and an enormous ecological imbalance [54,55]. In addition, feeding humanity also pressures marine, freshwater, and terrestrial ecosystems. According to Halpern et al. [56], the global system has fueled extensive degradation of the planet's capital at a faster rate than its natural resources are being replenished. In addition, urbanization is associated with an increase in energy demand, which escalates the global ecological footprint. Urbanization needs substantial resources and energy for its sustainment [57]. As noted previously, urbanization leads to a population increase, which research shows concurrently increases the demand for energy, mainly fossil fuels. Rehman et al. [58] emphasized that urbanization and population growth lead to a high demand for energy. Energy is a crucial component needed by humans to live comfortably on Earth while concurrently supporting economic stability and growth [59]. Urban centers are among the main sources of revenue in a country due to the substantial amount of energy spent per day. An upsurge in energy use due to the population of urban centers means that many natural resources will be exploited, leading to an increased ecological footprint [60,61]. A high energy demand puts pressure on natural oil and gas and other nonrenewable energy sources, such as coal, leading to an increased global ecological footprint.

There is also a correlation between urbanization, water demand, and an increased global ecological footprint. Urbanization is associated with the overconsumption of water to support population growth [62]. The relationship between urbanization, water consumption, and ecological footprint shows that the former increase the latter. The water demand is ever-increasing because of urbanization, which further strains natural water sources [63]. The demand for water stems from the water needed to sustain populations in urban centers and the water needed to support farming to supply cities and major towns with food. The above findings show that urbanization is associated with increased food, energy, and water consumption, which increases the ecological footprint. Importantly, it is necessary to note that urbanization also produces substantial amounts of waste related to transportation, solid water, and sewage, which must be absorbed and harnessed by nature [64,65]. The depletion of natural resources and land to supply urban centers with food, water, and electricity while concurrently producing a substantial amount of waste increases the global ecological footprint.

Environmental change has been substantially influenced by urbanization, specifically with regard to its ecological footprint. The existing body of literature explores the complex correlation between urbanization and ecological footprint, shedding light on a range of positive and negative consequences. Ahmed et al. [66] determined that human capital decreases the ecological footprint, whereas urbanization increases it. Fang and Lin [67] discovered a direct and positive correlation between urbanization and the ecological footprint, indicating that urbanization is a contributing factor to the increase in the ecological footprint. Conversely, research conducted by Yang, Usman and Jahanger [12] demonstrates that urbanization has a substantial impact on diminishing environmental damage and increasing healthcare expenses. Danish and Wang [68] state that urbanization leads to an increase in the ecological footprint. However, the combined effects of economic growth and urbanization act as moderators, resulting in a reduction in the ecological footprint and, therefore, decreases in environmental deterioration in Next-11 countries. Long et al. [69] state that urbanization, which is linked to greater income, has the capacity to reduce the ecological footprint, which is an environmentally beneficial effect.

Concerning renewable energy, it is important to note that its effects on the global ecological footprint can be negative or positive, with the timeframe as a critical determinant. Unlike urbanization and industrialization, which consume resources and produce significant amounts of waste, investment in renewable energy has little effect on natural resources and the release of environmentally harmful wastes. Research studies show that renewable energy is associated with improved environmental sustainability [70]. Unlike conventional energy sources, such as fossil fuels, renewable energy does not produce environmentally harmful wastes such as CO_2. According to Raghutla, Padmagirisan, Sakthivel, Chittedi, and Mishra [70], significant amounts of greenhouse gases degrade the environment and impair the ecological balance. Because the global ecological footprint also includes a measure of how much waste the environment absorbs, it is evident that renewable energy sources have positive effects on the ecological footprint. However, even though investment in renewable energy sources minimizes environmental destruction and global warming, it can potentially interfere with the aquatic ecological balance. For example, the construction of hydroelectric power plants to generate renewable energy involves displacing a significant amount of water and construction along major water sources [71,72]. This disruption interferes with and destroys aquatic life and ecological balance, which are outcomes that put pressure on natural resources. According to Renöfält et al. [73], hydropower production impairs ecological systems by fragmenting channels and changing water flows. In addition, hydroelectric dams alter delta and floodplain ecosystems. However, despite interfering with aquatic systems along rivers, it is necessary to note that renewable energy sources have little effect on the global ecological footprint.

Extensive studies have been conducted on the impact of renewable energy policies on environmental degradation [74]. Multiple studies have examined the correlation between the utilization of renewable energy and the impact on the environment. A few of them concluded that the use of renewable energy leads to a reduction in the ecological footprint [75]. In addition, Usman et al. [76] discovered negative impacts of renewable energy and innovation on the ecological footprint. The implementation of renewable energy sources is not devoid of obstacles. According to Wall et al. [77], the use of renewable energy is hindered by the expensive nature of purchasing renewable energy goods. A study conducted by Makki and Mosly [78] indicates that the public's willingness to adopt renewable energy technology is impacted by 19 specific attributes, which emphasize the behavioral and other challenges that impede its complete implementation.

Sustainable development is a complex notion that includes several aspects related to the environment, society, and economy. The literature on sustainable development offers many viewpoints of its definition and principles. Development can be defined as the progression from a specific state or form to a more intricate and sophisticated state [79]. Sustainable development, originally rooted in economics [80], has been described by the Brundtland Commission [81] as "meeting the needs of the present without compromising the ability of future generations to meet their own needs". Sustainability is expected to shape future development discussions, focusing on ecologically, economically, and socially sustainable options. These options should be ecologically and economically fair, as well as environmentally tolerable. Three interrelated domains of sustainability connect the environmental, economic, and social dimensions of sustainable development [82]. The concepts related to sustainability can be divided into two categories: those that strive for strong sustainability, such as buen vivir and degrowth, and those that may seem like innovative environmental approaches but are actually based on the same weak principles as sustainable development, such as green economy and circular economy [83]. The global community strongly desires sustainable development, with a focus on achieving an environmentally sound, harmonious, and secure state in terms of stability, health, energy, and food supply. The desire for this is apparent worldwide, with a specific emphasis on elevating sustainable development in the field of social sciences to the status of a new paradigm of behaviors and perspectives in contemporary civilization [84].

There has been a substantial global expansion in social and economic progress, resulting in an increased need for energy, namely, that which is derived from fossil fuels. Despite concerted attempts to reduce energy consumption, fossil fuels continue to maintain their position as the dominant source, hence contributing to environmental damage. Scholars are currently investigating the interplay among macroeconomic indicators, including GDP growth, energy consumption, and pollution levels across various geographical locations [85]. GDP serves as a metric to measure the total value of economic output inside a given country [86]. It is frequently employed as an indicator to assess the developmental status of a country. The literature has extensively examined the environmental Kuznets curve (EKC), a theoretical construct that posits a curvilinear association between income (measured by GDP) and environmental deterioration, taking the appearance of an inverted U [87]. On the basis of the EKC hypothesis, it is posited that during the process of economic development and wealth growth, there is an initial exacerbation of environmental degradation [88]. However, as countries progress and attain a specific threshold of development, a reversal in this trend occurs, leading to improved environmental conditions. Although economic expansion has the potential to result in greater utilization of resources and degradation of the environment, it also has the capacity to facilitate the development of innovative technologies and the implementation of policies that promote sustainability. The precise characteristics of the association can differ based on factors such as the country under study, the chosen research approach, and the specific variables considered.

The correlation between economic growth, as quantified by gross domestic product, and the state of the environment has been extensively studied. Multiple studies have examined the correlations among these factors in various regions, such as Middle Eastern and North African countries [89,90], China [91,92], the G20 group [93], East and South East Asian countries [94], and the Eurasian Economic Union [95]. Although certain studies have indicated a positive impact of economic expansion on environmental well-being, others have emphasized the possibility of environmental degradation as a result of economic development. Using the EKC, it is argued that environmental degradation initially increases during the early stages of economic expansion but then declines if income surpasses a certain threshold [96]. The EKC has been examined in numerous telling scenarios, including air pollution emissions in a study by Selden and Song [97], carbon dioxide emissions in research by Arango Miranda et al. [98], the impact of industrial construction on urban pollution from haze in the work of Wang et al. [99], and waste discharge as reported by Ichinose et al. [100]. There is research that provides evidence for the presence of the curve in some countries and for specific pollutants [101,102], whereas other studies [103] argue against its empirical accuracy.

Foreign direct investment is a monetary influx that has historically been linked to the transmission of information, technology, and managerial methodologies from the country of origin to the receiving country. Over the last two decades, FDI has emerged as an important component of global-scale globalization efforts [104]. The significance of examining the correlation between a reliance on foreign investment and environmental factors is emphasized by the recent surge in the global expansion of foreign investment, the increase in the production of global commodities, and the escalation of various forms of environmental deterioration, particularly in underdeveloped nations [105]. FDI has the potential to exert an influence on the environment through multiple channels, namely, the technology effect, size effect, income effect, and competition effect. Its utilization for these effects facilitates the creation of a more conducive environment by enabling domestic enterprises to acquire and use the latest technology. The phenomenon known as the scale effect has the potential to result in an increase in environmental pollution. The income effect serves as a motivating factor for nations to embrace more stringent environmental norms and laws. The competition effect incentivizes nations to seek and maintain FDI by reducing their environmental requirements [106]. Although FDI possesses significant potential for bolstering economic growth, it is imperative to acknowledge its possible adverse effects on environmental quality. This is particularly evident when industries from wealthy nations, adhering to stringent environmental standards, relocate to developing countries with comparatively weaker requirements [107].

