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RESEARCH ARTICLE

Does income inequality increase the ecological footprint in the US: evidence from FARDL test?

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Abstract

In recent years, there has been a great interest in identifying determinants of environmental degradation. Although the effects of many economic, social, and political factors on the environment have been studied, the evidence of the relationship between income distribution and the environment is still quite scant. Looking at previous studies, the effect of income distribution on carbon emissions has generally been examined. In the last two years, a new line of research has emerged that investigates the links between income distribution and ecological footprint. Therefore, we investigate the effect of income inequality on the ecological footprint also considering its components. In this study, Fourier ARDL and Fourier ADL (new econometric techniques) are utilized to determine the ecological footprint-income inequality nexus in the US covering the period 1965–2017. We included economic growth and energy consumption as explanatory variables in the model. In this context, the study is a pioneering study examining the impact of income inequality on the ecological footprint as an environmental indicator in the US. The empirical results of Fourier ARDL and Fourier ADL denote that income inequality, economic growth, energy consumption, ecological footprint, and its components (cropland, fishing ground, and carbon) are cointegrated. Besides, it is found that income inequality has a positive effect on ecological footprint and cropland. Results denoted that economic growth and energy consumption have a positive and significant effect on ecological footprint and cropland, fishing ground, and carbon footprint components.

Keywords Income inequality · Environmental degradation · US · FARDL · Fourier ADL

Introduction

Environmental problems, such as climate change and global warming, pose a significant threat to the world. These problems constitute a major obstacle to sustainable development. In the 2021 report of the United Nations (UN), it is stated that environmental problems are getting worse and that this situation is one of the most important obstacles to sustainable development strategies and social welfare (UN 2021). It is the fact that environmental degradation (ED) has become such an important problem and made it an important topic of discussion at the global level on how ED can be prevented. In this context, it is possible to say that there is a global consensus that environmental quality should be increased to ensure sustainable development and social welfare (Uzar 2021; Khan et al. 2022a). Therefore, researchers and policymakers make a great effort to identify the causes of ED.

In the environmental economics literature, there have been attempts to understand the causes of ED for a long time. Researchers have associated many economic, social, and sectoral factors with ED and tried to determine the relationship between the variables (Zakari et al. 2022a; Khan et al. 2022b; Eyuboglu and Uzar 2020; Aslanturk and Kiprizli 2020). In those pioneering studies examining the determinants of ED, economic growth (GDP) has generally been given close attention (Grossman and Krueger 1995; Balsalobre-Lorente et al. 2018). Following these pioneering

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studies, the researchers tested the effects of different parameters, especially energy consumption, on the environment. Many parameters like foreign direct investments, renewable energy, natural resources, urbanization, tourism, and institutional quality have been widely used to explain ED (Katircioglu et al. 2020; Zakari et al. 2022c).

Although these studies have made important contributions to the explanation of environmental problems, it is possible to say that some factors are still not taken into account. Although the effect of income level on the environment has been investigated for many years, the effect of income distribution has not come to the fore. Despite the effect of income inequality (GINI) being neglected in environmental studies, it is seen that increasing GINI has become a very important problem at the global level (Piketty 2014; Chancel and Piketty 2015; Saez and Zucman 2020; Chancel et al. 2021). The economic paradigm that changed all over the world in the 1980s adversely affected the dynamics of income distribution in countries. Both personal and functional income distributions have deteriorated rapidly, especially in the United States (US) and Organisation for Economic Co-operation and Development (OECD) countries (Stockhammer 2017). GINI has also negatively affected the distribution of wealth and has led to the concentration of wealth in a smaller group. According to Saez and Zucman (2016), while the share of the top 0.1% in total wealth in the US at the end of the 1980s was 7%, it increased to 20% in the 2010s. A similar trend is also observed in developing countries (Uzar 2020).

Today, ED and injustice in income distribution have become an important problem. It is fact that these factors have become the most urgent problems in today's world and also led to an increase in interest in both topics. This interest raises an important question that needs to be answered. Is unequal distribution responsible for the environmental crisis? The literature indicates that income distribution dynamics can affect environmental quality through various channels. Boyce (1994) and Torras and Boyce (1998) emphasized that income distribution and power asymmetry in society can be important parameters in understanding ED. In this context, income and power asymmetry can aggravate environmental problems by affecting politics and policymaking. In addition, the change in consumption patterns of households in different income groups may also have an impact on the environment by changing the marginal emission trend (Scruggs 1998; Ravallion et al. 2000). Also, long working hours caused by consumption competition and inequalities between different income groups have the potential to affect the environmental quality (Uzar and Eyuboglu 2019; Kazemzadeh et al. 2021).

These channels indicate that income distribution can have significant effects on the environment. Therefore, exploring the potential impact of GINI on environmental quality will be important for tackling environmental problems. Undoubtedly, the environmental indicator chosen to comprehensively investigate the effect of GINI on the environment is also very critical. Most of the studies in the literature use carbon dioxide emissions (CO_2) as an environmental indicator (Uzar 2021). However, the widespread use of CO_2 causes some criticism. Al-Mulali et al. (2015) point out that CO_2 represents a very small fraction of ED and is, therefore, a limited indicator. Similarly, Lu (2020) states that natural resources are one of the most basic inputs for economic activities, emphasizing that air pollution and CO_2 cannot adequately explain the degradation process of the environment. Therefore, using CO_2 causes other polluting activities such as deforestation, agriculture, and mining to be ignored.

For this reason, recent studies use ecological footprint (ECO) as an environmental indicator to reveal the extent of ED more comprehensively. ECO is an indicator that measures biologically productive land and water resources to regenerate all the resources that societies have and absorbs their wastes (Baloch et al. 2019; Zakari et al. 2022b). Therefore, ECO reveals the environmental impacts of human activities in terms of air, water, and soil. The rapid increase in global production and consumption needs the use of natural resources. Thus, excessive use and exploitation of natural resources reduce the regeneration capacity of these resources. The inability of natural resources to refresh themselves quickly causes ECO to exceed the biological capacity, increasing the ecological deficit (Danish et al. 2020; Arslan et al. 2022). Thus, the use of ECO enables more comprehensive detection of environmental degradation.

The study aims to examine the effect of GINI on the ECO in the US during the 1965–2017 period with new econometric techniques such as Fourier ADL and FARDL. In addition, GDP and ENE are included in the model to avoid the neglected variable problem. The choice of the US in examining the nexus between GINI and ECO carries some unique conditions. According to the Global Footprint Network's 2017 data, while the biocapacity per capita in the US is 3.4 gha, ECO per person is 8.0 gha. Therefore, the US is one of the countries with the highest ecological deficit in the world, with a level of − 4.6 gha. Similarly, the US' CO_2 has increased significantly over the years. According to BP (2021), 14% of global CO_2 in 2020 belongs to the US. This indicates that ED has reached serious levels in the US and that reducing ED is a priority. Similar to the deterioration in environmental indicators, GINI has increased significantly over the years. Thomas Piketty's book entitled "Capital in the Twenty-First Century" has shown that the US has experienced a serious deterioration in income and wealth distribution, especially since the 1980s. The Wall Street actions that took place in 2011 also proved that the extent of inequality has become an unacceptable political issue (Jorgenson et al. 2017). According to the Standardized World Income

Database (SWIID), the Gini index coefficient in disposable income after taxes and transfers in the US in 1965 was 31, while it increased to 39.1 in 2020. As can be seen, both environmental indicators and income distribution dynamics have seriously deteriorated in the US in recent years. All these realizations make the US an excellent laboratory for the study of the interaction between these two variables. Determining the nexus between these two factors may enable the discovery of new strategies to increase environmental quality and reduce GINI.

