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Harmonising progress: assessing the impact of economic freedom, economic growth, urbanisation and environmental protection expenditures on load capacity in selected European Union countries

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Abstract

This study investigates the relationships between the load capacity factor and urbanization, environmental protection expenditures, economic freedom and economic growth in the European Union from 1996 to 2021. The main motivation is the need for sustainable policies that reduce environmental degradation while promoting economic development. The analysis is conducted with empirical methods such as common correlated effects and augmented mean group using panel data from 24 European Union Countries. The results show that urbanization increases load capacity and can support sustainable practices when well managed. The impact of spending on environmental protection varies across countries, improving environmental quality in some regions but being counterproductive in others. The relationship between economic freedom and growth is complex; economic growth increases environmental pressure, emphasizing the need for green technologies. This highlights the need for sustainable development..

Keywords Load capacity factor, AMG, CCE, Panel data analysis, European Union, Sustainable development

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Graphical Abstract

Introduction

The most pressing global problem today is environmental destruction. Therefore, promoting sustainable ecological policies has become essential for all countries. Urbanization (UR) is an unstoppable global trend shaping the economic, social and environmental landscapes of the entire world [78]. As people migrate to urban areas, these centers become epicenters of economic activity and innovation. However, UR also brings challenges, especially in balancing economic growth (GDP) and environmental sustainability [32]. The relationship between urbanization, environmental protection expenditure, EF and GDP is intricate and affects the load capacity factor (LCF), that is, the ability of the environment to sustain human activities without suffering irreversible damage. Understanding these dynamics is crucial to formulating policies that promote sustainable development.

UR is a defining phenomenon of modern times, marked by the migration of the population from rural areas to urban areas [37]. This change is driven by the search for better economic opportunities, living standards, and access to services and infrastructure. Cities that are the locomotives of economic growth,It offers many advantages, such as economies of scale, rapid access to markets and increased productivity. Concentration of resources and talent in urban areas stimulates GDP and development by encouraging innovation, entrepreneurship and industrialization [40]. UR is not entirely detrimental to environmental quality. Well-planned urban areas promote sustainable living practices and reduce per capita resource consumption. Planned cities reduce transport emissions by encouraging public transport, walking and cycling. Urban areas also serve as centers for innovation and environmental management, leading to the development and implementation of green technologies and policies aimed at reducing environmental impacts (Oliveira, [52]). However, the rapid pace of UR also brings with it important problems. The expansion of urban areas often leads to overconsumption of natural resources, increased pollution and significant environmental degradation [34]. Urban sprawl, inadequate infrastructure and inefficient resource use strain the environment, reducing its capacity to sustainably support human activities. The balance between urban growth and environmental sustainability is, therefore, a critical issue [22]. As a result, the relationship between urbanization and environmental quality is characterized by both challenges and opportunities. While UR often leads to environmental degradation, it also provides opportunities for the implementation of sustainable practices and technologies. Addressing the environmental challenges associated with UR requires integrated planning, stringent environmental regulations and the promotion of green infrastructure. As urban populations continue to grow, it is imperative to balance development and environmental sustainability to ensure a livable future for all [66].

Environmental protection expenditures are of great importance to reduce the negative effects of UR on the environment [44]. These expenditures include investments in pollution control technologies, renewable energy sources, green infrastructure, waste management and conservation efforts. Governments and organizations reduce the negative environmental impacts associated with urban growth by allocating resources to environmental protection [12]. The relationship between environmental protection expenditures and the LCF is essentially based on the idea that increased expenditures on environmental protection can increase the environment's ability to sustain human activities. This recovery occurs through a variety of mechanisms, including pollution reduction, restoration of degraded ecosystems, and implementation of sustainable practices [16]. In addition, environmental protection expenditures play an important role in protecting biodiversity and natural habitats. Investments in the establishment and management of protected areas, such as national parks and wildlife reserves, protect critical ecosystems and species from human intervention and exploitation [18]. These protected areas serve as reservoirs of biodiversity, maintain ecological balance, and provide ecosystem services that support human well-being. For example, protecting forest areas not only protects biodiversity, but also increases carbon sequestration, regulates water cycles, and prevents soil erosion [76]. However, the effectiveness of environmental protection expenditures in increasing the LCF depends on various factors, such as the adequacy of financing, the effectiveness of resource allocation and the effectiveness of implementation [35]. Adequate financing is essential to ensure that environmental protection measures are comprehensive and sustainable. Insufficient funding leads to incomplete projects, inadequate maintenance, and limited impact. Effective resource allocation ensures that funds are directed to the most pressing environmental problems and the most effective solutions. This requires a comprehensive understanding of environmental challenges and the potential benefits of different interventions [71].

As a result, the relationship between environmental protection expenditures and the LCF is multifaceted and is affected by various factors, such as financing adequacy, resource allocation efficiency, implementation effectiveness, policy measures, international cooperation and public participation. Increased environmental protection spending increases the LCF by reducing pollution, restoring ecosystems, preserving biodiversity and promoting sustainable practices. However, the success of these expenditures depends on their strategic allocation, effective implementation, and supporting policy and regulatory frameworks. As environmental challenges continue to grow, it is imperative to prioritize and optimize environmental protection spending to ensure a sustainable future for both humanity and the natural world [21].