The impact of FDI on the environment is multifaceted, influenced by economic development, regulatory quality, technology transfer, and the type of FDI. According to Markusen and Venables [108], FDI can be categorized into vertical FDI and horizontal FDI. Both vertical and horizontal FDI play a crucial role in strengthening and production in developing countries, with horizontal FDI aiming to capture local markets, and vertical FDI focusing on lower-cost production. Tang [109] conducted a study to examine the effects of vertical FDI and horizontal FDI on the environment of the host country. The findings indicate that vertical FDI has a more significant negative impact on the quality of the environment, because vertical FDI is driven by the aim of minimizing costs. The convergence of technological advancements and FDI may have contributed to a rapid improvement in the effective utilization of energy resources, thus leading to a decline in CO_2 emissions [110]. Mert and Bölük (2016) concluded that foreign direct investment has the effect of introducing environmentally friendly innovations and increasing the sustainability of the environment [111]. FDI has been associated with pollution particularly through two ideas: the pollution haven hypothesis and the pollution halo hypothesis. These hypotheses emphasize the complex link between FDI and the deterioration of the environment. The halo effect hypothesis suggests that foreign investors, because of their advanced technology, can positively impact the host country by promoting cleaner, less harmful technologies [112]. According to the PHH, foreign direct investment contributes to environmental degradation by allowing industrialized countries to move companies that produce high levels of pollution to developing countries with cheaper labor expenses and environmental regulations [113,114].

3. Literature Review

Musah and Yakubu [115] conducted a study in Ghana to examine how industrialization and technology affect environmental quality. They used the ecological footprint (ECF) as a measure of environmental degradation and found that industrialization and technology have a significant effect on increasing the ecological footprint. Similarly, Destek and Okumus [116] investigated the pollution haven hypothesis in newly industrialized countries and its relationship with ecological footprint. They found that increased energy consumption and economic growth lead to an increase in the ecological footprint. They also confirmed the U-shaped relationship between FDI and ecological footprint in these countries. In China, Zhu and Xia [35] examined the impact of industrial agglomeration on environmental pollution. They found that the effect of industrial agglomeration on environmental pollution varies depending on the level of urbanization. This indicates that the ecological footprint is influenced by the spatial distribution of industries and the level of urban development. Budak [117] conducted a systematic literature review on the carbon footprint of logistics and transportation. The study highlights the increase in greenhouse gas emissions due to rapid industrialization and the significant role of carbon dioxide in these emissions.

Chaouachi and Balsalobre-Lorente [118] confirmed that foreign direct investment directly affects the ecological footprint. They identified a unidirectional causality between economic growth and ecological footprint, as well as a unidirectional relationship between electricity consumption and ecological footprint. Ponce et al. [119] examined the influence of FDI on the development of the private financial system and its ecological footprint. They found that changes in the private financial system, FDI, urbanization, and economic growth led to changes in the ecological footprint over the long term. Fatima et al. [120] studied the impact of energy consumption and FDI on environmental sustainability in Vietnam. They found an N-shaped relationship between the ecological footprint and FDI, suggesting that Vietnam may benefit from a decrease in environmental degradation at some point.

Alola et al. [121] found that renewable energy utilization has a positive effect on ecological footprint at certain quantiles, indicating a complex relationship between renewable energy consumption and ecological footprint. However, Nan, Sun, Mei, Yue and Yuliang [75] found that renewable energy consumption has a long-term negative effect on the ecological footprint in China, suggesting that increasing renewable energy consumption can lead to a decrease in the ecological footprint. Sharif et al. [122] found that renewable energy decreases the ecological footprint over long term for each quantile in Turkey. Albayrak et al. [123] found that economic growth, renewable energy production, and nonrenewable energy production have a positive effect on the ecological footprint in Turkey. Anser et al. [124] found that economic policy uncertainty and nonrenewable energy consumption increase the ecological footprint, whereas geopolitical risk and renewable energy reduce the ecological footprint.

According to Ozturk et al. [125], the findings from their study using a panel of 144 nations indicate that there is a significant relationship between urbanization and ecological footprints. A study conducted by Ibrahiem and Hanafy [126] examined the interconnections between ecological footprints, fossil fuel energy consumption, and globalization. The researchers discovered that the deterioration of the ecosystem can be ascribed to variables such as real income levels and the utilization of fossil fuels. On the other hand, scholars have recognized globalization and demographic dynamics as potential variables that could help alleviate the situation. A study conducted by Sahoo and Sethi [127] revealed positive relationships between the ecological footprint and many characteristics, including population density, urbanization, energy use, and life expectancy. According to a study conducted by Danish et al. [128], urbanization exerts a detrimental influence on the ecological footprint within the BRICS countries. In a study conducted by Ahmed, Zafar, Ali and Danish [66], a notable and statistically significant correlation was seen between urbanization and ecological footprint within the G7 nations. In contrast, human capital serves to reduce the ecological imprint. According to a study conducted by Zahra et al. [129], urbanization exerts a significant influence on Pakistan's ecological footprint over both short- and long-term durations. An asymmetric relationship was also discovered between physical infrastructure, trade (commercial), and the ecological footprint.

The research findings obtained by Kirikkaleli et al. [130] showed that over a long period of time, globalization has a positive effect on the ecological footprint. Additionally, in the short term, trade (commercial) openness leads to a reduction in the ecological footprint. However, both short-term and long-term GDP growth have a negative influence on the ecological footprint. In their study, Destek and Okumus [116] investigated the correlation between real income, foreign direct investment, energy consumption, and ecological footprint in a sample of ten newly industrialized countries over a period spanning from 1982 to 2013. The findings indicated that there was a positive correlation between increased energy consumption and economic growth, resulting in the expansion of the ecological footprint. This relationship is further supported by the observation of a U-shaped pattern. In Zafar, Zaidi, Khan, Mirza, Hou and Kirmani's [107] study, the ecological footprint is subject to the influence of factors such as economic growth, energy consumption, and human capital. The ecological footprint is negatively affected by both economic expansion and energy usage. The utilization of natural resources and human capital has the potential to reduce the ecological footprint, with foreign direct investment also playing a role in this regard. In order to enhance the standard of living and foster sustainable growth, it is imperative for the United States to actively seek greater inflows of foreign direct investment and human capital.

In summary, the process of industrialization has had significant effects on the ecological footprint, resulting in environmental contamination, degradation, and socio-environmental deterioration. In general, existing evidence indicates that the relationship between foreign direct investment and ecological footprint is intricate and subject to variability contingent upon factors such as energy consumption, economic growth, and institutional quality. Although certain studies have identified a U-shaped or N-shaped correlation, others have emphasized the negative effect of foreign direct investment on the environment. The effects of renewable energy consumption can exhibit variations contingent upon the country in question and the specific methodology employed in studies of ecological footprints. Existing scholarly research indicates that urbanization exerts both advantageous and detrimental effects on the ecological footprint. Urbanization has the potential to lead to heightened levels of resource consumption and environmental degradation. However, it is worth noting that developments related to technology and human capital, as well as the widespread use of renewable energy, can play a crucial role in alleviating these negative effects. The existing body of research concerning the impact of gross domestic product on an ecological footprint reveals a diverse range of results. Several studies have presented varying perspectives on the correlation between GDP and ecological footprint. Although some research indicates a positive relationship, others propose an inverted U-shaped link or advocate against prioritizing GDP growth as a sustainable objective.

This study highlights the significance of considering temporal changes in economic and environmental variables, which is in line with the purpose of the research currently being conducted. A complete examination of the relationship between foreign direct investment, gross domestic product, industrialization, consumption of renewable energy, urban population, and ecological footprint across 131 countries is provided in this research, which therefore contributes to the existing body of literature. In order to handle the nonnormally distribution of the data and the existence of outliers, the study is made more robust through the utilization of quantile regression analysis which addresses these issues. The results are consistent with those of earlier studies, demonstrating the importance of providing nuanced interpretations of the impact that foreign direct investment and urbanization have on ecological footprints. Furthermore, the findings show the potential of renewable energy use to reduce environmental deterioration.

4. Materials and Method

Within the scope of the research, it is aimed to estimate the econometric model in Equation (1) in order to determine the effects of the variables that are possible determinants of ecological footprint from the period sample between 1997 and 2020 for 131 countries.

$$LNEF_{i,t} = \alpha_{i,t} + \beta_1 LNFDI_{i,t} + \beta_2 LNIND_{i,t} + \beta_3 LNREN_{i,t} + \beta_4 LNURB_{i,t} + \beta_5 LNGDP_{i,t} + \varepsilon_{i,t} \quad (1)$$

In Equation (1), t is the subscript time (year), i is the subscript units (country), α is the equation constant term and ε is the equation error terms. LN at the beginning of the variables indicates that all variables are logarithmic. The study used the following data: the dependent variable is the ecological footprint data per capita obtained from the Global Footprint Network (GFN)—the independent variables are the net flow of foreign direct investment, the level of industrialization, the percentage of renewable energy consumption in total energy consumption, the percentage of the urban population in the total population, and gross domestic product per capita from the World Bank. These independent variables were chosen based on their potential impact on the ecological footprint.

