

Research paper

Fulfilling the SDG 13: The entitlement of green energy, green technology, and financial enrichment to ecological survival

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ABSTRACT

Financial enrichment can be a double-edged sword, yielding both beneficial and adverse ecological effects. Green energy and investment in green technology may be essential in accomplishing ecological survival and transforming the disadvantageous ecological impacts of financial enrichment into advantageous ones. This study offers novel perspective by delving into the financial enrichment's impact on ecological survival via the means of green technology. In this vein, the annual panel data are collected for 21 European Union (EU) members from 1995 to 2020. Empirical outcomes revealed that green energy and green technology encourage ecological survival. In contrast, utilization of resources from nature, population, and financial enrichment are exacerbating the ecological pressure. As per the moderating effects, this study reveals that financial enrichment encourages ecological survival via the channel of green technology. These findings suggest that European Union members should strengthen support for green technologies, while allocating financial activity toward eco-friendly economic activities. Financial institutions should also exert more stringent evaluation of environmental impact so that loan growth is better harmonized with the Sustainable Development Goals (SDGs).

1. Introduction

Global climate change and ecological pressure have instigated quests for strategies that harmonize economic upturn with ecological objectives. In this light, decisions makers and academia recognized the need to switch towards advanced green technologies and green energy to be able to achieve economic objectives while safeguarding environment (Mahmood et al., 2024). Innovative eco-friendly technologies and low-carbon solutions are acknowledged as vital mechanisms in mitigating anthropogenic emissions and sustaining ecological survival (Sadiq et al., 2024). In the same fashion, the utilization of clean energy is affirmed to pave way towards attaining the objectives of energy security (Sharif et al., 2024). This view has been strongly substantiated by studies to date. Specifically, (Sadiq et al., 2024) observed that clean energy and

the uphold of green technology mitigate anthropogenic emissions in Asia. Notwithstanding these outcomes, it is worth noting that (Sharif et al., 2024) corroborated the beneficial ecological impact of green technology. Likewise, economic upturn and financial enrichment is acting against ecological preservation of the observed countries. (Khan et al., 2021) observed that energy-intensive economic activity correlates with ecological pressure especially in early growth stages. The same holds true for natural resources use. Similarly, (Lv et al., 2024) revealed that natural resources exacerbate ecological quality at the global level.

Financial enrichment can be defined as the proliferation of financial services like borrowing, saving, and investment. There is mixed evidence to date on the ecological impact of financial enrichment. From one viewpoint, it may support ecological survival by providing

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affordable loans for green technology projects (Yasin et al., 2025). In contrast, financial enrichment may support energy-, carbon-, and resources-intensive economic activities and subsequently jeopardize ecological survival (Sadiq et al., 2024).

Plethora of studies to date dove into the ecological impact of financial enrichment, green technology and green energy with a special focus on bivariate relationships that overlook the multifaceted perspective of ecological survival. Against this backdrop, the present study captures interrelatedness of diverse macro-economic factors in explaining the dynamic of ecological survival. Moreover, the financial enrichment-green technology moderating role received limited attention in studies to date. For instance, (Fareed et al., 2022) authenticated that innovation activity reduces the adverse ecological impact of financial inclusion in Eurozone. However, this study focused solely on ecological facets of sustainability while neglecting economic or social facets.

The selection of EU members as investigative laboratory is justifiable on the following grounds. First, it has introduced the European Green Deal aiming to substantially decrease anthropogenic emissions and achieve net-zero region by 2050 (Satrovic et al., 2025). Second, considering financial enrichment, EU is the home of consistent and highly developed financial systems supporting sizable investment in green technologies. Third, there are substantial differences in terms of ecological survival. To be more specific, there are disparities across the member states with respect to the achievement of SDGs (Sena et al., 2024). Notably, there is a common tendency of higher sustainability in Western and Northern EU members contrasting lower sustainability in Eastern and Southern EU members. Regarding SDG13, Sweden establishes itself as the top performer especially for 13.1, 13.2, 13.4, and 13.5, while Croatia establishes itself as underperformer across all targets except 13.2 (Sena et al., 2024).

Additionally, Western and Northern EU members are outperforming the block in terms of green technology utilization and green energy (Mahmood et al., 2024). With this heterogeneity in mind, the following research question is pinpointed: do economic upturn and financial enrichment furnish ecological survival of the EU? In this vein, the research hypothesis is that financial enrichment endangers ecological survival in the EU, while its negative effects are weakened by means of green technology.

The main objective of this paper is to determine whether financial enrichment, when channeled through green technology, can support ecological survival rather than environmental deterioration. In doing so, the study contributes to the empirical and policy debate by clarifying how economic and financial systems can be aligned with the ecological goals of the European Union. In addition, it shows that promoting green technology and directing financial flows toward environmentally sustainable initiatives are necessary to mitigate the adverse ecological effects of economic and financial development in the European Union. Accordingly, the study highlights the need for stricter evaluation criteria by financial institutions and for policy measures that expand access to green investment financing aligned with SDG 13. It also uses a more comprehensive measure, namely ecological intensity, defined as the ratio of ecological footprint to gross domestic product. This measure captures both the ecological and economic dimensions of environmental pressure. In this context, lower ecological and carbon intensity (ESE and ESC) means that less greenhouse-gas-related pressure is generated per unit of output. Improvements in these indicators are therefore interpreted as progress toward climate action under SDG 13.

The succeeding section reviews the recent studies on the matter. Section 3 presents the theoretical foundation, discloses data and models, and describes methodology. The findings are tabulated and discussed in Section 4, while concluding remarks are presented in Section 5.

2. Literature review

A growing body of research has investigated the interplay between green technology, green energy, financial enrichment, economic

growth, and natural resource use, highlighting their individual and interactive effects on ecological sustainability. This section critically examines recent empirical studies to identify areas of consensus, contradiction, and gaps in the literature.

Several studies converge on the positive environmental impact of green technology and green energy. (Sharif et al., 2024), analyzing countries with the highest ecological footprints, found that both green technological innovation and renewable energy consumption significantly reduced environmental pressure. Using quantile regression, they showed that green patents and clean energy adoption lowered the ecological footprint across all pollution levels. Similarly, (Sadiq et al., 2024) demonstrated that in emerging Asian economies, green energy and green innovation had strong long-term effects in reducing CO₂ emissions. Their CS-ARDL estimations confirmed that green innovation had an even greater mitigating effect than renewables. Institutional and policy frameworks also emerge as critical mediating factors. (Hassan et al., 2024) demonstrated that renewable energy significantly reduced the ecological footprint only in countries above specific thresholds of institutional quality and human development. Below these thresholds, renewable energy had no significant environmental benefits, highlighting the need for supportive policy environments to realize sustainability gains.

The effectiveness of these technologies has also been confirmed in advanced economies. Mahmood et al. (2024), in a study of 25 Western European countries, reported that green innovation, proxied by patent activity, helped reduce emissions, albeit only in the long run. In the short term, the “scale effect” of economic and technological growth tended to increase energy demand and emissions, delaying environmental benefits. These findings align with those of (Fareed et al., 2022), who found that in Eurozone, innovation positively impacted environmental recovery.

