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Synergizing green energy, natural resources, global integration, and environmental taxation: Pioneering a sustainable development goal framework for carbon neutrality targets

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Abstract

Addressing the intricate associations between green energy consumption, natural resources, economic globalization, and environmental taxes is central focus of Europe's ecological sustainability. This study uses cutting-edge techniques to investigate the impacts of green energy consumption, economic globalization, environmental taxation, as well as the potential moderating effects of natural resource rent in conjunction with environmental taxation in European countries during 1995–2020. The empirical findings of this study show that green energy, environmental tax and globalization are negatively associated with ecological footprint, while natural resource is positively linkedwith ecological footprint. Green energy consumption in conjunction with environmental tax has a significant and negative moderating impact on ecological footprint. Similar findings were

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observedfor the concurrence between natural resources rent and environmental tax, which means that environmental tax has some ability to improve the natural resources management and consequently contribute to improve environmental quality. The establishment of environmental taxation schemes and the use of green energy enable the pursuit of environmentally conscious economic, and energy policies by better-aligning industries with sustainable practices and promoting a balance between economic growth and environmental stewardship. Environmental tax system should support a larger adoption of green energy into European countries for reaching the target of carbon neutrality until 2050. It also contributes to the worldwide effort to achieve carbon neutrality and a sustainable future by offering useful insights and concrete recommendations for the development and implementation of environmentally responsible economic and energy strategies.

Keywords

Ecological footprint, green energy, natural resource rent, environmental taxes, sustainable development goals

Introduction

Energy efficiency across the European Union's (EU) five most populous countries is tracked as part of the union's long-term energy plan.[1] The EU's energy description proposes that by 2020, annual energy consumption across Europe approximatly reduced by roughly 20%.[2] Regulating the dynamics of energy use inside the EU bloc is crucial for this standpoint. This information is also useful for foreseeing the coming revolution in the EU countries' electricity demand.[3] Due to elevates in greenhouse gas (GHG) emissions over the previous few decades, ecological footprint has turned out to be one of the highest world-wide subject matters.[4] Over the initial Kyoto Protocol promise period, the EU as a whole designed to alleviate GHG emissions by 8% associated to 1990 levels by 2012 even nevertheless apiece of member nations professed dissimilar aims.[5] For example, Germany and Luxemburg had a goal to diminishing GHG emissions by 21% and 28%, correspondingly, despite the fact that Sweden and Greece had an aim of cumulative the pollution level by 4% and 24%, associated with their 1990 levels.[6] While numerous members economies did not achieve their individual goals, the EU-15 as a whole had a mean of 11.8% decrease in environmental pollution by the culmination of the primary promise span. The EU has dedicated to reduce environmental pollution by a mean of 20% underneath 1990 levels by 2020. This panel economies have anticipated to upsurge in the proportion of alternatives and green energy consumption (GEC) in power mix up to 20% by 2020.[7] Conferring to the work of EEA;[5] one conceivable motive to initiative down the pollution level is to upsurge the GEC and alternative energy sources share in the total energy mix. The anticipated prognosis of augmented renewable power should be related to the adversative consequence of GEC on environmental pollution. The fundamental aim of this paper is to demonstrate whether or not upsurges in the alternative energy share and reduces in the fossil fuel energy share are economically and statistically evocative.[8]

The association between green energy consumption and environmental footprint (EFP) in European nations can be described as a positive correlation. Green energy use refers to the use of green energy sources such as solar, wind, hydro, and geothermal power, which have a much lower environmental impact compared to fossil fuels. on the other hand, EFP is a measurement of the impact that human activities have on the environment and takes into account a variety of factors in addition to carbon emissions, land use, and resource utilization.[9] Over the course of time, the EFPs of several European nations that have made significant financial investments in renewable forms of energy and have instituted policies designed to lessen their overall carbon footprint have usually shrunk.[10] Some of the greatest rates of GEC in Europe may be found in countries like Denmark, Sweden, and Finland, while having very low rates of EFP. However, it should be noted that there is not always a clear connection between EFP and the usage of green energy. However, other factors, such as excessive consumption or inefficient use of resources, may explain why certain countries with high GEC rates also have high EFP.[11] It is important to consider the bigger picture and the various elements at play while assessing the GEC and EFP in European countries.

The natural resource rent (NRR) and European nations EFP are directly related. Human activity and economic prosperity require natural resources, including water, land, minerals, and forests. However, the consumption of natural resources has a huge adverse influence on the surrounding environment, including the exhaustion of resources, the creation of polluted environments, and the elimination of habitats.[12] High EFP European nations consume lots of natural resources. Countries with substantial agricultural sectors and major industries need lots of land, water, and minerals. Countries that use fossil fuels for energy have a high carbon footprint, which can cause climate change. Natural resource utilization and EFP are not necessarily proportional. Some countries consume a lot of natural resources but have environmental regulations and technologies. Countries that extensively engage in green energy have lowered their EFP and fossil fuel use. Natural resources and EFP in Europe are complex and depend on economic growth, technical breakthroughs, and environmental policies. European nations must sustainably manage their natural resources and adopt environmental measures to lower their EFP.

There is a favourable and unfavourable feedback loop between economic globalization (EGL) and the EFP. Trade, investment, and the free flow of capital and labour across national borders all contribute to what is known as 'Economic Globalization'.[13] On the favourable side, EGL has contributed to the expansion and improvement of several European nations. As a result of this expansion, living standards have risen and new technologies have emerged that have the potential to lessen the EFP. Green energy and sustainable agriculture are only two areas where globalization has encouraged progress. However, in several European nations, EGL has also been linked to a rise in the EFP. This is because of things like rising rates of resource use, vehicular emissions, and industrial production of GHGs.[14] As countries compete with one another to attract investment and cut prices, globalization may also result in a 'race to the bottom' in terms of environmental constraints.[15] In general, the link between EGL and EFP in the European nations is a complicated one which is contingent on a wide variety of factors. Even if globalization has the potential to improve environmental conditions, if it is not controlled in an appropriate manner, it can make existing environmental issues much worse.[16] As a result, it is essential to give serious consideration to the environmental impacts of EGL and to enact laws that encourage sustainable development while simultaneously lowering EFP levels.