Observations for all variables in the table are collected for 131 countries between 1997 and 2020 to form a balanced panel data set (Appendix A). Since the data for 131 countries were analyzed, it was observed that the variables were far from a normal distribution and contained outliers for many periods and countries. Therefore, it is considered appropriate to utilize nonparametric estimators to estimate consistent coefficients. Quantile regression analysis was utilized among the nonparametric estimators. The hypotheses of the study were determined as follows:

$H_0$1. *Industrialization is one of the drivers for the rise of the global ecological footprint.*

$H_0$2. *Using renewable energy sources decreases the overall environmental impact on the world.*

$H_0$3. *Urbanization increases the global ecological footprint.*

$H_0$4. *There is a positive correlation between higher GDP per capita and an increasing global ecological footprint.*

$H_0$5. *A positive association exists between a higher global ecological footprint and foreign direct investments.*

The quantile regression method, unlike the least squares method, is a method for determining the effects of a dependent variable on all conditional distributions rather than determining the effect of the dependent variable on its conditional mean [131].

The quantile regression form can be expressed as in Equation (2).

$$Y_{i,t} = \gamma_\theta X'_{i,t} + \varepsilon_{i,t}; Quant_\theta(ED_{i,t}|X_{i,t}) = \gamma_0 X'_{i,t} \quad (2)$$

In Equation (2), Y is the dependent variable and X' is the vector of independent variables. $Quant_\theta(ED_{i,t}|X_{i,t}) = \gamma_\theta$ is the conditional quantile of Y to X for the θ^{th} quantile. While classical Least Squares estimators require prerequisites such as the variables being normally distributed and free of outliers, the Quantile Regression method does not require these prerequisites of parametric estimators [132]. On the other hand, there are methods such as the Simultaneous Boot-Strapped Quantile Regression Method, Quantile Regression with Clustered Data [133], and the Generalized Quantile Regression Method [134] for Quantile regression analysis on panel data. In this study, the Generalized Quantile Regression Method, which does not have stationarity and cointegration preconditions in addition to non-normality, is heterogenous and cross-sectionally robust and is known to eliminate the endogeneity problem by using the Generalized Method of Moments.

5. Results

In this part of the study, the findings obtained as a result of the data analysis are interpreted and shared. Descriptive statistics of the variables in the study are given in Table 1.

Table 1. Variable descriptive statistics.

Statistics	LNEF	LNFDI	LNIND	LNREN	LNURB	LNGDP
Mean	3.61	11,300,000,000	111,000,000,000	32.88	55.56	12,656.29
Median	2.83	814,000,000	9,520,000,000	24.015	56.84	5544.124
Max	43.67	734,000,000,000	5,770,000,000,000	96.04	100.00	87,123.66
Min.	0.00	−330,000,000,000	7,184,645	0.00	7.62	246.39
Std. Dev.	3.50	41,300,000,000	414,000,000,000	29.22	22.64	16,413.30
S	0.556	−23.654	−0.135	−0.648	−0.900	−0.068
K	3.608	1050.411	2.572	2.520	3.115	2.076
Normality	141.47 ***	190.53 ***	42.04 ***	193.82 ***	258.08 ***	384.63 ***
(χ^2(02))	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Obs.	3144	3144	3144	3144	3144	3144

*** (%1), denotes statistical significance at the significance level. S: skewness, K: kurtosis, Obs.: observation, χ^2: chi-Square test statistic. (): Parentheses contain the test degrees of freedom. []: [inside brackets are test significance values], normal distribution statistics are calculated for logarithmic variables.

The EF variable is non-normally distributed, with a mean of 3.61 between a minimum of 0.000 and a maximum of 43.67, with a standard deviation of 3.50. (χ^2(02) = 141.47, $p < 0.01$) The FDI variable is non-normally distributed with a mean of 11,300,000,000 between a minimum of 330,000,000,000 and a maximum of 734,000,000,000 with a standard deviation of 41,300,000,000. (χ^2(02) = 190.53, $p < 0.01$) The IND variable is non-normally distributed with a standard deviation of 414,000,000,000 around a mean of 111,000,000,000 between a minimum of 7,184,645 and a maximum of 5,770,000,000,000. (χ^2(02) = 42.04, $p < 0.01$) The REN variable is non-normally distributed with 29.22 standard deviation values around 32.88 and a mean between minimum 0.000 and maximum 96.04. (χ^2(02) = 193.82, $p < 0.01$) URB variable is abnormally distributed with 22.64 standard deviation values around 55.56 and a mean between minimum 7.62 and maximum 100.00. (χ^2(02) = 258.08, $p < 0.01$) The GDP variable is non-normally distributed with a standard deviation of 16,413.30 around the mean of 12,656.29 between the minimum 246.39 and maximum 87,123.66. (χ^2(02) = 384.63, $p < 0.01$)

As seen, all variables had a non-normal distribution. This situation can also be observed from the normal distribution graphs in Figure A1 (Appendix B). The graphs show that all variables deviate from the expected values for the normal distribution; in other words, deviations from the normal distribution are observed. Box-plot and histogram graphs of the variables were also analyzed in terms of normal distribution and outliers. It was decided that these graphs and normal distribution tests contain similar findings and that the variables have a non-normal distribution with outliers (Appendix B).

Due to the non-normal distribution of the variables, it was decided to complete the research model with quantile regression analysis. As explained in the Method section, the Generalized Quantile Regression Method was used during the Quantile Regression Analysis since it has some advantages over other methods.

Prior to the model estimations, correlation relationships between variables and scatter plots were analyzed. The correlation matrix between the variables is given in Table 2.

Table 2. Correlation matrix between variables.

	LNEF	LNFDI	LNIND	LNREN	LNURB	LNGDP
LNEF	1.000 -					
LNFDI	0.144 *** [0.000]	1.000 -				
LNIND	0.280 *** [0.000]	0.262 *** [0.000]	1.000 -			
LNREN	−0.530 *** [0.000]	−0.103 *** [0.000]	−0.199 *** [0.000]	1.000 -		
LNURB	0.623 *** [0.000]	0.128 *** [0.000]	0.530 *** [0.000]	−0.445 *** [0.000]	1.000 -	
LNGDP	0.831 *** [0.000]	0.171 *** [0.000]	0.478 *** [0.000]	−0.549 *** [0.000]	0.725 *** [0.000]	1.000 -

*** (%1), denotes statistical significance at the significance level. []: Square brackets contain test probability (*p*) values.

The table shows that there are statistically significant and positive correlations between the dependent variables LNEF and LNFDI, LNIND, LNURB and LNGDP at the 1% significance level. The positive correlations with the LNEF variable can be listed as follows in terms of magnitude: LNGDP, LNURB, LNIND and LNFDI. On the other hand, there is a statistically significant and negative correlation between the dependent variable LNEF and the independent variable LNREN at the 1% significance level. The correlation coefficients between the independent variables are all significant at the 1% significance level and range between −0.549 and 0.725.

To construct the scatter plots between the variables, the averages of the units for the period between 1997 and 2020 were first calculated for all variables. In other words, graphs were drawn over the average values between 1997 and 2020 for all countries. In the scatter plots, colors were used to indicate the continents in which the countries are located, and circle sizes were differentiated to indicate the human development levels of the countries. A larger circle size indicates a higher Human Development Index, while continent color pairings are indicated in the graphs.

The scatter plot of the dependent variable LNEF and the independent variable LNFDI is shown in Chart 1.

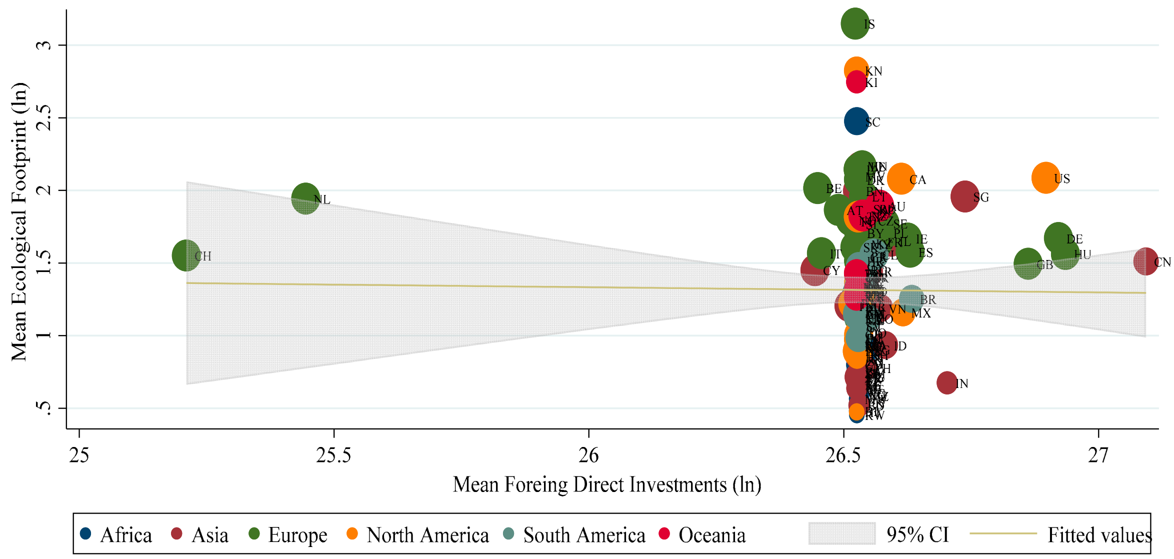

Chart 1. LNEF and LNFDI scatter plot.