Economic growth and natural resource use have generally been found to exert negative pressures on environmental indicators. (Khan et al., 2021) showed that economic expansion, resource depletion, and energy consumption worsened CO₂ emissions globally. Similarly, Mahmood et al. (2024) validated the Environmental Kuznets Curve (EKC) in Western Europe, with emissions increasing during early growth phases and declining only after a high-income threshold.

The impact of financial enrichment on environmental quality remains highly contested. Some authors highlight its potential to enhance ecological outcomes. (Yasin et al., 2025) reported that a well-functioning financial system can channel capital toward clean investments, reinforcing sustainability goals. Conversely, other studies present finance as an environmental threat. (Sadiq et al., 2024) found that in Asian countries, financial enrichment led to higher CO₂ emissions, likely by fueling energy-intensive industrial activity. (Khan et al., 2021) also reported that financial expansion, along with globalization, deteriorated environmental quality globally. This is justified because financial enrichment boosts production and consumption, raising energy use and related emissions.

Recent contributions have examined the interactions between financial enrichment and innovation. (Fareed et al., 2022) scrutinized if innovation activity makes a difference in the connectedness of financial development and carbon emissions/ecological footprint in Eurozone. They found that stronger innovation activity mitigates the adverse impact of financial development. Similarly, (Lv et al., 2024) showed that innovation activity was more effective in reducing the adverse ecological impacts of natural resources in developed and developing countries when accompanied by institutional quality and moderate energy use. These findings underscore the importance of synergy between finance, institutions, and technology.

However, these studies still differ from our approach in several ways. First, they focus on CO₂ emissions or aggregate ecological footprint, whereas we work with ecological and carbon intensity indicators that link environmental pressure to economic output. Second, they treat innovation mainly as an additional regressor, while our framework

places green technology in an explicit moderating role between financial enrichment and ecological survival. Third, they rely on mean-based estimators, whereas our method-of-moments quantile regression allows the finance–environment nexus to vary across the distribution of ecological intensity.

Literature broadly supports the positive environmental impact of green technology and green energy. However, the effects of financial enrichment and economic upturn are context-dependent, shaped by institutional settings, energy mix, and development stage. While many studies confirm that growth and resource exploitation worsen environmental outcomes, green finance and innovation can potentially moderate these effects—if properly regulated and targeted. Despite this progress, gaps remain. Most studies overlook the role of green technology as a moderator between finance and ecological outcomes, and few offer a comprehensive framework integrating all relevant drivers. Moreover, research on high-income, policy-driven regions such as the EU is still limited. Against this background, our study develops an integrated empirical framework that links green energy, green technology, financial enrichment, growth, and natural resource use to ecological outcomes. This approach offers a clearer view of the mechanisms through which financial and technological factors shape ecological survival in one of the world's most environmentally ambitious regions.

3. Conceptual framework, model, econometric techniques, and data

3.1. Description of data

We focus on EU countries for three main reasons: (i) European Union members are jointly responsible for 25% of the excess utilization of natural resources and therefore bear the intimidating burden for global ecological challenge (Hickel et al., 2022) (ii) the financial markets and institutions of EU faced major challenges in the previous decades due to the financial crisis, structural reforms, and the fragmentation of the markets. As a response to these challenges, policy makers have developed various initiatives that relied on the implementation of legal frameworks and technical support. These initiatives strengthened EU members' response towards dynamic market changes and empowered the financial sector's oversight (European Commission, 2024). (iii) European financial institutions and markets are relatively well developed and continue to grow, although the degree of integration with the

business environment still varies across members. Given data availability for green technology, this study examines the determinants of ecological survival in 21 EU countries over the period 1995–2020, as listed in Table A2 (Appendix 2). Table 1 presents the variables and their summary statistics.

This study uses a balanced panel drawn from several reliable sources. To examine the nonlinear relationship between economic upturn and ecological survival, we use GDP per capita in 2015 US dollars from the World Bank (WB, 2023) as the proxy for economic upturn. The same source provides data on natural resource use, measured as natural resource rents as a percentage of GDP, and on population dynamics, measured as the share of individuals aged 15–24 in the labor force. Data on green technology, measured as the share of environmental patents in total patents, come from the Organisation for Economic Co-operation and Development (OECD, 2024). Data on green energy, measured as the share of renewable electricity in total generation, come from (OECD, 2022). Financial enrichment data come from the International Monetary Fund (IMF, 2023) and are measured with three indicators that capture overall financial development (Fig. 1), financial institutions (Fig. 2), and financial markets (Fig. 3).

Lastly, this study relies on two proxies for ecological survival: ecological intensity (all components) and ecological intensity (carbon component) collected from the Global Footprint Network (GFN, 2022). Table 1 shows that economic upturn has the highest mean value among the variables, while the ecological indicators have the lowest means. Table 2 and Fig. 4 illustrate the relationships among the underlying variables.

The findings in Table 2 and Fig. 4 show statistically significant positive associations between economic upturn, green technology, financial development, development of financial markets and institutions, green energy, and population. However, there is a statistically significant negative relationship between economic upturn and natural resource use. Moreover, ESE and ESC are negatively and significantly correlated with FED, FEI, FEM, GRE, and DY.

3.2. Conceptual framework and model setup

Mainstream literature has examined the relationship between ecological survival and economic upturn through the Environmental Kuznets Curve (EKC), often overlooking other macroeconomic factors. The EKC reveals how ecological pressure responds to the intensification

Table 1
The construction of dependent and independent variables.

Var.	Definition	Source	Mean	St. Dev.	Max	Min	Skew.	Kurt.
UP	Economic upturn (gross domestic product - GDP per capita, in 2015 US\$)	(WB, 2023)	31556.47	21226.31	112418.00	3540.56	1.511	6.147
GRT	Green technology (environmental patents, % of total)	(OECD, 2024)	10.77	4.14	26.40	1.10	0.670	3.791
FED	Financial enrichment 1: financial development index	(IMF, 2023)	0.59	0.17	0.90	0.16	−0.389	2.054
FEI	Financial enrichment 2: financial institutions efficiency index	(IMF, 2023)	0.58	0.08	0.83	0.30	0.281	4.092
FEM	Financial enrichment 3: financial markets index	(IMF, 2023)	0.49	0.22	0.95	0.02	−0.371	2.305
RU	Natural resource use (natural resource rents, % of GDP)	(WB, 2023)	0.42	0.56	5.71	0.01	3.873	26.294
GRE	Green energy (generation of renewable electricity, % of total)	(OECD, 2022)	25.09	20.52	81.62	0.58	0.961	2.961
DY	Population dynamics (the percentage of population ages 15–24 participating in the total labor force)	(WB, 2023)	42.38	12.55	74.26	21.02	0.718	2.595
ESE	Ecological indicator 1: Ecological footprint (global hectare – gha per person/UP)	(GFN, 2022); (WB, 2023)	0.00025	0.00015	0.00092	0.00005	1.864	6.950
ESC	Ecological indicator 2: Carbon footprint (gha per person/UP)	(GFN, 2022); (WB, 2023)	0.00015	0.00009	0.00055	0.00003	1.876	6.934