Economic freedom, defined as the ease of doing business and the absence of excessive government intervention, is a key driver of GDP and development [60]. High levels of economic freedom (EF) are associated with greater entrepreneurial activity, innovation and efficient resource allocation. EF in urban areas facilitates the development of new technologies, industries and sustainable practices that contribute to GDP and environmental protection [5]. The relationship between EF and environmental sustainability is multifaceted. EF fosters a competitive business environment, innovation, and the adoption of green technologies and sustainable practices. For example, businesses in economically free environments are more likely to invest in energy-efficient technologies, sustainable supply chains, and corporate social responsibility initiatives [61]. On the other hand, EF without adequate regulatory frameworks leads to environmental neglect. The pursuit of deregulation and profit maximization results in unsustainable resource extraction, pollution and environmental degradation. Therefore, it is very important to strike a balance between EF and environmental protection. Effective governance and regulatory mechanisms are required to ensure that economic activities do not compromise environmental sustainability (Bektur, 2023). EF is intricately linked to a variety of issues, including human development, high levels of well-being, a healthy society, a clean environment, increased individual wealth, and democracy [10]. Many researchers argue that EF increases market efficiency and competitiveness, allowing more efficient and less resource use. It is believed that EF combined with environmental regulations aimed at producing clean goods and services for market consumers can reduce environmental degradation. Conversely, some researchers argue that EF encourages trade liberalization, leading many capital-intensive industries to shift towards more polluting activities. Moreover, EF stabilizes the macroeconomic environment in the long term, creates a safer investment environment, and potentially increases environmental degradation through resource-intensive industry combinations [48]. EF is also associated with a variety of social benefits, such as greater prosperity, a healthier society, a cleaner environment, human development, democracy and poverty reduction. Researchers argue that EF increases market efficiency and competitiveness, which leads to more efficient resource use. While it is assumed that EF combined with ecological regulations can reduce environmental degradation, there is also concern that it will encourage trade liberalization, leading to a shift towards more polluting industries. In addition, a stable macroeconomic environment attracts investments that lead to resource-intensive industrial mergers, which further affects environmental quality [23].

The relationship between GDP and LCF is critical for sustainable development and environmental balance. While GDP increases a country's level of prosperity, it also creates significant effects on the use of natural resources and environmental pressure [72]. The

LCF refers to the capacity of an ecosystem or natural environment to withstand the damage caused by human activities. This concept aims at the sustainable use of natural resources and prevention of environmental destruction [53]. The positive effects of GDP include factors, such as increasing income levels, employment opportunities and rising living standards. However, this growth also leads to negative consequences, such as overuse of natural resources and environmental pollution [45]. For example, intensive activities in the industrial and agricultural sectors cause water, soil and air pollution. This situation strains the load capacity of ecosystems and threatens environmental sustainability in the long term [72]. To maintain this delicate balance between GDP and LCF sustainable development goals (SDGs) are gaining importance [19]. In this context, targets such as SDGs 7 and 13 aim to preserve the capacity of future generations to meet their needs, taking into account the environmental and social dimensions of economic growth. In this context, the use of renewable energy sources, increasing energy efficiency and promoting environmentally friendly technologies both support GDP and reduce environmental pressure [13, 14].

The relationship between UR, environmental protection expenditures, EF and GDP variables and the LCF is multifaceted. Figure 1 shows the relationship between the variables. As UR continues to shape the global landscape, understanding these dynamics is vital to formulating policies that promote stable growth and environmental protection. By examining the synergies and trade-offs that exist in these interactions, this paper aims to provide a comprehensive understanding of how UR, environmental protection expenditure (EPE), EF and GDP can be aligned to promote sustainable environmental quality. The extensive literature review suggests that the variables we consider have impacts on environmental quality. However, this study is of critical importance, because; i) it is the first empirical investigation of the relationships among EPE, UR, EF, GDP and LCF, which are undoubtedly interconnected and closely related to environmental quality; ii) the study uses a comprehensive data set covering 24 European Union countries, spanning from 1996 to 2021. This comprehensive time period allows for the analysis of long-term trends and the effects of policy changes over time, which is a significant strength compared to studies with shorter time horizons; and iii) the study uses robust and advanced econometric methods, particularly the augmented average group (AMG) and common correlated effects (CCE) estimators. These methods provide more accurate and reliable results compared to traditional econometric techniques by accounting for cross-sectional dependence and heterogeneity across countries. iv) Unlike many studies that focus on common environmental quality measures, such as CO_2 emissions or ecological footprints, this study emphasizes the load capacity factor (LCF) as the primary dependent variable. LCF measures the capacity of the environment to support human activities without irreversible damage and offers a unique perspective on sustainable development. v) The comprehensive analysis of how EF affects LCF through environmental and economic policies distinguishes this study from others and makes it an important reference for policy makers and urban planners. vi) The study's innovative approach in linking EF to environmental protection efforts provides a new understanding of how LCF changes while improving environmental quality. vii) The findings of the study provide actionable insights for policy makers by highlighting the nuanced impacts of EF, EPE, EF and GDP on environmental sustainability. The results suggest specific policy recommendations to balance economic growth with environmental protection, making the research highly relevant for informing sustainable development policies. Moreover, considering the model used, the study is expected to fill an important gap in the literature. The rest of the paper is structured as follows. Sect. "Literature review" presents similar studies in the literature. Sect. "Data, model, and methodology" describes the data, econometric models, and methodological structure used in the study. Sect. "Discussion, conclusions and limitations" provides the econometric test results. Section "Data" discusses the test results, offers solutions to the problems identified, and provides a scientific path for future studies.

Fig. 1 Variables used in the study. Source: It is built using artificial intelligence tools and ready-made images.

Literature review

Today, in parallel with the increasing negative effects of global warming on the world, studies on improving environmental quality have gained importance in the literature. The impact of variables intertwined with economy and environment on environmental quality has an important place in sustainable environmental policy discussions. This study examines the effects of EF, EPE, UR and GDP on environmental quality. In the literature summary, studies examining the relationship between the variables used in the study and environmental quality are presented under four subheadings.