Chart 1 shows that LNFDI is a low variance variable and has a low correlation with LNEF. When the chart is interpreted with the continent and human development details, it is seen that especially Asian and African countries with low levels of human development have lower ecological footprint period averages, while countries with high levels of human development, especially European and North American countries, have higher ecological footprint period averages.

The scatter plot of the dependent variable LNEF and the independent variable LNIND is shown in Chart 2.

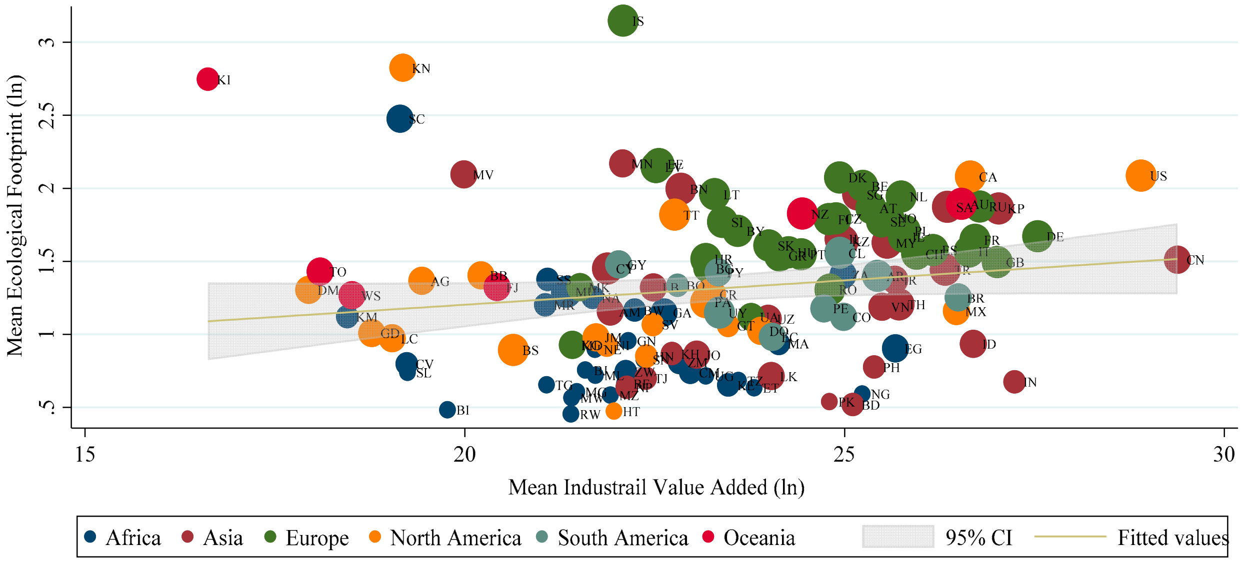

Chart 2. LNEF and LNIND scatter plot.

Chart 2 shows that low industry and low ecological footprint averages are observed for African and Asian countries with low human development levels and some North American countries with high human development levels, while Europe and some Asian and North American countries with high human development levels generally have a high industry and high ecological footprint pattern. When the chart is analyzed, it is seen that the correlation pattern can be interpreted as a low-intensity relationship. In terms of the general outlook, for countries with low industrial production and low levels of human development, medium and low ecological footprint values corresponding to low industrial values and high ecological footprint values corresponding to high industrial production were observed. It is noteworthy that both ecological footprint and industrial production are very close to the sample average for countries with moderate human development in North America, South America, Asia and Europe.

The scatter plot of the dependent variable LNEF and the independent variable LNREN is shown in Chart 3.

The chart shows that there is an inverse relationship between ecological footprint and renewable energy use. When this inverse relationship is analyzed in terms of human development levels and continents, there are high ecological footprint and low renewable energy use rates for some Asian and North American countries with medium and high human development levels, while there are high renewable energy use and low ecological footprint distributions for some Asian and many African countries with low human development levels. European countries, on the other hand, generally have high human development, medium and high levels of renewable energy use, but high ecological footprint dispersion. Northern European countries generally have lower levels of human development, medium and high levels of renewable energy use and low levels of ecological footprint.

The scatter plot of the dependent variable LNEF and the independent variable LNURB is shown in Chart 4.

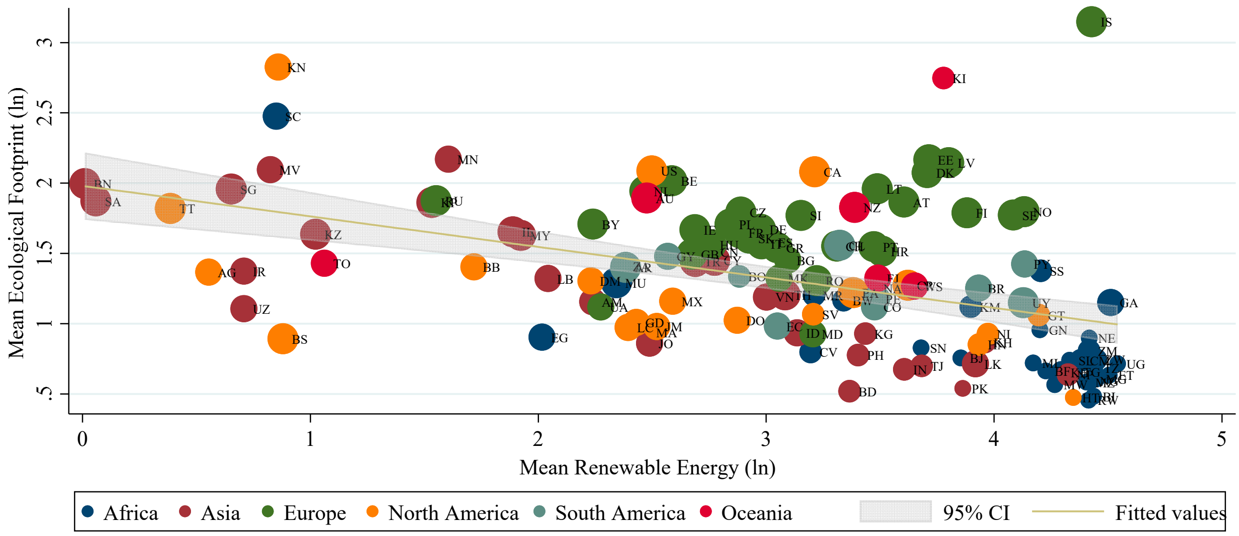

Chart 3. LNEF and LNREN scatter plot.

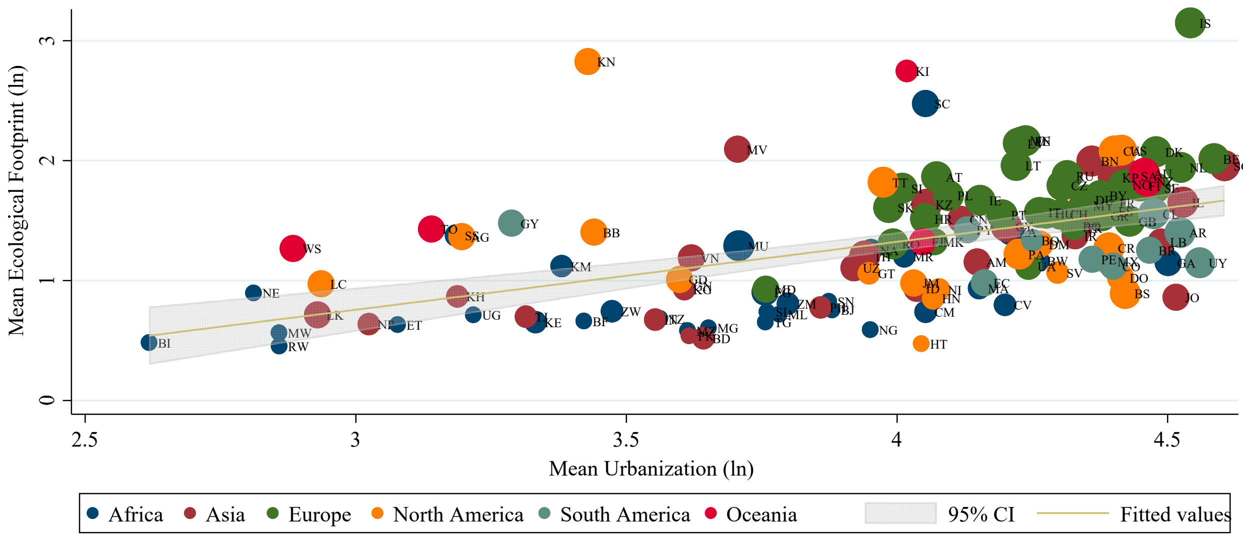

Chart 4. LNEF and LNURB scatter plot.

There is a positive relationship between urbanization rate and ecological footprint. It is observed that European, North American, South American, Asian and African countries, which have high urbanization rates and are in a better position in terms of human development, have a high urbanization rate and high ecological footprint pattern compared to both low human development countries on the same continent and low human development countries on other continents.

The scatter plot of the dependent variable LNEF and the independent variable LNGDP is shown in Chart 5.

There is a positive relationship between the LNEF variable and the LNGDP variable. It is seen that all countries with high GDP have medium and high levels of ecological footprint and these countries also have medium and high levels of human development.

Panel Generalized Quantile Regression estimation results of the research model are given in Table 3.