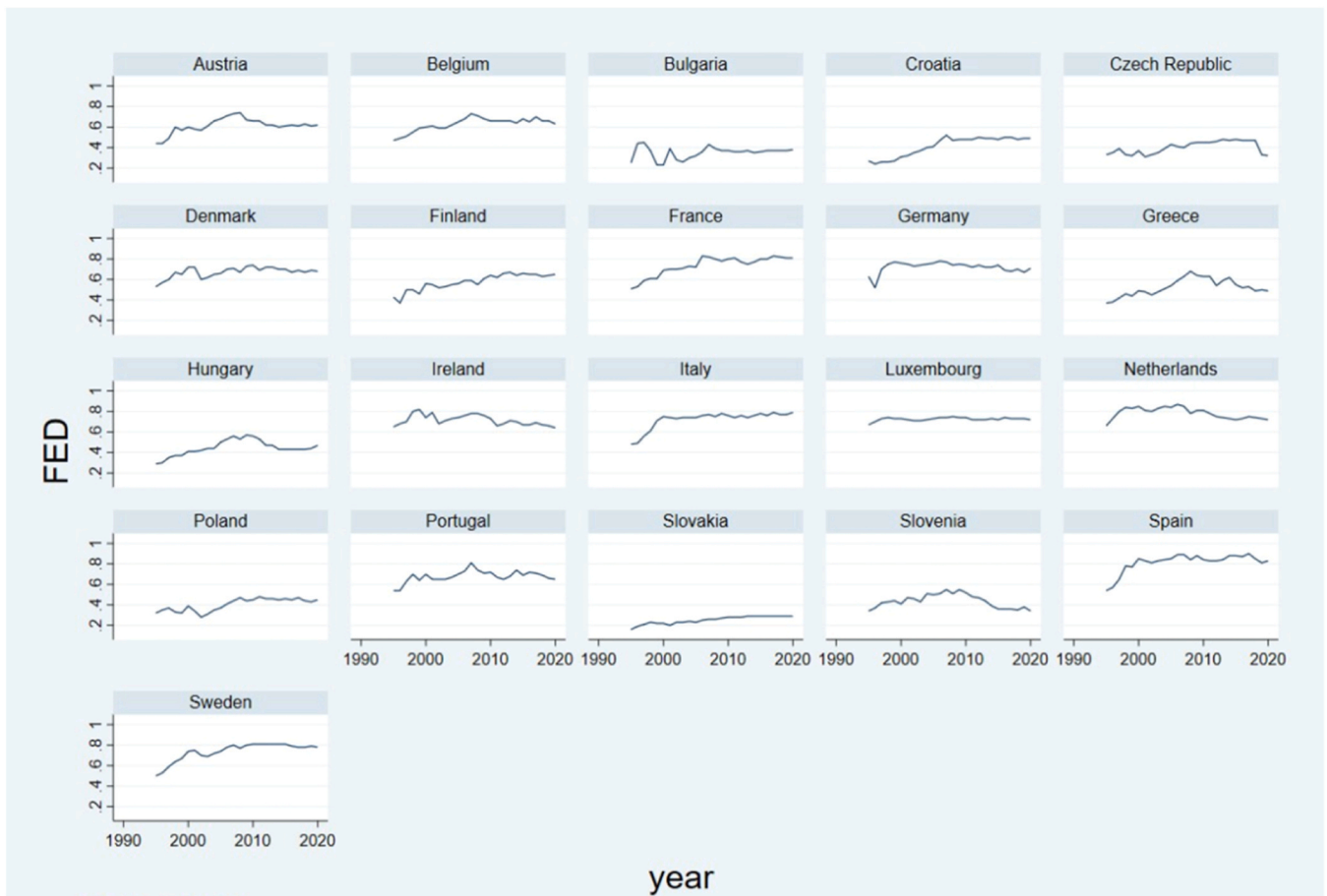


Fig. 1. Data trends (financial development index).

of economic activity (Hu et al., 2024; Ahmad and Satrovic, 2024). (Grossman and Krueger, 1995) observed that ecological pressure is positively associated with the intensification of economic activity at the early stages of growth reversing to favorable ecological impact at the higher levels of growth. This pattern asserts that economic upturn is relevant in explaining ecological pressure as nations focus more attention on gains in production, jobs opening, and earnings than on ecological quality in the early growth stages. Although the EKC helps explain the economic dimension of ecological survival, it does not fully capture the ecological effects of other forms of human activity. For this reason, the present study extends the EKC framework by examining whether green technology, green energy, financial enrichment, natural resource use, and population also help explain ecological survival. Pursuant to (Ahmad and Jabeen, 2024; Hassan et al., 2024; Hu et al., 2024; Lv et al., 2024; Naqvi et al., 2023; Xu et al., 2024), our subsequent model is established as follows (Eq. 1):

$$ECSW_{it} = f(UP_{it}, UP2_{it}, GRT_{it}, FE_{it}, RU_{it}, GRE_{it}, DY_{it}) \quad (1)$$

Based on Eq. (1), ECSW represents the ecological indicators used in the analysis. These include ecological intensity, denoted by ESE and used in Models 1–4, and carbon intensity, denoted by ESC and used in Models 5–8. In addition, UP and UP2 capture how ecological survival changes with economic upturn. GRT denotes green technology, GRE denotes green energy, and DY captures population dynamics through the labor force participation rate of people aged 15–24. To examine the financial enrichment–ECSW nexus, we use three proxies: financial development (FED), financial institutions (FEI), and financial markets (FEM). RU denotes natural resource use and is included to assess its ecological effect in EU members. Because the variables are measured in different units, all variables are transformed into logarithms, as shown

in Eq. (2).

$$LECSW_{it} = \alpha_{it} + \beta_1 LUP_{it} + \beta_2 LUP2_{it} + \beta_3 LGRT_{it} + \beta_4 LFE_{it} + \beta_5 LRU_{it} + \beta_6 LGRE_{it} + \beta_7 LDY_{it} + \varepsilon_{it} \quad (2)$$

Where L denotes the natural logarithm, elasticities are outlined by $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7$ and are computed to identify the change of ecological survival when a change in green technology, green energy, financial enrichment, economic upturn, population, and natural resources occurs. In Eq. (2), t denotes the period from 1995 to 2020, and i denotes the 21 European Union members in the sample. The stochastic error term is denoted by ε_{it} , whereas α_{it} denotes the constant term.

