

The link between economic growth, energy intensity, environmental taxes, trade openness, and environmental quality: Evidence for selected European OECD countries

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The link between economic growth, energy intensity, environmental taxes, trade openness, and environmental quality: Evidence for selected European OECD countries

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ABSTRACT

This study investigates how economic growth, energy intensity, environmental taxes, and trade openness impact environmental quality. The empirical analysis employs first- and second-generation panel data estimators that account for heterogeneity across sections and dependence issues. The empirical results highlight that economic growth and energy intensity, mainly from traditional industries, negatively affect environmental quality. On the contrary, environmental taxes positively affect the load capacity factor, reflecting their success in countries with low environmental quality. There is also potential for beneficial implications of trade openness on the load capacity factor, but further research is necessary to determine their significance. Furthermore, asymmetric effects have been found to indicate that decoupling is more effective in countries with higher load capacity. Policy-makers should capitalize on these findings to balance economic progress with environmental protection.

1. Introduction

If the world continues to be driven by exponential consumption and unlimited extraction of resources, sustainability will be an unreachable goal [1]. According to Dasgupta et al. [2], monitoring the ecological footprint is, more than ever, necessary to achieve sustainable development. Although the ecological footprint measures the demand for natural resources, there has to be a consideration of both the human environmental impact and the supply of natural resources [3]. Balancing both sides of the equation is critical for responsible resource management; this can be measured as the ratio of the natural resources supply over demand, defined as the load capacity factor [4].

The ecological footprint measures resource consumption and waste generation to nature's resource generation and absorption [5,6]. However, the ecological footprint reflects only human demand for natural resources and environmental protection. To fill this gap, an alternative concept, also considering the supply side, called biocapacity, has been established. Biocapacity denotes the supply side that nature offers to humans. Considering these two dynamics simultaneously, Siche et al. [4] propose a new indicator, the load capacity factor (LCF), calculated as biocapacity divided by the ecological footprint. Based on this ratio, an

LCF value higher than one favors sustainability. Pata [7] was one of the first researchers to analyze LCF determinants empirically.

Investigating and improving the load capacity factor is essential for several reasons, which we aim to address in this study. First, we focus on the European OECD group of countries. The focus on specific European OECD countries, as compared to all of the OECD countries, is justified by several vital factors. To begin with, European OECD countries have a uniform regulation environment in the form of the European Green Deal, Paris Agreement, and other EU and OECD environmental guidelines that offer consistency and relevance of policies. According to the Global Footprint Network, most European OECD countries experience an ecological deficit, highlighting the critical need for sustainable resource management. Focusing on these countries makes it easy for research to target region-specific environmental challenges while advising on policies that conform to EU green objectives. Aside from that, these results have implications for regional measures like environmental taxation reforms and research and development investments that have implications within the context of the EU that make focusing on European OECD countries not only methodologically sound but more necessary for region-specific results that have implications for green resource management.

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Second, in contrast to most of the previous literature that has essentially focused on CO₂ emissions as the proxy variable for environmental degradation, an indicator used in the present study accounts for nature's demand, supply of resources, and environmental quality. An unexpected ecological footprint boom or a fall in ecological reserve may eventually affect environmental quality levels. Third, based on the authors' knowledge, only a few works have focused on the load capacity factor [8,3,9], whereas almost all European countries present an ecological deficit (Global Footprint Network) while they all refer to the same environmental Directives. Fourth, to understand the relationship between environmental quality and distinct production patterns, it is essential to incorporate institutional parameters proxied by ecological regulations, such as environmental tax policies, into the analysis [10]. In addition, this work tries to provide new empirical data concerning the causality relations between economic growth, energy intensity, environmental taxation, globalization, and environmental quality. The analysis employs reliable panel econometric methods that consider the interdependency and variations in the relationships between variables across different groups. Furthermore, the panel Granger non-causality bootstrapping approach proposed by Juodis et al. [11] is employed, as it offers more elaborate information about underlying linkage. This strategy minimizes potential errors and aligns more effectively with appropriate policy actions, such as investments in research and development and environmental initiatives. Also, quantile models robust to CSD issues are used to estimate possible asymmetric effects of our independent variables on LCF. The empirical findings can suggest suitable policy implications and recommendations for both sides - demand and supply - of natural resources.

One of the key motivations for focusing on this particular region is that many of these advanced economies are experiencing notable ecological deficits, as highlighted by the Global Footprint Network. In these countries, the consumption of natural resources exceeds the capacity of their ecosystems to replenish them, placing them in a state of environmental strain. This situation makes exploring the underlying factors affecting ecological quality crucial. By concentrating on this group of nations, the study can offer more precise insights into how economic processes intersect with environmental sustainability in settings marked by similar ecological pressures.

To sum up, the novelty of this research is that it examines determinants of the load capacity factor (LCF) in European OECD countries, a group of countries with a high level of interrelationships that offer all-around environmental sustainability measurement by considering resource demand (ecological footprint) as well as resource supply (biocapacity). Additionally, compared to other research, the current work focuses on several policy variables, such as environmental taxation, which are incorporated into the analysis to offer sustainable resource management suggestions. Furthermore, by considering European OECD countries with similar environmental policies in their jurisdictions and experiencing notable ecological deficiencies, the research offers region-specific results and suggestions for environmental policies per EU sustainability objectives. It further expands on the literature on environmental economics by utilizing LCF as an all-around environmental indicator to bridge research on LCF determinants while offering relevant suggestions for environmental policies for sustainable development. Finally, employing advanced panel econometric approaches like panel Granger non-causality bootstrapping and robust-to-cross-sectional-dependence quantile models offers sound empirical results that offer in-depth insight.

Following this introduction, Section 2 reviews the empirical literature. Section 3 illustrates the data and the models used in the analysis. Section 4 presents the empirical results, Section 5 discusses the results while the final section (Section 6) concludes with the main findings and recommendations.

2. Literature review

After the early 1990s, when three seminal studies independently analyzed the relationship between environmental degradation and economic status [12–14], there has been a plethora of studies investigating this relationship. Nevertheless, this topic remains highly debated, with many studies on the relationship between CO₂ emissions and their main drivers at a macro level. Findings also suggest that decoupling economic growth and environmental degradation is possible, particularly in advanced economies, after adopting cleaner technologies and more sustainable strategies [15]. Another group of studies has found mixed results supporting the fact that the relationship between economic growth and environmental degradation varies across countries [16].

However, a new trend in the empirical literature is conducting research using the ecological footprint instead of air pollution variables [17]. In particular, several studies have explored the impact of economic growth [18,19], energy intensity [20], environmental regulation [21, 22], and trade openness [23] on ecological footprint. The current study goes beyond this aim and investigates the relationship between the ratio of biocapacity over the ecological footprint, known as the load capacity factor, and economic growth for selected European economies.

Recent literature has seen a diversification of environmental quality indicators, with growing attention to the load capacity factor (LCF) as a more comprehensive alternative to the ecological footprint. Several recent studies (e.g., [24,3]) emphasize the utility of LCF in capturing the dual dimensions of ecological supply and demand. However, comparative panel analyses for European OECD countries remain limited, particularly those integrating multiple policy and economic variables. This study addresses that gap by incorporating broader determinants and newer empirical techniques.

2.1. Economic growth and environmental quality nexus

Research in environmental economics has extensively explored the relationship between economic growth and its influence on ecological sustainability. Many authors, such as Danish et al. [25], Wang & Dong [26], Usman et al. [27], Çakmak & Acar [28], and Ahmed et al. [29], found a positive relationship between growth and environmental deprivation. At a macro level, Danish et al. [19] concluded that there is a positive impact of income on EF in Pakistan, while Wang & Dong [26] confirmed that for the Sub-Saharan African countries. Additionally, Usman et al. [27] confirmed growth's positive impact on EF in advanced economies.

However, a pivotal shift occurred when Siche et al. [4] introduced the load capacity factor as a more comprehensive indicator of environmental quality. Subsequently, the load capacity factor gained prominence in the literature as a tool for assessing ecological quality. Various researchers, including Pata & Isik [3], Shang et al. [9], Guloglu et al. [8], Jin & Huang [30], Mehmood et al. [31], and Pata & Samour [32], have employed load capacity factor to explore the intricate relationship between economic growth and environmental quality.

Recent studies confirm the Environmental Kuznets Curve (EKC) hypothesis, with studies such as Fakher et al. [33] finding a U-shaped relationship between growth and environmental quality in BRICS countries. However, in studies focusing on LCF, such as Agila et al. [34] and Pata & Balsalobre-Lorente [35], economic growth steadily shows a negative impact, especially in emerging and OECD economies. This highlights the importance of examining this relationship using alternative indicators like LCF.

2.2. Energy intensity and environmental quality nexus

The relationship between energy intensity and environmental deprivation has been broadly investigated in environmental economics. For instance, Shahbaz et al. [36] focused on 12 selected African countries from 1980 to 2012 and concluded a positive impact of energy intensity on CO₂ emissions. Murshed [37] employed Westerlund cointegration and Dumitrescu and Hurlin causality in six selected South Asian countries from 2000 to 2015. They found that technological advancements can improve and decouple economic growth from environmental degradation by lowering energy intensity.

However, the connection between energy intensity and ecological footprint is not uniform. Aydin & Turan [38] examined the BRICS countries and found that higher energy intensity increases ecological footprint, challenging the validity of the environmental Kuznets curve in the examined countries. In contrast, Hou et al. [39] focused on China and found a dynamic threshold effect, indicating that stronger environmental regulation could compensate for the adverse effects of air pollution and decrease energy intensity. More recent studies, such as Hasanov et al. [40] and Kostakis et al. [41], highlight the environmental cost of non-renewable energy intensity across multiple economies. These findings confirm the negative impact of fossil-based energy use to LCF and underline the potential for renewable sources to mitigate this effect.