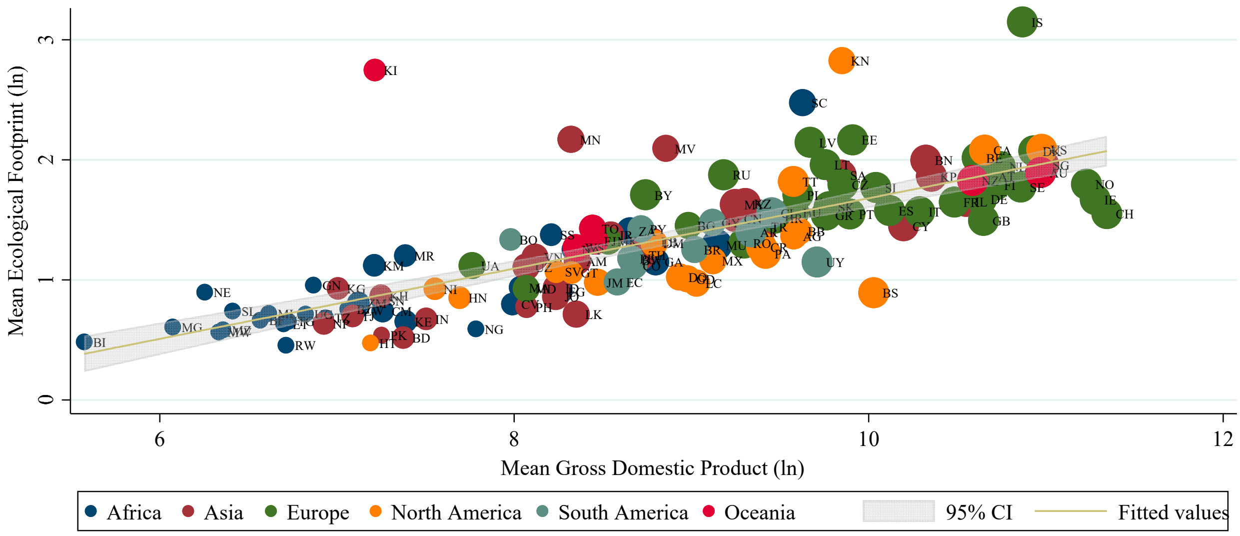

Chart 5. LNEF and LNGDP scatter plot.

Table 3. Panel Generalized Quantile Regression estimation results.

Variable	**Quantiles**				
	OLS	**10**	**20**	**30**	**40**
LNFDI	0.122 0.036 3.34 *** [0.001]	0.359 0.096 3.74 *** [0.000]	0.331 0.077 4.29 *** [0.000]	0.290 0.072 4.06 *** [0.000]	0.238 0.095 2.5 *** [0.012]
LNIND	−0.039 0.003 −15.16 *** [0.000]	−0.007 0.003 −1.95 *** [0.051]	−0.016 0.003 −5.7 *** [0.000]	−0.020 0.003 −6.89 *** [0.000]	−0.023 0.003 −6.8 *** [0.000]
LNREN	−0.037 0.005 −7.21 *** [0.000]	−0.043 0.009 −4.67 *** [0.000]	−0.030 0.006 −4.82 *** [0.000]	−0.039 0.005 −7.38 *** [0.000]	−0.047 0.005 −8.72 *** [0.000]
LNURB	0.113 0.016 7.12 *** [0.000]	0.033 0.016 2.03 *** [0.042]	0.041 0.014 2.97 *** [0.000]	0.068 0.015 4.50 *** [0.000]	0.068 0.017 4.03 *** [0.000]
LNGDP	0.301 0.006 52.34 *** [0.000]	0.273 0.008 34.11 *** [0.000]	0.285 0.006 46.08 *** [0.000]	0.283 0.006 45.02 *** [0.000]	0.286 0.006 45.82 *** [0.000]
Constant	−3.877 0.957 −4.05 *** [0.000]	−10.640 2.492 −4.27 *** [0.000]	−9.782 2.018 −4.85 *** [0.000]	−8.600 1.873 −4.59 *** [0.000]	−7.106 2.493 −2.85 *** [0.004]
R2	0.719	0.473	0.534	0.559	0.567
Variable	Quantiles				
	50	60	70	80	90
LNFDI v	0.237 0.101 2.34 *** [0.000]	0.250 0.102 2.45 *** [0.014]	0.296 0.102 2.91 *** [0.004]	0.351 0.112 3.13 *** [0.000]	0.368 0.104 3.53 *** [0.000]
LNIND	−0.027 0.004 −7.11 *** [0.000]	−0.035 0.004 −8.06 *** [0.000]	−0.050 0.006 −8.84 *** [0.000]	−0.069 0.005 −12.55 *** [0.000]	−0.088 0.006 −15.71 *** [0.000]

Table 3. *Cont.*

LNREN	−0.055 0.005 −10.57 *** [0.000]	−0.059 0.006 −10.04 *** [0.000]	−0.067 0.007 −9.37 *** [0.000]	−0.088 0.008 −10.58 *** [0.000]	−0.114 0.011 −10.00 *** [0.000]
LNURB	0.080 0.019 4.28 *** [0.000]	0.103 0.021 4.94 *** [0.000]	0.092 0.024 3.76 *** [0.000]	0.057 0.023 2.49 ** [0.013]	0.073 0.032 2.31 ** [0.021]
LNGDP	0.284 0.006 46.73 *** [0.000]	0.288 0.007 42.14 *** [0.000]	0.301 0.008 36.56 *** [0.000]	0.321 0.008 39.82 *** [0.000]	0.332 0.010 34.39 *** [0.000]
Constant	−6.906 2.642 −2.61 *** [0.009]	−7.119 2.652 −2.68 *** [0.007]	−7.986 2.625 −3.04 *** [0.002]	−8.890 2.906 −3.06 *** [0.002]	−8.865 2.698 −3.29 *** [0.001]
R2	0.566	0.557	0.539	0.504	0.453

*** (%1), ** (%5), denotes statistical significance at the significance level. []: Square brackets contain test probability (*p*) values. While the coefficient of determination in OLS regression is Adjusted R^2, Pseudo R^2 values are reported in Quantile Regressions (the pseudo-R square values calculated for all percentile regressions are above 0.4. These results demonstrate the effectiveness of the percentile regressions in capturing and explaining the variation in the data [135]).

The first column of Table 3 shows the Classical Pooled Least Squares estimation. The coefficients in this estimation are reported for comparison with other coefficients, and since it is known that the research model does not meet the OLS estimation assumptions, the model is analyzed with Panel Generalized Quantile Regression analysis. Quantile values between 10 and 90 Quantile values in percentage terms were used as quantile.

The effect of the LNFDI variable on the LNEF variable is statistically significant and positive at the 1% significance level for quantile values. Therefore, it is observed that FDI has a positive impact on ecological footprint. When the coefficients for quantile values are analyzed separately, it is seen that the effect of FDI on ecological footprint decreases from the 10% segment with the lowest ecological footprint to the 50% segment, while the effect increases again when moving from the 50% segment to the 90% segment in terms of ecological footprint.

The effect of the LNIND variable on the LNEF variable is statistically significant and negative at the 1% significance level for quantile values. It is observed that the industrialization rate has a negative impact on the ecological footprint. When the coefficients for the quantile values are analyzed separately, it is seen that there is no clear pattern in terms of coefficient magnitudes. While the highest effect was in the 90% quantile countries, the lowest effect was in the 10% quantile countries.

The effect of the LNREN variable on the LNEF variable is statistically significant and negative at the 1% significance level for the quantile values. It is observed that renewable energy use has a negative impact on the ecological footprint. When the coefficients for quantile values are analyzed separately, it is seen that while there is no significant character and difference for the countries in the first 50% quantile, the impact of the countries in the 50% quantile and above is higher than the countries below the 50% quantile. In other words, the impact of renewable energy utilization rates on ecological footprint in countries with the highest ecological footprint is higher than the impact in countries with the lowest ecological footprint. Moreover, the impact increases with the quantile value above the 50% quantile. In other words, as the ecological footprint increases, the negative impact of renewable energy on the ecological footprint also increases.

The effect of the LNURB variable on the LNEF variable is statistically significant and positive for quantile values at least at the 5% significance level. It is observed that the urbanization rate has a negative impact on the ecological footprint. When the coefficients for quantile values are analyzed separately, there is an increase from 10% to 60% and then a decrease. In other words, while the impact of urbanization rates on ecological footprint is less in countries with lower ecological footprint, the impact of urbanization rates on ecological footprint increases as ecological footprints increase. For countries with the highest ecological footprint of 70% and above, the effect of urbanization rate on ecological footprint continues to decrease.

The effect of the LNGDP variable on the LNEF variable is statistically significant and positive at the 1% significance level for quantile values. It can be said that gross domestic product per capita has a positive effect on ecological footprint. When the coefficients for quantile values are analyzed separately, it is observed that there is no significant difference between the countries in the 50% quantile with the lowest ecological footprint in terms of the said relationship, while for the countries in the 50% quantile with the highest ecological footprint, as the ecological footprint increases, the positive effect of GDP per capita on ecological footprint also increases.