There is an inverse relationship between environmental tax (ETX) and EFP in the countries that make up European nations. ETX, are levies that are imposed on activities that have a detrimental effect on the surrounding environment, such as the production of carbon emissions, pollution, and waste.[17] These taxes are meant to discourage environmentally detrimental behaviour by raising the cost of such activities.[18] Successful ETX policy implementers in European nations have seen their EFP fall over time. Sweden, Germany, and the Netherlands have reduced waste and carbon emissions by implementing ETX. ETX and EFP's link isn't always clear. Even with high ETX rates, some nations may have high EFP due to other factors including wasteful resource consumption.[19] ETX may cause low-income people to spend more or firms to move to countries with lower environmental regulations. The context and components must be considered to accurately assess the relationship between ETX and EFP in European nations. This paper is even more valuable as its results can be helpful in enhancing the relevance and effectiveness of the methodology for estimating the SDG implementation index in the region of the European Nations and refining the approach in shaping a necessary basis for futures indicators applied in the process of reconstructing the Ukrainian economy or any other states economy in the analysed region that will require post-war reconstruction, taking also into consideration the carbon neutrality targets. This study helps us comprehend EFP parameters and the importance of renewable energy and environmental taxation in European nations. The study sheds light on environmental sustainability by examining GEC, NNR, EGL, and ETX's varied effects on EFP. Understanding NNR and GEC's moderating effects with ETX helps us understand their relationship. The study emphasizes the significance of ETX in promoting the GEC and facilitating tax reforms for sustainable economic development and environmental protection. The implications of these findings extend to the development and implementation of environmentally sound economic and energy policies, providing policymakers and industries in European nations seeking to prioritize sustainability and incursion a balance between economic growth and environmental considerations with useful recommendations.

Literature review

The stride in the direction of recognizing significant contributors to the tenacious increase in environmental pollution that attract sample of investigations both from developing and developed countries. The majority of the existing studies has recognized many important indicators that have meaningfully subsidized to environmental pollution. The current research appraisals applicable components of the works, concentrating on green energy, natural resources, ETX and EGL in the context of European nations.

Energy use, natural resources, and the environment nexus

In a practical examination by Zafar et al.,[20] discovered the influence of NRR on the EFP in the USA from 1970 to 2015. The findings of ARDL bound tests explored that NRR is adversely linked with EFP, therefore enlightening ecological excellence in the long run. Using the novel structural break cointegration and ARDL model, Badeeb et al.[21] checked the function of NRR on environmental excellence within the context of the EKC hypothesis. The findings of this study designated that NRR provisions the link between GDP growth and ecological quality. Similarly, Khan et al.,[22] explored the dynamic linkages between population growth, energy consumption, NRR and EFP from 1971 to 2016 in the United States. The empirical evidence explores that GEC and NRR increase environmental pollution. However, fossil fuel energy use, biocapacity and population growth, increase the level of EFP. The pairwise result of the causality method explores that bidirectional causality exists between NRR and EFP, while unidirectional causality explores from population growth to EFP, and energy consumption. Also, Bekun et al.,[23] investigated the causal and long-term interaction between, green energy, fossil fuel energy, GDP growth, and NRR in carbon emission from 1996 to 2014 for EU-16 economies. The outcomes of this study reveal that NRR, GDP growth, and non-renewable energy increase the carbon emissions levels. In contrast, green energy improves the environmental quality. Moreover, Granger causality test exposed a feedback device between green energy, GDP growth, and fossil fuel energy. Also, it is found that a feedback causality hypothesis exists between GDP growth and NRR. Besides, Majeed et al.,[24] inspected the influence of real income growth, NRR, energy use, urban population, and EGL, on environmental quality from 1990 to 2018 in GCC countries.

The findings of long-term estimates GDP growth, nonrenewable, and population growth deteriorate the environmental quality.[25] However, dependence of natural resources, and green energy significantly safeguard the environment. Employing a system GMM approach, Khan et al.,[26] explored the nexus between natural resources and carbon emissions from 1990 to 2016 in fifty-one BRI countries. The results estimated a negative link between them, confirming the 'curse of natural resources' spectacle for these economies. Nevertheless, this study's authors suggested a traditional policy outline on natural resources as conceivably being cooperative in enlightening ecological excellence.[27] inspected the association between economic growth, green energy, natural resources, fossil fuels on CO_2 emissions from 1995 to 2019 in ten Asian countries. The empirical evidences explore that both types of energy boost the pace of economic growth. While, natural resources reduce it. On the other side, GDP growth, and non-renewable energy increases the pollution levels, whilst GEC diminishes ecological contamination. In each panel countries, the dependence of natural resource deteriorates environmental pollution in the long-term. In addition, Wang et al.,[28] conducted a study on CO_2 emissions in 208 countries from 1990 to 2018, focusing on human capital, trade activities, natural resources, and Global Environmental Uncertainty (GEU). The study confirmed the EKC hypothesis, suggesting that CO_2 emissions increase during economic development, but decline as economies grow. The research also found that human capital and GEC affect CO_2 emissions differently across countries. The study highlights the need for targeted policy interventions to address environmental consequences of economic development and resource exploitation.

Robust population and economic growth possess great challenges on energy consumption and that represents a burden for environment in terms of ecological footprint and for population health. That is why, green energy is the solution for reaching both targets of economic growth, for preserving the environment and for people wellbeing, being an essential condition for sustainable development goals.[29] Greening industries and greening activities are strongly related to the use of energy, namely green energy and to the resources consumption and waste management.[30] Green innovation supports the decrease of total energy use, reduces costs, improve efficiency of energy system and of whole economic activity, and alleviate the environmental burden.[31]

Environmental taxes and the environment nexus

This subsection of the literature review analyses the association between ETX and EFP. In this regard, He et al.,[32] established the influence of the policies related to ETX on GHG emissions in the case of China and OECD economies from 1996 to 2016. The outcomes of this study illustrate that ETX sustenance to decrease the influence of contamination levels in China and OECD nations. These ETX provide assistance increase the revenue of governmental tax and boosts the pace of economic growth. Besides, Liu et al.,[33] investigated the influence of governance, ETX, and power sector prices on ecological excellence in OECD economies from 1996 to 2019. The estimated evidences designate that governance and ecological tax upsurge ecological excellence.[34] examined the impression of R&D and ETX on consumption-based CO_2 emissions from 1990 to 2019 in G-7 nations. The long-term cointegration association test outcomes display a steady long-term connotation exist between R&D, ETX, exports, imports, economic growth, and consumption-based carbon emissions. The findings also reveal that in the long- and short-run, R&D, ETX and exports meaningfully decrease the levels of environmental pollution, while imports and real income growth pointedly augment pollution levels. The second-generation causality evidences findings expose that any strategy that aims R&D, ETX, imports, exports, and income growth meaningfully fluctuate the pollution levels in the region. Besides, Depren et al.[35] investigated the impact of ETX (disaggregated and aggregated levels) on carbon emissions in Nordic economies from 1994/Q1 to 2020/Q4. This study incorporates disaggregated and aggregated levels of conservational taxes as independent variables. The estimated evidences show that causal influences of ETX on environmental pollution occur in most quantiles at the levels of disaggregated exclusive of few higher, middle, and lower quantiles, while indicator-, nation-, and quantile-based findings differ. Moreover, ETX on environmental pollution has the uppermost reducing influence in most of the quantiles in the case of Norway, Iceland, and Denmark. Moreover, Rybak et al.[36] found a similar relationship between ETX and environmental pollution in their respective region.