2.3. Environmental regulation and environmental quality nexus

In examining the relationship between environmental regulation and ecological sustainability, previous studies [42,43] emphasize the beneficial impact of environmental policies in reducing ecological degradation. For instance, Murshed et al. [43] analyzed data from four South Asian countries, using Dumitrescu and Hurlin causality analysis, and demonstrated the significant impact of environmental regulations on reducing the ecological footprint. Similarly, Chu & Tran [42] employed quantile regressions to highlight the beneficial role of environmental regulation in curbing consumption-related ecological footprint for 27 OECD countries. Afshan et al. [21] conclude that stringent environmental policies significantly negatively affect the ecological footprint of OECD economies, reinforcing the global relevance of such regulations. Similarly, Rafique et al. (2019) investigated the role of taxes on ecological footprint, employing several estimators (ARDL, DOLS, FMOLS, and fixed effect) and found that environmental taxes play a crucial role in achieving better environmental quality.

Recent studies highlight the rising role of environmental taxes and regulations in improving ecological outcomes. Papadas et al. [44] and Nathaniel et al. [45] concluded that well-designed policy tools substantially improve environmental quality.

2.4. Trade openness and environmental quality nexus

Previous empirical literature [10,46–49] found that enlarged trade openness may cause increased environmental degradation. In contrast, other studies [50,41,51,52] found that trade openness can raise the adoption of cleaner technologies, leading to decreased emissions. However, findings from studies like Heil & Selden [53], Le et al. [54], and Udeagha & Breitenbach [55] provide mixed or inconclusive results.

Kongbuamai et al. [56] found a positive association between trade openness, economic growth, and energy consumption with the ecological footprint of Thailand. On the contrary, Alola et al. [57] extended the scope to 16 EU countries, finding a decreasing effect of trade openness on EF. Destek and Sinha [58] investigated OECD countries, highlighting the decreasing impact of trade openness and renewable energy on EF and the intricate U-shaped association between economic growth and EF. Lu [59] considered 13 Asian countries, challenging the significance of trade openness in determining EF while emphasizing the positive impacts of economic growth and energy consumption.

Recent studies have found that the environmental effects of trade openness remain inconclusive. While Alola et al. [57] and Papadas [24] suggest trade openness can reduce environmental pressure, other studies (e.g., [33,60]) indicate a negative impact depending on trade structure.

2.5. Other independent variables and environmental quality nexus

Several authors investigated LCF determinants and revealed complicated relationships between various variables and LCF across different regions and periods. In the case of China [3], factors such as human capital were pivotal in affecting environmental quality. In contrast, a study on ASEAN countries by Shang et al. [9] indicates that renewable energy and health spending positively affect LCF, while economic growth exhibits an inverse relation.

Mehmood et al. [31] focused on G8 nations and found that green energy sources, government investment in technology development, and state-of-the-art information and communication technologies can significantly raise LCF. Finally, research on South Africa by [30] underscores the positive impact of renewable energy consumption on the LCF. Another study by Caglar et al. [10] in APEC economies confirms the positive effect of renewable energy and human capital on LCF. Overall, the above findings significantly help identify the parameters that determine LCF globally. A summary of selected recent findings from the literature is shown in Table 1.

Beyond conventional factors, studies like Guloglu et al. [8] and Nathaniel et al. [45] highlight the significance of human capital, urbanization, financial development, and innovation in shaping environmental quality. While these variables are gaining interest in ecological footprint models, their role in LCF-oriented studies, particularly within European OECD contexts, remains insufficiently examined. Addressing this gap offers new insight into multidimensional policy design.

While growing attention has been given to the ecological footprint as a measure of environmental degradation, the load capacity factor (LCF), a more comprehensive indicator that accounts for both ecological demand and supply, remains underexplored, especially within the context of European OECD countries. Although recent research has started to examine LCF, there is a lack of studies that integrate this metric with critical policy variables, such as environmental taxation, alongside conventional economic and globalization indicators like GDP growth, energy intensity, and trade openness. This gap is particularly relevant in a region marked by shared environmental legislation and persistent ecological overshoot. Moreover, advanced panel econometric methods, such as panel Granger non-causality tests with bootstrapping and robust quantile regressions that account for cross-sectional dependence and heterogeneity, have been relatively limited in this area. This study aims to fill these gaps by offering a more refined analysis of the factors influencing LCF in European OECD countries, incorporating key policy tools and employing methodological approaches tailored to the complexities of a highly interconnected regional framework.

3. Research methodology

The research methodology for this work is presented in this section. In particular, it details the data sources utilized, including their scope and relevance to our study and the econometric methods employed, emphasizing their suitability for addressing our research objectives and warranting robust and reliable results.

3.1. Data sources

The data set used in the present study is a balanced panel of selected European OECD countries from 1995 to 2018. The data availability dictates both countries' inclusion and the data period selected. Our study investigates the load capacity factor by employing aggregated proxy variables on behalf of key dimensions of the economy, energy, globalization, and institutional factors. This approach allows us to

Table 1
Summary of the literature regarding their region, period, methodology, and key findings.

Authors	Countries/regions	Period	Methods	Findings
a. Economic growth (EG)– Ecological footprint (EF)				
Danish et al. [19]	Pakistan	1971-2014	Bayer-Hanck cointegration, ARDL, VECM	EG has a positive impact on the EF, biocapacity has a positive relationship with the EF, and between the EF and EG are neutral.
Wang and Dong [26]	14 Sub-Saharan African countries	1990-2014	Westerlund cointegration, Dumitrescu and Hurlin causality	EG has a positive impact on the EF, Bidirectional causality relationships exist among the EF, GDP.
Usman et al. [27]	12 advanced economies	1980-2015	Westerlund cointegration, PMG-ARDL, GS-ARDL	EG positively impacts the EF, the population does not affect the EF, and nuclear energy can reduce the carbon footprints.
Çakmak and Acar [28]	8 oil-producing countries	1999-2017	GMM, Dumitrescu-Hurlin Causality	EG positively impacts the EF, no significant effect of renewable energy consumption on ecological footprint.
Ahmed et al. [29]	G7	1985-2017	Westerlund cointegration, Dumitrescu and Hurlin's Causality	Democracy and environmental regulations alleviate EF, EG and trade globalization drive EF.
Kostakis and Arauzo-Carod [61]	G7	1980-2018	FMOLS, DOLS, ARDL	EG has a non-linear impact on EF. EKC is confirmed.
Lu [59]	13 Asian countries	1973-2014	PMG, Causality	Impact on EF: Trade Openness: Not Significant Positive Impact: Economic Growth (EG); Energy Consumption
Sabir and Gorus [60]	South Asian countries	1975-2017	ARDL	Positive Impact on EF: Trade Openness; Foreign Direct Investment (FDI); KOF Index
Alola et al. [57]	16-EU countries	1997-2014	PMG-ARDL	Trade openness decreases the EF
Destek and Sinha [58]	OECD countries	1980-2014	Cointegration, FMOLS, DOLS	Effect on Ecological Footprint (EF): Trade Openness and Renewable Energy: Decrease EF; Economic Growth (EG): U-shaped Association with EF
b. Energy intensity (EI)– Ecological footprint (EF)				
Shahzad et al. [36]	12 selected African countries	1980-2012	Johansen, VECM Causality, Pedroni Cointegration, Panel causality	EI has a positive impact on CO ₂ emissions
Murshed [37]	6 selected South Asian countries	2000-2015	Westerlund cointegration, Dumitrescu and Hurlin causality	Trade also indirectly decreases carbon dioxide emissions through increased energy efficiencies, levels of consumption of renewable energy sources, and greater availability of cleaner cooking fuels
Aydin and Turan [38]	BRICS countries	1996-2016	AMG, CCEMG	EI increased EF, EKC not valid
Hou et al. [39]	China	2010-2015	Dynamic threshold regression	More stringent environmental regulation might affect "reversed transmission," mitigating negative effects on air pollution and promoting energy intensity decline.
c. Environmental regulations (ER)– Ecological footprint (EF)				
Peng et al. [62]	China	2000-2016	Computable General Equilibrium (CGE)	An energy excise tax is beneficial for energy saving.
Murshed et al. [43]	4 fossil fuel-dependent South Asian countries	1990-2016	Dumitrescu and Hurlin causality	Environmental regulations play significant roles in indirectly reducing the EF.
Chu and Tran [42]	27 OECD countries	0990-2015	Quantile regressions	The benefit of environmental regulation on EF consumption reduction
Afshan et al. [21]	OECD countries	1990-2017	Method of Moment Quantile Regression	A strong negative influence of stringent environmental policy index on EF is evident.
Rafique et al. [63]	OECD countries	1994-2016	ARDL, DOLS, FMOLS	Environmental taxes are essential to achieve better environmental quality.
Fang et al. [64]	30 provinces in China	2010-2020	panel smooth transition regression model	Environmental protection tax as transition variable, matters fishing grounds' and forest land's EF
Caglar et al. [10]	APEC countries	1992-2018	Cup-FM, Cup-BC	Environmental regulations are insufficient for APEC countries.
d. Trade openness (TO)– Ecological footprint (EF)				
Sabir and Gorus [60]	South Asian countries	1975-2017	ARDL	Trade openness, FDI and the KOF index positively affect the ecological footprint.
Kongbuamai et al [56]	Thailand	1974-2016	ARDL, VECM Granger causality	Trade openness, economic growth, and energy consumption have positive relationships with the EF, while tourism and population density are negatively associated with the EF
Alola et al. [57]	16-EU countries	1997-2014	PMG-ARDL	Trade openness decreases the EF
Destek and Sinha [58]	OECD countries	1980-2014	Cointegration, FMOLS, DOLS	Trade openness and renewable energy decreases the EF, U-shaped association persists between EG and EF,
Lu [59]	13 Asian countries	1973-2014	PMG, Causality	Trade openness is not a significant determinant of EF. EG and energy consumption have a positive impact on the EF.
e. Other independent variables– Load capacity factor (LCF)				

(continued on next page)

Table 1 (continued)