Table 1 contains existing studies in the literature investigating the relationship between EF and environmental quality. Shahnazi and Shabani [63] found a U-shaped relationship between EF and CO_2 emissions in their study using 2000–2017 data, especially for EU countries. Sart et al. [62] found bidirectional causality between EF and CO_2 emissions in EU countries. Alola et al. [8] reported that EF increases EF in G-20 countries. Işık et al. [39] found that the impact of EF on environmental quality was higher in BRIC countries and weaker in G7 countries.

Table 2 shows that the relationship between UR and environmental quality varies significantly across different regions and periods. Although UR is associated with improved environmental outcomes, such as lower CO_2 emissions or lower LCF, it also causes environmental degradation in some regions, such as sub-Saharan Africa, OECD countries, Mexico, and major economies, such as the United States and Canada. UR banization appears to increase LCF in other regions, such as West Africa, China, Pakistan, and the broader Asia–Pacific region. The mixed results highlight the complexity of the impact of UR on environmental quality, which is influenced by regional policies, economic conditions, and methodologies used in the studies.

Examining the studies discussed in Table 3 shows that the results largely depend on the region, time and methodology used. Some studies, particularly in the European Union and Brazil, show improvements in environmental

Table 1 Economic freedom and environmental quality

Authors	Countries	Periods	Method	Result
Joshi and Beck [41]	109 nations	1995–2010	GMM Estimation	Mixed results
Adesina and Mwamba [3]	24 African countries	1995–2013	GMM Estimation	Reduces environmental degradation
Shahnazi and Shabani [63]	EU Countries	2000–2017	GMM estimation	U-shaped effect on CO_2
Koçak et al. [43]	48 Sub-Saharan African countries	2010–2016	Quantile regression technique	Lowers CO_2
Assi et al. [11]	ASEAN + 3 Countries	1998–2018	Panel ARDL	Lowers clean energy
Alola and Nwulu [7]	Russia	1995–2018	ARDL	Insignificant impact on CO_2
Majeed et al. [47]	Pakistan	1990–2019	ARDL	Lowers CO_2 in the long term
Alola et al. [8]	G-20 Countries	2000–2016	GMM estimation	Increases EF
Sart et al. [62]	EU Countries	2000–2018	Bootstrap Granger causalitY	Bidirectional causality with CO_2
Alola et al. [9]	G7 countries	2000–2016	AMG and CCEMG Estimation	Lowers Environmental Quality
Işık et al. [39]	G7 and BRIC countries	1996–2019	Panel ARDL	Mixed results

Table 2 Urbanization and environmental quality

Authors	Countries	Periods	Method	Result
Adams et al. [1]	sub-Saharan Africa	1980–2011	IV-GMM estimator	Lowers CO_2
Solarin et al. [65]	Nigeria	1977–2016	ARDL	No environmental degradation
Radoine et al. [58]	Western Africa Countries	1991–2018	Driscoll–Kraay (DK) panel regression	Increasing environmental degradation
Khan et al. [42]	China	1971–2016	FMOLS, DOLS, CRR	Deteriorates environmental quality
Xu et al. [77]	Brazil	1970–2017	ARDL	No environmental degradation
Guloglu et al. [33]	26 OECD countries	1980–2018	QMG estimator	Lowers LCF
Raihan et al. [59]	Mexico	1971–2018	ARDL	Lowers LCF
Teng et al. [68]	France, USA, Canada, China, Russia	1990–2021	CS-ARDL	Lowers LCF
Lin & Ullah [46]	Pakistan	1970–2021	DARDL	increases LCF
Sun et al. [67]	17 Asian–Pacific Economic Cooperation countries	1990–2019	CCEMG tests	increases LCF

Table 3 Environmental protection expenditures and environmental quality

Authors	Countries	Periods	Method	Result
Drăcea et al. [24]	Romania	2009–2018	Dynamic Models	Lowers EFP
Moshiri & Daneshmand [49]	Iran	1976–2014	ARDL	No impact on EFP
Fan et al. [28]	286 Cities in China	2007–2017	GMM model	Increasing environmental quality
Wu & Chen [75]	31 Cities in China	2007–2020	Porter Hypothesis	Increasing environmental degradation
Aydin et al. [15]	European Union	1995–2018	CS-ARDL	Mixed Result
Caglar & Yavuz [18]	European Union	1995–2018	CS-ARDL	Lowers LCF
Bozatli & Akca [16]	Netherlands	1996–2021	ARDL	Increases LCF
Akdag et al. [6]	European Union	1995–2019	GMM Panel	Environmental quality improved
Costa Holanda et al. [20]	Brazil	2011–2020	Pooled regression model	Environmental quality improved

quality or reductions in environmental footprint, while studies in the Netherlands and certain cities in China report mixed or negative effects. The variability in results highlights the complexity of environmental factors and the influence of local policies, economic conditions, and analytical methods.

When we look at the studies discussed in Table 4; The relationship between GDP and environmental quality appears to have different results depending on countries and regions. Umar et al. (2021) found that GDP in the US led to an increase in CO_2 emissions. Nguyen [50] reported that GDP in Southeast Asia resulted in lower CO_2 emissions. Sharma et al. [64] investigate the extent of the ecological footprint of GDP in the European Union. Addai et al. [2] identified a long-run unidirectional causality from GDP to increasing ecological footprint in Eastern Europe. Ahmed et al. [5] found that GDP in G-11 countries increases the ecological footprint. Aydin et al. [15] and Fakher et al. [27] both observed mixed results for the European Union and OPEC countries, respectively,this shows that the relationship between GDP and quality can vary significantly depending on different factors and linkages.