Globalization and the environment nexus

Several scholars have examined the nexus between globalization and environmental quality.[13] Globalization influences real GDP growth by cumulative feature foreign investment, commerce, and productivity but globalization also has an ancillary effect on the deployment of energy and ecological damages. Numerous indicators of globalization have been applied in the existing body of literature to investigate its ecological influence.[37] Of these studies, the work of Shahbaz et al.[38] privileged that the Japanese economy is increasing at the ecological excellence cost that is mainly owing to augmented energy use and the process of globalization. Opposing to general acceptance, numerous researchers oppose that globalization process significantly progresses environmental excellence by helping trade and spreading green expertise around the globe. Financial venture, trade, and other arrangements of financial globalization all subsidize to enhanced ecological excellence.[14] Furthermore, Kirikkaleli et al.[39] studied how energy usage, trade liberalization, and economic growth in Turkey reflect the effects of the EGL on the EFP. According to the evidence looked at, the EGL impacted EFP positively over the long run, whereas trade had an adverse influence on the EFP in the short run. Moreover, Ahmed et al.[40] assessed the long-term nonlinear influence of overall globalization process and social, economic, and political globalization process on EFP in the case of the United States. It was observed that adverse shocks overall and EGL boosts the level of EFP, however positive shocks in social globalization process reduce the EFP level in the long-term. Moreover, Huo et al.[41] investigated the link between EGL and financial innovations on environmental dilapidation in the case of China. The evidences exposed that financial innovation unswervingly influences ecological dilapidation; though, it also indirectly influences ecological dereliction via economic process of globalization, suggesting that strategies concerning EGL process would also influence the ecological superiority in China. Besides, Farooq et al.[42] assessed the panel data of 180 different economies around the world. The findings explored that the overall process of globalization peremptorily protects the environment; nevertheless, dichotomizing globalization process into dissimilar sectors accessible different findings. The outcomes of this research found that EGL process increases carbon emissions, however, the political process of globalization reduces the level of ecological deficiency. The connection between EFP, and globalization process has not been intense by researchers, and the previous outcomes lack any shape. Under these settings, the major determination of this paper is to assess the association between EGL process and environmental pollution in European nations.

Data, empirical model construction and econometric methodology

The entire study is based on this section. The dataset's source and chronology, variables of relevance, and econometric methods are described. This section describes how the data were produced and analysed, rendering the research technique transparent and reproducible. This crucial first step establishes the study's empirical rigour and credibility.

Description of data

The present paper uses longitudinal data relating to 33 European nations during the period from 1990 to 2020. The selected countries are provided in Table 1. The primary aim of this study is to provide an estimate of the effect of GEC, NRR, EGL, and ETX on EFP in European nations. To do this, this study uses the data of GEC is a proportion of the total amount of energy consumed., NRR as a percentage of GDP, EGL as KOF EGL index, ETX as calculated in term of tax revenue (% of GDP), and EFP gathered in global hectares per person.

This study's variables' data, notations, measurements, and sources are summarized in Table 2.

Empirical model construction

Model 1: Ecological Footprints = *f* (GEC, NRR, EGL, ETX)

$$EFP_{it} = f\,(GEC_{it},\ NRR_{it},\ EGL_{it},\ ETX_{it}) \quad (1)$$

Model 2: Ecological Footprints = *f* [GEC, NRR, EGL, ETX, (NRR* ETX)]

$$EFP_{it} = f\,(GEC_{it},\ NRR_{it},\ EGL_{it},\ ETX_{it},\ (NRR*ETX)_{it}) \quad (2)$$

Model 3: Ecological Footprints = *f* [GEC, NRR, EGL, ETX, (GEC * ETX)]

$$EFP_{it} = f\,(GEC_{it},\ NRR_{it},\ EGL_{it},\ ETX_{it},\ (GEC*ETX)_{it}) \quad (3)$$

The econometric framework for this study is shown in Figure 1. The first stage consisted of conducting a cross-sectional dependency (CSD) test to determine whether the variables were interdependent. The variables' stationary properties were subsequently evaluated to assure their suitability for further analysis. Cointegration analysis was used to investigate the long-term relationships between the variables in the third phase. Using the cross-sectionally augmented autoregressive distributed lag (CS-ARDL) method, the study estimated the long-term effects. The Autoregressive Mean Group (AMG) test was then performed to verify the reliability of the CS-ARDL findings. This exhaustive econometric strategy provides a rigourous and systematic

Table 1. Panel of European nations.

Albania	France	Montenegro
Austria	Germany	Netherlands
Belarus	Greece	Norway
Belgium	Hungary	Poland
Bosnia & Herzegovina	Iceland	Portugal
Bulgaria	Ireland	Romania
Croatia	Italy	Slovakia
Czech Republic	Latvia	Slovenia
Denmark	Lithuania	Spain
Estonia	Luxembourg	Sweden
Finland	Macedonia	Ukraine

Table 2. Description and sources of data variables.

Variables	Notation	Measurement	Data sources
Ecological footprint	EFP	Global hectares per person	GFN
Green energy consumption	GEC	% of total final energy use	WDI
Natural resource rent	NRR	% of GDP	WDI
Economic globalization	EGL	KOF economic globalization index	KOF Swiss Economic Institute
Environmental tax	ETX	Tax revenue (% of GDP)	OECD

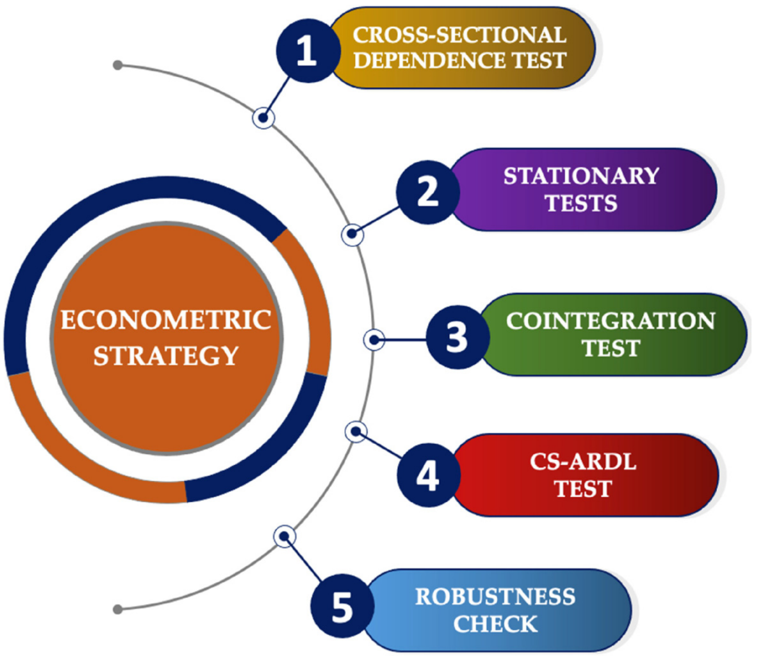

Figure 1. Econometric framework.

approach to data analysis, allowing for the investigation of long-run relationships and the assessment of the findings' reliability via robustness checks.