It is expected that this study will contribute to the literature with several features. First, although many factors are used to explain environmental pollutants, the political economy of ED has been neglected. The literature examining the environmental effects of power inequalities between income, wealth, and social classes is missing. This and similar studies focusing on political economy factors can open a new research area in the field of environmental economics. Second, a limited number of empirical studies testing the impact of GINI on the environment have mostly used CO_2 as an environmental indicator (see, e.g., Wolde-Rufael and Idowu 2017; Uzar and Eyuboglu 2019; Mushtaq et al. 2020; Liu et al. 2020; Shabani et al. 2021). As stated, CO_2 has some constraints and does not reveal all dimensions of ED. This study aims to reach more comprehensive findings and policy recommendations by using the ECO and its subcomponents. The third contribution is specific to the US. In those studies examining the US, the effect of GINI on the environment has been investigated with CO_2 (Baek and Gweisah 2013; Jorgenson et al. 2017; Sager 2019). This study differs from other studies by using ECO for the US. In addition, the results of the study can help policymakers develop new strategies to combat ED. The final contribution concerns the method of the study. The paper examines the effect of GINI, GDP, and ENE on ECO and its components (cropland (CROP), grazing land (GRAZ), forest land (FORE), fishing ground (FISH), built-up land (BUILT), and carbon footprint (CARBON)) by utilizing bootstrap autoregressive distributed lag model with a Fourier function (FARDL) test for cointegration. The FARDL test has some advantages over traditional cointegration tests. Firstly, the test enables to analyze the long-term nexus among variables that are stationary $I(0)$ or $I(1)$ like the ARDL test. Secondly, the additional F test submitted by McNown et al. (2018) gives a better understanding to discover degenerate cases (1 and 2) for long-term linkages. Thirdly, the execution of the bootstrap test surpasses the asymptotic test on power and size, as mentioned by McNown et al. (2018). Fourier cointegration tests provide robust results despite the number and form of the structural changes. Finally, the FARDL test takes into account both integer and fractional values for the frequency of the model (Yilanci et al. 2020). Many studies have disregarded the impacts of structural breaks while testing the linkages between the environment and GINI. To fill this gap, we employ FARDL developed by Yilanci et al. (2020) which takes into account endogenous structural breaks and can provide reliable results in small samples. Our study is a new attempt on this issue which is also the cointegration tests considering both temporary and permanent breaks for environment-income inequality studies.

The study addresses a timely and crucial issue for the US. Thus, it is thought that the integration of political-economic factors into environmental studies and the use of current econometric techniques are important contributions to the environmental economics literature. The organization of the study is as follows: "Conceptual framework" section gives a conceptual framework on this issue. "Literature review" section provides an overview of the existing literature. "Data and methodology" section introduces the data and methodology. "Findings" and "Discussion" sections present the analyses and empirical results, and "Conclusion and policy implications" section draws policy implications and concludes the study.

Conceptual framework

Berthe and Elie (2015) emphasized that the modern age is characterized by social and environmental crises at the global level. For the last 10 years, many international institutions, especially the UN, have made a significant effort to bring ED and inequality issues to the fore. In the Human Development Report published by the UN in 2011, it was stated that a sustainable environment and inequalities are urgent agenda items. They also pointed out that these problems should be handled together and policies should be determined at the national/global level (UN 2011). These indicate that equality is a prerequisite for sustainable development. Furthermore, it can be said that the environment-inequality relationship is still a "missing link" in sustainable development. With a similar emphasis, Laurent (2015) and Uzar (2020) stated that sustainable development has economic, social, and ecological legs and argued that social-ecological connections are still under investigated at the theoretical and empirical levels. As can be seen in Fig. 1, the economic-social and economic-environmental dimensions of sustainable development have been extensively studied. However, there are still shortcomings in determining the impact of social events, such as inequalities, on the environment.

Although the interest in the nexus between GINI and ED has increased in recent years, there are several conflicting approaches to the potential links between these two variables. Berthe and Elie (2015) and Uzar and Eyuboglu (2019) provide a framework for theoretical approaches between GINI and ED. Three different approaches stand out through

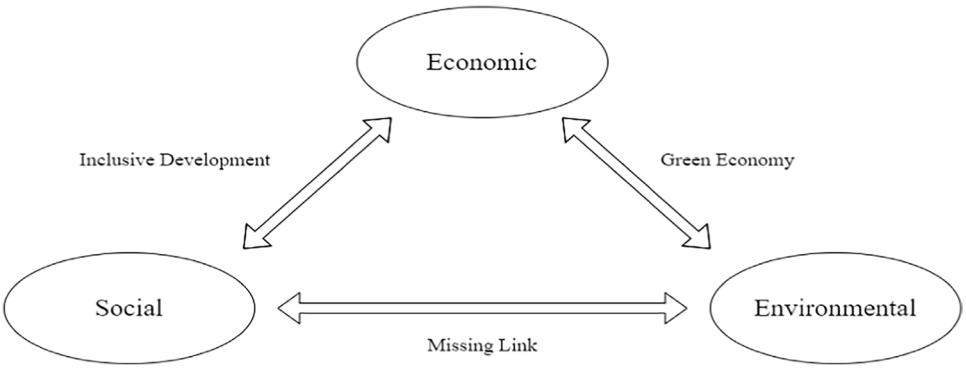


Fig. 1 Components of sustainable development (Laurent 2015; Uzar 2020)

this framework. The first of these is the political economy framework (PEF), which is based on the power relations between social classes in the determination of environmental policies. The second approach focuses on the economic behaviors of households based on the consumption of goods and services and the marginal properties to emit (MPE) (Scruggs 1998; Ravallion et al. 2000; Heerink et al. 2001). The third approach is considered within the framework of Veblen's (1899) emulation theory and points out that inequalities can increase environmental pressure by causing consumption competition and long working hours (Jorgenson et al. 2017).

Boyce (1994) is one of the first studies to address the linkages between ED and GINI within the framework of PEF. Accordingly, the impacts of economic activities on the environment depend on the power asymmetry between those who gain from these activities and those who bear the costs of these activities. According to Boyce (1994) and Torras and Boyce (1998), the deepening of political and economic power differences between social classes facilitates the realization of negative activities for the environment because groups that have greater economic and political power can easily control the policy-making process at the national level. For example, in a country with poor income distribution, wealthy groups aiming to maximize their earnings may have projects approved with negative ecological impacts (Uzar 2020). In addition, the power asymmetry between the rich and the poor can prevent the control of environmental activities and reduce the rigidity of environmental policies. In this context, groups that have political and economic power may impose environmental costs on the rest of the society through projects with negative environmental impacts. Thus, inequalities in society cause an undemocratic decision-making process in the making of environmental policies and disregard for social interest (Wolde-Rufael and Idowu 2017).

In the process that Boyce (1994, 1997) defines as a power-weighted social decision rule, the power asymmetry between the rich and the poor causes the interests of certain groups to be protected in the planning of environmental policies. In such a system where power relations come to the fore, wealthy groups overuse natural resources to maximize their earnings (Kazemzadeh et al. 2021). Moreover, the negative effects of the activities carried out by the companies owned by these groups in terms of soil, water resources, and air are ignored. While wealthy groups have the power to protect themselves from these negative ecological consequences, the costs are imposed on the rest of society (Jorgenson et al. 2017). Thus, reducing GINI becomes an important catalyst in preventing ED because reducing the income gap in society is an important factor for a more balanced distribution of power. A more balanced distribution of power ensures a more balanced and democratic policy-making process. In addition, the improvement in income distribution can reduce people's economic concerns and create environmental awareness (Magnani 2000). The development of environmental awareness in society increases the demand for environmental quality and prevents activities with negative environmental effects.

The second theoretical framework that relates income inequality to environmental quality focuses on the economic behaviors of households, and MPE. Thus, it explains how income distribution dynamics affect household consumption patterns and how consumption patterns put pressure on the environment (Heerink et al. 2001; Sager 2019) because consumption patterns are important determinants of the MPE (Scruggs 1998). Some studies show that income distribution can affect consumers' preferences and these preferences also change the MPE. At this point, a relationship can be established between income distribution and the environment (Grunewald et al. 2017; Berthe and Elie 2015). Essentially, there is a Keynesian influence here. According to the Keynesian approach, while the marginal propensity to consume of the poor is high, their MPE is low. In other words, the impact of a one-unit increase in income on the environment is higher for low-income people (Scruggs 1998). In this regard, the redistribution of income from upper-income groups to lower-income groups is expected to make pressure on the environment through the consumption channel. Ravallion et al. (2000)