Literature gap

Most existing research focuses primarily on environmental quality metrics, such as CO_2 emissions and ecological footprints, with limited attention given to the LCF as the dependent variable. More studies are needed to investigate how economic and environmental factors directly affect LCF. While EF is often linked to overall GDP and development, its specific impact on LCF has not been well researched. The interaction between regulatory policies, market freedom and load capacity in the environmental context has not been adequately investigated. UR is known to affect environmental quality and resource use, but its direct relationship with LCF has not been fully examined. Understanding how urban growth and infrastructure development affects load capacity can provide insight into sustainable urban planning. The role

Table 4 Economic growth and environmental quality

Authors	Countries	Periods	Method	Result
Umar et al. [69]	USA	1981Q1–2019Q4	DOLS, FMOLS, CCR	Increases CO_2
Sharma et al. [64]	European Union	1990–2016	Arellano-Bond dynamic panel	LOWERS EFP
Addai et al. [2]	Eastern European countries	1998Q4–2017Q4	Dumitrescu–Hurlin causality	Long-term unidirectional causality to EFP
Ahmad et al. [4]	G-11 countries	1990–2018	CS-ARDL	Increases EFP
Aydin et al. [15]	European Union	1995–2018	CS-ARDL	Mixed Result
Fakher et al. [27]	Organization of the Petroleum Exporting Countries	1994–2019	DOLS, and FMOLS	Mixed Result
Nguyen [50]	Southeast Asian countries	1990–2019	ARDL	Lowers CO_2
Wang et al. [72]	BRICS	1990–2018	LM-Bootstrap	Lowers LCF
Olaoye [51]	selected African Countries	1981–2019	FMOLS, DOLS	Environmental quality improved

of government and private spending on environmental protection in improving or sustaining LCF is an area with limited empirical evidence. More research is needed to evaluate the effectiveness of these expenditures in reducing environmental stress and increasing load capacity. As a result of the extensive literature review, no study was found in which variables that are intricately connected to each other were used together. However, it is essential to use these variables together for environmental sustainability. Thanks to the findings obtained in this study, attention will be drawn to this gap and will shed light on new studies.

Data, model, and methodology

Data

This research investigates the impact of GDP growth (GDP), Economic Freedom (EF), Urbanization (UR) and Environmental protection expenditures (EPE) on load capacity factor (LCF) in countries. The study uses panels of 24 European Union countries selected for the period 1996–2021. Data sources are detailed in Table 5.

Table 6 summarizes descriptions of the model variables.

Logarithms have been taken for all data used. There are 624 observations in total. The average LCF value is 0.6223, which is below the expected threshold of 1. According to LCF theory, the threshold of 1 indicates a sustainable environment. This value indicates that sustainable environmental policies are insufficient. In the study with 24 selected EU countries, the average GDP value is at high levels with 30.6 thousand $. The average UR is 71.115, EF is 67.5226 and EPE is 0.6936. The VIF values of the explanatory variables are below 5, meaning that there is no multicollinearity problem.

Model

The model to be used in this study is shown in the following equation:

$$lnLCF_{ct} = \beta_{0c} + \beta_{1c}lnGDP_{ct} + \beta_{2c}lnEF_{ct} + \beta_{3c}lnUR_{ct} + \beta_{4c}lnEPE_{ct} + \varepsilon_{\mathrm{ct}} \tag{1}$$

where c, t, and ε_{ct} denote the countries, the time, and the error term, respectively. $\beta_{0c,1c,2c,3c,4c}$ are the coefficients of constant, GDP, EF, UR, and EPE, respectively. LCF, GDP, EF, UR, and EPE are employed in natural logarithm form.

Methodology and empirical results

The first step in panel data analysis is to test for cross-sectional dependence and slope heterogeneity. cross-sectional dependence test refers to the condition that the cross-sectional units that make up the panel data are in a relationship with the effect of globalization. The cross-sectional dependence (CSD) of the variables and the model is examined by CDLM1 [17], CDLM2 and Pesaran CD tests [54, 55]. The null and alternative hypotheses for this test are null and alternative hypotheses, respectively. Slope homogeneity is examined with Pesaran and Yamagata's [57] test, where the null and alternative hypotheses are homogeneous and heterogeneous slopes, respectively. Then, the stationarity of the variables is examined, the existence of cointegration between the variables is tested and long-run coefficient

Table 5 Descriptions of the variables

Variables	Description	Source
Load capacity factor (LCF)	Global hectares per person	Global Footprint Network
Urbanization (UR)	(% of GDP)	World Bank
Economic freedom (EF)	Index	American Heritage Foundation
Environmental protection expenditures (EPE)	(% of GDP)	International Monetary Fund
Economic growth (GDP)	GDP per capita (constant 2015 US$)	World Bank

Table 6 Descriptive statistics

Variables	Obs	Mean	Std. Dev	Min	Max	VIF
LCF[a]	624	0.622334	0.464068	0.066004	2.362295	–
GDP[b]	624	33,635.63	24,206.23	3540.556	112,417.9	1.12
EF[bc]	624	67.5226	7.04623	45.7	82.6	1.28
UR[b]	624	71.11507	11.54938	51.77	98.117	1.18
EPE[b]	624	0.693654	0.345936	0.030294	1.77907	1.05

[a] Global Footprint Network [30], [b] World Bank [74], [c] American Heritage Foundation [10], [d] International Monetary Fund [38]