On the left-hand side of Eq. (2), the study departs from mainstream work by using two broader indicators of ecological survival: ecological footprint per unit of output (ESE) and carbon footprint per unit of output (ESC). Ecological survival refers to the capacity of ecosystems to continue functioning and renewing despite intensive use of natural resources (Rohde, 2013). In this study, ESE and ESC capture the amount of ecological pressure associated with generating one unit of GDP. Lower values of ESE or ESC indicate more efficient use of natural capital and less pressure per unit of output. For this reason, lower ecological and carbon intensity are interpreted as higher ecological survival. The advantage of these indicators over the ecological footprint alone is that they incorporate both the ecological and the economic dimensions of environmental pressure. Against this backdrop, the present study utilizes the ecological footprint (all/carbon components)/UP to comprehensively assess ecological survival in a sense that lower ecological footprint (all/carbon components)/UP means higher ecological survival and vice versa.

The conventional EKC theory is substantiated if the coefficient of

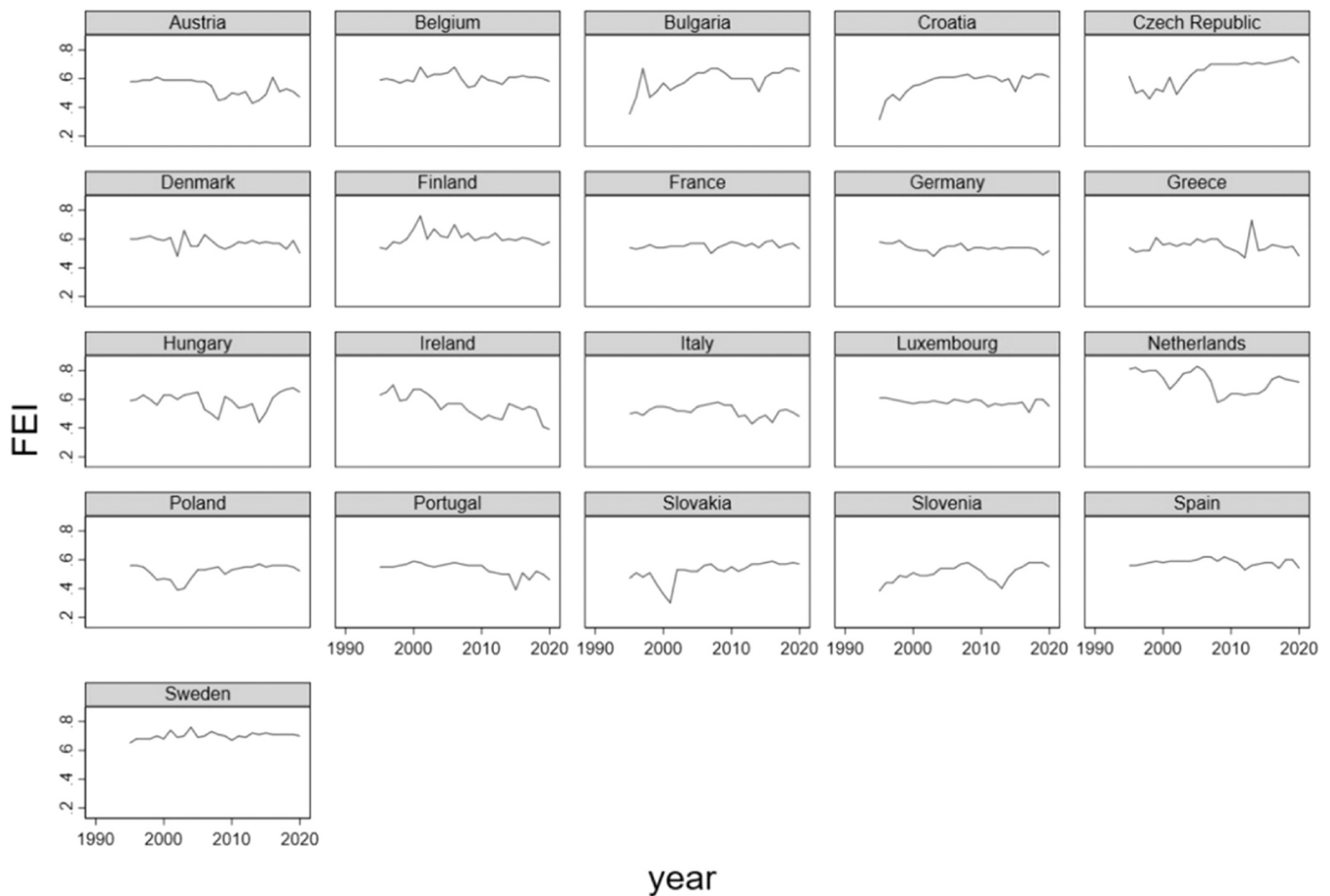


Fig. 2. Data trends (financial institutions efficiency index).

economic upturn is statistically significant and positive (i.e. $\beta_1 = \frac{\partial ECSW}{\partial UP} > 0$) and if the coefficient of economic upturn squared is statistically significant and negative (i.e. $\beta_2 = \frac{\partial^2 ECSW}{\partial UP^2} < 0$) (Naqvi et al., 2023; Qalati et al., 2023). This study uses two indicators of ecological survival: dependent variable 1, ecological footprint (global hectare, gha per person/UP), and dependent variable 2, carbon footprint (gha per person/UP). By means of these indicators, the present study introduces modifications to the traditional EKC relation (Hu et al., 2024).

On the right-hand side of Eq. (2), various determinants of ecological survival are considered. In addition to examining the relationship between economic upturn and ECSW, this study also assesses the ecological impacts of green technology. The aim of green technology is to ensure ecological resilience through responsible and environmentally friendly technology. As such, green technologies have been identified as a critical determinant of ecological survival. Green technologies can help reduce ecological vulnerability and limit natural resource use by improving energy efficiency and reducing reliance on conventional non-renewable energy sources (Xu et al., 2024). They also aim to induce the production and consumption of items that will be consuming less energy in comparison with traditional gadgets and by that means reduce anthropogenic emissions (Ahmad and Jabeen, 2024; Bergougui and Satrovic, 2025). In juxtaposition to these channels, it is pertinent to note that green technologies promote cleaner energy sources and technological advancements that are less harmful to the environment than non-renewable energy sources (Amin et al., 2023). In this context, efforts to develop green technologies are expected to promote sustainable consumption and production and to improve the ecological survival of EU members (i.e. $\beta_3 = \frac{\partial ECSW}{\partial GRT} < 0$).

The environmental impact of financial enrichment can be viewed

from two opposing perspectives. On one hand, financial enrichment may worsen ecological outcomes if cheaper credit encourages firms to expand or start highly polluting activities. The expansion of output might use energy-intensive machinery and thus diminish the ecological quality of EU members (Naqvi et al., 2023; Qalati et al., 2023; Satrovic et al., 2025). On the other hand, financial enrichment can help in safeguarding the ecological survival of EU members (Udeagha and Breitenbach, 2023). Given these arguments, financial enrichment may negatively or positively relate to ECSW (i.e. $\beta_4 = \frac{\partial ECSW}{\partial FE} < 0$ or $\beta_4 = \frac{\partial ECSW}{\partial FE} > 0$).