Authors	Countries/regions	Period	Methods	Findings
Pata and Isik [3]	China	1981-2017	ARDL	Support for EKC, resource rent, energy intensity, and per capita income reduce the LCF, while human capital increases it.
Shang et al. [9]	ASEAN Countries	1980-2018	Banerjee & Carrion-i-Silvestre cointegration, ARDL	HLT and REC are positively and significantly affecting the LCF, the EG inversely correlated with the LCF
Guloglu et al. [8]	26 OECD countries	1980-2018	QMG estimator, Westerlund cointegration	Income has a U-shaped relationship with LCF, while LCC hypothesis is supported. Urbanization degrades environmental quality, whereas renewable energy, natural resources, and human capital improve it.
Jin and Huang [30]	South Africa	1990 and 2019	NARDL	RECE and HC improve LCF, but Industrialization and economic growth negatively affect LCF.
Mehmood et al. [31]	G8	1980-2018	GS-ARDL	Sustainable energy resources, governmental funding for technological progress, and implementing state-of-the-art information and communication technologies boost LCF.
Pata and Isik [3]	China	1981–2017	Dynamic ARDL	GDP, EI, NRR decrease LCF; HC increase LCF
Pata and Samour [65]	France	1977–2017	Fourier TY causality; Fourier ARDL	GDP decreases LCF; NEC increases LCF GDP and NEC affect LCF
Agila et al. [34]	South Korea	1970-2018	Quantile cointegration	GDP reduces LFC
Guloglu et al. [8]	26 OECD countries	1980–2018	Westerlund cointegration	URB decreases LCF; HC, NRR and REC increase LCF; GDP mixed LCF
Pata and Balsalobre-Lorente [35]	Turkey	1965-2017	Dynamic ARDL	GDP reduces LFC
Nathaniel et al. [45]	20 emerging markets	1995-2019	AMG (Augmented Mean Group) Driscoll-Kraay and Prais-Winsten regressions MMQR (Modified Median Quantile Regression)	International Tourism: Negative & Significant, Technological Innovation: Negative & Significant, REC: Negative & Significant, GDP: Positive & Significant, Population Growth: Positive & Significant, FDI: Negative & Significant
Fakher et al. [33]	BRICS	2005-2019	Panel data analysis	CFDP: Negative & Significant (improves environmental quality), Agricultural Activities: Negative & Significant (intensify environmental deterioration), Economic Growth: U-shaped relationship (Inverted U-type Environmental Kuznets Curve hypothesis), Renewable Energy: Positive & Significant (improves environmental quality), NREC: Negative & Significant (decreases environmental quality)
Fakher and Murshed [33]	13 OPEC countries	2000-2019	Panel Smooth Transition Regression (PSTR) method	Composite trade share CTS Negative & Significant, GDP increases pollution initially, but reduces it in the long term, Financial development FD increases pollution initially, but reduces it in the long term, Energy Consumption EC Negative & Significant
Hasanov et al. [40]	GEFC countries	1990- 2020	Panel Unit root tests, Panel Cointegration, Long-run estimations from 1st and 2nd generation methods, Country-specific long-run estimates AUG-MG method.	REC Negative & Significant, TFP Negative & Significant, GDP Positive & Significant, Exports Negative & Significant, Imports Positive & Significant.
Papadas et al. [44]	selected European countries	1995-2022	Panel unit root tests, Cointegration tests, Second-generation models and Quantile regression, Causality test.	NREC Positive & Significant, REC Negative & Significant, AVA, AVI, AVS Positive & Significant, GDP Negative & Significant, TO Positive & Significant.
Papadas [24]	N11 countries	1995-2021	Panel unit root tests, Cointegration tests, Second-generation models and Quantile regression, Causality test.	REC Positive & Significant, NREC Negative & Significant, GDP Negative & Significant, TO Negative & Significant, AVS Positive & Significant.
Kostakis et al. [41]	OECD countries	2014-2019	Panel unit root tests, Cointegration tests, Second-generation models and Quantile regression, Causality test.	Renewables Positive & Significant, Nuclear Energy Positive & Significant, Trade Openness Positive & Significant Economic Development Positive & Significant, Petroleum Negative & Significant, Natural Gas Negative & Significant, Urbanization Negative & Significant, Coal Negative & Significant.

Table 2

Documentation of variables and sources.

Variable	Definition	Measurement	Source
LCF_{it}	Load capacity factor	The ratio between the biocapacity and the ecological footprint	GFN
GDP_{it}	Gross domestic product per capita	Constant 2010 US\$	WDI
EI_{it}	Energy intensity	Total energy consumption divided by real gross domestic product	EIA
ET_{it}	Environmental taxes	Environmentally related taxes, % GDP	OECD
TO_{it}	Trade openness	The ratio between the sum of exports and imports and gross domestic product (GDP)	EIA

Notes: GFN: Global Footprint Network; WDI: World Development Indicators; EIA: Energy Information Administration; OECD: Organization for Economic Cooperation and Development.

capture broad, multidimensional impacts on environmental sustainability within a cohesive framework. Table 2 summarizes variables, their measurements, definitions, and sources.

Several empirical studies have examined the association of these variables with environmental quality using various environmental indicators, although there is no agreement on which dependent variable would be the most suitable. Along with CO_2 , researchers have also used other greenhouse gas emissions and several other environmental quality indicators. At the same time, the ecological footprint, proposed by Rees [5], measures air, water, and soil pollution but only reflects human demand for natural resources and environmental degradation, omitting ecosystem response and supply opportunities. The LCF, calculated as the ratio between the biocapacity and the ecological footprint, could offer a better evaluation.

Regarding the independent variables, economic status affects the environment through three different channels: the scale effect, the composition effect, and the technique effect [66]. Real income per capita is usually used to analyze the impact of economic growth on the environment. The energy sector has been widely investigated for its widespread and multiplier effects on the environment, a significant source of pollution and greenhouse gases. This is mainly because of the industry's heavy reliance on fossil fuels, which emit carbon dioxide into the atmosphere and cause global warming and ecological degradation. Also, energy intensity is a key measurement generally defined as the ratio of overall economic output and energy use. It represents the level of efficiency with which an economy uses energy in its output processes. The higher the energy intensity, the greater the amount of energy consumed for every output, and this could imply inefficient machinery, outdated industrial processes, and excessive use of energy-intensive industries, such as heavy industry or manufacturing.

Regarding environmental and institutional regulation, the level of environmental taxes is an additional and vital indicator. Higher environmental taxes and strict regulation can improve environmental quality and promote sustainable development. Lastly, considering LCF as a measure of environmental quality has advantages since it accounts for the national and international demand and supply. Thus, it adjusts for international trade, making it easy to identify the ecological effect caused by one foreign country. In this study, we analyze the environmental quality effects of international trade [67].

3.2. Econometric methodology

The empirical analysis uses annual data from 1995 to 2018 to examine the correlation between load capacity factor, economic growth, energy intensity, environmental taxes, and trade openness in 21 European OECD countries. The model is formulated using the following equation:

$$\ln LCF_{it} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln EI_{it} + \beta_3 ET_{it} + \beta_4 TO_{it} + \varepsilon_{it} \quad (1)$$

where, t denotes the time (1995 to 2018), i denotes the 21 countries, ε_{it} denotes a stochastic error, respectively. $\ln LCF_{it}$ is the log-transformed load capacity factor, $\ln GDP_{it}$ is the log-transformed income per capita, $\ln EI_{it}$ is the log-transformed energy intensity, ET_{it} is the environmental taxes as a share of GDP, and TO_{it} is the trade openness variable. Specifying our model and collecting the necessary data, we proceed to the empirical process using the following flowchart (Fig. 1).

Before analyzing our panel data, we must examine the level of cross-sectional correlation (CD by [68,69]; CDw by [70]; $CDw+$ by [71]; CD^* by [72]). This will help us decide on the appropriate empirical methods of analysis. The particular set of countries comprises both members of the European region and those belonging to the OECD. We then test whether the slope coefficients are constant across countries [73]. Later, Blomquist and Westerlund [74] developed a novel test extending the Pesaran and Yamagata [73] approach by incorporating heteroskedasticity and autocorrelation consistency. Moreover, Bersvendsen and Ditzen [75] proposed a different test that yields robust statistics for assessing cross-sectional dependence by dropping cross-section averages.

To account for potential cross-sectional dependence and varying slope coefficients, we utilize second-generation panel unit root tests, specifically the cross-sectionally augmented IPS (CIPS) and the cross-sectionally augmented Dickey-Fuller (CADF) tests [76]. These tests handle cross-section dependence and slope heterogeneous coefficients while capturing possible multiple structural breaks and unobserved dynamic factors. Then, to investigate possible long-term associations among the variables, we employ multiple panel cointegration techniques, which encompass the Pedroni [77,78] and Kao [79], as well as the bootstrapping methods proposed by Westerlund [80] and Westerlund [81]. These tests can handle cross-section dependence and heterogeneous slopes. Pedroni and Kao tests apply the demean option to consider CSD by averaging each variable in the cross sections. Similarly, the Westerlund [80] test uses bootstrapping to produce robust cointegration results under CSD issues. Finally, Westerlund [81] addresses the models' slope heterogeneity and cross-sectional dependence issues.

Once a long-term equilibrium relationship has been established between the variables, we further analyze the information in the data and perform econometric testing using cointegration models. In particular, we include fixed-effect models with Driscoll & Kraay's [82] standard errors, pooled mean-group, fully modified ordinary least squares, and dynamic ordinary least squares. Then, we apply the novel quantile regressions method (MMQR) from Machado & Silva [83], which allows for estimating distributional and heterogeneous effects across quantiles, controlling for cross-sectional dependence [15]. Finally, the Granger causality test by Juodis et al. [11] determines the possible causal relationship between the dependent and independent variables. Specifically, this test determines the causal relationship between load capacity factor and economic growth, energy intensity, environmental taxes, and trade openness.

4. Empirical results

Initially, we present the mean values and visualization of the LCF. Then, we perform the necessary tests, concluding with the estimations of our models. Table 3 provides average values across time, followed by the standard deviation for all countries included in the analysis for the period 1995 to 2018, regarding the indicators employed, such as LCF (load capacity factor), GDP (gross domestic product), EI (energy intensity), ET (environmental taxes), and TO (trade openness). It is evident that only the four Scandinavian countries have an LCF index exceeding one, indicating a surplus of natural resources compared to human demand, promoting sustainability. Conversely, countries like the Netherlands, Belgium, Luxembourg, Italy, and the UK have alarmingly low LCF values, indicating environmental vulnerability.