6. Discussion

The ecological footprint is a quantitative approach employed to quantify and assess the ecological consequences stemming from human activity. The assessment primarily focuses on the utilization of resources and the production of waste as pivotal elements. The indicator incorporates multiple dimensions, including energy consumption, industrialization, urbanization, FDI, and GDP, to offer a comprehensive evaluation. To effectively formulate and implement sustainable policies and practices, it is crucial to possess a thorough comprehension of the impacts of these elements on the ecological footprint. By conducting an analysis of the ecological impacts of human activities, policymakers can identify specific areas where resource utilization can be improved, and waste generation can be reduced. This study offers significant information concerning the possible long-term effects on ecosystems and biodiversity, facilitating the formulation of solutions that promote a more equitable and ecologically sustainable approach to economic development. Moreover, comprehending the relationships between these variables and the ecological footprint facilitates the assessment of the efficacy of current policies and the formulation of well-informed choices toward a more environmentally sustainable future. In order to formulate effective methods for reducing the ecological footprint, it is crucial to take into account these aspects within the framework of individual countries and areas. In order to develop efficacious strategies for reducing ecological footprints, it is imperative to consider the various elements that influence these footprints in different countries and regions. There is considerable variability observed in parameters such as population density, industrial activities, and patterns of resource utilization across various countries and regions. By considering these discrete elements, policymakers have the capacity to tailor strategies that efficiently address specific challenges and opportunities with the aim of reducing ecological footprints. Furthermore, the inclusion of stakeholders from different sectors and groups in the decision-making process can enhance the comprehensiveness and inclusivity of efforts toward achieving sustainable development goals.

The ecological footprint has emerged as a major concern owing to the increasing impact of foreign direct investment, gross domestic product, industrialization, adoption of renewable energy sources, and the phenomenon of urbanization on the limited resources of the planet. The process of industrialization significantly influences the global ecological footprint, mostly as a result of its substantial need for energy and resources. Conversely, urbanization is correlated with deforestation, soil erosion, and increasing demands for energy and water resources. The research is motivated by a series of questions that focus on examining the interplay between industrialization, renewable energy, urbanization, foreign direct investment, GDP per capita, and the global ecological footprint. The results of this study have the potential to contribute substantial insight for informing policy and decision-making efforts focused on reducing ecological consequences and advancing objectives related to sustainable development.

This study examines the effects of foreign direct investment, gross domestic product, industrialization, consumption of renewable energy, and urban population on ecological footprints in 131 countries between 1997 and 2020. The objective of this study is to establish a thorough understanding of the relationship between these variables and ecological footprint while considering temporal variations from economic and environmental aspects. Through an analysis of a substantial dataset encompassing many countries, this study aims to discern recurring patterns and trends that can provide valuable insight into the formulation of policies and strategies pertaining to sustainable development on a global level. Upon analyzing the data from 131 countries, it was noted that the variables exhibited a significant deviation from a normal distribution and featured outliers in many periods and countries. Therefore, it was deemed appropriate to use quantile regression analysis, one of the nonparametric estimators to estimate consistent coefficients.

In conclusion, it was observed that foreign direct investment had a statistically significant and positive effect on ecological footprint at the 1% significance level for quantile values. Therefore, it can be said that foreign direct investment has the effect of increasing ecological footprints. The impact of FDI on ecological footprint diminishes when we transition from the lowest 10% section with the least ecological footprint to the middle 50% segment. The statistical analysis reveals a significant and negative relationship between industrialization and ecological footprint at the 1% significance level for quantile values. It can be argued that industrialization reduces ecological footprints. Renewable energy consumption demonstrated a statistically significant and negative effect on ecological footprint, as determined by the 1% significance level for the quantile values. One could argue that the utilization of renewable energy sources has the effect of reducing ecological footprints. The statistical analysis reveals that there was a significant and positive relationship between urbanization and ecological footprint, as indicated by quantile values that were, at the least, significant at the 5% level. One could argue that there is a positive correlation between the rate of urbanization and ecological footprints. The relationship between ecological footprint and urbanization is discovered to exhibit a U-shaped pattern across various countries and quartiles. The statistical analysis reveals that there was a significant and positive relationship between GDP and the ecological footprint at the 1% significance level for quantile values. It might be argued that there is a positive correlation between gross domestic product per capita and ecological footprints.

Upon comparing the acquired study results with the existing literature, it is evident that the research aligns with studies supporting the notion that foreign direct investment has a detrimental effect on ecological footprint, which is in line with the pollution haven hypothesis [136,137]. However, there are studies claiming that investments made in developed countries, especially in the field of high technology, reduce the ecological footprint because they consume less energy [107,138]. According to Ashraf et al. [139], the inflow of FDI into economically disadvantaged countries exacerbates environmental degradation, whereas mergers and acquisitions directed toward developed economies contribute to a reduction in pollution levels. The process of industrialization has been observed to result in an increase in the sizes of ecological footprints, thereby leading to the degradation of the environment [140,141]. The available statistical data indicate that newly industrialized nations have high levels of energy consumption, with a predominant reliance on fossil fuels. Consequently, the current scenario gives rise to environmental degradation when these indicators collectively interact [142]. According to some studies, the effect of industrialization on ecological footprint varies according to a country's level of development. Although it reduces the ecological footprint in developed countries, it has the opposite effect in the rest of the countries [61,143–145]. The results of the panel quantile regression model reveal that economic development implies environmental degradation in all quantiles and decreases with an increase in development [61]. A study by Musah and Yakubu [115] revealed that industrialization has a negative, significant impact on the ECF, suggesting that industrialization contributes to environmental sustainability in Ghana. Significant technological advances and innovations in the use of energy and the production of energy carriers have mitigated the negative impacts of industrialization [110]. The empirical findings indicate that the utilization of renewable energy sources is associated with a reduction in the ecological footprint [146,147]. Hence, in order to achieve enhanced economic growth while minimizing the environmental footprint, it is advisable to advocate for the adoption and utilization of renewable energy sources. Urbanization has been found to have significant beneficial effects on ecological footprints, indicating that it plays a role in the degradation of the ecosystem [148,149]. Policymakers should prioritize sustainable urbanization over de-urbanization. Because de-urbanization might harm economic growth, it may not be a good way to reduce environmental deterioration [61,66,150]. The results obtained in this study show that, as in the examples in the literature [1,151], the increase in the GDP leads to an increase in the ecological footprint. On the other hand, in countries that rely on the service sector, the ecological footprint and the GDP formations are different economic subsystems [152]. The phenomenon of economic growth has the potential to result in an increase in ecological footprint. However, the presence of abundant natural resources and the adoption of effective environmental regulations can serve as mitigating factors to alleviate the adverse consequences.

7. Conclusions

7.1. Conclusions

FDI, GDP, industrialization, urbanization, and renewable energy consumption all impact ecological footprints. Understanding these relationships is crucial for formulating effective environmental and economic policies. Incentivizing renewable energy, prioritizing ecofriendly practices, and incorporating sustainability principles in urban planning can reduce ecological footprints while also balancing growth with ecological impact. The analysis reveals complex relationships among economic variables, such as FDI, GDP, industrialization, urbanization, and renewable energy usage, and their impacts on the ecological footprint. Gaining a comprehensive understanding of these interactions is of utmost importance in order to develop and implement efficient environmental and economic strategies. In summary, on the basis of the analysis of the obtained research findings in relation to the available literature, it is recommended that policymakers give precedence to the implementation of measures aimed at controlling and overseeing foreign direct investment in order to address and minimize its negative impacts on the ecological footprint.

Furthermore, it is imperative for policymakers to actively promote the widespread adoption and effective use of renewable energy sources. Additionally, they should emphasize the implementation of sustainable urbanization strategies. Policymakers should also make necessary efforts to decouple economic growth from its associated ecological effect. These policy approaches have the potential to facilitate increased economic growth while simultaneously mitigating environmental degradation and lowering the ecological imprint. One potential approach entails implementing measures to decelerate the rate of industrialization, particularly within the manufacturing sector, which exhibits a clear correlation with increased consumption of natural resources to meet energy requirements. Furthermore, it is imperative for the government to establish ecological guidelines and legislation specifically targeting industrial establishments that contribute significantly to environmental pollution, such as those with a large ecological footprint. A further significant conclusion arises from the fact that foreign direct investment is widely recognized as a catalyst for economic growth in developing countries. Consequently, these governments should prioritize the attraction of environmentally sustainable and energy-efficient firms through FDI as a means of addressing the issue of global warming. It is imperative for governments to enact and modify their environmental regulations and legislation in order to achieve effectiveness in environmental management and facilitate the dissemination of energy-saving technology. Prioritization of policies aimed at promoting efficiency in energy production, enhancing community awareness, and fostering a sustainable green economy is imperative. In a similar vein, the provision of tax holidays to foreign investors could serve as an incentive to encourage their participation in renewable energy projects. The regulation of population density and the promotion of economic growth in a given region should be undertaken through the application of appropriate management strategies and in accordance with an assessment of available resources. Furthermore, it is imperative for policymakers to prioritize increasing natural resource reserves, closely monitor their depletion rates, and address pressing issues such as forest fires and the unsustainable exploitation of these resources. The implementation of strategies such as the expansion of green spaces, the monitoring of pollution and environmental degradation, and the promotion of reduce–reuse–recycle initiatives can effectively contribute to the deceleration of natural resource depletion.

Limitations: The study has limitations, including focusing only on certain variables and not considering all possible factors affecting ecological footprints. The geographical and temporal coverage may have affected the applicability, and the timeframe may not have captured long-term trends or cyclical patterns. The granularity of the data may have prevented the detailed analysis of subnational variations or sector-specific footprints. Technological advancements and policy changes may not have been considered, and differences in consumption patterns and lifestyle choices may not have been fully accounted for, leading to potential inaccuracies in estimating the overall ecological footprint.