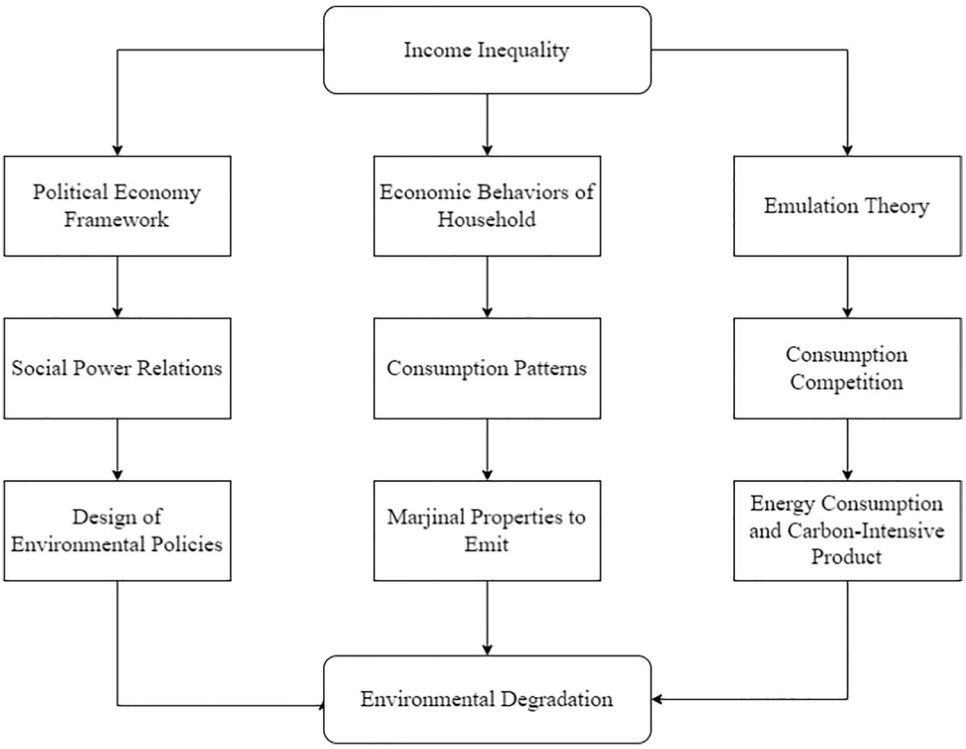


Fig. 2 Income distribution and environmental degradation: potential links

show that there is a trade-off between income distribution and environmental policies as the Keynesian effect is more realistic. This is because, with a fair distribution of income, more people increase their consumption of energy and high-carbon products (Jorgenson et al. 2017). In this context, positive redistribution of income may increase activities such as heating, electricity, transportation, and travel, so it increases the amount of direct and indirect emissions. Unlike the PEF, this approach states that high environmental quality in a country is associated with higher levels of inequality.

Finally, the interaction between income inequality and the environment is explained by Veblen's (1899) emulation theory. In societies with poor income distribution, disadvantaged groups may be interested in the consumption patterns of the rich and want to imitate them. This imitation creates consumption competition and increases status consumption. The development of the financial system has made it easier for people to use credit. As a known, access to financial resources through credit facilitates some consumption expenditures. This can trigger consumption competition and status consumption. Undoubtedly, this situation causes an increase in indirect emissions embedded in the production chain of many goods and services (Sager 2019). It has also been pointed out that increasing inequalities can affect environmental quality through longer working hours (Jorgenson et al. 2017). Longer working hours increase fossil-based energy consumption and CO_2 with effects on both GDP and ENE. These are important catalysts in accelerating ED.

Figure 2 outlines the channels of interaction between GINI and the environment. While the PEF explains this relationship through the power asymmetry among individuals that make up the society, the second approach focuses on the economic behavior of households. The last approach is based on status consumption and consumption competition created by inequalities. The potential mechanisms described by all three approaches are quite plausible. All three explanations have the potential to affect air, water, and soil quality through different channels. Therefore, an empirical examination of the nexus between inequalities and ED will provide important information about the validity of these theories.

Literature review

Many researchers make significant efforts to understand the economic and social origins of environmental problems and to reverse this process. Early studies in literature generally identified environmental degradation as a result of production and consumption activities. For this reason, these studies generally focused on the relationship between the environment and GDP (Ozturk 2010). The increasing interest in the subject has led to the expansion of the relevant literature (Kijima et al. 2010). In this framework, macroeconomic, social, and political phenomena have been used to explain ED (Eyuboglu and Uzar 2020). In addition, factors such as CO_2, sulfur dioxide (SO_2), particulate matter, and water quality were used extensively in earlier studies. On the other

hand, more recent studies prefer to use ECO as an environmental indicator (Uzar 2021).

As GINI has become a serious problem at the global level, the interest in the subject has started to increase rapidly. The enthusiasm to reveal the potential effects of income distribution has enabled inequalities to be adapted to the environmental economics literature. Thus, initiatives that analyze the environmental effects of GINI have started to increase. Since this study focuses on the linkages between GINI and ED, the relevant literature will be examined through three categories. It is aimed to better understand the literature and reveal the existing gaps. Studies in the first group are those that test the effect of GINI on the environment through CO_2 and other pollutants (excluding ECO). The second group is composed of studies that examine the effect of GINI on the environment by considering the ECO. These are studies that have been published recently and are very few. The last part of the literature section consists of studies considering the effect of GINI on the environment in the US, which is the main focus of this study. All these studies generally used CO_2 as an environmental indicator. Similar to the theoretical literature, results are heterogeneous in empirical studies investigating the links between GINI and ED.

The studies in the first group examined the effect of income distribution on CO_2 and other pollutants for different countries and country groups. The focus of these studies on different countries, regions, periods, and methods has led to different results. Some studies in this group found that income inequality causes higher deterioration, as it supports the PEF. Torras and Boyce (1998), one of the pioneering empirical studies, examined the impacts of income, income distribution, and institutional indicators on environmental quality in countries with different income levels from the period 1977 to 1991. In this study, in which seven different environmental indicators were used, it was concluded that the improvement in income distribution positively affected the environmental quality. Zhang and Zhao (2014) and Hao et al. (2016) examined the nexus between GINI and CO_2 in China. Both of these studies concluded that poor income distribution increases CO_2 in China. Kasuga and Takaya (2017) found that the effect of GINI on SO_2 and NO_2 (azote dioxide) was positive in Japan during the 1990–2012 period. Khan et al. (2018) researched the impact of GINI on CO_2 in Bangladesh, India, and Pakistan over the period 1980–2014. Findings showed that fair income distribution reduces CO_2 in Pakistan and India, and it increases CO_2 in Bangladesh. Uzar and Eyuboglu (2019) tested the effect of income distribution on CO_2 during the 1984–2014 period in Turkey. The findings indicated that the improvement in income distribution positively affects environmental quality. Baloch et al. (2020) tested the linkages between GINI and CO_2 in 40 countries in the African region. The findings showed that GINI increases ED in Africa. Yang et al. (2022) found that GINI increased CO_2 in 42 developing countries covering the 1984–2016 period.

Unlike studies supporting the PEF, some studies have concluded that GINI reduces ED or has no effect. For example, Ravallion et al. (2000) examined the effect of GINI on CO_2 in some countries for the period 1975–1992. The findings indicated that GINI leads to lower CO_2. Heerink et al. (2001) tested the nexus between GINI and ED in a group of countries. While GINI negatively affects CO_2, no relationship was found between GINI and other pollutants. Brännlund and Ghalwash (2008) tested the relationship between GINI and the environment based on household data. The findings concluded that higher inequality leads to lower CO_2, SO_2, and NO_2. Grunewald et al. (2017) examined the trade-off between GINI and CO_2 for the period 1980 to 2008. In this study, it was concluded that an increase in the GINI causes lower CO_2 in low and middle-income countries. Wolde-Rufael and Idowu (2017) analyzed the impact of GINI on ED in China and India and did not find a significant relationship in both the short and long term. Wu and Xie (2020) researched the relationship between GINI and CO_2 for OECD and non-OECD countries. The findings showed that GINI reduces CO_2 for OECD and high-income non-OECD countries. Also, no nexus was found for low-income non-OECD countries. Guanghua et al. (2022) tested effect of GINI on CO_2 in 217 countries for the time period 1960 onwards. They found a trade-off between GINI and CO_2.

The studies in the second category are quite new. Researchers examining the impact of GINI on the environment have used ECO as a measure of ED in the last few years. Ekeocha (2021) examined the linkages in 46 African countries with Pedroni cointegration and quantile regression methods and concluded that an increase in the GINI increased ECO. Kazemzadeh et al. (2021) researched impact of GINI on ECO for the period 1970–2016 in 25 countries by using the OLS model. The findings showed that GINI positively affects ECO. Khan and Yahong (2021), using the Driscoll and Kray methodology, researched the impact of GINI on CO_2 and ECO in 18 Asian countries. Findings indicated a positive relationship among CO_2, ECO, and GINI. Khan et al. (2022) extended the model for the same period and same country group by adding the poverty variable to Khan and Yahong (2021). They found that GINI and poverty increase ED. Idrees and Majeed (2022) studied the trade-off between GINI, financial development, and ECO in Pakistan cover the period 1972–2018. Findings indicate that GINI increases ED. Ehigiamusoe et al. (2022) investigated the relationship among poverty, GINI, and ECO in 70 countries from the period 2000–2018 with the GMM method. The results show that inequality reduces the ecological footprint in high-income countries. These fresh studies examining the relationships between GINI and ECO (except Ehigiamusoe et al. 2022) explored results supporting the PEF.