Regarding GDP per capita, Luxembourg stands out with the highest

value (98,629€), while Poland has the lowest (9524 €). Norway exhibits the most increased energy inefficiency, while Ireland demonstrates superior energy efficiency among the analyzed countries. Denmark has the highest level of environmental taxes as a percentage of GDP, while Luxembourg boasts the most open economy in terms of trade.

Subsequently, Fig. 2 illustrates each country's load capacity factor (LCF) over time. There is considerable variability in LCF for all countries, indicating a lack of a consistent sustainability trend. Notably, except for the UK, nearly all European countries have exhibited a decline in LCF since 2015. Considering Europe's leadership in environmental regulation, this finding is concerning, as it suggests a persistent increase in environmental degradation. Moreover, the graphical analysis reveals that, except for France, Germany, Hungary, and the UK, European OECD countries generally have a lower LCF recently compared to 1995, indicating a chronic deterioration in environmental quality for European citizens. This observation underscores the need for concerted efforts to address and reverse this trend.

Table 4 presents the cross-sectional dependence (Panel A) and slope homogeneity (Panel B) test findings. Results reject the null of cross-sectional independence for the variables under study, suggesting that a shock in one country may spread to other economies.

As can be seen, strong interdependencies and heterogeneities across the studied economies can be determined. Whereas cross-sectional dependence tests suggest that shocks in one economy impact other economies, slope homogeneity tests suggest that the underlying relationships between variables differ significantly across countries. Panel B (Table 4) shows the results of the slope homogeneity tests [75,73] that support the existence of cross-country heterogeneity between the coefficients.

In light of the results obtained in the previous analysis, second-generation panel unit root tests are applied with cross-sectional interdependence and country-specific variability considered, especially CIPS and CADF. Table 5 reports the results of second-generation panel unit root tests by Pesaran [76]. Table 6 presents cointegration tests.

More specifically, both the CIPS and CADF test results indicate that the load capacity factor is stationary at constant series across different countries, while the rest of the variables are non-stationary at the 0.05 or 0.1 significance levels. On the contrary, all variables are stationary at 1% significance level at their first differences. Hence, we conclude that

the variables are integrated I(1) and have no unit root issues. After that, we report (Table 6) the results of a cointegration relationship between the considered variables [79,77,78,80,81]. All statistics reject the null hypothesis of no cointegration at 1% significance level, while Gt and Pt also highly indicate cointegration between the variables of interest. These results show evidence of a long-run relationship between the variables of interest.

These results confirm a long-run relationship between load capacity factor, real gross domestic product, energy intensity, environmental taxes, and trade openness. Next, we present the empirical results from the long-run estimation models. The coefficients for first and second generation estimators are presented in Table 7. The coefficient associated with per capita real GDP (LNGDP) is negative, implying that an increase in real per capita income corresponds to a decrease in environmental quality. This outcome indicates that economic growth significantly negatively affects environmental sustainability in our countries. The average elasticity across the models is -0.66, showing an inelastic relationship. This means that for every one-unit increase in economic growth, the load capacity factor will be reduced by 0.66%, if all other factors are constant.

Similarly, as expected, the coefficient for energy intensity is negative. Energy intensity refers to the energy required to produce a unit of economic output. Consequently, this underscores the pivotal role of energy intensity in shaping environmental quality. A higher energy intensity, indicative of lower energy efficiency and a comparatively more substantial energy demand for economic value generation, is found to be associated with a decline in environmental quality. To illustrate, a 1% increase in energy intensity corresponds to an average 0.34% rise in environmental degradation. This relationship highlights the importance of energy efficiency considerations in the broader context of environmental sustainability. The coefficients for environmental taxes and trade openness are positive, confirming the hypothesis that stricter environmental regulations and more trade-open economies are associated with higher environmental quality. However, the impact of trade is only marginally statistically significant. The average coefficient for environmental taxes is 0.05, indicating that a 1% increase in environmental taxes could drive a 0.05% improvement in the load capacity factor, thereby improving environmental quality.

Moreover, by performing quantile regressions with fixed effects methodology [83], we consider the presence of heterogeneities in economic growth, energy intensity, trade and environmental taxation across different quantiles of the conditional load capacity curve. This approach accommodates cross-sectional dependence and slope heterogeneity with quantile regressions with fixed effects. The results from the quantile regressions for nine deciles (10%–90%) are shown in Table 8, while Fig. 3 plots the coefficients from the panel quantile regression. Results show asymmetric effects across the distribution of the dependent variable.

The quantile models provide additional insights into the distribution of the effects compared to previous estimations. These empirical findings stretch robust evidence of a significant negative relationship between economic growth and conditional load capacity distribution. In particular, the real gross domestic product coefficients are negative and statistically significant at all quantiles, suggesting that an increase in economic growth leads to lower environmental quality. Nevertheless, the higher the quantile, the more the impact is evident. More specifically, the size of the coefficient increases as environmental quality increases, indicating that the magnitude of effects is higher for the examined countries found on the higher quantiles.

Correspondingly, comparable results emerge for energy intensity. In other words, high energy intensity is significantly negatively correlated with the load capacity curve. More specifically, this correlation's harmful association increases the distribution of the conditional load capacity curve and is stronger in countries with a high degree of environmental quality. Energy efficiency-enhancing efforts can help strengthen environmental sustainability and work toward realizing



Fig. 1. Methodological scheme.

Table 3

Mean values (st. dev in parenthesis) for the variables employed per country.

Country	LCF	GDP	EI	ET	TO
Austria	0.502 (0.044)	41,320 (3687)	3.752 (3.752)	2.511 (0.175)	92.5 (92.5)
Belgium	0.123 (0.006)	37,904 (3270)	5.910 (0.755)	2.392 (0.237)	144.8 (15.38)
Czech Republic	0.426 (0.026)	15,114 (2627)	6.030 (1.067)	2.536 (0.086)	118.8 (26.53)
Denmark	0.576 (0.037)	50,744 (3430)	3.283 (0.580)	4.489 (0.527)	90.2 (13.12)
Estonia	1.353 (0.205)	13,853 (3801)	3.055 (0.963)	2.298 (0.617)	142.4 (14.9)
Finland	2.042 (0.161)	40,751 (4805)	5.885 (0.788)	2.949 (0.175)	73.4 (5.86)
France	0.518 (0.019)	37,777 (2353)	4.422 (0.492)	2.350 (0.136)	55.0 (5.66)
Germany	0.323 (0.017)	36,990 (3523)	4.082 (0.488)	2.195 (0.246)	71.0 (14.9)
Greece	0.306 (0.041)	19,599 (2437)	4.106 (0.252)	2.818 (0.717)	54.8 (10.7)
Hungary	0.653 (0.066)	10,803 (1896)	4.676 (0.868)	2.820 (0.197)	138.5 (28.4)
Ireland	0.640 (0.039)	47,535 (10,736)	2.750 (0.607)	2.406 (0.382)	173.7 (27.9)
Italy	0.192 (0.012)	31,708 (1412)	3.273 (0.190)	3.168 (0.312)	51.1 (5.07)
Luxembourg	0.109 (0.011)	98,629 (11,284)	3.635 (0.528)	2.445 (0.438)	284.0 (49.27)
Netherlands	0.143 (0.013)	42,278 (3827)	5.280 (0.646)	3.483 (0.105)	130.0 (17.2)
Norway	1.266 (0.101)	70,619 (4911)	7.027 (0.761)	2.760 (0.423)	70.2 (2.40)
Poland	0.443 (0.023)	9,524 (2575)	5.482 (1.457)	2.359 (0.277)	74.8 (17.8)
Portugal	0.299 (0.299)	18,885 (1220)	3.447 (0.114)	2.743 (0.370)	69.6 (8.3)
Slovakia	0.648 (0.064)	12,482 (3317)	6.951 (2.337)	2.187 (0.203)	147.1 (30.8)
Slovenia	0.465 (0.042)	18,870 (2949)	5.138 (0.881)	3.856 (0.670)	122.6 (22.4)
Sweden	1.621 (0.151)	45,356 (5673)	5.779 (1.182)	2.518 (0.321)	81.0 (6.5)
UK	0.224 (0.020)	41,592 (3676)	3.896 (0.772)	2.424 (0.144)	55.4 (4.825)

sustainable development goals [84].

Also, the results indicate a robust positive association between environmental taxes and environmental quality in environmental regulation. The positive effect of environmental taxes on the load capacity curve is more substantial and statistically significant for lower and middle deciles. Based on this, we can suggest that environmental taxes, as an essential and critical policy, can be highly influential within countries with low levels of environmental quality. At the extremes and in the middle area of the conditional load capacity curve distribution, these empirical results eventually converge to the prior assessments and do not find significant evidence to hint at meaningful causality between trade openness and quality. Finally, Table 9 presents the heterogeneous panel causality test introduced by Juodis et al. [11], trying to discover possible causal links between the variables.

The causality test shows a bidirectional relationship between economic growth and the load capacity curve. Similarly, the feedback hypothesis is confirmed between energy intensity and environmental quality at a 1% significance level. On the contrary, the neutrality hypothesis is evident between environmental taxes and the load capacity curve in the short run. Nevertheless, this outcome is anticipated, considering that implementing new regulations, such as an environmental tax, requires time to influence the behavior of consumers and stakeholders and subsequently impact environmental quality. Finally, one-way significant causality runs from LCF to trade openness in the countries of the EU, flowing from the load capacity factor to international trade.

5. Discussion

The relationship between economic growth, energy intensity, and their impact on environmental quality has been the subject of extensive research in recent years. The current study highlights the negative impacts of economic growth and energy intensity on the load capacity factor. At the same time, empirical findings underscore the positive effects of environmental regulation through taxes and the marginal beneficial role of open trade in improving environmental quality.