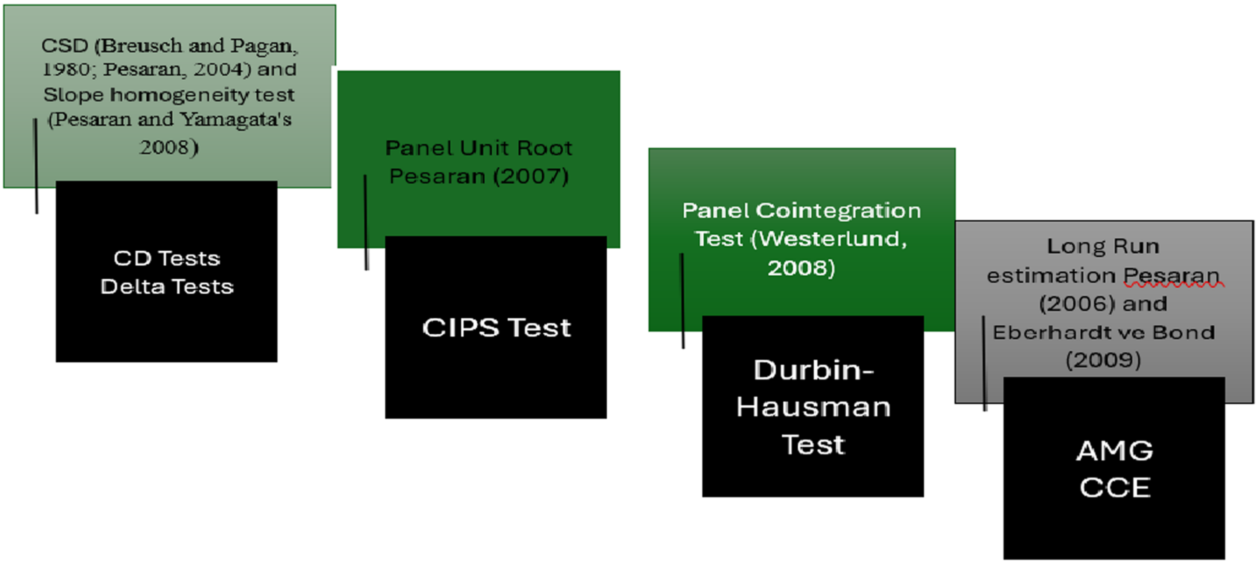

Fig. 2 Methodology. Source: Created by the author

estimates are made. Figure 2 illustrates the methodological steps of panel data analysis in this study.

Errors in panel data models are assumed to be independent across units [54, 55]. However, it shows that the independent variables included and excluded in the model are in a relationship with a common shock. This implies that any shock that may occur in any panel unit may also affect other units [36, 55]. This situation is analyzed by the LM test proposed by Breusch and Pagan [17]. These test statistics are based on the square of the correlation between the cross-sectional units. These test statistics are used when (T > N) is very large. The test statistics for this test are

$$CD_{LM1} = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{p}_{ij}^{2} \tag{2}$$

To address this issue, Pesaran [54, 55] proposed the Lagrange multiplier (LM) test, which is a CD $_{LM2}$ test that takes into account the larger time and cross-sectional dimension. These test statistics are used when (T > N) is not very large. CD $_{LM2}$ test statistic:

$$CD_{LM2} = \sqrt{\frac{1}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(T\hat{p}_{ij}^{2}-1)\right) \tag{3}$$

This test statistic is not normally distributed when the time dimension is larger than the cross-sectional dimension and the CD test was proposed in the same paper. CD test statistic:

$$\mathrm{CD} = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\mathrm{p}}_{ij}\right) \tag{4}$$

In this test, it is used in (N > T) cases.

In all 3 test statistics, $\widehat{p}_{ij}^{2}$ denotes the correlation between errors, where and N denote the squares of the estimated pairwise correlation of among the residuals and countries, respectively. In all 3 test statistics, pij denotes the correlation between errors. The null hypothesis in all three proposed tests is that there is no cross-sectional dependence.

The test methods to be used in panel data analysis are shaped according to the results of cross-sectional dependence and slope homogeneity tests. For this reason, the Delta homogeneity test developed by Pesaran and Yamagata [57] is used for slope homogeneity in the second stage. Another factor in using this test is to report the results within units if the slope coefficients generated in the panel model have a heterogeneous structure. Two statistics are proposed for this test. The statistics for this test, which differs according to the sample size, are as follows:

Test statistic used for large samples:

$$\hat{\Delta} = \sqrt{N} = \left(\frac{N^{-1}\tilde{S}-k}{\sqrt{2k}}\right) \tag{5}$$

Test statistic for small samples:

Table 7 CSD and slope homogeneity

Variables	CD_{LM1}	CD_{LM2}	Pesaran CD
Lnlcf	1769.21*	63.55540*	31.14338*
Lngdp	5260.124*	212.1384*	68.38420*
Lngdp2	5245.256*	211.5056*	68.22441*
Lnef	2454.135*	92.70760*	39.70021*
Lnur	5141.207*	207.0769*	32.04737*
Lnepe	1521.596*	53.01610*	2.377001*
Model	2294.258*	85.90275*	17.44328*
Delta test	**Test statistics**		***P* value**
$\widehat{\Delta}$	17.412		0.000*
$\widehat{\Delta}_{adj}$	20.231		0.000*

* p < %1

$$\hat{\Delta}_{adj} = \sqrt{N} = \left(\frac{N^{-1}\tilde{S} - E(\tilde{z}_{it})}{\sqrt{var}(\tilde{z}_{it})} \right) \quad (6)$$

The $\widetilde{S}$ in the model is the modified Swamy test statistic that forms the basis of the homogeneity test. In the model $E(\widetilde{z}_{it})$=k and $var(\widetilde{z}_{it}) = \frac{2k(T-k-1)}{T+1}$ expresses. The null hypothesis for the Delta test states homogeneity of slopes, while the alternative hypothesis states heterogeneity.