Table 1 Summary of literature review

1. GINI-CO_2/SO_2/particulate matter/water quality (excluding ECO): country groups, periods, methods and results are often different in studies.	
Studies that found a positive relationship	Studies that found negative or no relationships
Torras and Boyce (1998)	Ravallion et al. (2000)
Zhang and Zhao (2014)	Heerink et al. (2001)
Hao et al. (2016)	Brännlund and Ghalwash (2008)
Kasuga and Takaya (2017)	Grunewald et al. (2017)
Khan et al. (2018)	Wolde-Rufael and Idowu (2017)
Uzar and Eyuboglu (2019)	Wu and Xie (2020)
Baloch et al. (2020)	Guanghua et al. (2022)
Yang et al. (2022)	
2. GINI-ECO: country groups, periods, methods, and results are often different in studies.	
Studies that found a positive relationship	Studies that found negative or no relationships
Ekeocha (2021)	Ehigiamusoe et al. (2022)
Kazemzadeh et al. (2021)	
Khan et al. (2022)	
Idrees and Majeed (2022)	
3. GINI-CO_2 in the US: studies focus on the US and ECO is not taken into account as an environmental indicator.	
Studies that found a positive relationship	Studies that found negative or no relationships
Baek and Gweisah (2013)	Sager (2019)
Jorgenson et al. (2015)	
Jorgenson et al. (2017)	

The US is at the center of the third group of studies. These studies research the relationship between GINI and ED without using ECO for the US. Baek and Gweisah (2013) examined the nexus between GINI and CO_2 for the period 1967–2008 and concluded that the improvement in income distribution in the short and long term increases the environmental quality. Jorgenson et al. (2015) tested the relationship between GINI and CO_2 at the state level during the period 1990–2012. The results denoted that GINI is a determinant of ED. Jorgenson et al. (2017) studied the effect of two different GINI indicators on CO_2 for the 1997–2012 period. In this study, the results are heterogeneous. While the top 10% of incomes affect CO_2 positively, no significant nexus was found between the Gini coefficient and CO_2. Sager (2019) analyzed the nexus between GINI and CO_2 using the data for the period 1996–2009. Unlike other studies, Sager (2019) found that redistribution of income from rich to poor increases CO_2.

Table 1 summarizes the literature divided into three categories. Studies examining the nexus between GINI and the environment in the literature have generally focused on CO_2. Recently, new literature has emerged that measures the impact of GINI on the environment through ECO. The studies published in 2021 and 2022 indicate that the trade-off between inequality and the environment is beginning to be examined in a new line of research. In a few studies examining the US, only CO_2 is used as an environmental indicator. Therefore, these studies shed light on a very small extent of ED by not using ECO for the US. Given the relevant studies, this study contributes to a new line of research examining the relationship between GINI and ED. It also differs from other studies that have previously studied the US by examining the impact of GINI on ED through ECO. Therefore, the study is a pioneering attempt to examine the GINI-ECO connection for the US.

Data and methodology

In this paper, annual data is employed covering the period from 1965 to 2017 to test the nexus among GINI, GDP, ENE, and ECO and its components, CROP, GRAZ, FORE, FISH, BUILT, and CARBON for the US. We included GDP and ENE because these variables are significant contributors to the ecological pressure in the earlier literature. We take the logarithm form of all variables. The functional nexus among the variables can be represented as follows:

$$\ln z_t = \alpha_0 + \alpha_1 \ln \mathrm{GINI}_t + \alpha_2 \ln \mathrm{GDP}_t + \alpha_3 \ln \mathrm{ENE}_t + \varepsilon_t \quad (1)$$

where z symbolizes ECO and its components (CROP, GRAZ, FORE, FISH, BUILT, and CARBON), t denotes the year 1965 to 2017, and ε_t denotes the stochastic error, respectively**.** The ECO is measured in an aggregate of CROP, GRAZ, FISH, FORE, BUILT, and CARBON land footprints. GINI symbolizes income inequality, GDP is the economic growth (per capita constant 2010 US dollars), and ENE is the energy consumption (per capita tons of oil equivalent). ECO and its component data are taken from the Global footprint network (2020) database; GINI is acquired


eco
gini
gdp
ene
crop
gra
fore
fish
built
carbon

◂**Fig. 3** Trends of the variables

from The Standardized World Income Inequality Database (SWIID). SWIID offers a standardized Gini index of income inequality for many countries. This is a reliable dataset preferred by researchers in income inequality studies in recent years (Solt 2016; Mikkelson 2021). This index shows the income inequality after taxes and transfers and takes a value between 0 and 100. While 0 indicates absolute equality in income distribution, 100 denotes absolute inequality. In addition, GDP is gathered from World Development Indicator, and ENE is taken from BP statistical review. Historical patterns of all the series are plotted in Fig. 3.

The integration levels of the variables are investigated by utilizing augmented Dickey-Fuller (ADF) and Fourier-ADF (FADF) tests. We do not have to specify the number, shape, and duration of breaks in Fourier unit root tests (Yilanci et al. 2014).

The nexus in Eq. 1 can be investigated by applying the ARDL bounds introduced by Pesaran et al. (2001). For this purpose, we can re-write Eq. 1 under error correction as follows:

$$\begin{aligned}\Delta \ln z_t = {} & \beta_0 + \beta_1 y_{t-1} + \beta_2 \ln \mathrm{GINI}_{t-1} + \beta_3 \ln \mathrm{GDP}_{t-1} + \beta_4 \ln \mathrm{ENE}_{t-1} \\ & + \sum_{i=1}^{p-1} \chi_i \Delta \ln z_{t-i} + \sum_{i=1}^{p-1} \delta_i \Delta \ln \mathrm{GINI}_{t-i} \\ & + \sum_{i=1}^{p-1} \phi_i \Delta \ln \mathrm{GDP}_{t-i} + \sum_{i=1}^{p-1} \gamma_i \Delta \ln \mathrm{ENE}_{t-i} + e_t\end{aligned} \tag{2}$$

where Δ and p denote the first difference operator and lag length. Pesaran et al. (2001) emphasized that the validity of cointegration compels the rejection of the H_0 hypotheses utilizing F test (F_A) and t test (t):

$$\begin{aligned}&\mathrm{H_{0A}} : \beta_1 = \beta_2 = \beta_3 = \beta_4 = 0 \\ &\mathrm{H_{0B}} : \beta_1 = 0\end{aligned} \tag{3}$$

As introduced by Pesaran et al. (2001), ARDL assumes that there is no response from the dependent variable to the regressors. However, in many cases, it is not reasonable to suppose that any series in each model is weakly exogenous (McNown et al. 2018). In addition, cointegration cannot exist if the estimated test statistic is in the range between the upper and lower critical values (Pesaran et al. 2001). McNown et al. (2018) developed a bootstrap ARDL bounds test to improve the weak power and size characteristics of the conventional ARDL test. Bootstrap ARDL indicates better power properties than the conventional ARDL test when there is more than one explanatory variable (Pata and Aydin 2020). McNown et al. (2018)[1] propose an extra F test (F_B) to analyze the following H_0 hypothesis to supplement the method of Pesaran et al. (2001):

$$\mathrm{H_{0C}} : \beta_2 = \beta_3 = \beta_4 = 0 \tag{4}$$

Solarin (2019) extended the bootstrap ARDL test with Fourier terms. Gallant and Souza (1989) pointed out that a small number of low-frequency components of Fourier approximation can capture an unknown number of progressive and sharp structural brakes. For this purpose, we use a Fourier function instead of applying dummy variables, as proposed by Yilanci et al. (2020). Yilanci et al. (2020) also proposed FARDL approach. Yilanci et al. (2020) stated that four different cases can be occurred in FARDL estimations according to the test results of F_A, F_B, and t:

Case 1: If F_A, F_B, and t are significant, there is cointegration between the series.
Case 2: If F_A, F_B, and t are insignificant, there is no cointegration between the series.
Case 3: If F_A and F_B are significant but t is insignificant, degenerate case #1 appears.
Case 4: If F_A and t are significant but F_B is insignificant, degenerate case #2 appears.