7.2. Policy Recommendations

Recommendations for future research: Research on ecological footprints can offer valuable insight into enduring patterns and policy changes. Using advanced statistical methods and machine learning techniques, researchers can examine the factors influencing ecological footprints. Analyzing demographic groups, industries, and policy changes can provide insight into successful ways to reduce ecological footprints. Studying historical trends and interactions between consumer behaviors and systemic factors can inform decision-making processes.

Recommendations for economic authorities: Economic authorities play an important role in promoting sustainable practices and reducing environmental concerns. They enforce rules for reducing emissions and promoting renewable energy utilization. They also implement regulations for environmentally friendly production practices in various industries. Strategies for sustainable land management, deforestation reduction, and forest restoration are also implemented. Partnerships with international organizations establish universal benchmarks for sustainability. Financial support and tax advantages promote sustainable energy sources like solar, wind, and hydroelectric power. Penalties are imposed on industries exceeding emission thresholds or violating environmental standards. Community-focused initiatives involve individuals in sustainable practices. These efforts not only promote ecological sustainability but also economic growth, attract foreign investment, and support international cooperation.

With growing concerns about environmental sustainability, understanding how these factors interact is crucial for policymakers, businesses, and society as a whole. By understanding the effects of FDI, GDP, industrialization, renewable energy consumption, and urban population on ecological footprint, stakeholders can make informed decisions that promote a more sustainable and environmentally friendly future. The results of this study can benefit a wide range of stakeholders, each in their unique ways. Here is how various groups can benefit from the findings: Governments can use the study's findings to inform and adjust their policies and regulations related to foreign direct investment, industrialization, urban planning, and renewable energy adoption. Environmental advocacy groups can use the study's results to strengthen their arguments for sustainable development and ecological conservation. Understanding the connection between economic growth and ecological footprint can help businesses make informed decisions about resource management and sustainability initiatives. Financial institutions can develop investment strategies that align with sustainable development goals, taking into account the impacts of FDI and industrialization. Researchers can build upon this study's findings to delve deeper into specific aspects of the relationship between economic factors and ecological footprints. Professionals involved in urban planning and architecture can use the findings to design and develop ecofriendly cities and buildings that mitigate the environmental impact of urbanization. Renewable energy companies and organizations can benefit from understanding how their efforts contribute to reducing ecological footprints and can use this information for marketing and policy advocacy. By providing a better understanding of the complex relationships between economic factors and ecological footprints, stakeholders can work together to achieve a more sustainable and environmentally responsible future. This knowledge can also help organizations identify areas where they can make improvements and implement strategies to minimize their ecological impact. Additionally, understanding the connection between economic factors and ecological footprints can lead to the development of innovative solutions and technologies that promote sustainability and reduce environmental harm.

Funding: This research received no external funding.

Data Availability Statement: The data will be made available on request from the author.

Acknowledgments: During the preparation of this work the author used [QUILLBOT] in order to [Grammar Checker]. During the preparation of this work the author used [DEEPL] in order to [Translation]. After using this tool/service, the author reviewed and edited the content as needed and take full responsibility for the content of the publication.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. List of Countries

Country	Country	Country	Country
Antigua and Barbuda	Egypt	Lithuania	Senegal
Argentina	El Salvador	Madagascar	Seychelles
Armenia	Estonia	Malawi	Sierra Leone
Australia	Eswatini	Malaysia	Singapore
Austria	Ethiopia	Maldives	Slovakia
Bahamas	Fiji	Mali	Slovenia
Bangladesh	Finland	Mauritania	South Africa
Barbados	France	Mauritius	Spain
Belarus	Gabon	Mexico	Sri Lanka
Belgium	Germany	Moldova	St. Kitts and Nevis
Benin	Greece	Mongolia	St. Lucia
Bolivia	Grenada	Morocco	Sweden
Botswana	Guatemala	Mozambique	Switzerland
Brazil	Guinea	Namibia	Tajikistan
Brunei Darussalam	Guyana	Nepal	Tanzania, United Republic of
Bulgaria	Haiti	Netherlands	Thailand
Burkina Faso	Honduras	New Zealand	Togo
Burundi	Hungary	Nicaragua	Tonga
Cabo Verde	Iceland	Niger	Trinidad and Tobago
Cambodia	India	Nigeria	Turkiye
Cameroon	Indonesia	North Macedonia	Uganda
Canada	Iran, Islamic Republic of	Norway	Ukraine
Chile	Ireland	Pakistan	United Kingdom

Country	Country	Country	Country
China	Israel	Panama	United States of America
Colombia	Italy	Paraguay	Uruguay
Comoros	Jamaica	Peru	Uzbekistan
Costa Rica	Jordan	Philippines	Viet Nam
Croatia	Kazakhstan	Poland	Zambia
Cyprus	Kenya	Portugal	Zimbabwe
Czech Republic	Kiribati	Romania	
Denmark	Korea, Republic of	Russian Federation	
Dominica	Kyrgyzstan	Rwanda	
Dominican Republic	Latvia	Samoa	
Ecuador	Lebanon	Saudi Arabia	