Table 7 indicates the CSD and homogeneity results. Findings suggest that there is cross-sectional dependence and slope coefficients are heterogeneous.

Table 7 shows that there is horizontal cross-sectional dependence and the slope coefficients are heterogeneous. The next step in the study is to calculate the stationarity of the variables. The stationarity test of the variables is examined with the CIPS unit root test proposed by Pesaran [56]. This test statistic is among the 2nd generation tests that take CD into account. The following model is used for this test:

$$\Delta Y_{it} = \alpha_i + b_i Y_{i,t-1} + c_i \overline{Y}_{t-1} + d_i \Delta \overline{Y}_t + e_{it} \quad (7)$$

It is expressed as.

$$\bar{Y}_t = N^{-1} \sum\nolimits_{i=1}^{n} Y_{i,t}$$

$\Delta \overline{Y}_{t-1} = N^{-1} \sum_{i=1}^{N} \Delta Y_{i,t}$ In the equation and Δ is the first difference operator.

The CADF test statistic in Eq. 7 generates the CADF value for each cross-sectional unit in the model. The CIPS statistic (cross sectionally IPS) is the average of these values across the panel [56]. CIPS test statistic,

$$CIPS(N,T) = N^{-1} \sum\nolimits_{i=1}^{N} t_i(N,T) \quad (8)$$

For the CIPS test, the null hypothesis states a unit root, while the alternative hypothesis states stationarity. Table 8 presents the findings of the test. According to the results, all variables except lnef are stationary at first differences.

The stationarity criteria of the variables included in the model are suitable for cointegration. For the study, the Durbin–Hausman test statistic developed by Westerlund [73], which takes CD into account and does not assume that the stationarity orders of the variables (except for the second and higher) are the same, is used. An important assumption of this test statistic is that the dependent variable is stationary of order I(1). This test suggests two different test statistics. Test statistics:

$$\mathbf{DHg} = \sum_{i=1}^{n} \hat{S}_i \left(\tilde{\phi} - \hat{\phi}_i \right)^2 \sum_{t=2}^{T} \hat{e}_{it}^2 - 1 \quad (9)$$

$$\mathbf{DHp} = \sum_{i=1}^{n} \hat{S}_{it} \left(\tilde{\phi} - \hat{\phi} \right)^2 \sum_{i=1}^{n} \sum_{t=2}^{T} \hat{e}_{it}^2 - 1 \quad (10)$$

These two proposed test statistics refer to group and panel cointegration, respectively. The null hypothesis of

Table 8 CIPS test results

	Constant and Trend		Decision
	I (0)	**I (1)**	
Lnlcf	−2.37714	−2.80045**	I(1)
Lngdp	−2.47712	−2.69037***	I(1)
Lngdp2	−2.40722	−2.64499***	I(1)
Lnef	−2.65665***	–	I(0)
Lnur	−1.92732	−2.77378**	I(1)
Lnepe	−2.04433	−2.7875**	I(1)

** p < %5, *** p < %10; (CIPS table: %1, %5 and %10: − 2.87, − 2.70 and − 2.61) this test states that there is no cointegration. Table 9 presents the findings of cointegration test statistics. Table 9 shows that there is cointegration both in the group and in the model.

In the model with cointegration, the long-run coefficients are calculated and the significance levels of the variables are examined both in the panel and in the countries. In this direction, two different estimators were used in the model. The first estimator is the Common Correlated Effects (CCE) estimator proposed by Pesaran (2006) and the Augmented Mean Group (AMG) estimator proposed by Eberhardt and Bond [25].

According to the robust results in Table 10, UR increases LCF in France, Hungary, Norway, Slovak Republic, Norway, Slovak Republic and the whole panel, while GDP reduces environmental sustainability in Latvia. EF decreases LCF in Estonia and increases it in the Netherlands.

Discussion, conclusions and limitations

Discussion

Consequently, the following are the noteworthy outcomes:

- Belgium, Latvia, and the Netherlands have better environmental conditions due to economic independence. Conversely, in Slovakia, Austria, Estonia, Finland, and France, environmental quality declines with economic independence.
- The quality of the environment is improved by urbanisation in Austria, France, Hungary, Italy, Norway, Poland, Portugal, Slovakia, and Slovenia. However, in Germany, urbanisation degrades the quality of the environment.
- Greece and Austria's environmental quality declined due to spending on environmental protection. However, Germany is spending more on environmental protection.
- Environmental quality declines with economic expansion in Austria, Latvia, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, and Switzerland. In Lithuania, on the other hand, GDP is increasing.