Econometric methodology

The study used a sophisticated econometric framework to analyse the interconnected dynamics between key factors like renewable energy consumption, NRR extraction and use, EGL, and environmental taxation policies. Many critical steps ensure the accuracy and trustworthiness of our analysis. The variables' time series data were then tested for stationarity. Stationarity is necessary for accurate regression estimates since non-stationary data might lead to incorrect conclusions. We can trust our analysis by ensuring stationarity. To test for long-term equilibrium, we did cointegration tests. Cointegration analysis helps formulate policies and make judgments by determining whether these critical components move together over time.

The CS-ARDLs model specifically captures short- and long-term dynamics. This invention allows us to simultaneously study short-term adaptations and long-term equilibrium relationships. The AMG test verified our CS-ARDL estimates. The AMG test checks the consistency of predicted coefficients across entities to enhance our conclusions. AMG testing eliminates heterogeneity, making our findings applicable to all European economies. In conclusion, this rigourous Econometric Framework, which includes CSD tests, stationary tests, cointegration analysis, CS-ARDL estimation, and AMG testing, provides nuanced and reliable insights into the complex relationships between green energy adoption, NRR, EGL, and environmental taxation. This methodological approach strengthens our research and advances sustainable development and environmental economics.

CSD tests. Panel data is longitudinal subject data. Panel data analysis with interlaced observations can lead to CSD. Many statistical models assume independence, which can bias estimates and inaccurate inference.[43] CSD can emerge for a variety of reasons, including common shocks hitting all entities, geographical spillovers, and unobserved heterogeneity affecting many entities. Second-generation panel data models, which take into consideration the correlation between items across time, might be used by researchers to tackle this problem. CSD tests were performed first since the degree of dependence across variables could affect our findings. Cross-sectional correlation reduces bias and improves our econometric analysis. Few CSD methods are available for perceiving CSD, such as the LM test,[44] the CSD test, and the spatial dependence test.[45] The CSD test[45] can be illustrated as:

$$\mathrm{CD} = \sqrt{\frac{2(\boldsymbol{T})}{\boldsymbol{N}(\boldsymbol{N}-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\boldsymbol{\beta}}_{ij}\right) \sim \boldsymbol{N}(0,1)\ \ i,\ j \tag{4}$$

CD= (1, 2, 3……55……N)

$$\boldsymbol{M} = \sqrt{\frac{2(\boldsymbol{T})}{\boldsymbol{N}(\boldsymbol{N}-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\boldsymbol{\beta}}_{ij}\right)\left[\frac{(\boldsymbol{T}-\boldsymbol{K})\hat{\boldsymbol{\beta}}_{ij}^{2}-(\boldsymbol{T}-\boldsymbol{K})\hat{\boldsymbol{\beta}}_{ij}^{2}}{\mathrm{Var}(\boldsymbol{T}-\boldsymbol{K})\hat{\boldsymbol{\beta}}_{ij}^{2}}\right] \tag{5}$$

Stationary tests. Unlike first-generation tests, which assume that the individual units in the panel are independent of each other, second-generation tests account for CSD and heterogeneity issues among the units. There are two most common second-generation tests like the cross-sectionally augmented Dickey-Fuller (CADF) and cross-sectional Augmented Im Pesaran and Shin (CIPS) tests developed by Pesaran,[46] which can be extended to panel data by incorporating the dependence structure among the units. These tests are useful in panel data analysis because they allow researchers to test the stationarity of the data while accounting for the correlation among the units, which can lead to more accurate and reliable results. The CADF test[46] statistic can be reported as:

$$\boldsymbol{\Delta X}_{it} = \rho_i + \boldsymbol{\pi}_i\boldsymbol{x}_{i,t-1} + \boldsymbol{\sigma}_i\bar{\boldsymbol{x}}_{t-1} + \sum_{j=0}^{p}\Omega_{ij}\boldsymbol{\Delta}\bar{\boldsymbol{x}}_{t-j} + \sum_{j=1}^{p}W_{ij}\boldsymbol{\Delta x}_{i,t-j} + \boldsymbol{\varepsilon}_{it} \tag{6}$$

In view of this, the CIPS statistic can be reported as:

$$\mathrm{CIPS} = \boldsymbol{N}^{-1}\sum_{i=1}^{N}\boldsymbol{\sigma}_i(\boldsymbol{N},\boldsymbol{T}) \tag{7}$$

where the $\sigma_i(N, T)$ term presents the coefficient of estimated (CADF) statistics that can be substitute with the current term as:

$$\text{CIPS} = N^{-1} \sum_{i=1}^{N} \text{CADF}_i \tag{8}$$

Cointegration test. The Error Correction Model (ECM) based[47] cointegration test is a statistical test used to determine whether there is a long-run relationship between two or more variables in a panel data setting. Tests for cointegration, in which two or more non-stationary factors are integrated to the same order, are based on the hypothesis that the resulting linear function will be stationary.[12] Lagged differences of the variables of interest and the lagged error correction term are estimated for each unit in the panel to conduct the test. The absence of cointegration between the variables is the null hypothesis, and its presence is the alternative hypothesis, in this test. If the test statistic exceeds a predetermined threshold, the null hypothesis is rejected and it is concluded that there is a long-term correlation between the variables. Because it takes CSD across units into account, the ECM-based Westerlund cointegration test is a potent tool for panel data analysis.[47] The Westerlund cointegration test is provided in its generic form, which is based on error correction (ECM).