The negative relationship between economic growth and environmental quality has been a recurring theme in the literature [85,86]. Our results align with a substantial body of literature highlighting the need for sustainable development strategies [19,87]. In the same direction as the findings of this work, empirical results of previous studies [29,3,27, 26], also identify the adverse effect of economic growth on environmental quality, supporting the need for decoupling economic growth from environmental degradation [88].

Our study expands on this concept by providing evidence that the impact of energy intensity is a driver of ecological degradation [36]. This finding corresponds, *inter alia*, with the studies of Shahbaz et al. [36] in selected African countries, of Murshed [37] in South Asia (2020), and Aydin and Turan [38] in BRICS countries, which reported that energy intensity increases in expense of environmental quality. Energy intensity is a crucial indicator of the connection between the economy and energy consumption while measuring how effectively an economy transforms energy into monetary output. In our case, higher energy intensity means a lower environmental load capacity factor. Thus, shifting the energy mix in favor of renewables could lead to a reduction in environmental degradation.

In contrast to the negative implications of economic growth and energy intensity, our research sheds light on the positive role of environmental taxes in improving environmental quality. Thus, even with an heterogeneous impact [89], environmental taxes appear as practical policy tools for moderating environmental degradation [64,62,63]. Additionally, we confirm the positive influence of strong environmental regulations in lowering the ecological footprint, which agrees with findings of studies by Afshan et al. [21] and Rafique et al. [63], emphasizing the effectiveness of stringent policies and environmental taxes. Contrary to Caglar et al. [10], who suggested that regulatory measures are inadequate in APEC countries, our analysis indicates that well-enforced environmental rules via taxation can substantially improve ecological outcomes. These findings highlight the critical role of tailored policy implementation across different regions. Also, these comparisons demonstrate that our results are consistent with the broader academic discourse while revealing important regional and methodological differences.

Lastly, the role of trade openness over environmental quality has been a contemporaneous topic of debate. Our paper contributed to this debate by showing an initial positive relation between trade openness and ecological quality similar to several previous empirical studies [57, 58,41,51]. Conversely, this finding challenges the notion that increased trade necessarily leads to environmental degradation, a result supported by Caglar et al. [10]. Also, our observations regarding trade openness differ from those of Alola et al. [57], who found trade openness to reduce EF in European nations. Instead, our study aligns more closely with Lu [59], who reported that trade openness may have an insignificant effect on EF in various Asian countries. This variation might stem from regional disparities in trade policies and environmental governance.

This study contributes valuable insights into the nexus between economic growth, energy intensity, environmental taxes, trade, and environmental quality. By comparing our findings with previous empirical studies, we navigate the existing research landscape, providing a more detailed understanding of the factors affecting environmental sustainability. The discussion advances the theoretical discourse and informs policymakers and stakeholders on the complicated nature of sustainable development.

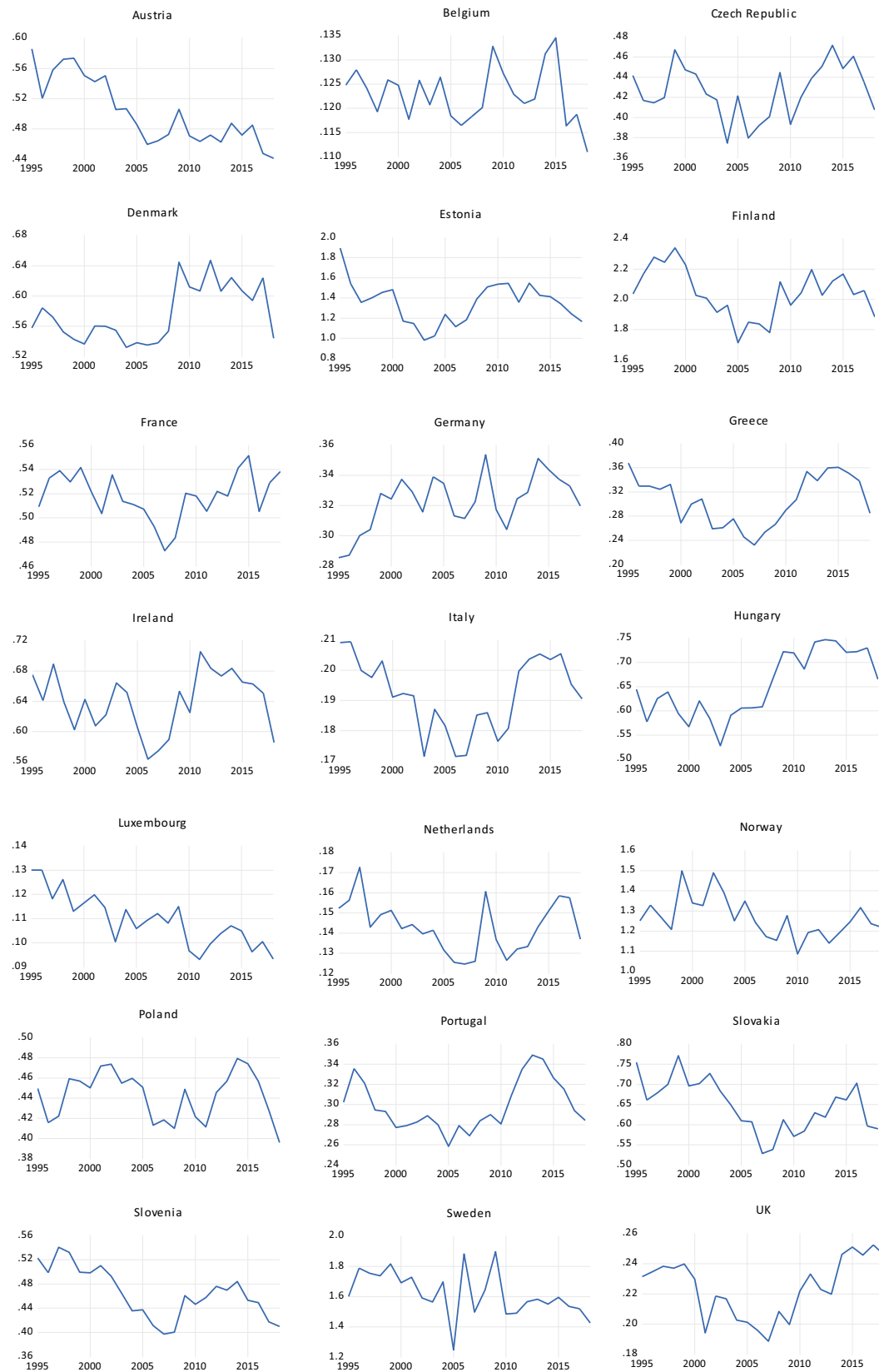


Fig. 2. LCF performance for the countries under investigation.

Table 4

Cross-section dependence (Panel A) and slope homogeneity tests (Panel B).

Panel A: Cross-section dependence				
Variables	CD	CD _W	CD _{W+}	CD _{W*}
lnLCF	21.84***	-2.08**	363.48***	-0.58***
lnGDP	60.60***	-3.27***	873.80***	-2.20**
lnEI	63.04***	-3.23***	910.27***	-0.51
ET	5.76***	-0.70	392.85***	4.02***
TO	52.17***	-1.73*	771.68***	-0.51
Panel B: Slope homogeneity tests				
Statistic	Δ		Δ_{adj}	
	3.956***		5.060***	
p-value	0.000		0.000	

Notes: ***, ** and * denote 1%, 5% and 10% significance level, respectively. CD [68,69]; CD_W [70]; CD_{W+} [71] CD_{W*} [72]. Δ denotes the first difference operator.

Table 5

Panel unit root tests.

Variables	CIPS	CADF	Variables	CIPS	CADF
lnLCF	-3.223***	-1.610*	Δ lnLCF	-5.508***	-10.888***
lnGDP	-1.736	-0.266	Δ lnGDP	-2.930***	-3.652***
lnEI	-2.284	1.510	Δ lnEI	-4.871***	-8.721***
ET	-2.275	2.235	Δ ET	-4.246***	-5.167***
TO	-1.635	2.211	Δ TO	-3.525***	-4.497***

Notes: ***, ** and * denote 1%, 5% and 10% significance level, respectively. Δ denotes the first difference operator. All the variables in level were tested with intercept and trend. Pesaran's CADF test presents Z t -bar values.

However, it is crucial to acknowledge the study's limitations that, when possible, future research should focus on the following areas to address these constraints. Firstly, adopting a global perspective with aligned objectives would enhance the study's robustness. For instance, investigating the moderating role of fiscal and monetary policies within the European Community could provide valuable insights. Furthermore, evaluating alternative indicators of environmental quality would contribute to a more comprehensive understanding of the subject. Incorporating additional demographic and socioeconomic components into a more experimental model to expand empirical research represents

a promising avenue for future exploration. Also, while the present study did not delve into the hypothesis of the Environmental Kuznets Curve, given its extensive recent coverage, exploring its applicability for this specific group of countries in the future could trigger valuable research interest.

6. Conclusions and policy implications

Economic growth and high energy intensity grow at the expense of the load capacity factor used as a two-dimensional proxy for environmental quality. It is thus crucial to monitor economic growth closely in the context of ecological impacts. This monitoring will help ensure that these policies effectively achieve their intended ecological objectives and supply of resources. While economic growth is necessary for our communities, energy efficiency policies that decrease energy intensity are essential to improve environmental quality. Europe should proactively promote renewable or green aviation fuels. The transition to a green economy has demonstrated its efficiency in reducing ecological degradation. Encouraging the industry to adopt these cleaner and more sustainable fuel sources can significantly reduce environmental degradation. On the contrary, environmental taxation was found to have a positive effect on reducing environmental pollution, as it negatively affects the load capacity factor. This shows the power of environmental regulations countries, should focus on to improve their environmental impact. Europe should continue to uphold and optimize its existing environmental tax policies. The positive relationship between taxes and environmental quality suggests that fostering substitute regulation can promote the adoption of environmentally friendly technologies in production processes, which will lead to a decoupling of the traditional economic growth model.