Table 9 Cointegration test results

Test	Test Stat	P-değeri
Durbin–Hausman Group	23.271	0.000*
Durbin–Hausman Panel	8.334	0.000*

* p < %1

The impact of urbanisation, spending on environmental protection, economic growth, and EF on environmental quality in EU member states between 1996 and 2021 is examined in this paper. EF impacts environmental quality in both positive and destructive ways. A society's understanding of environmental issues, enacted laws, and policies are other variables that affect how EF affects the quality of the environment. Our study's findings indicate that EF enhances environmental quality in the Netherlands, Belgium, and Latvia. Conversely, it degrades the environmental quality of Slovakia, Austria, Estonia, Finland, and France. This result is similar to that of Alola et al. [9] and Koçak et al. [43]

The study's findings indicate that nearly every EU nation has improved environmental quality due to urbanisation. Our study's findings concur with those of Radoine et al. [58], Lin & Ullah [46] ve Sun et al. [67]. Countries make environmental protection expenditures through taxation and other policies for environmentally friendly production and consumption activities. These expenditures are realised for purposes, such as the protection of natural resources and the improvement of air and water quality. The link between environmental protection spending and the quality of the environment indicates that in Austria and Greece, spending on environmental protection lowers the quality of the environment. However, spending on environmental protection improves Germany's environmental quality. Policy flaws such as preserving energy and industrial subsidies and upholding property rights over natural resources could undermine environmental protection initiatives in Austria and Greece. Our result is similar to that of Drăcea et al. [24], Caglar and Yavuz [18].

Conclusions

Environmental deterioration has grown to be a global issue in recent decades. Using various policy tools, organisations throughout nations are having difficulty addressing the detrimental effects of human activity on the environment. Economies are now collaborating to create shared resources and solutions to these problems and to ensure sustainable development [31]. Among the organisations looking for answers in this area is the EU. The European Union reaffirmed its commitment to environmental sustainability in 2016 when it signed the Paris Climate Agreement. However, in the struggle against the problems brought on by global warming, it has concentrated on getting rid of carbon and a few other dangerous pollutants (United Nations, [70]). The European Green Deal, which is almost identical to the goals of the Paris Climate Agreement, implemented two major environmental initiatives in 2019. The first environmental policy is to reduce greenhouse gas emissions by at least

Table 10 AMG and CCE estimations

Countries		lnUR	lnEPE	LNGDP	LnGDP2	lnEF
Austria	AMG	1.246**	−0.044***	37.897*	−1.782*	−0.297
	CCE	0.359	−0.015	−20.054	0.902	0.038
Belgium	AMG	−92.256	0.029	43.193	−2.029	0.636**
	CCE	−236.81	0.020	115.910	−5.394	0.816
Denmark	AMG	6.703	−0.043	−18.993	0.889	0.476
	CCE	8.314	−0.006	−69.687	3.292	0.058
Estonia	AMG	−11.383	−0.283	−82.791	3.84	**−1.886*** **
	CCE	−17.018	-0.666	589.114**	−27.388**	**−2.879*** **
Finland	AMG	2.358	−0.066	−19.185	0.978	−0.552**
	CCE	−5.349	−0.063	−136.014***	6.661***	−0.281
France	AMG	**41.035***	0.014	0.216	−0.009	−0.366**
	CCE	**45.544*** **	0.045	7.319	−0.390	−0.105
Germany	AMG	−4.626***	0.164**	−15.574	0.762	−0.255
	CCE	−10.278	0.081	5.418	−0.239	−0.338
Greece	AMG	12.035	−0.184***	90.379	−4.326	0.012
	CCE	1.352	−0.211	77.241	−3.623	0.089
Hungary	AMG	**5.679***	0.020	11.395	−0.556	0.376
	CCE	**6.310****	−0.027	−23.122	1.157	−0.434
Ireland	AMG	17.915	−0.022	3.877	−0.200	−0.245
	CCE	−8.334	−0.029	10.833	−0.521	0.307
Italy	AMG	9.049***	0.001	6.352	−0.359	−0.290
	CCE	9.309	0.074	26.443	−1.451	0.198
Latvia	AMG	−16.004	0.055	**−21.883*** **	**0.970*** **	1.954*
	CCE	20.954	−0.437	**−57.714****	**2.616****	1.012
Lithuania	AMG	5.025	−0.124	307.446**	−14.877**	0.128
	CCE	7.234	−0.018	279.607	−13.603	−0.239
Luxembourg	AMG	0.588	0.091	−2.985	0.212	0.731
	CCE	7.742	−0.060	−0.039	0.037	0.313
Netherlands	AMG	−0.198	0.115	−4.307	0.188	**0.778*** **
	CCE	2.847	0.005	37.404	−1.624	**1.681*** **
Norway	AMG	**31.754***	0.044	−5.197***	0.283***	−0.994
	CCE	**38.138*** **	0.049	−13.088	0.687	−1.238
Poland	AMG	10.959*	−0.022**	43.594*	−2.089*	0.217
	CCE	7.909	−0.011	66.301	−3.192	0.453
Portugal	AMG	9.128**	0.004	−214.262*	9.573*	−0.541
	CCE	−0.033	−0.033	−147.674	6.629	0.520
Romania	AMG	−5.589	−0.121	13.898**	−0.731**	−0.307
	CCE	−0.413	0.063	18.543	−0.982	−0.023
Slovak Republic	AMG	**7.093****	0.092	89.963*	−4.596*	−0.850*
	CCE	**10.923****	0.190	14.633	−0.818	0.069
Slovenia	AMG	13.555**	0.029	8.728***	−0.557**	−0.094
	CCE	5.374	0.149	−1.179	0.028	0.262
Spain	AMG	22.153	0.576	−23.172	1.241	0.782
	CCE	−56.520	0.150	−12.122	0.727	0.914
Sweden	AMG	−0.405	0.147	−2.145	0.173	−0.190
	CCE	−11.628	−0.624	30.287	−1.613	0.030
Switzerland	AMG	−50.492	0.141	−82.337***	3.789***	−0.140
	CCE	−147.763***	0.228**	−17.754	0.785	1.226
PANEL	AMG	**5.413****	−0.001	1.948	−0.055	-0.058
	CCE	**0.208*** **	−0.238	5.133	0.026	2.566

*** p < %1, ** p < %5, * p < %10

The bold values show robust results

55% by 2030. By 2050, the European continent intends to become the first region to be ultimately climate neutral. This is the second environmental goal. The EU submitted the "Fit for 55" green package, which includes several legislative initiatives, to the Commission in 2021 [63]. In one of its recent working papers, the EU stated that investments in environmental protection are seen as necessary to reduce the environmental costs of such development, with a focus on green infrastructure and nature-based solutions to enhance urban resilience. However, the inequality in the distribution of resources between regions and communities emphasises the need for equitable urban planning and environmental investments. The report calls for integrated planning that addresses both the environmental pressures from urbanisation and the rising costs of climate adaptation (European Environment Agency, [26]).