$$\mathbf{G_\tau} = \frac{1}{\mathbf{N}} \sum_{i=1}^{N} \frac{\mathbf{\Omega_i}}{\mathbf{SE(\hat{\Omega}_i)}} \tag{9}$$

$$\mathbf{G_a} = \frac{1}{\mathbf{N}} \sum_{i=1}^{N} \frac{\mathbf{T\Omega_i}}{\mathbf{\Omega_i}(1)} \tag{10}$$

$$\mathbf{P_\tau} = \frac{\mathbf{\hat{\Omega}_i}}{\mathbf{SE(\hat{\Omega}_i)}} \tag{11}$$

$$\mathbf{P_a} = \mathbf{T\hat{\Omega}} \tag{12}$$

CS-ARDL method. Scholars have applied the CS-ARDL test within the context of a panel data setting to ascertain whether or not a number of variables share a long-term link with one another. In time-series analysis, the ARDL model is frequently used to estimate the long-run connection between two or more variables; this model is an extension of that model. By including a lagged dependent variable and lagged independent variables in the model, the CS-ARDL test permits CSD among the units in the panel. Under the null hypothesis, the test statistic follows a conventional normal distribution; if the absolute value of the test statistic is larger than a critical value, the null hypothesis is rejected, and a long-run association is inferred.

One advantage of the CS-ARDL test is that it allows for the presence of heterogeneous coefficients and CSD among the units in the panel. This makes it a useful tool for panel data analysis, especially when dealing with variables that exhibit different behaviours across the units. However, it is important to note that the CSD test assumes that the errors are serially uncorrelated and homoscedastic, and violations of these assumptions can lead to incorrect inference. In this study, both short-term and long-term valuations are performed using the CS-ARDL test proposed by Chudik and Pesaran[48] as:

$$\text{LEFP} = \beta_{it} + \sum_{j=1}^{p} \pi_{it}\text{LEFP}_{it-j} + \sum_{j=0}^{p} \alpha_{it}X_{it-j} + \sum_{j=0}^{p} \delta\bar{Y}_{t-j} + \varepsilon_{it} \tag{13}$$

$$\bar{Y}_t = (\Delta \overline{\text{LEFP}}_t,\ \bar{X}_t) \tag{14}$$

$$X_{it} = (\text{GEU}_{it},\ \text{NRR}_{it},\ \text{EGL}_{it},\ \text{ETX}_{it}) \tag{15}$$

Robustness check. Moreover, as a robustness, the authors also applied panel AMG approach developed by Eberhardt and Bond[49] and Eberhardt and Teal[50] as follows:

AMG (First stage):

$$\Delta Z_{it} = \Psi_i + \beta_i \Delta Y_{it} + \eta_i k_t + \sum_{t=2}^{T} \xi_i \Delta D_t + \varepsilon_{it} \tag{16}$$

AMG (Second stage):

$$\hat{\beta}_{AMG} = N^{-1} \overset{N}{\underset{i=1}{\mathring{a}}} \hat{\beta}_i \tag{17}$$

Results and discussion

In this research paper, we use a comprehensive dataset containing the EFP, GEC, NRR, EGL, and ETX variables to elucidate the intricate interrelationships that exist between these variables in a subset of European nations. Utilizing the EFP measure permits us to assess the ecological impact of human activities, hence offering a comprehensive evaluation of resource use and environmental deterioration. By combining this metric with Green Energy Use statistics, we intend to investigate the extent to which sustainable energy practices contribute to mitigating environmental damage and lowering the EFP in the selected European nations. We also look into how NNR affects the EFP, given the centrality of resource extraction and management to the issue of environmental sustainability. We think that by investigating the connection between NNR and EFP, we might better understand the potential role that resource exploitation plays in ecological decline and locate openings for more conscientious resource management. Our study also looks into how widespread EGL is and how it affects environmental metrics. EGL encompasses a wide range of economic activities that can have far-reaching effects on resource consumption and environmental repercussions, such as trade, investment, and technical exchange. We hope that by examining the connection between EGL and EFP, we can better understand the potential tensions and synergies between economic growth and environmental protection. We conclude by evaluating ETX's potential as a policy instrument for internalizing environmental externalities and promoting sustainable practices. We hope to assess the effectiveness of such governmental actions in encouraging environmentally aware behaviour and reducing ecological burden by looking into the connection between ETX and EFP. Our study sheds light on the intricate dynamics that define environmental sustainability in a few select European nations by analysing the interplay between these many parameters.

CSD test results

Table 3 presents the outcomes of the CSD (CD) test, which is conducted to ascertain the presence of interdependencies across different cross-sectional units in our estimated panel data. By referring to the P values, we can determine the statistical significance of the test results and make informed conclusions regarding the null and alternative hypotheses. In this case, the obtained p-value is below the conventional significance level of 0.01 ($p < 0.01$), providing substantial evidence to reject the null hypothesis in favour of the alternative hypothesis. Based on the CSD test, we can ascertain that the variables under investigation, namely EFP, GEC, NRR, EGL, and ETX, exhibit CSD within the series. This signifies that the observed variables are not independent of each other across the different units in the panel dataset, suggesting the presence of interconnections or shared influences among these variables.

Stationary test results

This study applied the second-generation CIPS and CADF panel unit root tests to investigate the absence of unit root problems in the variables of interest. Table 4 provides a summary of the results of the unit root testing. The investigation for unit roots at the level and initial difference took into account both constant and constant tendencies. The results of the constant and trend at the level tests in the panel unit root analysis show that none of the variables under study are stationary. At the standard 1% significance level, all the parameters became stationary when the unit root tests were expanded to include constant and constant trends at the first difference. This result is crucial because it shows that, unlike when unit root problems still exist in the dataset, our regression methodology may produce accurate estimations. Regression estimates derived from datasets with

Table 3. Cross-sectional dependence test results.

	Breusch-Pagan LM		Pesaran scaled LM		Bias-corrected scaled LM		Pesaran CSD	
Variables	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.
EFP	305.8170*	0.000	69.5210*	0.000	64.8521*	0.000	23.7014*	0.000
GEC	521.3751*	0.000	91.8821*	0.000	83.6782*	0.000	50.0975*	0.000
NRR	238.1287*	0.000	75.3685*	0.000	68.2291*	0.000	42.8831*	0.000
EGL	685.5821*	0.000	196.5278*	0.000	165.7102*	0.000	56.9531*	0.000
ETX	267.0785*	0.000	86.2785*	0.000	76.2104*	0.000	43.2891*	0.000

EGL: economic globalization; ETX: environmental tax; NRR: natural resource rent CSD: cross-sectional dependency; EFP: environmental footprint. *** indicates the significance level at 1%.

Table 4. Stationary test results.