Green energy has become a key tool for easing ecological pressure and moving toward net-zero emissions (Satrovic et al., 2025). As the consumption of dirty energy (i.e. oil and coal) has deepened ecological challenges, both advanced and emerging countries have approved frameworks for sustainable growth based on the adoption of green energy. It is persuasive in curtailing ecological deterioration, supporting energy security, and shrinking the dependence on dirty fuels (Hassan et al., 2024; Yıldız et al., 2024; Ma et al., 2024). The foregoing discussion indicates a beneficial ecological effect of green energy ($\beta_6 = \frac{\partial ECSW}{\partial GRE} < 0$).

Achieving a balance between economic activity and ecological survival requires the joint action of several factors, including green technology, green energy, natural resource use, and environmental regulation. Natural resource use may hinder ecological survival for several reasons. First, production often depends on resources that are used unsustainably, which can increase pollutant emissions (Tang and Jiang, 2024; Bajja et al., 2024). Second, some natural resources used in energy generation, such as cropland and wood, can contribute to deforestation and ecological insecurity (Lv et al., 2024). Third, the extraction and processing of resources such as oil and coal generate large

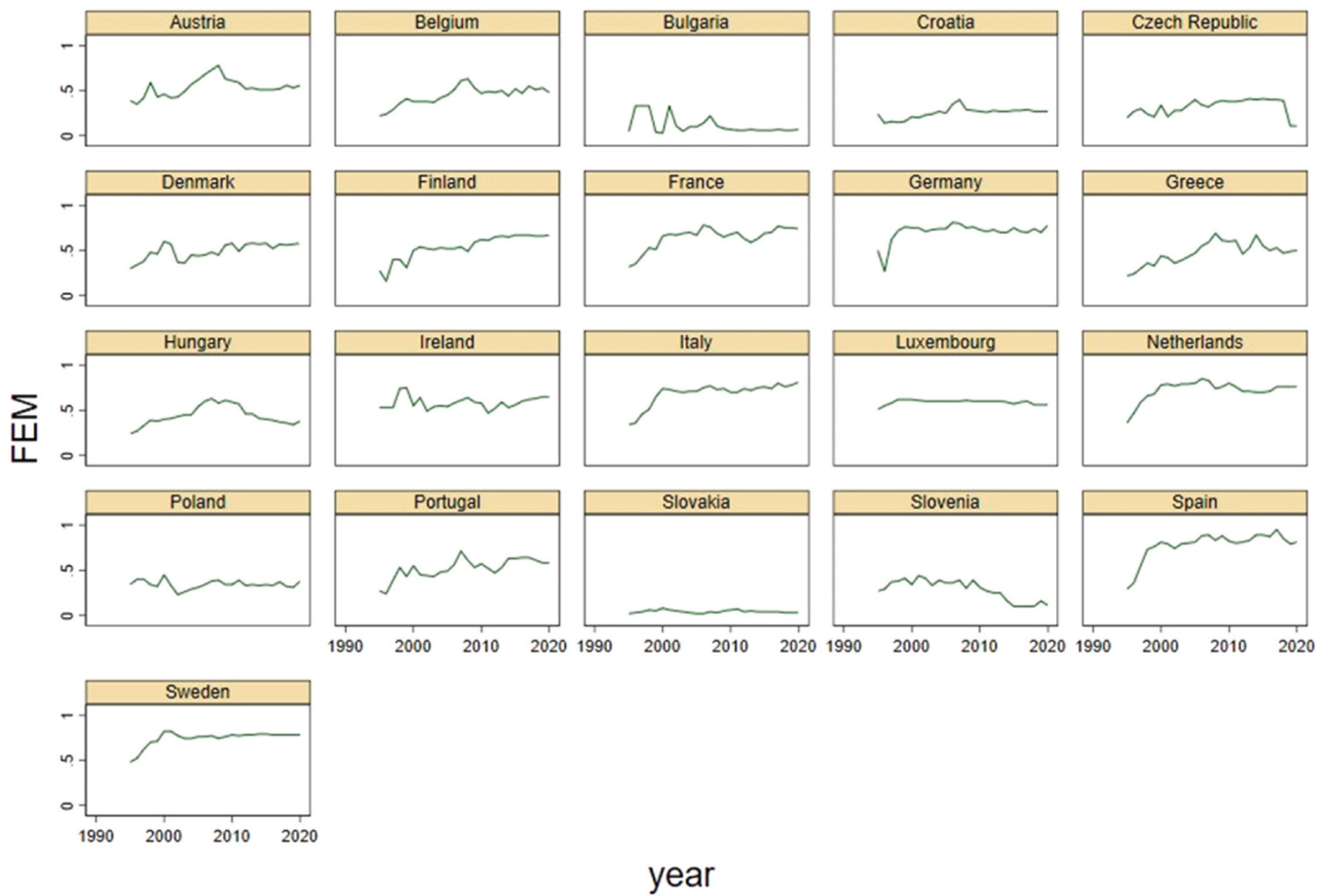


Fig. 3. Data trends (financial markets index).

Table 2
Bivariate analysis.

	UP	GRT	FED	FEI	FEM	RU	GRE	DY	ESE	ESC
UP	1									
GRT	0.109b <u>0.011</u>	1								
FED	0.613a <u>0.000</u>	0.043 <u>0.312</u>	1							
FEI	0.152a <u>0.000</u>	-0.041 <u>0.343</u>	0.243a <u>0.000</u>	1						
FEM	0.512a <u>0.000</u>	0.005 <u>0.910</u>	0.928a <u>0.000</u>	0.189a <u>0.000</u>	1					
RU	-0.256a <u>0.000</u>	0.225a <u>0.000</u>	-0.278a <u>0.000</u>	0.092b <u>0.032</u>	-0.266a <u>0.000</u>	1				
GRE	0.215a <u>0.000</u>	0.204a <u>0.000</u>	0.169a <u>0.000</u>	-0.088b <u>0.039</u>	0.160a <u>0.000</u>	-0.069 <u>0.107</u>	1			
DY	0.306a <u>0.000</u>	-0.063 <u>0.143</u>	0.358a <u>0.000</u>	0.241a <u>0.000</u>	0.327a <u>0.000</u>	0.043 <u>0.312</u>	0.188a <u>0.000</u>	1		
ESE	-0.661a <u>0.000</u>	-0.020 <u>0.634</u>	-0.738a <u>0.000</u>	-0.142a <u>0.001</u>	-0.661a <u>0.000</u>	0.384a <u>0.000</u>	-0.384a <u>0.000</u>	-0.366a <u>0.000</u>	1	
ESC	-0.609a <u>0.000</u>	-0.025 <u>0.559</u>	-0.734a <u>0.000</u>	-0.151a <u>0.000</u>	-0.645a <u>0.000</u>	0.361a <u>0.000</u>	-0.412a <u>0.000</u>	-0.352a <u>0.000</u>	0.986a <u>0.000</u>	1

Notes: a, b, and c denote significance at the 1%, 5%, and 10% levels, respectively; p-values are underlined.

amounts of pollution, threaten biodiversity, and disrupt ecosystems (Mohsin and Jamaani, 2023). However, previous studies suggest that the ecological effect of natural resources may vary across contexts (Huo and Peng, 2023). Thus, natural resources may exert either adverse or beneficial ecological effects (i.e. $\beta_5 = \frac{\partial ECSW}{\partial RU} < 0$ or $\beta_5 = \frac{\partial ECSW}{\partial RU} > 0$). Population dynamics may also increase ecological intensity because a

larger population raises food demand, land conversion, and energy consumption. As a result, this may increase reliance on dirtier energy sources and intensify ecological pressure (Xaisongkham and Liu, 2024; Ng et al., 2023). Thus, population is expected to increase ecological intensity (i.e. $\beta_7 = \frac{\partial ECSW}{\partial DY} > 0$).