Unlimited freedom for countries can lead to market failure, which is the basis for declining environmental performance. One could argue that more stringent government regulations are the best action in these situations [13, 14]. The accountability and responsibility for the effects of EF on environmental quality should be a priority for policymakers. This is thus because the incentives offered by the elements of EF and the degree of accountability and responsibility for the deeds of all economic and political players determine the quality of the environment. A greater degree of environmentally focused economic development may result from structural changes that boost EF concurrently with enhanced accountability and responsibility. In environments of high economic freedom, firms can invest in environmentally friendly projects with less bureaucracy and more incentives. Competitive market conditions push companies to innovate both to reduce costs and to differentiate themselves with environmentally friendly solutions. Entrepreneurs and companies can develop innovative technologies thanks to economic freedom. Companies can play a role in environmental projects, such as innovations to reduce carbon emissions or waste management systems.

Deforestation, transportation, infrastructure, health care, clean energy, and clean water are all linked to urbanisation. People can live more peacefully in cities with parks, green places, and recreational locations. Nonetheless, social interaction has a role in the generation of novel concepts. Environmental consciousness may rise as a result of urbanisation. Positive benefits are produced, mainly by environmentally friendly methods like low-carbon urban planning. Generally speaking, policymakers in the study's participating countries have mitigated the adverse effects of urbanisation on environmental quality by educating urban residents about energy-efficient household appliances, establishing environmental quality departments within educational institutions, and offering financial incentives to urban businesses implementing sustainable production practices. These nations should create sustainable urbanisation policies by coming up with solutions for issues, such as waste management, energy efficiency, green space preservation, and transportation planning to improve the quality of the environment.

This emphasises how these nations' environmental spending plans need to incorporate the sources of pollution through more effective legislation. By altering its spending on environmental protection, Germany is attempting to improve its environmental performance. Spending on natural ecosystems and biodiversity has gone up as a result. This demonstrates its goal of developing more robust and successful environmental policies. Germany's strategy is to move in the right direction towards raising the standard of the environment. Countries such as Germany, with effective planning and supervision, utilise environmental protection expenditures in a way that contributes to environmental quality, while in countries such as Austria and Greece, deficiencies in planning and implementation may limit these effects.

One can discuss the relationship between environmental quality and GDP positively and negatively. Our research indicates that GDP has a detrimental effect on environmental quality in most EU nations. Because of growing demand and technological advances, GDP may adversely affect the environment. Growth in the economy has the potential to raise energy consumption and greenhouse gas emissions. On the other hand, economic expansion may also result in higher spending on environmental protection technology, which may enhance the quality of the environment over time. To accomplish sustainable development aims, policy makers should create policies that support green technologies, renewable energy, and ecologically friendly practices. Specifically, the efficient use of financial instruments such as tax and expenditure policy can significantly enhance the implementation of the European Green Strategy accord. Promoting both environmental sustainability and economic growth depends on this process, also known as green growth [29]. Furthermore, the EU might pilot several worldwide policy proposals derived from the achievements of carbon-negative nations such as Bhutan, Suriname, and Panama to advance the region's net zero carbon aim. However, differences in financial and technical capacities between EU Member States may prevent uniform implementation. By overcoming these problems, European countries can become a low-emission, resource-efficient, green and competitive economy.

Limitations

This study is subject to certain constraints. First off, there are many features included in the EF indicator. More information on EF metrics, including tax burden, investment freedom, and public spending on the environment, needs to be provided. As the constraints in these data are removed, more focused research in the environmental field can be carried out in the future. More in-depth research on the impacts of institutional quality, foreign direct investment, economic freedom, and the strictness of environmental regulations on environmental quality across various geographic regions can be done in the future. As a result, in different nations or areas, the influence of various variables on environmental quality may vary. Finally, this study analyses the years between 1996 and 2021. Since the last data of the study is from 2021, it ignores more recent developments that may significantly affect environmental quality. As the data of recent years are updated, different studies can be conducted in the future by providing the context of the variables used in this study with different variables. In addition, long-term trends and changes can be evaluated by conducting longer-term studies in the future.

Abbreviations

UR	Urbanization
AMG	Augmented mean group
ARDL	Autoregressive distributed lag bound test
CCE	Common correlated effects
CSD	Cross-sectional dependence
EF	Economic freedom
EPE	Environmental protection expenditure
EU	European Union
GDP	Economic growth
GMM	Generalized method of moments
LCF	Load capacity factor
LM	Lagrange multiplier
OECD	Organisation for economic co-operation and development

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AI disclosure
Artificial intelligence tools (GPT-4o and Adobe Firefly) were employed to obtain the images in the graphical abstract and Figure 1 of the studies.

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YS and ND wrote the introduction, summary and conclusion parts of the article. EG wrote the analysis and methodology part of the article. YK and CS provided language control and wrote the literature part of the article and handled it as a whole.

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The authors declare no competing interests.

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