	CIPS		CADF	
Variables	I(0)	I(1)	I(0)	I(1)
EFP	−2.5975	−6.1158*	−3.1790	−6.627*
GEC	−3.5842	−6.3262*	−2.2964	−4.6378*
NRR	−2.5478	−7.9320*	−1.6785	−6.8940*
EGL	−2.9612	−5.1297*	−2.0733	−4.2621*
ETX	−2.1631	−4.5962*	−3.0421	−5.6801*
NRR*ETX	−2.1921	−4.0067*	−3.1325	−4.6428*
GEC*ETX	−2.6286	−4.6656*	−3.9742	−4.8555*

EGL: economic globalization; ETX: environmental tax; NRR: natural resource rent; CADF: cross-sectionally augmented Dickey-Fuller; CIPS: cross-sectional Augmented Im Pesaran and Shin; EFP: environmental footprint. * indicates the significance level at 1%.

unit root issues violate fundamental assumptions of econometric theory and tend to generate misleading and inappropriate results, rendering them unsuitable for informing policy decisions.

The panel unit root analysis in this study confirms that the variables under scrutiny align with theoretical expectations, providing a robust foundation for further analysis and policy recommendations based on the collected dataset. The results of both the CIPS and CADF tests, presented in Table 4, support the rejection of the null hypothesis for the EFP, GEC, NRR, EGL, and ETX variables at their respective levels (at 1% and 5% significance levels). Moreover, all the analysed variables exhibit stationarity at their first differences for both CIPS and CADF tests at the 1% significance level, indicating that they are integrated at order one [I(1)]. Given these findings, it is necessary to proceed with a cointegration test to explore potential long-term relationships among the variables.

Cointegration test results

To facilitate long-term forecasting and investigate the influence of a set of independent factors on a dependent variable, it is necessary to establish the existence of a long-term connection. Prior to estimating the impact of this relationship, this research undertook Westerlund cointegration test to determine the existence of such a linkage. The outcomes of the Westerlund cointegration tests are presented in Table 5, where all the statistics (Gt, Ga, Pt, Pa) demonstrate statistical significance, thereby leading to the rejection of the null hypothesis at the conventional 5% significance level. As a consequence of this, we agree with the competing explanation, which asserts that the models used in this investigation have a component of cointegration. Given these findings, we proceed to estimate the appropriate regression model in alignment with the research objectives. The results of these second-generation tests validate the existence of cointegration among the variables under investigation within the panel dataset comprising European nations.

CS-ARDL test results

The long-run coefficients of all examined indicators show statistical significance at different levels, including 1%, 5%, and 10% (refer to Models' Equation 1, 2, and 3), as shown in Table 6 obtained through the CS-ARDL estimation. *P*-values between 0.1 and 0.9 are considered inconclusive for the tested hypothesis, under Fisher's recommended grading method,[51] which is used to determine significant levels.[52] Fisher recommended using $P < 0.01$ and $P < 0.05$, with $P < 0.001$ for reporting results. Due to the use of the same environmental proxy across many nations, the results of panel series analysis are susceptible to the validity of these proxies.[53] Next, using the CS-ARDL econometric method, we estimate the long-run coefficients to foretell the response of the EFP to changing levels of global environmental uncertainty, NRRs, environmental globalization, and ETXs. Remarkably, all three models agree on the sign, magnitude, and relevance of each variable.

In all regression models, a negative relationship between GEC, and EFP is observed. The significant adverse impact of green energy use on EFP suggests that its adoption contributes to the reduction of EFP in European nations, indicating its environmental benefits over non-renewable energy consumption. The adverse and significant impact of green energy use on EFP, as demonstrated in all models presented in Table 6, suggests that it is an effective strategy for controlling environmental degradation through efficient energy utilization.[54] These findings underscore the role of green energy adoption in reducing EFP among European nations. The use of green energy minimizes the impact on these countries' natural resources. These results align with studies conducted on ASEAN countries,[55] African countries,[56] and European nations.[57] Green

Table 5. Cointegration test results.

	Model 1			Model 2			Model 3		
Statistics	Values	*Z*-values	*P*-values	Values	*Z*-values	*P*-values	Values	*Z*-values	*P*-values
Gt	−8.8541*	−4.9347	0.0000	−4.8532*	−2.3892	0.0000	−2.872*	−2.3331	0.0000
Ga	−14.0821*	4.2210	0.0000	−10.2231*	4.2194	0.0700	−8.397*	3.6347	0.0700
Pt	−16.3912*	−4.2631	0.0000	−13.5271**	−2.2678	0.0000	12.287**	−2.1167	0.0620
Pa	−18.3381*	−2.0098	0.0120	−15.4450*	−1.9754	0.0130	15.298**	−1.0002	0.0180

* and ** denote significance at 1% and 5% level, respectively.

Table 6. CS-ARDL test results.

	Model 1			
	Short-run		Long-run	
Variables	Coeff.	Prob.	Coeff.	Prob.
GEC	−0.0861*	0.0000	−0.4581*	0.0000
NRR	0.0957*	0.0002	0.9217*	0.0000
EGL	−0.0214*	0.0030	−0.2576*	0.0070
ETX	−0.1631***	0.0601	−0.6610*	0.0000
ECM (−1)	−0.9554**	0.0412	-	-
Model 2				
GEC	−0.0264**	0.0301	−0.1503**	0.0100
NRR	0.0354*	0.0000	0.7521*	0.0000
EGL	−0.0765*	0.0050	−0.2741*	0.0000
ETX	−0.0586**	0.0300	−0.5130*	0.0020
NRR*ETX	−0.0627*	0.0000	−0.0565*	0.0000
ECM (−1)	−0.7901**	0.0300	-	-
Model 3				
GEC	−0.0310**	0.0300	−0.1233*	0.0000
NRR	0.0245*	0.0000	0.6614*	0.0010
EGL	−0.0725***	0.0520	−0.0251*	0.0000
ETX	−0.0457***	0.0600	−0.037*	0.0000
GEC*ETX	−0.0492**	0.0430	−0.0428*	0.0000
ECM (−1)	−0.6401*	0.0044	-	-

EGL: economic globalization; ETX: environmental tax; NRR: natural resource rent; CS-ARDL: cross-sectionally augmented autoregressive distributed lag; ECM: Error Correction Model. *, **, and *** denote the significance level at 1%, 5% and 10%, respectively.

energy use[29] and green innovations[31] support environment quality. ETX is an important factor for reducing carbon emissions, but fuel consumption is the main determinant of pollution, so it is necessary to reduce fossil fuel consumption which is high-pollutant in favour of green energy consumption.[58] Tax on fossil fuels consumption decreases emissions and supports green transportation and green economy as a whole.[59] Lowering tax on energy non-intensive commodities combined with carbon tax can have the most effective impact on reducing emissions and boosting green energy consumption in the same time.[60] Emissions trading system combined with carbon tax can prove to be very effective too in lowering carbon emissions.[61]

The negative association between natural resources and ecological footprint was demonstrated by Khan et al.[26] for BRI nations and by Wang et al.[28] for a large international panel of countries, confirming the ‘natural resources curse’. Zafar et al.[20] proved this adverse impact of natural resources on ecological footprint in the United States, while Bekun et al.[23] investigated selected EU countries and proved the same adverse effect, proving the bad management of natural resources in the analysed countries.