We next examine the moderating role of green technology in the

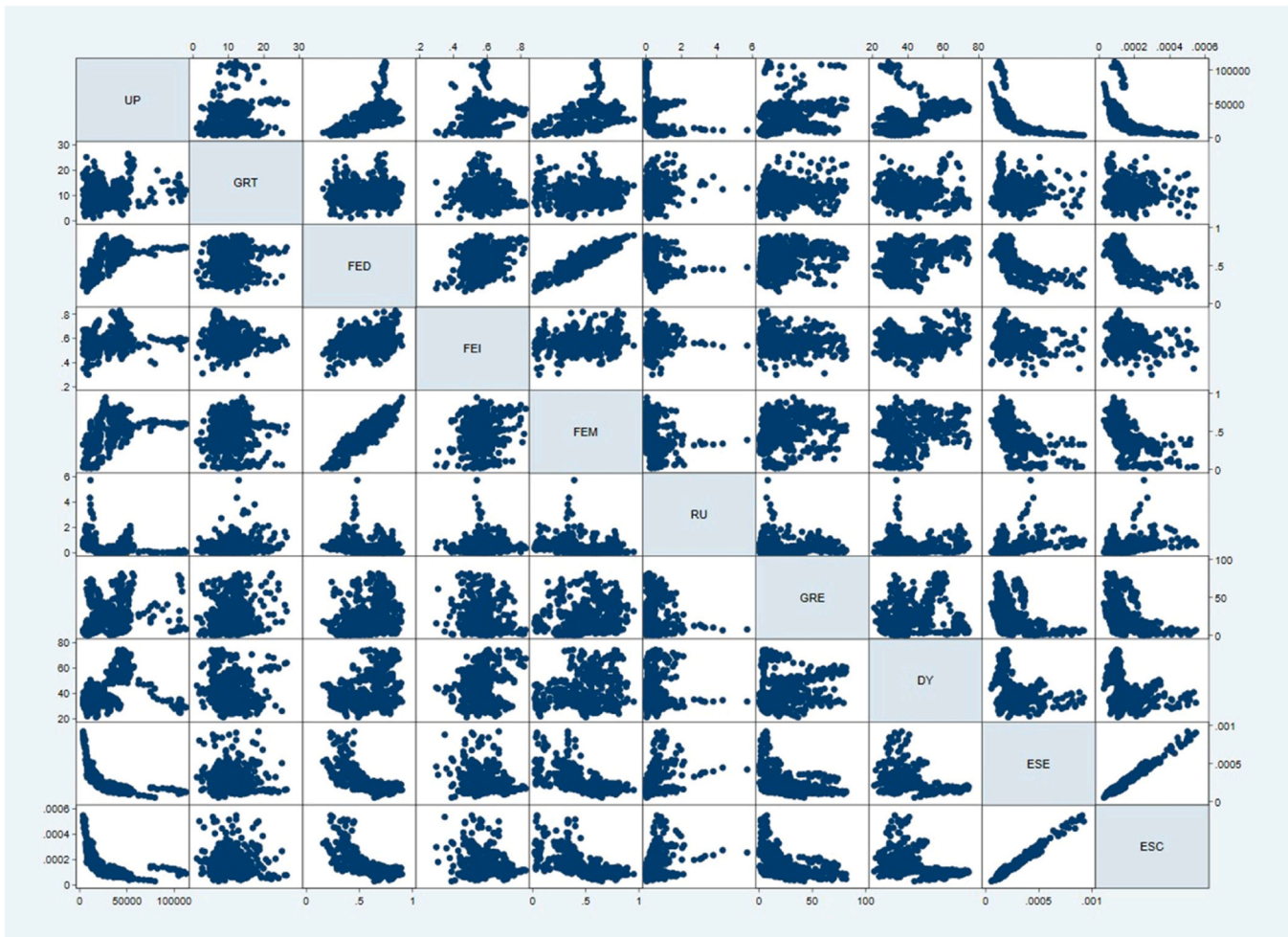


Fig. 4. Correlation coefficients.

relationship between financial enrichment and ecological survival. This channel has received limited attention from previous studies. Stronger green technology can redirect financial resources toward cleaner production, energy-efficient technologies, and research and development. Green technology in the European Union was primarily advanced through the European Green Deal during the 2019–2024 period. Its key support mechanisms included funding for green and digital technological innovation under Horizon Europe; financial support for clean investments via NextGenerationEU and the Recovery and Resilience Facility; targeted funding for green energy through REPowerEU; and carbon pricing implemented through the Carbon Border Adjustment Mechanism (CBAM) (European Commission, 2026a). Despite its holistic approach, European Green Deal was lacking strategies that navigate EU's industry pattern towards eco-friendly processes. Against this backdrop, the European Commission has launched Clean Industrial Deal in 2025 that places green technology at the core of EU competitiveness and circularity (European Commission, 2026b). More recently, in 2026 European Commission introduced local content requirements under the Industrial Accelerator Act in March 2026 to instigate the utilization and production of domestic green technologies (European Commission, 2026b). By integrating green technology with financial enrichment, EU redesigns the allocation of resources, extending funds for eco-friendly economic activities (Fig. 5). Notably, EU taxonomy is at the heart of sustainable finance initiative by guiding investments into activities supported by Horizon Europe, Recovery and Resilience Facility, and REPowerEU to foster ecological survival (European Commission, 2026c). Moreover, the advancement of green technologies is

encouraged by sustainable financial instruments such as green bonds allowing investors to support eco-friendly projects under affordable conditions (European Commission, 2025). In line with Clean Industrial Deal, financial institutions are compelled to evaluate climate change-related hazards, advancing a steady divergence from eco-unfriendly assets (European Commission, 2026b). Investments in green technologies support the transition from resource-intensive to resource-efficient economic systems, enabling production with minimal ecological impact. Additionally, carbon pricing internalizes the cost of pollution, thereby enhancing the relative affordability of sustainable alternatives compared to conventional investments (European Commission, 2026a).