Except for case 1, all other cases show that there is no cointegration between the variables (Yilanci and Pata 2020). Thus, we can re-write our model with Fourier expansion:

$$\begin{aligned}\Delta \ln z_t = {} & \beta_0 + y_1 \sin\left(\frac{2\pi kt}{T}\right) + y_2 \cos\left(\frac{2\pi kt}{T}\right) + \beta_2 \ln z_{t-1} + \beta_3 \ln \mathrm{GINI}_{t-1} \\ & + \beta_4 \ln \mathrm{GDP}_{t-1} + \beta_5 \ln \mathrm{ENE}_{t-1} + \sum_{i=1}^{p-1} \chi_i \Delta \ln z_{t-i} + \sum_{i=1}^{p-1} \delta_i \Delta \ln \mathrm{GINI}_{t-i} \\ & + \sum_{i=1}^{p-1} \phi_i \Delta \ln \mathrm{GDP}_{t-i} + \sum_{i=1}^{p-1} \gamma_i \Delta \ln \mathrm{ENE}_{t-i} + e_t\end{aligned} \tag{5}$$

The optimal lag length and the optimal value of k that lies in the interval $k = [0.1,\ldots,5]$ is chosen utilizing AIC. The reason to allow fractional frequencies is that they can capture permanent breaks while integer frequencies refer to temporary breaks. The cointegration among the variables is also investigated by applying Fourier ADL which is developed by Banerjee et al. (2017). Simulations denote that the test provides robust results. The test also extends Enders and Lee (2012) Fourier cointegration and takes into account multiple breaks. The Fourier ADL model can be denoted as follows:

$$\Delta y_{1t} = d(t) + \delta_i y_{1,t-1} + \gamma^l y_{2,t-1} + \varphi^l \Delta y_{2t} + \varepsilon_t \tag{6}$$

where γ, φ, and y_{2t} are $n \times 1$ vectors of parameters and explanatory variables. $d(t)$ is the deterministic term. $d(t)$ can be computed as follows:

$$d(t) = \gamma_0 + \sum_{k=1}^{q} \gamma_{1,k} \sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{q} \gamma_{2,k} \sin\left(\frac{2\pi kt}{T}\right), \leq T/2 \tag{7}$$

[1] A description of the bootstrap procedure can be analyzed in McNown et al. (2018).

Table 2 The descriptive statistics

	ECO	GINI	GDP	ENE	CROP
Mean	2.273	3.546	10.474	5.748	− 0.090
Median	2.290	3.544	10.493	5.768	− 0.063
Maximum	2.407	3.651	10.888	5.840	0.153
Minimum	2.084	3.428	9.944	5.570	− 0.645
Std. deviation	0.084	0.084	0.289	0.064	0.156
Skewness	− 0.753	− 0.189	− 0.193	− 0.679	− 1.576
Kurtosis	2.788	1.369	1.681	2.622	6.056
Observations	53	53	53	53	53
	GRAZ	FORE	FISH	BUILT	CARBON
Mean	− 0.881	0.139	− 2.186	− 2.820	1.950
Median	− 0.882	0.203	− 2.151	− 2.806	1.972
Maximum	− 0.537	0.355	− 1.953	− 2.400	2.115
Minimum	− 1.204	− 0.310	− 2.469	− 3.188	1.731
Std. deviation	0.180	0.175	0.147	0.215	0.095
Skewness	0.143	− 1.243	− 0.308	− 0.053	− 0.593
Kurtosis	2.156	3.213	1.856	1.956	2.658
Observations	53	53	53	53	53

*** and ** indicate significance for 0.01 and 0.05

Findings

Table 2 shows the descriptive statistics for ECO, GINI, GDP, ENE, CROP, GRAZ, FORE, FISH, BUILT, and CARBON. The results denote that the GDP has the highest mean among the series. All the series have a negative skewness that shows that they are skewed left except the GRAZ. The kurtosis is below 3 except for CROP and FORE.

The FARDL bound test cannot be utilized when any of the variables included in the analysis are stationary at $I(2)$ (Yilanci and Pata 2020). As a first step of the analysis, we use ADF and FADF unit root tests to determine the integration levels of the variables. Table 3 reports the results of ADF and FADF unit root tests. The H_0 hypothesis of the two tests denotes that variables are nonstationary. The test statistics for the natural logarithm levels of ECO, GINI, GDP, ENE, GRAZ, FORE, FISH, BUILT, and CARBON are statistically insignificant except for CROP. In other words, all variables are nonstationary in their levels except CROP. The series is either $I(0)$ or $I(1)$. The first difference of all the variables except CROP rejects the H_0 hypothesis. Thus, we can pass on testing the cointegration among the variables

Table 3 ADF and FADF unit root tests

Variables	minSSR	$\hat{k}$	FADF	$F(k)$	ADF	Result
ECO	0.164	2	− 1.92(0)		− 1.01(0)	Nonstationary
GINI	0.074	1	− 0.65(1)		− 0.68(1)	Nonstationary
GDP	1.447	1	− 0.93(1)		− 0.21(1)	Nonstationary
ENE	0.105	2	− 2.19(1)		− 2.50(0)	Nonstationary
CROP	0.995	1	− 7.64(0)***	6.86***	− 6.03(0)	Stationary
GRAZ	0.806	1	− 0.96(0)		− 0.75(1)	Nonstationary
FORE	0.752	1	− 2.01(1)		− 0.60(0)	Nonstationary
FISH	0.494	1	− 1.55(0)		− 0.57(4)	Nonstationary
BUILT	1.201	1	− 2.37(1)		− 1.01(0)	Nonstationary
CARBON	0.173	2	− 2.07(0)		− 1.14(0)	Nonstationary
ΔECO	0.065	2	− 7.69(0)***	3.22	− 6.79(0)***	Stationary
ΔGINI	0.002	5	− 5.61(0)***	7.65***	− 4.81(0)***	Stationary
ΔGDP	0.018	3	− 5.97(0)***	1.58	− 5.76(0)***	Stationary
ΔENE	0.027	2	− 6.24(0)***	7.23***	− 5.21(0)***	Stationary
ΔGRAZ	0.051	4	− 8.33(0)***	1.50	− 7.73(0)***	Stationary
ΔFORE	0.185	3	− 6.41(0)***	2.038	− 5.97(0)***	Stationary
ΔFISH	0.169	2	− 5.90(3)***	0.606	− 6.99(1)***	Stationary
ΔBUILT	0.217	3	− 7.49(3)***	0.217	− 7.23(0)***	Stationary
ΔCARBON	0.063	2	− 6.76(0)***	5.81**	− 5.70(0)***	Stationary

*** and ** indicate significance for 0.01 and 0.05. FADF test critical values ($k = 1$) are − 3.52, − 3.85, and − 4.43 at 0.10, 0.05, and 0.01 levels, respectively.

where γ_0 is the usual deterministic term, k is frequency, $\pi = 3.1416$, t is the trend term, and T is the number of observations. If the estimated value is higher than the critical value of Banerjee et al. (2017), the H_0 hypothesis, which states that there is no cointegration, will be rejected.

utilizing FARDL.

Table 4 denotes the results of the FARDL test. When we take into account ECO as the dependent variable, all the test statistics are higher than the bootstrap critical values,

Table 4 FARDL test

Dependent variable	Frequency	AIC	Lags	Test values	Bootstrap critical values			Cointegration
					0.9	0.95	0.99	
ECO	0.10	− 5.212	2-3-5-0	$F_A = 7.645$**	5.805	6.887	7.686	Cointegrated
				$t = -4.493$**	− 4.16	− 4.468	− 4.997	
				$F_B = 8.363$**	4.197	6.026	8.536	
CROP	0.20	− 1.174	5-3-5-0	$F_A = 9.013$**	6.232	7.181	9.611	Cointegrated
				$t = -5.772$***	− 4.272	− 4.627	− 5.732	
				$F_B = 6.333$*	5.514	6.749	9.332	
GRAZ	5.00	− 4.099	4-0-3-5	$F_A = 2.186$	4.045	5.219	9.152	No cointegration
				$t = -2.337$	− 2.360	− 2.722	− 3.666	
				$F_B = 2.768$	3.977	4.928	8.963	
FORE	3.20	− 3.551	3-5-1-3	$F_A = 1.895$	3.175	3.825	4.927	No cointegration
				$t = -1.687$	− 2.729	− 3.223	− 4.079	
				$F_B = 2.522$	3.856	4.270	6.152	
FISH	4.70	− 3.357	3-0-5-1	$F_A = 6.041$*	5.262	6.665	8.125	Cointegrated
				$t = -3.877$**	− 3.147	− 3.602	− 4.080	
				$F_B = 5.598$*	5.283	6.285	9.746	
BUILT	0.90	− 2.364	4-0-5-5	$F_A = 2.963$	5.407	6.113	7.702	No cointegration
				$t = -2.430$	− 2.692	− 3.077	− 3.947	
				$F_B = 1.431$	4.588	5.884	7.754	
CARBON	4.90	− 5.797	5-4-0-1	$F_A = 5.691$*	5.589	6.023	7.856	Cointegrated
				$t = -3.997$*	− 3.821	− 4.187	− 5.315	
				$F_B = 7.059$*	6.607	7.511	8.813	

***, **, and * indicate significance for 0.01, 0.05, and 0.10

Table 5 Fourier ADL (2017) cointegration test

Dependent variable	F_{ADL}	$(\hat{k})$	AIC	Result
ECO	− 3.27*	3	− 4.117	Cointegrated
CROP	− 6.21***	1	− 0.977	Cointegrated
GRAZ	− 3.046	3	− 2.954	No cointegration
FORE	− 3.069	1	− 2.678	No cointegration
FISH	− 4.061**	1	− 3.102	Cointegrated
BUILT	− 1.056	4	− 3.932	No cointegration
CARBON	− 5.296***	3	− 2.041	Cointegrated

***, **, and * indicate significance for 0.01, 0.05, and 0.10. The frequency is selected based on AIC criteria

Table 6 FARDL model long-term estimation results

Dependent variable	Constant	GINI	GDP	ENE
ECO	− 2.687**	0.804***	0.783***	0.761***
CROP	− 10.233***	0.930**	0.685*	0.194**
FISH	− 11.788***	0.439	0.252**	0.938***
CARBON	− 4.743***	1.288	0.470***	1.227***

***, **, and * shows the significance at the 0.01, 0.05, and 0.10

so we conclude that there is cointegration among the ECO, GINI, GDP, and ENE. In other words, these variables move together in the long term. If we consider CROP, FISH, and CARBON as the dependent variable, there exists a cointegration nexus among the variables. On the other hand, if GRAZ, FORE, and BUILT are considered as the dependent variable, no long-term nexus exists among the variables.