EGL has the potential to improve the environment through structural economic transformations and the adoption of efficient, cleaner technologies, particularly in high-income countries with stringent environmental regulations. As depicted in Table 6, EGL demonstrates a reduction in EFP at the 1% significance level in European nations. This suggests that a one percent increase in EGL leads to a 0.2576 percent decrease in EFP, holding all other factors constant. In other words, a high level of

EGL contributes to environmental quality improvement by reducing EFP. These findings support the viewpoint expressed by the work of Rudolph and Figge[62] for 146 countries and the work of Wang et al.[63] for World's largest economically complex economy Japan, although they differ from the work of Charfeddine[64] findings for Qatar, but the economic structure of Qatar is quite different against the European markets. Increased wealth and population development are two of the main drivers of rising material needs in modern society, both of which put stress on the world's limited supply of natural resources. It is observed that EGL considered a step forward in promoting global environmental sustainability through increasing economic growth, per capita income, and funding.[65] Increased global market access facilitates the recruitment of new business partners and provides options for environmentally responsible investment, so preventing further degradation of the natural world. Through foreign investment, and EGL introduces environmentally friendly products, innovative production techniques, technological spillovers, and managerial expertise, boosting economic growth and ensuring environmental sustainability. Mismanagement of natural resources as inputs in production lines is mitigated as a result of the internationalization of industry and the subsequent waves of technical innovation, which in turn reduces adverse ecological impacts.[66] International liberalization, with positive externalities such as increased R&D, awareness, and eco-friendly technologies stimulated by foreign investments, can have a significant positive impact on the environment. EGL demonstrates an adverse and significant impact in Model 2 and Model 3, with a one percent increase in EGL resulting in a 0.2741% and 0.0251% decrease in EFP, at the one percent significance level.

According to the results, the adoption of ETX is a significant factor in reversing the positive significant status of EFP in the countries of the European nations. In particular, according to each of the three different regression models, an increase of one percent in ETX will, in the long run, result in a reduction of 0.6610%, 0.5130%, and 0.037%, respectively in EFP. These results agree with those of prior studies by Fang et al.,[67] which highlight the positive effect of ETX in promoting GEC. These studies emphasize the role of taxes in driving the transition towards environmentally friendly energy sources. The effectiveness of ETX in improving environmental quality is evident, particularly in countries with lower levels of EFP. ETXs are crucial to the system, encouraging sustainability and environmentally responsible behaviour. It helps internalize external environmental costs into economic decision-making, integrating environmental deliberations into policy agendas. Environmental taxation mitigates environmental impacts by discouraging resource-intensive and polluting actions through taxes and indictments and generates revenue streams that can be reinvested in sustainable development initiatives like green energy adoption and natural resource management. It supports carbon neutrality and sustainable development by encouraging cleaner production, renewable energy transitions, and environmental and social well-being initiatives.

Moreover, the interaction between NRR and ETX (NRR*ETX) in Model 2, following equation 2, significantly contributes to the mitigation of EFP in European nations. A 1% increase in the moderating variable (NRRETX) results in a 0.6610% decrease in EFP. These results highlight how efficient management of natural resources through ETX can potentially yield environmental benefits in European nations. Similarly, the interaction between GEC and ETX (GEC*ETX) in Model 3, following Equation 3, significantly contributes to the mitigation of EFP in European nations. When the moderating variable (GEC*ETX) is increased by 1%, the effect on EFP is to reduce it by 0.0428%. These results imply that European nations can benefit environmentally from ETX-facilitated management of GEC.

The implementation of carbon or emissions taxes appears to play a significant role. A 1% increase in ETX is associated with a 0.6610%, 0.5130%, and 0.037% decrease in EFP in the long run under all regression models. These results align with previous studies conducted by

Fang et al.,[67] which demonstrate the positive role of taxes in promoting GEC and improving environmental quality. Liu et al.[33] and He et al.[32] proved the same negative association between environmental taxation and ecological footprint for OECD countries and China. Safi et al.[34] and Depren et al.[35] demonstrated a short-run and a long-run effect of ETX on improving environmental quality and decreasing pollution in G-7 and in Northern European countries. Same findings were achieved by Sohail et al.[68] for BICST economies, showing that ETX in transportation reduces carbon emissions. Environmental regulations generally reduce pollution and supports FDI (as a measure of globalization) to generate positive externalities in the host economies, contributing even more to improving environmental quality and proving the pollution halo hypothesis for those economies.[69] The estimated results of this study are in line with most of the previous studies because environmental taxation has exactly this aim of reducing environmental burden, just like green energy use reduce emissions and globalization supports the exchange of clean technologies among different economies, with a positive impact on environment.[63,70] In the long-run, we can notice from Table 6 that the impact of ETX is considerably higher than in the short run. However, from all models we can notice that the higher impact belongs to NRR, which is positively associated with ecological footprint, contributing to the environment deterioration. However, the mediation effect of ETX in conjunction with natural resources is negative on the ecological footprint. So, environmental taxation is the solution for decreasing the ecological footprint. ETX can also support economic activity, which allows economies to achieve their targets of growing, but also protecting environment in the same time. Dökmen[71] demonstrated the positive effect of ETX on economic growth in European countries, while decreasing pollution. Also, Andrei et al.[72] proved the same positive effects for Romania.

Overall, this research highlights the significance of considering the interaction between variables such as NRR and ETX, as well as GEC and ETX, in mitigating EFP in European nations. These findings provide valuable insights into the potential benefits of efficiently managing natural resources and promoting the use of green energy sources through ETX in the context of environmental management in the European nations.

Robustness check (AMG)

The robustness of the CS-ARDL method was also assessed using the AMG approach. The long-term estimates obtained from both the AMG and CS-ARDL methods exhibit consistent patterns, with the exception of a few variations. Overall, the dimensions of the estimates are largely comparable. However, it is worth noting that the coefficients obtained through the CS-ARDL approach tend to be larger in magnitude when compared to the AMG method. This observation aligns with the findings of Zhongwei and Liu,[73] they used the CS-ARDL technique to probe the short- and long-term relationships between variables and evaluated the results' robustness with the help of the AMG technique.