When credit expands in economies with greater green-technology capacity, financial enrichment is more likely to support low-carbon projects and efficiency gains. As a result, the joint effect of finance and technology may contribute to climate action by reducing ecological and carbon intensity. In addition, stronger green technology may improve the functioning of the financial sector by supporting environmentally oriented firms and reducing financing frictions (Fareed et al., 2022). Under this argument, a negative coefficient on the interaction term indicates that green technology weakens the adverse ecological effect of financial enrichment (i.e. $\frac{\partial ECSW}{\partial (GRT \times FE)} < 0$). The equation below is formulated to capture the joint impact of green technology and financial enrichment on ECSW, as follows (Eq. 3):

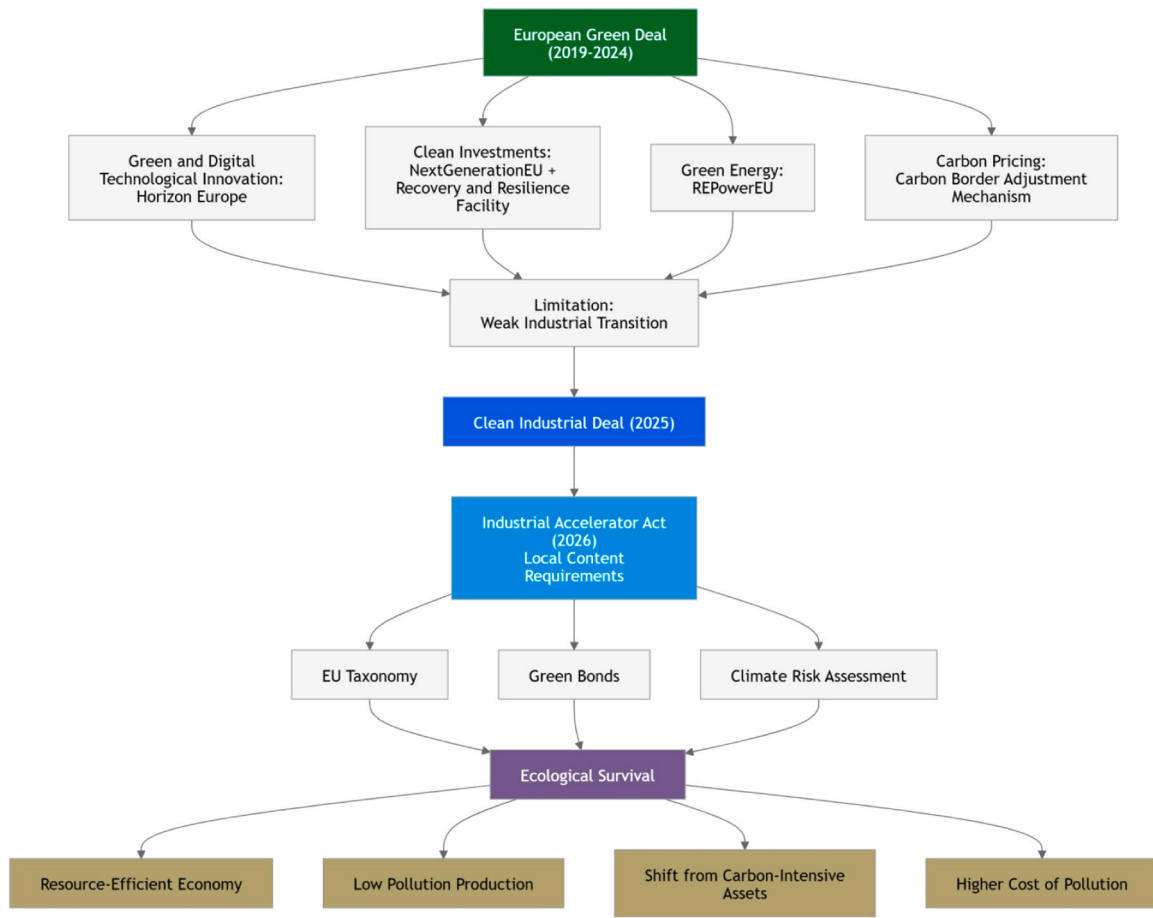


Fig. 5. The interaction between green technology, financial enrichment, and ecological survival.

$$LECSW_{it} = \alpha_{it} + \beta_1 LUP_{it} + \beta_2 LUP2_{it} + \beta_3 LMod_{it} + \beta_4 LFE_{it} + \beta_5 LRU_{it} + \beta_6 LGRE_{it} + \beta_7 LDY_{it} + \varepsilon_{it} \quad (3)$$

where $Mod = GRT \times FE$.

3.3. Econometric techniques

Consistent with the study's objectives, we apply several econometric techniques to address cross-sectional dependence (ISCD) and slope heterogeneity (SPHR). To inspect the ISCD issue, the present study applies the robust (Pesaran, 2004) test detailed as (Eq. 4):

$$ISCD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij} \right) \quad (4)$$

Here, N denotes the European Union members under consideration, and T denotes the annual time span. $\hat{\rho}_{ij}$ shows the strength of a linear relationship between the drivers of ecological survival. The null hypothesis indicates no ISCD in the errors, whereas rejection of the null indicates the presence of ISCD necessitating the application of econometric techniques robust to this issue. For slope heterogeneity (SPHR) testing, the present study hinges on the test by (Pesaran and Yamagata, 2008) given below (Eq. 5 and Eq. 6):

$$\tilde{\Delta}_{SPHR} = (N)^{1/2} (2k)^{1/2} \left(\frac{1}{N} \tilde{S} - k \right) \quad (5)$$

$$\tilde{\Delta}_{ASPHR} = (N)^{1/2} \left(\frac{2k(T-k-1)}{T+1} \right)^{-1/2} \left(\frac{1}{N} \tilde{S} - 2k \right) \quad (6)$$

Given the Eq. 5. and Eq. 6, delta SPHR test is signaled by $\tilde{\Delta}_{SPHR}$, whereas delta adjusted SPHR test is denominated by $\tilde{\Delta}_{ASPHR}$. $\tilde{S}$ is the symbol for the t-statistics while the drivers of ecological survival are outlined by k .

After utilizing the ISCD and SPHR inspections, the third step in the current research uses a unit root test to assess the stationarity of the variables. First generation unit root tests may provide unreliable findings if the data are subject of ISCD and SPHR issue, constraining the utilization of second-generation Cross-section Im, Pesaran and Shin (SDST) test. Based on (Pesaran, 2007), the SDST test is gauged as (Eq. 7):

$$\widehat{SDST} = N^{-1} \sum_{i=1}^N CADF \quad (7)$$

which is based on the cross-sectional augmented Dickey–Fuller (CADF) test. If the null hypothesis is not rejected, this indicates the presence of a unit root. However, under the alternative hypothesis the selected variables follow a stationary process.