Given the results of unit roots, we also applied Fourier ADL (2017) cointegration test for robustness checks of FARDL results. Fourier ADL test results are denoted in Table 5, and we can reject the H_0 hypothesis for ECO, CROP, FISH, and CARBON models. Thus, the results of Fourier ADL approve the results of FARDL.

Table 6 shows the results of long-term estimation based on the FARDL model. First of all, the model in which ECO is the dependent variable and GINI, GDP, and ENE are the independent variables is estimated. The GINI coefficient has a positive and significant effect on the ecological footprint in the long term. Specifically, a 1% increase GINI enhances the ECO by 0.804%. This finding is consistent with the PEF (Boyce 1994; Torras and Boyce 1998) and Veblen's (1899) emulation theory, which states that GINI will negatively affect environmental quality. The findings are similar to Ekeocha (2021), Khan et al. (2022), and Idrees and Majeed (2022), who explored a positive nexus between the GINI and the ECO. In addition, the findings are similar to Baek and

Gweisah (2013) and Jorgenson et al. (2015), who discovered positive linkages between the GINI and CO_2 in the US but not to Sager (2019).

The long-term impact of GDP on ECO is positive and significant. A 1% rise in GDP enhances the ECO by 0.783%. This result is compatible with the theoretical and empirical literature. According to Aşıcı and Acar (2016) and Ali et al. (2019), excessive use of natural resources for the realization of economic activities creates significant pressure on air, water, and soil. This situation increases the ECO and enhances the ecological deficit. Similar to GDP, ENE also has a positive and significant effect on the ECO. A 1% increase in ENE increases the ECO by 0.761%. Uzar (2021) states that emissions from ENE damage biodiversity and they have a polluting effect on air, water, and soil. Kazemzadeh et al. (2021) and Ehigiamusoe et al. (2022) also found that ENE is an important determinant of the ECO.

In addition, the subcomponents of the ECO were also examined as the dependent variable. First of all, when CROP is considered as the dependent variable, it is seen that all of the independent variables are positive and significant. A 1% increase in the GINI enhances CROP by 0.903%. Considering the coefficient size, the change in the GINI affects CROP more than ECO. In addition, the impact of GDP and ENE on CROP is positive and significant. A 1% increase in GDP and ENE enhances CROP by 0.685% and 0.194%, respectively. While FISH and CARBON are dependent variables, it is seen that the GINI is positive but not statistically significant. In this context, the impact of GINI dynamics on FISH and CARBON in the US is not clear. In addition, GDP and ENE affect both factors positively. One percent increases in GDP and ENE enhance FISH by 0.252% and 0.938% while increasing CARBON by 0.470% and 1.227%, respectively. Findings on the subcomponents of the ECO indicate that GDP and ENE are very important determinants of ED in the US. The results clearly show that the dynamics of income distribution mostly affects the lands and cultivation areas (CROP).

Discussion

Increasing inequalities and ED in the US are at the level of a serious crisis in recent years. Piketty (2014), Saez and Zucman (2016), and Stockhammer (2017) emphasize that income and wealth inequality in the US is far above the historical level. On the other hand, the increasing pressure of human activities on air, water, and soil threatens socioeconomic stability. The findings suggest that the increase in GINI is an important determinant of the ECO. This finding can be explained in several ways.

First, the PEF that Boyce (1994) and Torras and Boyce (1998) suggest creates an important area of discussion. GINI which has been deepening for a long time in the US also negatively affects the social power distribution. Undoubtedly, the increasing power of companies and the reflection of this power in the political arena can reduce the rigidity of environmental policies. In addition, this power asymmetry can lead to the approval of projects with negative ecological effects and to bear the ecological costs of the relatively weak ones. For example, Boyce (1994) states that the vast majority of hazardous waste sites in the US are located in areas where low-income racial minorities live, giving an important clue about power and environmental policies.

Second, another impact of GINI on the environment in the US may be reduced ecological awareness. Because the gradual increase in GINI enhances people's economic and future concerns. Environmental issues do not attract much attention in such a conjuncture. In this context, Laurent (2015) states that in the surveys conducted in the US, people are more concerned about growth and employment and are not concerned with environmental issues. Therefore, in a society with poor income distribution, the environmental consequences of economic activity are hardly taken into account. This causes the long-term negative effects of economic activities to be ignored and short-term economic interests to be at the forefront in terms of both the poor and the rich (Berthe and Elie 2015; Uzar 2020). The decrease in social cohesion and the loss of environmental awareness may cause environmental damage to be ignored. In addition, increasing economic concerns may cause people to work longer or even do several different jobs. This can increase ED by increasing ENE and resource use.

Third, Acemoglu et al. (2015) emphasize that democracies facilitate income redistribution and reduce inequalities. However, it is stated that this theoretical expectation will fail if democracy is seized by a wealthy part of the population. This situation, which Boyce (1994) defines as a power-weighted social decision rule, may cause the democratic channels to be compressed, and a free discussion environment cannot be provided. Undoubtedly, environmental sensitivities and demands cannot be freely expressed in such an environment caused by income and power inequality. If income and power were distributed fairly, the policy-making power of powerful minorities could be reduced and pressure on the government over environmental degradation could increase. In societies where income and power are equally distributed and democratic channels are opened, environmental decisions can be taken within the framework of the median voter model, and these decisions can increase the quality of the environment.

Other findings of the study are that GDP and ENE increase the ECO. According to the IMF, the US is the world's largest economy with a nominal GDP of $22.9 trillion and a per capita income of $69,000 (IMF 2022). This indicates that economic activities in the US are quite

dynamic. In addition, as Laurent (2015) emphasizes, the fact that the demand for growth and employment is higher than the environmental quality causes the limits of biological capacity to be exceeded. Growth performance leads to aggressive use of natural resources, leading to an increase in the ECO in the US. In other words, intensive and inefficient resource consumption causes air and water pollution, especially in fertile soil areas. For these reasons, the GDP process will inevitably put pressure on the environment in the US.

Similar to GDP, ENE is also an important environmental pressure factor. Increasing working hours and increasing economic output requires more and more energy. According to BP (2021), the primary ENE of the US is 94.90 exajoules in 2019. Although primary ENE has decreased somewhat due to the COVID-19 epidemic slowing down the production process all over the world in 2020, approximately 16% of primary ENE in the world is still made by the US. The predominance of primary ENE increases greenhouse gas emissions and puts significant pressure on the atmosphere. In addition, this indicates that energy efficiency should become a priority strategy in the US. In this context, more consumption of renewable energy instead of fossil-based sources may be a critical element to reduce the pressure on the environment. Although the US accounts for 19% of the world's renewable energy consumption in 2020, the use of renewable energy is still at a low level.

Conclusion and policy implications

The UN's Sustainable Development Goals report emphasizes reducing GINI, preventing ecological destruction, and creating harmonious societies. However, both developed and developing countries face inequalities and ED. Although both phenomena are important problems, potential mechanisms explaining the interaction between GINI and environmental quality are still insufficient. This raises important questions remaining to be answered: Does income distribution affect environmental quality? Is it possible to improve environmental quality by reducing income inequalities? Could this offer policymakers a win-win option?

In this context, this study aims to examine the effect of GINI on the ECO and its subcomponents in the US during the 1965–2017 period with the new econometric techniques known as FARDL and Fourier ADL. The US is an important example due to the increasing income inequality and ED in recent years. ECO has been preferred because it is a comprehensive environmental indicator. In this way, it is thought that the effect of GINI on the environment will be determined more clearly. In addition, GDP and ENE are included in the model. After the unit root analysis, the long-term nexus among the variables is examined with FARDL and Fourier ADL cointegration tests. Findings denoted that ECO, GINI, GDP, and ENE are cointegrated. In addition, a cointegration relationship was determined between the three subcomponents of ECO (CROP, FISH, and CARBON) and the independent variables.