Appendix B

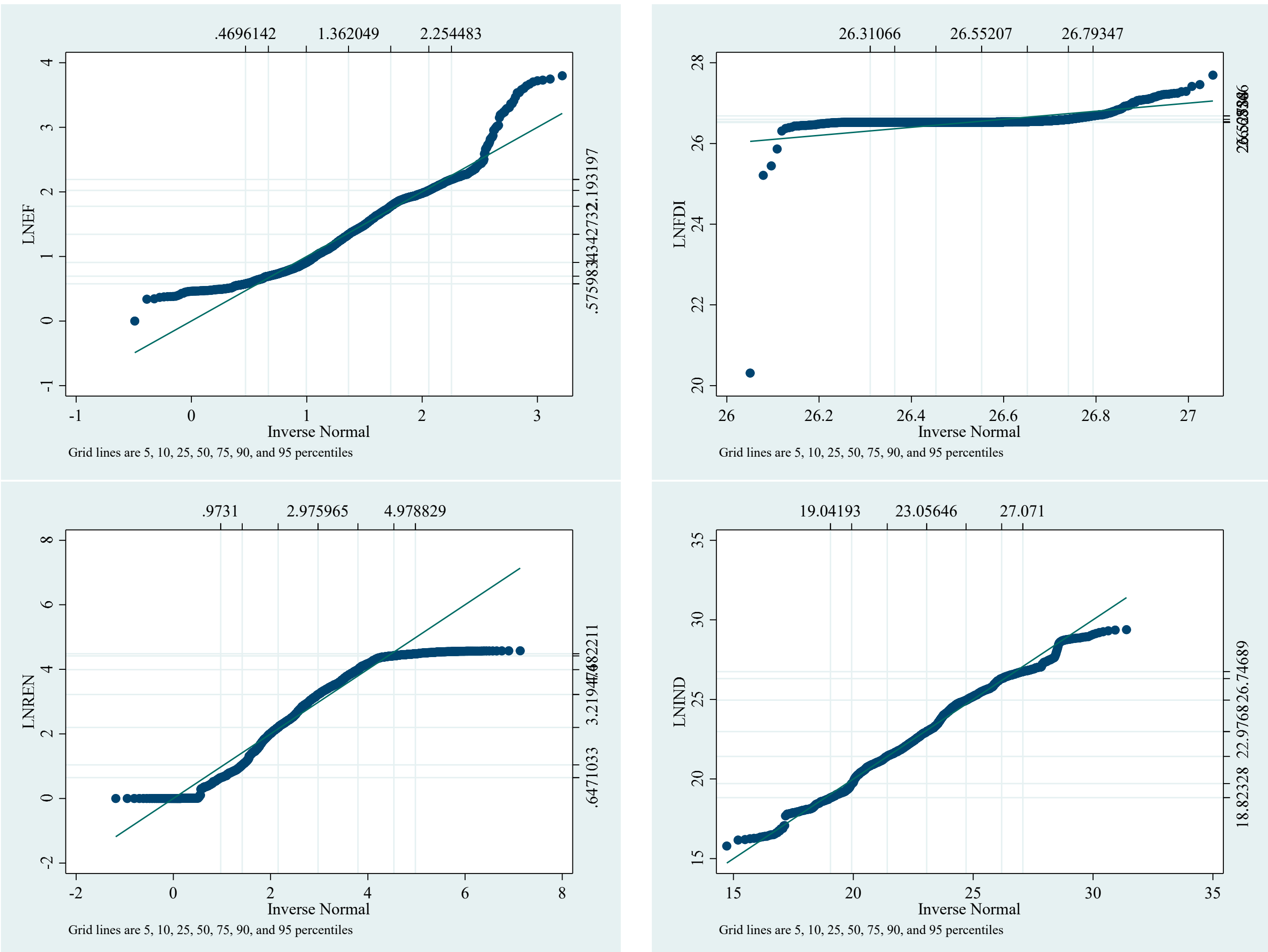

Figure A1. *Cont.*

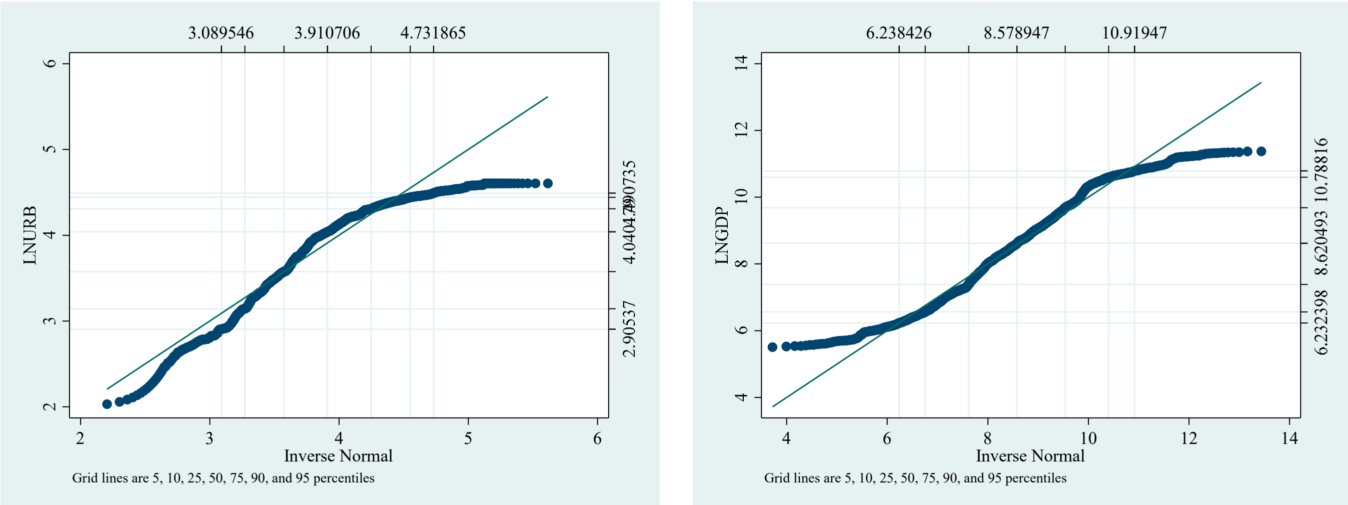

Figure A1. Variable normal distribution graphs.

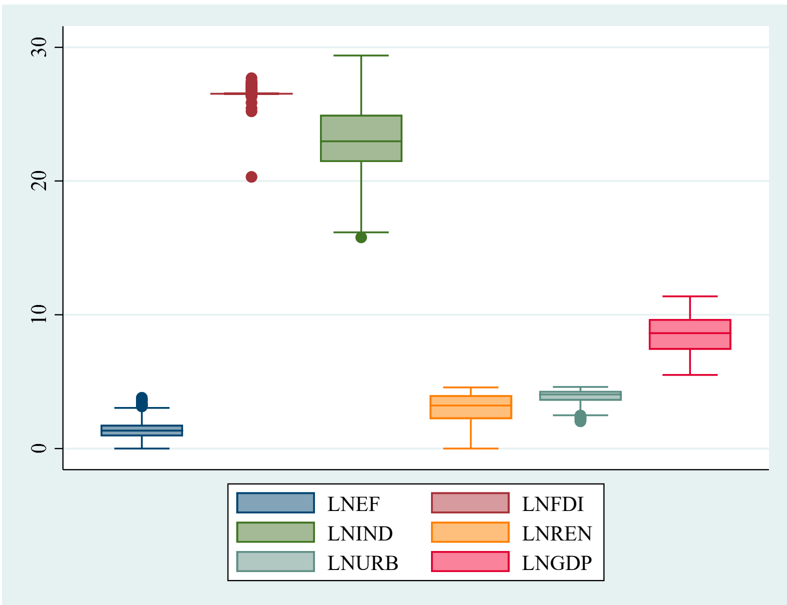

Figure A2. Variable box-plot graphs.

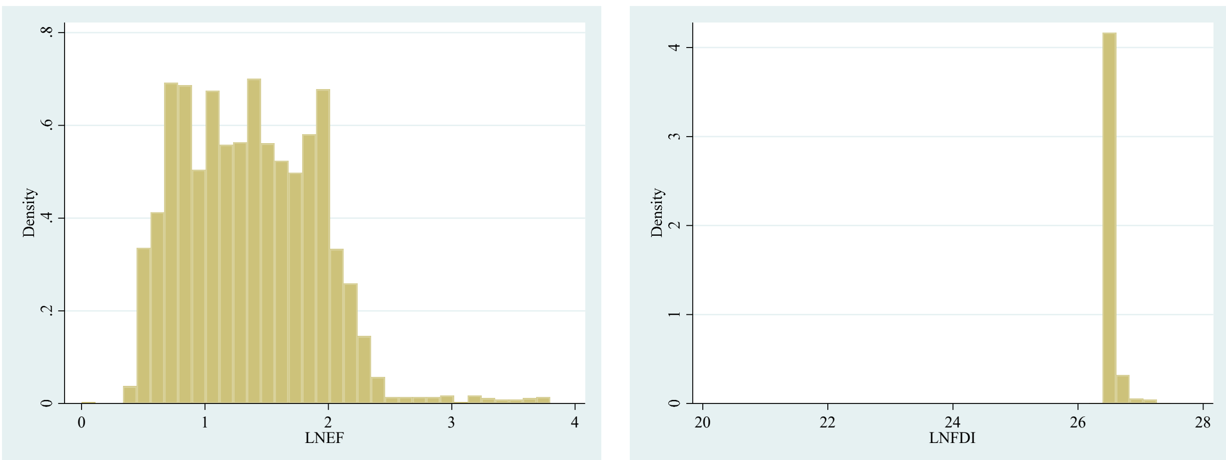

Figure A3. *Cont.*

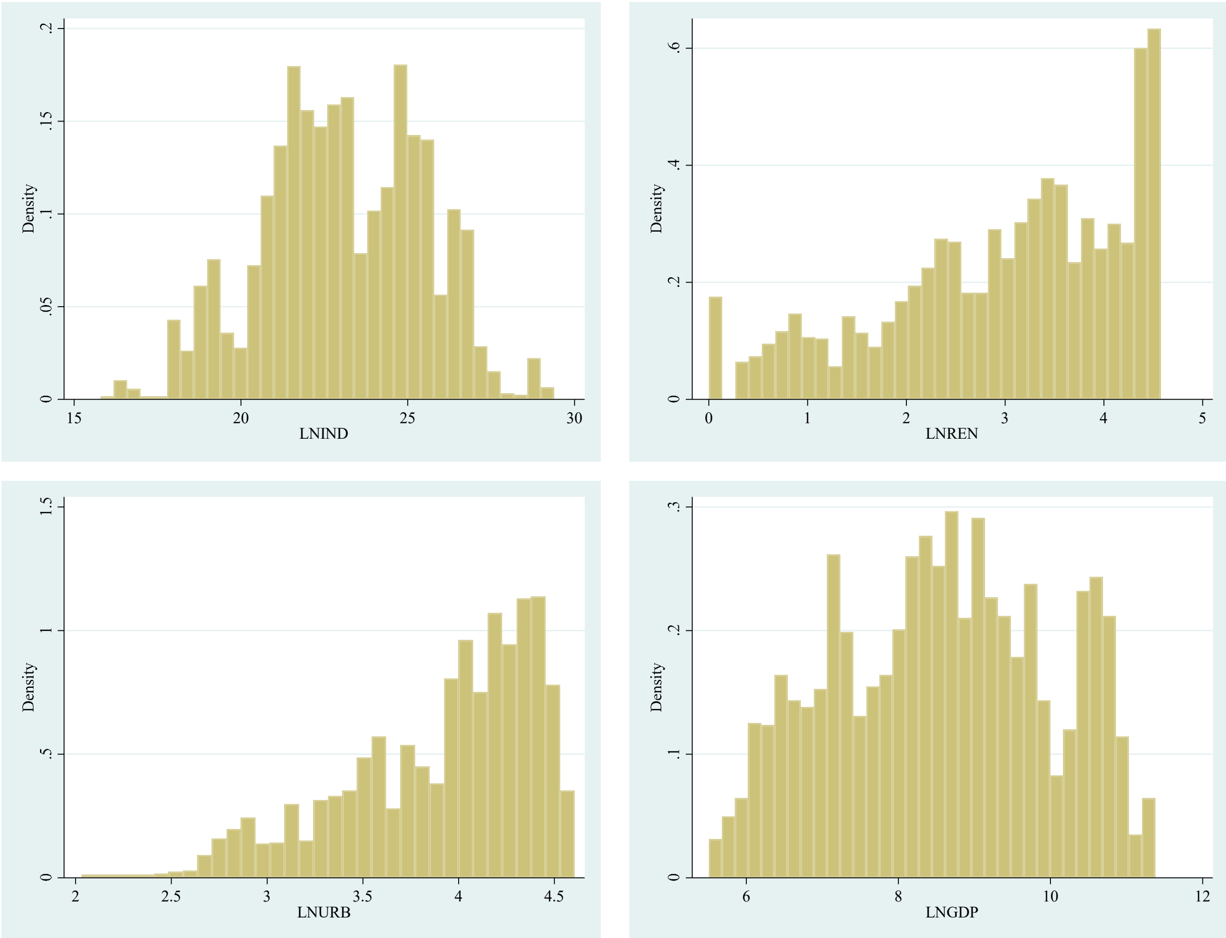

Figure A3. Variable histogram graphs.

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