The findings point to several important considerations for policymakers in European OECD nations. The persistent negative association between economic growth and the load capacity factor signals a pressing need to decouple economic growth from environmental impacts. This can be achieved through advancing circular economy strategies and accelerating investment in clean technologies. The strong influence of energy intensity highlights the importance of comprehensive energy efficiency policies and the expansion of renewable energy and sustainable mobility initiatives. Furthermore, the positive effect of

Table 6

Panel cointegration tests.

Pedroni [77,78] with constant and trend					
Statistics	Modified Phillips-Perron t	Phillips-Perron t	Augmented Dickey-Fuller t		
Sample value	1.879**	-10.055***	-9.901***		
p -values	0.030	0.000	0.000		
Kao [79] with constant					
Statistics	Modified Dickey-Fuller t	Dickey-Fuller t	Augmented Dickey-Fuller t	Unadjusted modified Dickey-Fuller t	Unadjusted Dickey-Fuller t
Sample value	-7.230***	-6.109***	-2.036***	-9.930***	-6.817***
p -values	0.000	0.000	0.000	0.000	0.000
Westerlund [80] with constant and trend					
Statistics	Variance ratio				
Sample value	-1.907**				
p -values	0.028				
Westerlund [81] with constant and trend					
Statistics	Gt	Ga	Pt	Pa	
Sample value	-4.246***	-8.053	-17.747***	-7.976	
p -values	0.000	1.000	0.000	1.000	
Westerlund [81] with constant and trend (bootstrap)					
Statistics	Gt	Ga	Pt	Pa	
Sample value	-4.246**	-8.053	-17.747**	-7.976	
p -values	0.010	0.220	0.010	0.200	

Notes: ***, ** and * denote 1%, 5%, and 10% significance level, respectively. Kao-ADF, Pedroni-PP, and Pedroni ADF indicate ADF based on Kao [79] and PP-based and ADF-based on Pedroni [77,78]. The variance ratio statistic stands for the cointegration test of Westerlund [81]. Pedroni and Westerlund cointegration vectors include time trend. The kernel method estimates the long-run variance of each panel's series.

Table 7

First and second-generation regression models.

Variables	FE	PMG	FMOLS	DOLS	FE-with DK	AUG-MG
lnGDP	-0.543*** (0.088)	-1.175*** (0.067)	-0.514*** (0.037)	-0.593*** (0.068)	-0.543*** (0.081)	-0.590*** (0.140)
lnEI	-0.343*** (0.070)	-0.444*** (0.054)	-0.325*** (0.031)	-0.363*** (0.061)	-0.343*** (0.072)	-0.199** (0.099)
ET	0.050** (0.019)	-0.009 (0.010)	0.060*** (0.007)	0.021* (0.012)	0.050*** (0.012)	0.091*** (0.025)
TO	0.000 (0.001)	0.002*** (0.001)	0.000* (0.0002)	0.001* (0.000)	0.000 (0.000)	0.000 (0.113)

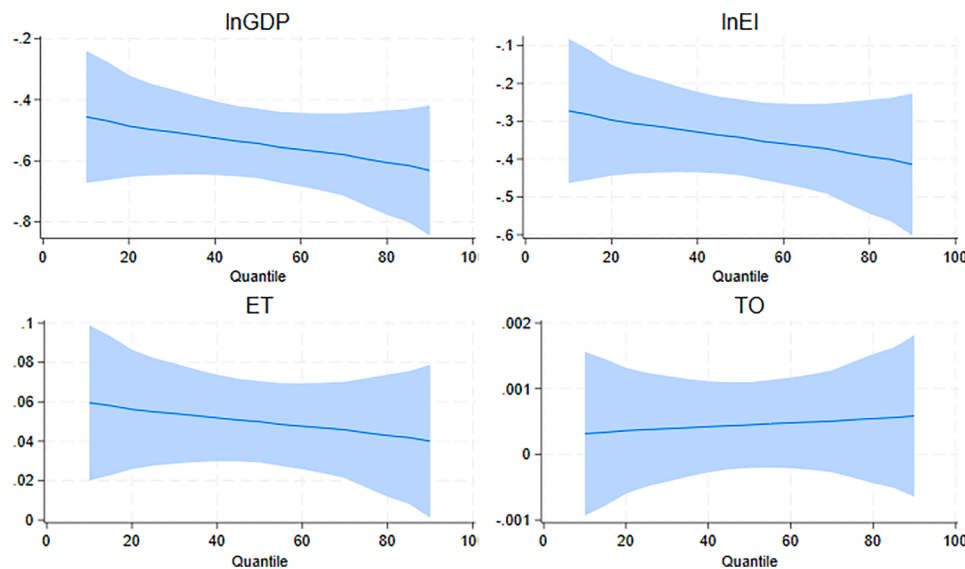
Notes: ***, ** and * denote 1%, 5% and 10% significance level, respectively. Numbers in parentheses represent standard errors. The heterogeneous pooled estimation method is employed with constant levels as the deterministic trend for all specifications. The Newey-West Automatic bandwidth is used to calculate the long-run variance estimator. The FMOLS estimation method uses heterogeneous long-run coefficients in the first stage of residuals calculation. A fixed number of lags and leads is selected for the DOLS estimation method.

Table 8

Quantile regression models (MMQR).

Variables	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
lnGDP	-0.456*** (0.110)	-0.486*** (0.084)	-0.505*** (0.071)	-0.525*** (0.061)	-0.543*** (0.061)	-0.563*** (0.061)	-0.579*** (0.069)	-0.606*** (0.087)	-0.632*** (0.109)
lnEI	-0.272*** (0.097)	-0.297*** (0.075)	-0.312*** (0.063)	-0.328*** (0.054)	-0.342*** (0.051)	-0.359*** (0.054)	-0.372** (0.060)	-0.393*** (0.077)	-0.414*** (0.096)
ET	0.060*** (0.020)	0.056*** (0.015)	0.054*** (0.013)	0.052*** (0.011)	0.050*** (0.010)	0.048*** (0.011)	0.046*** (0.013)	0.043*** (0.016)	0.040** (0.020)
TO	0.000 (0.001)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.001 (0.000)	0.001 (0.000)	0.001 (0.001)	0.001 (0.001)

Notes: ***, ** and * denote 1%, 5% and 10% significance level, respectively.

**Fig. 3.** Panel quantile graph.**Table 9**

Panel Granger causality tests.

H ₀	HPJ Wald-Stat	BIC selection
lnGDP does not Granger-cause lnLCF	5.072**	-2456.05* (1 lag)
lnLCF does not Granger-cause lnGDP	4.380**	-3193.82* (1 lag)
lnEI does not Granger-cause lnLCF	7.434***	-2450.23* (1 lag)
lnLCF does not Granger-cause lnEI	9.530***	-2858.17* (1 lag)
ET does not Granger-cause lnLCF	2.206	-2452.47* (1 lag)
lnLCF does not Granger-cause ET	0.039	-1567.17* (1 lag)
TO does not Granger-cause lnLCF	2.217	-2438.67* (1 lag)
lnLCF does not Granger-cause TO	19.719***	1175.77* (4 lags)

Notes: ***, ** and * denote 1%, 5% and 10% significance level, respectively. The bootstrapping approach is implemented.

environmental taxation suggests these tools remain effective levers for encouraging greener practices among industries and consumers alike and may warrant further strategic enhancement.

CRediT authorship contribution statement

Ioannis Kostakis: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Dimitrios Papadas:** Writing – review & editing, Writing – original draft, Validation, Investigation, Conceptualization. **Konstantinos P. Tsagarakis:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.sfr.2025.101183](https://doi.org/10.1016/j.sfr.2025.101183).

Data availability

Data will be made available on request.