The main finding of the study refers that GINI increases ED. This result indicates that negative developments in income distribution dynamics in the US will have environmental consequences. It is compatible with the political economy framework and emulation effects. The results also show that GDP and ENE are important factors that increase ECO of the US. In this context, the current growth and energy strategies of the US cause environmental pressure to increase. In this study, the subcomponents of the ECO, CROP, FISH, and CARBON are analyzed as dependent variables. The findings show that the increase in GINI significantly increased CROP. We could not find any linkages between FISH, CARBON, and GINI. Thus, the change in GINI is most effective in lands and cultivation areas. According to the findings, the effects of GDP and ENE on these three subcomponents are positive and significant. The positive relationship between GINI and ECO shows that environmental problems are not independent of social problems such as income and power inequalities. This positive relationship is very promising and creates an important win-win opportunity for policymakers. In this context, the combination of policies that will ensure justice in income distribution and policies that increase environmental quality will help reduce two very important problems in the US. In line with the results, some critical policy propositions can be developed for the US.

Stiglitz (2012), Piketty (2014), and Saez and Zucman (2020) emphasize that the main factor that causes the deterioration of income distribution in the US is the inadequacy of progressive taxation and transfer policies. For this reason, economic policies should focus primarily on income distribution and tax policies. In this framework, the primary step can be taken to create a progressive taxation system and diversify the tax base with serious tax reform. The corporate tax, wealth tax, and financial transaction tax can be designed more progressively to avoid the concentration of income and wealth. Income obtained in this way can be transferred to public services such as education and health, where the poor will benefit more. Also, direct transfers can be quite functional in the redistribution of income, such as in the 1945–1980 period in the US.

Full-time job creation is an important antidote to GINI. Part-time and temporary employment opportunities feed income inequality and poverty. A full-time job provides people to have a steady income and the opportunity to develop themselves. In addition, jobs to be created in the fields of clean energy and green technology can optimally combine income distribution and environmental policies. The

government can support this process with incentives, tax exemptions, and infrastructure investments. Although this situation creates a burden on the budget, it is clear that the social benefits of these supports will be high.

An effective combination of income distribution and environmental policies can be made by taxing negative activities for the environment. Within this framework, the government can increase taxes on emissions and other pollutants. Increasing such taxes reduces activities that have negative environmental impacts. Income from these practices can also be redistributed to disadvantaged groups through public expenditures and direct transfers.

Education is also very effective in both improving income distribution and raising environmental awareness. A person can break the cycle of poverty and increase his/her income level with a good education life. For this reason, it is very critical to expand education and increase its inclusiveness. In addition, having environmental lessons at every stage of education and organizing workshops and events can increase environmental awareness. This is important to create a society with high environmental awareness and promote harmonious and collective action.

Current US growth and energy strategies should be more environmentally oriented. Although the US is at the forefront of total renewable energy consumption, renewable energy investments and use should be encouraged. Increasing energy efficiency will also ensure that the growth process is environmentally friendly.

By examining the effects of GINI on ECO and its subcomponents, this study contributes to a relatively new line of research and the US literature. It should be noted, however, that the study has some limitations. These limits can create a recommendation and opportunity for future studies. In this context, future studies could focus on individual countries suffering from GINI and ED and develop specific policy recommendations. In addition, due to its scope, this study focused on a single-income distribution criterion (Gini coefficient). Future studies may examine the inequality-environment relationship, focusing, for example, on the top 1%, 5%, and 10% incomes, or wage inequality. Finally, revealing the impact of wealth inequality on the environment can be quite exciting for the literature.

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Author contribution Umut Uzar: introduction, supervision, literature review, and policy implications. Kemal Eyuboglu: estimates, conclusions, and discussion of the results.

Declarations

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References

Acemoglu D, Naidu S, Restrepo P, Robinson JA (2015) Democracy, redistribution, and inequality. In Handbook of income distribution (Vol. 2, pp. 1885-1966). Elsevier

Ali HS, Zeqiraj V, Lin WL, Law SH, Yusop Z, Bare UAA, Chin L (2019) Does quality institutions promote environmental quality? Environ Sci Pollut Res 26(11):10446–10456

Al-Mulali U, Weng-Wai C, Sheau-Ting L, Mohammed AH (2015) Investigating the environmental Kuznets curve (EKC) hypothesis by utilizing the ecological footprint as an indicator of environmental degradation. Ecol Indic 48:315–323

Arslan HM, Khan I, Latif MI, Komal B, Chen S (2022) Understanding the dynamics of natural resources rents, environmental sustainability, and sustainable economic growth: new insights from China. Environ Sci Pollut Res: 1-16

Aşıcı AA, Acar S (2016) Does income growth relocate ecological footprint? Ecol Indic 61:707–714

Aslanturk O, Kiprizli G (2020) The role of renewable energy in ensuring energy security of supply and reducing energy-related import. Int J Energy Econ Policy 10(2):354–359

Baek J, Gweisah G (2013) Does income inequality harm the environment? Empirical evidence from the United States. Energy Policy 62:1434–1437

Baloch MA, Khan SUD, Ulucak ZŞ, Ahmad A (2020) Analyzing the relationship between poverty, income inequality, and CO2 emission in Sub-Saharan African countries. Sci Total Environ 740:139867

Baloch MA, Zhang J, Iqbal K, Iqbal Z (2019) The effect of financial development on ecological footprint in BRI countries: evidence from panel data estimation. Environ Sci Pollut Res 26(6):6199–6208

Balsalobre-Lorente D, Shahbaz M, Roubaud D, Farhani S (2018) How economic growth, renewable electricity and natural resources contribute to CO2 emissions? Energy Policy 113:356–367

Banerjee P, Arčabić V, Lee H (2017) Fourier ADL cointegration test to approximate smooth breaks with new evidence from crude oil market. Econ Model 67:114–124

Berthe A, Elie L (2015) Mechanisms explaining the impact of economic inequality on environmental deterioration. Ecol Econ 116:191–200

Boyce J (1997) Ecological distribution, agricultural trade liberalization, and in situ genetic diversity. J Income Distrib 6(2):5–5

Boyce JK (1994) Inequality as a cause of environmental degradation. Ecol Econ 11(3):169–178

BP (2021) Statistical Review of World Energy 2022, 70th edition. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-co2-emissions.pdf (accessed 13 March 2021).

Brännlund R, Ghalwash T (2008) The income–pollution relationship and the role of income distribution: an analysis of Swedish household data. Resour Energy Econ 30(3):369–387

Chancel L, Piketty T (2015) Carbon and inequality: from Kyoto to Paris (Unpublished paper. Paris School of Economics. http://piketty.pse.ens.fr/files/ ChancelPiketty2015.pdf). (accessed 11 March 2021)

Chancel L, Piketty T, Saez E, Zucman G (2021) World inequality report 2022. World Inequality Lab

Danish, Ulucak R, Khan SUD (2020) Determinants of the ecological footprint: role of renewable energy, natural resources, and urbanization. Sustain Cities Soc 54:101996

Ehigiamusoe KU, Majeed MT, Dogan E (2022) The nexus between poverty, inequality and environmental pollution: evidence across different income groups of countries. J Clean Prod 130863

Ekeocha DO (2021) Urbanization, inequality, economic development and ecological footprint: searching for turning points and regional homogeneity in Africa. J Clean Prod 291:125244

Enders W, Lee J (2012) A unit root test using a Fourier series to approximate smooth breaks. Oxf Bull Econ Stat 74:574–599

Eyuboglu K, Uzar U (2020) Examining the roles of renewable energy consumption and agriculture on CO2 emission in lucky-seven countries. Environ Sci Pollut Res 27(36):45031–45040

Gallant AR, Souza G (1989) On the asymptotic normality of Fourier flexible form estimates. Department of Statistics, North Carolina State University, Raleigh

Global footprint network (GFN) (2020). Global footprint network. Retrieved from http://data.footprintnetwork.org/#/countryTrends?type=BCtot,EFCtotandcn=165. Accessed 10 Mar 2021

Grossman GM, Krueger AB (1995) Economic growth and the environment. Q J Econ 110(2):353–377

Grunewald N, Klasen S, Martínez-Zarzoso I, Muris C (2017) The trade-off between income inequality and carbon dioxide emissions. Ecol Econ 142:249–256

Guanghua W, Wang C, Wang J, Zhang X (2022) The income inequality-CO2 emissions nexus: Transmission mechanisms. Ecol Econ. https://doi.org/10.1016/j.ecolecon.2022.107360