The econometric results obtained through the AMG method in Table 7 demonstrates that all variables, except for NRR, have a detrimental impact on EFP. Specifically, variables such as GEC, EGL, and ETX are found to exert a significant influence on EFP. These results support the assertions made in the study conducted by Saqib et al,[54] which highlight the potential benefits of alternative energy sources and ETX in improving environmental conditions. To provide a comprehensive overview of the empirical findings, the AMG robustness test results for the study, as presented in Table 7, were further interpreted through graphical representation in Figure 2, its provided econometric results are complemented by this graphic depiction, which also contributes to a better summarizing of the overall empirical results.

Table 7. Robustness check (AMG).

	Model 1	
	AMG	
Variables	Coeff.	Prob.
GEC	−0.0375*	0.0000
NRR	0.2278*	0.0000
EGL	−0.2675*	0.0000
ETX	−0.3284*	0.0000
Constant	1.9321*	0.0000
Model 2		
GEC	−0.0301*	0.0000
NRR	0.1892*	0.0000
EGL	−0.2843*	0.0000
ETX	−0.3965*	0.0000
NRR*ETX	−0.1492*	0.0000
Constant	1.729***	0.0600
Model 3		
GEC	−0.0217*	0.0000
NRR	0.1885*	0.0000
EGL	−0.3045*	0.0000
ETX	−0.2984*	0.0000
GEC*ETX	−0.1720*	0.0000
Constant	1.5682***	0.0700

NRR: natural resources rent; EGL: economic globalization; ETX: environmental tax; AMG: Autoregressive Mean Group. *, and *** indicate the significance level at 1%, and 10% respectively.

Figure 2. Visual depiction of empirical results.

Conclusion and policy recommendations

Conclusion

This study reveals how other parameters affects ecological footprint in European nations. Green energy and smart taxation policy are crucial to minimizing ecological footprint. The innovative CS-ARDL approach and AMG technique reveal the long- and short-term effects of parameters on ecological footprint. Green energy, EGL, and ETXs significantly reduce ecological footprint. Green energy reduces non-renewable energy use and energy consumption's environmental impact, promoting environmental sustainability. EGL improves environmental quality and EFP through structural changes and cleaner technology. The study also emphasizes ETX's significance in promoting sustainable practices and green energy adoption. ETXs encourage European firms to balance economic growth and environmental sustainability by imposing taxing polluting activities and rewarding eco-friendly ones. It effectively internalizes resource extraction and consumption environmental costs. Natural resources adversely affected the ecological footprint. This underlines the significance of sustainable natural resource management, especially through ETX integration. Policymakers can reduce resource extraction's environmental impact by taxing resource-intensive sectors and encouraging cleaner technology.

The findings of this study have important repercussions for the formulation and implementation of policies that promote cleaner energy and economic practices. Policymakers should prioritize the promotion of green energy, the enhancement of ETX policies, and the integration of natural resource management. Fostering EGL while ensuring adherence to stringent environmental regulations and standards is crucial for achieving sustainable development. In a nutshell, the findings of this study contribute to the existing body of knowledge by shedding light on the various effects that green energy, natural resources, EGL, and ETX have on ecological footprint in European nations. It highlights the importance of efficient taxation policies and the consistent use of green energy as significant drivers for lowering ecological footprint. Policymakers may promote sustainable growth, protect the environment, and improve the lives of present and future generations by taking the study's suggestions into account.

Policy recommendations

Based on the findings of this study, several policy recommendations can be derived to effectively reduce the ecological footprint in European nations. The persistent utilization of green energy use and the implementation of efficient taxation policies are crucial in achieving this goal. In order to significantly reduce on ecological footprint, policymakers should put a premium on finding and using renewable energy sources. Incentives, subsidies, and investments in renewable energy sources are all ways to accomplish this goal. There needs to be a push to raise awareness and get people and businesses to use renewable energy sources. ETX is emphasized as a key factor in promoting eco-friendly behaviours and cutting down on ecological footprint. Policymakers should think about enacting and strengthening environmental laws that encourage people to engage in ecologically sustainable behaviours and punish those who engage in practices that have an adverse impact on the environment. Taxes of this type can be placed on activities that contribute to climate change, deplete natural resources, or endanger human health. Green projects and sustainable technology R&D can both benefit from the proceeds of these taxes. The research highlights the moderating roles of rent from natural resources and green energy consumption in conjunction with ETXs on ecological footprint. To diminish the adverse effects of resource extraction and to encourage sustainable resource consumption, policymakers should investigate systems that combine NRR management and ETXs. Some possible solutions include increasing taxes on resource-intensive businesses and promoting the use of cleaner technology during the extraction of those resources.

The results indicate that EGL can improve environmental quality by encouraging structural changes in the economy and the use of cleaner technology. The policy community should make use of EGL's potential to advance environmentally sound behaviours. To that end, we must create binding international agreements and work together to solve pressing environmental problems, and we must also implement strict laws and standards for the world's largest enterprises. If policymakers are serious about reducing ecological footprint, they need to take an integrated approach that employs multiple policy instruments and initiatives. This includes a combination of regulatory measures, economic incentives, public awareness campaigns, and technological advancements. Collaboration between civil society organizations and governments is crucial to implement comprehensive and coordinated policies that address ecological footprint reduction at multiple levels. In summary, the study provides valuable insights and recommendations for the development and implementation of environmentally sound economic and energy policies. By prioritizing green energy use, implementing efficient taxation policies, integrating NRR management, considering the impact of EGL, and adopting an integrated approach, policymakers can effectively reduce ecological footprint and promote sustainable development in European nations.

Limitations of the study

The inclusion of broad datasets was hampered by missing values and data unavailability, constituting a significant limitation of our work. The restricted number of countries represented on the panel is an additional limitation. Future research should adopt a global perspective when studying the effects of green energy, natural resources, EGL, and ETXs on ecological footprint. Future studies can also benefit from using additional control variables and large datasets. Lastly, future studies can consider load capacity factor as a proxy of ecological quality. Unlike the ecological footprint, the load capacity factor considers both the demand and supply side of the environment.

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Authors' contributions

N.S. contributed to the conceptualization, methodology, formal analysis, software, writing – original draft. M.U. contributed to the review literature, methodology, validation writing – review and editing. M.R. contributed to the supervision, validation, project administration, writing – review and editing. R.S.S contributed to the data curation, funding, writing – review and editing. M.K. contributed to the investigation, writing – review and editing. L.A.B. contributed to the investigation; writing – review and editing.

Data availability

The dataset used during the current study is available from the author on request.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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