References

- [1] H. Pollitt, Can economic growth last forever?. *Economic policies for sustainability and resilience* Springer, 2021, pp. 45–90.
- [2] P. Dasgupta, A. Dasgupta, S. Barrett, Global ecological footprint and the sustainable development goals, *Environ. Resour. Econ.* (2021).
- [3] U.K. Pata, C. Isik, Determinants of the load capacity factor in china: a novel dynamic ARDL approach for ecological footprint accounting, *Resour. Policy* 74 (2021) 102313, <https://doi.org/10.1016/j.resourpol.2021.102313>.
- [4] R. Siche, L. Pereira, F. Agostinho, E. Ortega, Convergence of ecological footprint and energy analysis as a sustainability indicator of countries: peru as case study, *Commun. Nonlinear Sci. Numer. Simul.* 15 (10) (2010) 3182–3192.
- [5] W.E. Rees, Ecological footprints and appropriated carrying capacity: what urban economics leaves out, *Environ. Urban.* 4 (2) (1992) 121–130.
- [6] M. Wackernagel, W. Rees, Our ecological footprint: reducing human impact on the earth, *New Soc. Publ* (1998).
- [7] U.K. Pata, Do renewable energy and health expenditures improve load capacity factor in the USA and japan? A new approach to environmental issues, *Eur. J. Health Econ.* 22 (9) (2021) 1427–1439.
- [8] B. Guloglu, A. Emre Caglar, U. Korkut Pata, Analyzing the determinants of the load capacity factor in OECD countries: evidence from advanced quantile panel data methods, *Gondwana Res.* 118 (2023) 92–104, <https://doi.org/10.1016/j.gr.2023.02.013>.
- [9] Y. Shang, A. Razzaq, S. Chupradit, N. Binh An, Z. Abdul-Samad, The role of renewable energy consumption and health expenditures in improving load capacity factor in ASEAN countries: exploring new paradigm using advance panel models, *Renew. Energy* 191 (2022) 715–722, <https://doi.org/10.1016/j.renene.2022.04.013>.
- [10] A.E. Caglar, U.K. Pata, M. Ulug, M.W. Zafar, Examining the impact of clean environmental regulations on load capacity factor to achieve sustainability: evidence from APEC economies, *J. Clean. Prod.* (2023) 139563, <https://doi.org/10.1016/j.jclepro.2023.139563>.
- [11] A. Juodis, Y. Karavias, V. Sarafidis, A homogeneous approach to testing for granger non-causality in heterogeneous panels, *Empir. Econ.* 60 (1) (2021) 93–112, <https://doi.org/10.1007/s00181-020-01970-9>.
- [12] G.M. Grossman, A.B. Krueger, Economic growth and the environment, *Q. J. Econ.* 110 (2) (1995) 353–377.
- [13] T. Panayotou, *Empir. Tests Policy Anal. Environ. Degrad. Differ. Stages Econ. Dev.* (1993).
- [14] N. Shafik, S. Bandyopadhyay, *Economic growth and environmental quality: time-series and cross-country evidence*, World Bank Publications, 1992.
- [15] S.A. Sarkodie, V. Strezov, A review on environmental kuznets curve hypothesis using bibliometric and meta-analysis, *Sci. Total Environ.* 649 (2019) 128–145, <https://doi.org/10.1016/j.scitotenv.2018.08.276>.
- [16] R. Alvarado, P. Ponce, A. Criollo, K. Córdova, M.K. Khan, Environmental degradation and real per capita output: new evidence at the global level grouping countries by income levels, *J. Clean. Prod.* 189 (2018) 13–20, <https://doi.org/10.1016/j.jclepro.2018.04.064>.
- [17] R. Ulucak, F. Bilgili, A reinvestigation of EKC model by ecological footprint measurement for high, middle and low income countries, *J. Clean. Prod.* 188 (2018) 144–157, <https://doi.org/10.1016/j.jclepro.2018.03.191>.
- [18] H. Altıntaş, Y. Kassouri, Is the environmental kuznets curve in europe related to the per-capita ecological footprint or CO2 emissions? *Ecol. Indic.* 113 (2020) 106187, <https://doi.org/10.1016/j.ecolind.2020.106187>.
- [19] S.T. Danish Hassan, M.A. Baloch, N. Mahmood, J. Zhang, Linking economic growth and ecological footprint through human capital and biocapacity, *Sustain. Cities Soc.* 47 (2019) 101516, <https://doi.org/10.1016/j.scs.2019.101516>.
- [20] A. Usman, I. Ozturk, S.M.M.A. Naqvi, S. Ullah, M.I. Javed, Revealing the nexus between nuclear energy and ecological footprint in STIRPAT model of advanced economies: fresh evidence from novel CS-ARDL model, *Prog. Nucl. Energy (New Ser.)* 148 (2022) 104220, <https://doi.org/10.1016/j.pnucene.2022.104220>.
- [21] S. Afshan, I. Ozturk, T. Yaqoob, Facilitating renewable energy transition, ecological innovations and stringent environmental policies to improve ecological sustainability: evidence from MM-QR method, *Renew. Energy* 196 (2022) 151–160, <https://doi.org/10.1016/j.renene.2022.06.125>.
- [22] C. Lee, M. Chen, W. Xu, Assessing the impacts of formal and informal regulations on ecological footprint, *Sustain. Dev. (Bradf. West Yorks. Engl.)* 30 (5) (2022) 989–1017, <https://doi.org/10.1002/sd.2295>.
- [23] Y. Liu, F. Sadiq, W. Ali, T. Kumail, Does tourism development, energy consumption, trade openness and economic growth matters for ecological footprint: testing the environmental kuznets curve and pollution haven hypothesis for pakistan, *Energy (Oxf.)* 245 (2022) 123208, <https://doi.org/10.1016/j.energy.2022.123208>.
- [24] D. Papadas, Exploring the nexus of economic growth, energy mix, services, trade openness, and environmental quality: evidence from N11 countries, *Dev. Sustain. Econ. Finance* 2-4 (2024) 100028, <https://doi.org/10.1016/j.dsef.2024.100028>.
- [25] R. Danish Ulucak, S. Khan, Relationship between energy intensity and CO2 emissions: does economic policy matter? *Sustain. Dev. (Bradf. West Yorks. Engl.)* 28 (5) (2020) 1457–1464, <https://doi.org/10.1002/sd.2098>.
- [26] J. Wang, K. Dong, What drives environmental degradation? Evidence from 14 sub-Saharan african countries, *Sci. Total Environ.* 656 (2019) 165–173, <https://doi.org/10.1016/j.scitotenv.2018.11.354>.
- [27] M. Usman, M.S.A. Makhadm, R. Kousar, Does financial inclusion, renewable and non-renewable energy utilization accelerate ecological footprints and economic growth? Fresh evidence from 15 highest emitting countries, *Sustain. Cities Soc.* 65 (2021) 102590, <https://doi.org/10.1016/j.scs.2020.102590>.
- [28] E.E. Çakmak, S. Acar, The nexus between economic growth, renewable energy and ecological footprint: an empirical evidence from most oil-producing countries, *J. Clean. Prod.* 352 (2022) 131548, <https://doi.org/10.1016/j.jclepro.2022.131548>.
- [29] Z. Ahmed, M. Ahmad, H. Rjoub, O.A. Kalugina, N. Hussain, Economic growth, renewable energy consumption, and ecological footprint: exploring the role of environmental regulations and democracy in sustainable development, *Sustain. Dev.* 30 (4) (2022) 595–605.
- [30] G. Jin, Z. Huang, Asymmetric impact of renewable electricity consumption and industrialization on environmental sustainability: evidence through the lens of load capacity factor, *Renew. Energy* 212 (2023) 514–522, <https://doi.org/10.1016/j.renene.2023.05.045>.
- [31] U. Mehmood, S. Tariq, M.U. Aslam, E.B. Agyekum, S.E. Uzunamure, K. Shale, M. Kamal, M.F. Khan, Evaluating the impact of digitalization, renewable energy use, and technological innovation on load capacity factor in G8 nations, *Sci. Rep.* 13 (1) (2023) 9131, <https://doi.org/10.1038/s41598-023-36373-0>.
- [32] U.K. Pata, A. Samour, Assessing the role of the insurance market and renewable energy in the load capacity factor of OECD countries, *Environ. Sci. Pollut. Res. Int.* 30 (16) (2023) 48604–48616, <https://doi.org/10.1007/s11356-023-25747-6>.
- [33] H.A. Fakher, M. Murshed, Does financial and economic expansion allow for environmental sustainability? Fresh insights from a new composite index and PSTIR analysis, *J. Environ. Plan. Manag.* 67 (12) (2024) 2885–2908, <https://doi.org/10.1080/09640568.2023.2205997>.
- [34] T. Abdulmagid Basheer Agila, W.M.S. Khalifa, S. Saint Akadiri, T.S. Adebayo, M. Altuntaş, Determinants of load capacity factor in South Korea: does structural change matter? *Environ. Sci. Pollut. Res.* 29 (46) (2022) 69932–69948, <https://doi.org/10.1007/s11356-022-20676-2>.
- [35] U.K. Pata, D. Balsalobre-Lorente, Exploring the impact of tourism and energy consumption on the load capacity factor in Turkey: a novel dynamic ARDL approach, *Environ. Sci. Pollut. Res.* 29 (9) (2022) 13491–13503, <https://doi.org/10.1007/s11356-021-16675-4>.
- [36] M. Shahbaz, S.A. Solarin, R. Sbia, S. Bibi, Does energy intensity contribute to CO2 emissions? A trivariate analysis in selected african countries, *Ecol. Indic.* 50 (2015) 215–224, <https://doi.org/10.1016/j.ecolind.2014.11.007>.
- [37] M. Murshed, An empirical analysis of the non-linear impacts of ICT-trade openness on renewable energy transition, energy efficiency, clean cooking fuel access and environmental sustainability in south asia, *Environ. Sci. Pollut. Res. Int.* 27 (29) (2020) 36254–36281, <https://doi.org/10.1007/s11356-020-09497-3>.
- [38] M. Aydin, Y.E. Turan, The influence of financial openness, trade openness, and energy intensity on ecological footprint: revisiting the environmental kuznets curve hypothesis for BRICS countries, *Environ. Sci. Pollut. Res. Int.* 27 (34) (2020) 43233–43245, <https://doi.org/10.1007/s11356-020-10238-9>.
- [39] J. Hou, J. Wang, J. Chen, F. He, Does urban haze pollution inversely drive down the energy intensity? A perspective from environmental regulation, *Sustain. Dev. (Bradf. West Yorks. Engl.)* 28 (1) (2020) 343–351, <https://doi.org/10.1002/sd.2022>.
- [40] F.J. Hasanov, R. Sbia, D. Papadas, I. Kostakis, The consumption-based carbon emissions effects of renewable energy and total factor productivity: the evidence from natural gas exporters, *Energy Rep.* 12 (2024) 5974–5989, <https://doi.org/10.1016/j.egyr.2024.11.054>.
- [41] I. Kostakis, D. Paparas, K.P. Tsagarakis, Disaggregated energy use and socioeconomic sustainability within OECD countries, *J. Environ. Manag.* 334 (2023) 117475, <https://doi.org/10.1016/j.jenvman.2023.117475>.
- [42] L.K. Chu, T.H. Tran, The nexus between environmental regulation and ecological footprint in OECD countries: empirical evidence using panel quantile regression, *Environ. Sci. Pollut. Res. Int.* 29 (33) (2022) 49700–49723, <https://doi.org/10.1007/s11356-022-19221-y>.
- [43] M. Murshed, M.A. Rahman, M.S. Alam, P. Ahmad, V. Dagar, The nexus between environmental regulations, economic growth, and environmental sustainability: linking environmental patents to ecological footprint reduction in south asia, *Environ. Sci. Pollut. Res. Int.* 28 (36) (2021) 49967–49988, <https://doi.org/10.1007/s11356-021-13381-z>.
- [44] D. Papadas, B. Ghosh, I. Kostakis, Investigating the role of energy mix and sectoral decomposition on environmental sustainability in selected European countries,