Hao Y, Chen H, Zhang Q (2016) Will income inequality affect environmental quality? Analysis based on China's provincial panel data. Ecol Indic 67:533–542

Heerink N, Mulatu A, Bulte E (2001) Income inequality and the environment: aggregation bias in environmental Kuznets curves. Ecol Econ 38(3):359–367

Idrees M, Majeed MT (2022) Income inequality, financial development, and ecological footprint: fresh evidence from an asymmetric analysis. Environmental Science and Pollution Research 1-15

IMF (2022) World Economic Outlook: rising caseloads, a disrupted recovery, and higher inflation, January 2022

Jorgenson A, Schor J, Huang X (2017) Income inequality and carbon emissions in the United States: a state-level analysis, 1997–2012. Ecol Econ 134:40–48

Jorgenson AK, Schor JB, Huang X, Fitzgerald J (2015) Income inequality and residential carbon emissions in the United States: a preliminary analysis. Hum Ecol Rev 22(1):93–106

Kasuga H, Takaya M (2017) Does inequality affect environmental quality? Evidence from major Japanese cities. J Clean Prod 142:3689–3701

Katircioglu S, Katircioglu S, Saqib N (2020) Does higher education system moderate energy consumption and climate change nexus? Evidence from a small island. Air Qual Atmos Health 13(2):153–160

Kazemzadeh E, Fuinhas JA, Koengkan M (2021) The impact of income inequality and economic complexity on ecological footprint: an analysis covering a long-time span. J Environ Econ Policy 1-21

Khan AQ, Saleem N, Fatima ST (2018) Financial development, income inequality, and CO2 emissions in Asian countries using STIRPAT model. Environ Sci Pollut Res 25(7):6308–6319

Khan S, Yahong W, Zeeshan A (2022) Impact of poverty and income inequality on the ecological footprint in Asian developing economies: assessment of sustainable development goals. Energy Rep 8:670–679

Khan S, Yahong W (2021) Income inequality, ecological footprint, and carbon dioxide emissions in Asian developing economies: what effects what and how?. Environ Sci Pollut Res: 1-12

Khan I, Tan D, Hassan ST (2022a) Role of alternative and nuclear energy in stimulating environmental sustainability: impact of government expenditures. Environ Sci Pollut Res 29(25):37894–37905

Khan I, Zakari A, Zhang J, Dagar V, Singh S (2022b) A study of trilemma energy balance, clean energy transitions, and economic expansion in the midst of environmental sustainability: new insights from three trilemma leadership. Energy 248:123619

Kijima M, Nishide K, Ohyama A (2010) Economic models for the environmental Kuznets curve: a survey. J Econ Dyn Control 34(7):1187–1201

Laurent E (2015) Social-Ecology: exploring the missing link in sustainable development. HAL archives-ouvertes.fr, HAL Id:hal-01136326 https://hal-sciencespo.archives-ouvertes.fr/hal-01136326

Liu Z, Zhang H, Zhang YJ, Qin CX (2020) How does income inequality affect energy efficiency? Empirical evidence from 33 Belt and Road Initiative countries. J Clean Prod 269:122421

Lu WC (2020) The interplay among ecological footprint, real income, energy consumption, and trade openness in 13 Asian countries. Environ Sci Pollut Res 27(36):45148–45160

Magnani E (2000) The Environmental Kuznets Curve, environmental protection policy and income distribution. Ecol Econ 32(3):431–443

McNown R, Sam CY, Goh SK (2018) Bootstrapping the autoregressive distributed lag test for cointegration. Appl Econ 50(13):1509–1521

Mikkelson GM (2021) Invisible hand or ecological footprint? Comparing social versus environmental impacts of recent economic growth. Organ Environ 34(2):287–297

Mushtaq A, Chen Z, Ud Din N, Ahmad B, Zhang X (2020) Income inequality, innovation and carbon emission: perspectives on sustainable growth. Econ Res-Ekonomska istraživanja 33(1):769–787

Ozturk I (2010) A literature survey on energy–growth nexus. Energy Policy 38(1):340–349

Pata UK, Aydin M (2020) Testing the EKC hypothesis for the top six hydropower energy consuming countries: evidence from Fourier Bootstrap ARDL procedure. J Clean Prod 264:121699

Pesaran MH, Shin Y, Smith R (2001) Bounds testing approaches to the analysis of level relationships. J Appl Econ 16:289–326

Piketty T (2014) Capital in the twenty-first century. Harvard University Press, Cambridge

Ravallion M, Heil M, Jalan J (2000) Carbon emissions and income inequality. Oxf Econ Pap 52(4):651–669

Saez E, Zucman G (2016) Wealth inequality in the United States since 1913: evidence from capitalized income tax data. Q J Econ 131(2):519–578

Saez E, Zucman G (2020) The rise of income and wealth inequality in America: evidence from distributional macroeconomic accounts. J Econ Perspect 34(4):3–26

Sager L (2019) Income inequality and carbon consumption: evidence from Environmental Engel curves. Energy Econ 84:104507

Scruggs LA (1998) Political and economic inequality and the environment. Ecol Econ 26(3):259–275

Shabani E, Hayati B, Pishbahar E, Ghorbani MA, Ghahremanzadeh M (2021) A novel approach to predict CO2 emission in the agriculture sector of Iran based on Inclusive Multiple Model. J Clean Prod 279:123708

Solarin SA (2019) Modelling the relationship between financing by Islamic banking system and environmental quality: evidence from bootstrap autoregressive distributive lag with Fourier terms. Qual Quant 53(6):2867–2884

Solt F (2016) The Standardized World Income Inequality Database. Social Science Quarterly 97: 1267-1281. SWIID Version 9.2, January 2022. Retrieved from https://dataverse.harvard.edu

Stiglitz JE (2012) The price of inequality: how today's divided society endangers our future. WW Norton and Company, New York-London

Stockhammer E (2017) Determinants of the wage share: a panel analysis of advanced and developing economies. Br J Ind Relat 55(1):3–33

Torras M, Boyce JK (1998) Income, inequality, and pollution: a reassessment of the environmental Kuznets curve. Ecol Econ 25(2):147–160

United Nations (2011) Human Development Report 2011. Sustainability and Equity: A better future for all. Sustainability and Equity: A Better Future for All (November 2, 2011). UNDP-HDRO Human Development Reports

United Nations (UN) (2021) The sustainable development goals report. https://unstats.un.org/sdgs/report/2021/The-Sustainable-Development-Goals-Report-2021.pdf. (accessed 13 March 2021)

Uzar U (2020) Is income inequality a driver for renewable energy consumption? J Clean Prod 255:120287

Uzar U (2021) The relationship between institutional quality and ecological footprint: is there a connection?. Natural Resources Forum 45(4): 380-396. Oxford, UK: Blackwell Publishing Ltd

Uzar U, Eyuboglu K (2019) The nexus between income inequality and CO2 emissions in Turkey. J Clean Prod 227:149–157

Veblen T (1899) The theory of the leisure class: an economic study of institutions. Macmillan, New York, U.S.

Wolde-Rufael Y, Idowu S (2017) Income distribution and CO2 emission: a comparative analysis for China and India. Renew Sust Energ Rev 74:1336–1345

Wu R, Xie Z (2020) Identifying the impacts of income inequality on CO2 emissions: empirical evidences from OECD countries and non-OECD countries. J Clean Prod 277:123858

Yang B, Ali M, Hashmi SH, Jahanger A (2022) Do income inequality and institutional quality affect CO2 emissions in developing economies?. Environ Sci Pollut Res 1-22

Yilanci V, Bozoklu S, Gorus MS (2020) Are BRICS countries pollution havens? Evidence from a bootstrap ARDL bounds testing approach with a Fourier function. Sustain Cities Soc 55:102035

Yilanci V, Pata UK (2020) Investigating the EKC hypothesis for China: the role of economic complexity on ecological footprint. Environ Sci Pollut Res: 1-12

Yilanci V, Saridogan E, Artar O (2014) A stochastic convergence analysis for selected East Asian and Pacific countries: a Fourier unit root test approach. Theor Appl Econ 18:51–60

Zakari A, Khan I, Tawiah V, Alvarado R (2022b) Reviewing the ecological footprints of Africa top carbon consumer: a quantile on quantile analysis. Intl J Environ Sci Technol 1-12

Zakari A, Khan I, Tawiah V, Alvarado R, Li G (2022c) The production and consumption of oil in Africa: the environmental implications. Res Policy 78:102795

Zakari A, Li G, Khan I, Jindal A, Tawiah V, Alvarado R (2022a) Are abundant energy resources and Chinese business a solution to environmental prosperity in Africa? Energy Policy 163:112829

Zhang C, Zhao W (2014) Panel estimation for income inequality and CO2 emissions: a regional analysis in China. Appl Energy 136:382–392

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