- Dev. Sustain. Econ. Finance 1 (2024) 100001, <https://doi.org/10.1016/j.dsef.2024.100001>.
- [45] S.P. Nathaniel, C.J. Solomon, K.B. Ajide, Z. Ahmed, H.A. Fakher, Striving towards carbon neutrality in emerging markets: the combined influence of international tourism and eco-friendly technology, *Int. J. Sustain. Dev. World Ecol.* 30 (7) (2023) 760–775, <https://doi.org/10.1080/13504509.2023.2195831>.
- [46] L. Dauda, X. Long, C.N. Mensah, M. Salman, K.B. Boamah, S. Ampon-Wireko, C. S. Kofi Dogbe, Innovation, trade openness and CO2 emissions in selected countries in africa, *J. Clean. Prod.* 281 (2021) 125143, <https://doi.org/10.1016/j.jclepro.2020.125143>.
- [47] D.C. Ekwueme, J.D. Zoaka, Effusions of carbon dioxide in MENA countries: inference of financial development, trade receptivity, and energy utilization, *Environ. Sci. Pollut. Res. Int.* 27 (11) (2020) 12449–12460, <https://doi.org/10.1007/s11356-020-07821-5>.
- [48] S. Farhani, S. Mrizak, A. Chaibi, C. Rault, The environmental kuznets curve and sustainability: a panel data analysis, *Energy Policy*. 71 (2014) 189–198, <https://doi.org/10.1016/j.enpol.2014.04.030>.
- [49] B. Li, N. Haneklaus, The role of clean energy, fossil fuel consumption and trade openness for carbon neutrality in china, *Energy Rep.* 8 (2022) 1090–1098, <https://doi.org/10.1016/j.egyr.2022.02.092>.
- [50] U. Al-mulali, C.F. Tang, I. Ozturk, Does financial development reduce environmental degradation? Evidence from a panel study of 129 countries, *Environ. Sci. Pollut. Res. Int.* 22 (19) (2015) 14891–14900, <https://doi.org/10.1007/s11356-015-4726-x>.
- [51] A. Mavragani, I.E. Nikolaou, K.P. Tsarakis, Open economy, institutional quality, and environmental performance: a macroeconomic approach, *Sustainability* 8 (7) (2016) 601.
- [52] S. Saud, S. Chen, A. Haseeb, K. Khan, M. Imran, The nexus between financial development, income level, and environment in central and eastern european countries: a perspective on belt and road initiative, *Environ. Sci. Pollut. Res. Int.* 26 (16) (2019) 16053–16075, <https://doi.org/10.1007/s11356-019-05004-5>.
- [53] M.T. Heil, T.M. Selden, International trade intensity and carbon emissions: a cross-country econometric analysis, *J. Environ. Dev.* 10 (1) (2001) 35–49, <https://doi.org/10.1177/107049650101000103>.
- [54] T. Le, Y. Chang, D. Park, Trade openness and environmental quality: international evidence, *Energy Policy*. 92 (2016) 45–55, <https://doi.org/10.1016/j.enpol.2016.01.030>.
- [55] M.C. Udeagha, M.C. Breitenbach, The role of financial development in climate change mitigation: fresh policy insights from south africa, *BioPhys. Econ. Resour. Qual.* 8 (1) (2023) 1–34, <https://doi.org/10.1007/s41247-023-00110-y>.
- [56] N. Kongbuamai, M.W. Zafar, S.A.H. Zaidi, Y. Liu, Determinants of the ecological footprint in thailand: the influences of tourism, trade openness, and population density, *Environ. Sci. Pollut. Res. Int.* 27 (32) (2020) 40171–40186, <https://doi.org/10.1007/s11356-020-09977-6>.
- [57] A.A. Alola, F.V. Bekun, S.A. Sarkodie, Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in europe, *Sci. Total Environ.* 685 (2019) 702–709, <https://doi.org/10.1016/j.scitotenv.2019.05.139>.
- [58] M.A. Destek, A. Sinha, Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: evidence from organisation for economic co-operation and development countries, *J. Clean. Prod.* 242 (2020) 118537, <https://doi.org/10.1016/j.jclepro.2019.118537>.
- [59] W. Lu, The interplay among ecological footprint, real income, energy consumption, and trade openness in 13 asian countries, *Environ. Sci. Pollut. Res. Int.* 27 (36) (2020) 45148–45160, <https://doi.org/10.1007/s11356-020-10399-7>.
- [60] S. Sabir, M.S. Gorus, The impact of globalization on ecological footprint: empirical evidence from the south asian countries, *Environ. Sci. Pollut. Res. Int.* 26 (32) (2019) 33387–33398, <https://doi.org/10.1007/s11356-019-06458-3>.
- [61] I. Kostakis, J. Arauzo-Carod, The key roles of renewable energy and economic growth in disaggregated environmental degradation: evidence from highly developed, heterogeneous and cross-correlated countries, *Renew. Energy* 206 (2023) 1315–1325, <https://doi.org/10.1016/j.renene.2023.02.106>.
- [62] J. Peng, Y. Wang, X. Zhang, Y. He, M. Taketani, R. Shi, X. Zhu, Economic and welfare influences of an energy excise tax in jiangsu province of china: a computable general equilibrium approach, *J. Clean. Prod.* 211 (2019) 1403–1411.
- [63] M.Z. Rafique, Z. Fareed, D. Ferraz, M. Ikram, S. Huang, Exploring the heterogeneous impacts of environmental taxes on environmental footprints: an empirical assessment from developed economies, *Energy* 238 (2022) 121753, <https://doi.org/10.1016/j.energy.2021.121753>.
- [64] G. Fang, K. Yang, G. Chen, L. Tian, Environmental protection tax superseded pollution fees, does china effectively abate ecological footprints? *J. Clean. Prod.* 388 (2023) 135846, <https://doi.org/10.1016/j.jclepro.2023.135846>.
- [65] U.K. Pata, A. Samour, Do renewable and nuclear energy enhance environmental quality in France? A new EKC approach with the load capacity factor, *Prog. Nucl. Energy* 149 (2022) 104249, <https://doi.org/10.1016/j.pnucene.2022.104249>.
- [66] M. Grossman, B. Krueger, *Environ. Impacts N. Am. Free Trade Agreem.* (1991).
- [67] F.J. Hasanov, Z. Khan, M. Hussain, M. Tufail, Theoretical framework for the carbon emissions effects of technological progress and renewable energy consumption, *Sustain. Dev. (Bradf. West Yorks. Engl.)* 29 (5) (2021) 810–822, <https://doi.org/10.1002/sd.2175>.
- [68] M.H. Pesaran, Testing weak cross-sectional dependence in large panels, *Econom. Rev.* 34 (6–10) (2015) 1089–1117.
- [69] M.H. Pesaran, General diagnostic tests for cross-sectional dependence in panels, *Empir. Econ.* 60 (1) (2021) 13–50.
- [70] A. Juodis, S. Reese, The incidental parameters problem in testing for remaining cross-section correlation, *J. Bus. Econ. Stat.* 40 (3) (2022) 1191–1203.
- [71] J. Fan, Y. Liao, J. Yao, Power enhancement in high-dimensional cross-sectional tests, *Econometrica* 83 (4) (2015) 1497–1541.
- [72] M.H. Pesaran, Y. Xie, A bias-corrected CD test for error cross-sectional dependence in panel data models with latent factors, *Arxiv Prepr. (2021) arXiv:2109.00408*.
- [73] M.H. Pesaran, T. Yamagata, Testing slope homogeneity in large panels, *J. Econom.* 142 (1) (2008) 50–93.
- [74] J. Blomquist, J. Westerlund, Panel bootstrap tests of slope homogeneity, *Empir. Econ.* 50 (2016) 1359–1381.
- [75] T. Bersvendson, J. Ditzgen, Testing for slope heterogeneity in stata, *Stata J.* 21 (1) (2021) 51–80.
- [76] M.H. Pesaran, A simple panel unit root test in the presence of cross-section dependence, *J. Appl. Econom.* 22 (2) (2007) 265–312.
- [77] P. Pedroni, Critical values for cointegration tests in heterogeneous panels with multiple regressors, *Oxf. Bull. Econ. Stat.* 61 (S1) (1999) 653–670.
- [78] P. Pedroni, Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis, *Econom. Theory* 20 (3) (2004) 597–625.
- [79] C. Kao, Spurious regression and residual-based tests for cointegration in panel data, *J. Econom.* 90 (1) (1999) 1–44.
- [80] J. Westerlund, New simple tests for panel cointegration, *Econom. Rev.* 24 (3) (2005) 297–316.
- [81] J. Westerlund, Testing for error correction in panel data, *Oxf. Bull. Econ. Stat.* 69 (6) (2007) 709–748.
- [82] J.C. Driscoll, A.C. Kraay, Consistent covariance matrix estimation with spatially dependent panel data, *Rev. Econ. Stat.* 80 (4) (1998) 549–560.
- [83] J.A. Machado, J.S. Silva, Quantiles via moments, *J. Econom.* 213 (1) (2019) 145–173.
- [84] A. Zakari, I. Khan, D. Tan, R. Alvarado, V. Dagar, Energy efficiency and sustainable development goals (SDGs), *Energy* 239. (2022) 122365, <https://doi.org/10.1016/j.energy.2021.122365>.
- [85] S. Erdogan, On the impact of natural resources on environmental sustainability in african countries: a comparative approach based on the EKC and LCC hypotheses, *Resour. Policy* 88 (2024) 104492, <https://doi.org/10.1016/j.resourpol.2023.104492>.
- [86] A. Mardani, D. Streimikiene, F. Cavallaro, N. Loganathan, M. Khoshnoudi, Carbon dioxide (CO2) emissions and economic growth: a systematic review of two decades of research from 1995 to 2017, *Sci. Total Environ.* 649 (2019) 31–49, <https://doi.org/10.1016/j.scitotenv.2018.08.229>.
- [87] M. Ramzan, K.R. Abbasi, H.A. Iqbal, T.S. Adebayo, What's at stake? The empirical importance of government revenue and debt and renewable energy for environmental neutrality in the US economy, *Renew. Energy*. 205 (2023) 475–489.
- [88] K. Bithas, P. Kalimeris, E. Koilakou, Re-estimating the energy intensity of growth with implications for sustainable development. The myth of the decoupling effect, *Sustain. Dev.* 29 (2) (2021) 441–452.
- [89] M.T. Kartal, Impact of environmental tax on ensuring environmental quality: quantile-based evidence from G7 countries, *J. Clean. Prod.* (2024) 140874, <https://doi.org/10.1016/j.jclepro.2024.140874>.