The fourth step of the analytical framework examines the long-run relationship between ecological survival and its key drivers using the second-generation (Westerlund, 2005) cointegration technique. After the SDST results, the final stage of the empirical analysis estimates the baseline models using the Method of Moments Quantile Regression (LMUQ). As noted by (Machado and Santos Silva, 2019), this technique works better than conventional mean-based estimators because it justifies the effects of the regressors across the lower, middle, and upper

quantiles of the ecological indicator. In addition, LMUQ can provide trustworthy findings in the case of outliers and non-normal distribution. Given that LMUQ opts for the position and size of the independent variables, it exhibits more reliable empirical outcomes in comparison with traditional mean estimators (Tang and Jiang, 2024). It is also suitable for nonlinear and asymmetric relationships. Another advantage is that LMUQ helps address endogeneity concerns. In this setting, LMUQ distinguishes location effects from scale effects and estimates conditional quantiles. Therefore, it provides distributional evidence that is useful for decision-makers. The conditional LMUQ specification is given in Eq. (8):

$$Q_{Y_{it}}(\tau|X_{it}) = \alpha(\tau)'X_{it} + \beta_i, \quad i = 1, \dots, N; t = 1, \dots, T \quad (8)$$

Following Eq. (8), the elasticities are denoted by $\alpha(\tau)$. The response variable is represented by Y_{it} , while the drivers of ecological survival are captured by X_{it} . Our baseline model specification (Model 1) investigates the impact of green technology (GRT), economic upturn (UP & UP2), green energy (GRE), financial development index - FED, population (DY), and natural resources (RU) on ecological intensity (all components) - ESE. Moreover, the impact of UP, UP2, GRT, RU, GRE, DY, and financial institutions efficiency index - FEI on ESE is outlined in Model 2. In similar fashion, Model 3 unravels the impact of UP, UP2, GRT, RU, GRE, DY, and financial markets index - FEM on ESE. Further, Model 4, Model 5, and Model 6 introduce the GRT-FED; GRT-FEI; and GRT-FEM interaction terms, respectively to showcase the role of green technology in moderating the impact of financial enrichment proxied by FED, FEI, and FEM on ESE. To enhance robustness, the analysis is conducted in terms of the alternative dependent variable i.e. ecological intensity (carbon component) - ESC. Subsequently, Model 7 analyzes the effect of UP, UP2, GRT, RU, GRE, DY, and FED on ESC; Model 8 the effect of UP, UP2, GRT, RU, GRE, DY, and FEI on ESC, and Model 9 the effect of UP, UP2, GRT, RU, GRE, DY, and FEM on ESC, while the model specifications Model 10, Model 11, and Model 12 introduce the GRT-FED; GRT-FEI; and GRT-FEM interaction terms, respectively. Our model specifications are expressed as (Models1&7 - Eq. 9; Models2&8 - Eq. 10; Models3&9 - Eq. 11; Models4&10 - Eq. 12; Models5&11 - Eq. 13; Models6&12 - Eq. 14):

$$Q_{LESE|ESC}(\tau|X_{it}) = a_{1\tau}LUP_{it} + a_{2\tau}LUP2_{it} + a_{3\tau}LGRT_{it} + a_{4\tau}LFED_{it} + a_{5\tau}LRU_{it} + a_{6\tau}LGRE_{it} + a_{7\tau}LDY_{it} + \beta_i \quad (9)$$

$$Q_{LESE|ESC}(\tau|X_{it}) = a_{1\tau}LUP_{it} + a_{2\tau}LUP2_{it} + a_{3\tau}LGRT_{it} + a_{4\tau}LFEI_{it} + a_{5\tau}LRU_{it} + a_{6\tau}LGRE_{it} + a_{7\tau}LDY_{it} + \beta_i \quad (10)$$

$$Q_{LESE|ESC}(\tau|X_{it}) = a_{1\tau}LUP_{it} + a_{2\tau}LUP2_{it} + a_{3\tau}LGRT_{it} + a_{4\tau}LFEM_{it} + a_{5\tau}LRU_{it} + a_{6\tau}LGRE_{it} + a_{7\tau}LDY_{it} + \beta_i \quad (11)$$

$$Q_{LESE|ESC}(\tau|X_{it}) = a_{1\tau}LUP_{it} + a_{2\tau}LUP2_{it} + a_{3\tau}LMod1_{it} + a_{4\tau}LFED_{it} + a_{5\tau}LRU_{it} + a_{6\tau}LGRE_{it} + a_{7\tau}LDY_{it} + \beta_i \quad (12)$$

$$Q_{LESE|ESC}(\tau|X_{it}) = a_{1\tau}LUP_{it} + a_{2\tau}LUP2_{it} + a_{3\tau}LMod2_{it} + a_{4\tau}LFEI_{it} + a_{5\tau}LRU_{it} + a_{6\tau}LGRE_{it} + a_{7\tau}LDY_{it} + \beta_i \quad (13)$$

$$Q_{LESE|ESC}(\tau|X_{it}) = a_{1\tau}LUP_{it} + a_{2\tau}LUP2_{it} + a_{3\tau}LMod3_{it} + a_{4\tau}LFEM_{it} + a_{5\tau}LRU_{it} + a_{6\tau}LGRE_{it} + a_{7\tau}LDY_{it} + \beta_i \quad (14)$$

The robustness of the main empirical technique (LMUQ) is assessed by applying the non-parametric (Driscoll and Kraay, 1998) regression. This method is appropriate when cross-sectional dependence is present. In this setting, the KRDR approach examines the relationship between ecological survival and its key drivers and is specified in Eq. (15):

$$LECSW_{it} = \gamma_0 + X_{it}'\mu + u_{it} \begin{cases} i = 1, 2, 3, \dots, N \\ t = 1, 2, 3, \dots, T \end{cases} \quad (15)$$

In Eq. (15), the measures of ecological destruction are signaled by $LECSW_{it}$; while the explanatory variables are as detailed in Table 1. To summarize the conceptual logic developed in this section, Fig. 6 presents a concise framework that links the key explanatory variables, the moderating role of green technology, and the empirical testing strategy.

4. Results and interpretation

To assess whether the sampled EU members are mutually economically and ecologically dependent, this study establishes on the (Pesaran, 2004) ISCD test. The ISCD test results are reported in Table 3.

Table 3 shows that the null hypothesis is rejected in all baseline models, which indicates the presence of cross-sectional dependence among the EU members in the sample. This result suggests that economic and ecological changes in one country may spill over to others, which is consistent with the strong policy and market linkages within the European Union. Table 4 also shows that the slope coefficients are heterogeneous across countries.

This means that the relationship between the explanatory variables and ecological survival is not uniform across EU members. Given the presence of both ISCD and SPHR, the next step is to examine the order of integration, as reported in Table 5.

According to the results reported in Table 5, the log-transformed series are non-stationary at levels, as the null hypothesis of a unit root cannot be rejected under the specification with a constant and trend. However, the SDST results show that all variables become stationary after first differencing. Therefore, the alternative hypothesis is accepted for all first-differenced series, supporting the absence of a unit root at first difference. Given these results, it is appropriate to proceed with the cointegration analysis reported in Table 6.

The results in Table 6 support the use of a second-generation cointegration test to examine the long-run relationship between ecological survival and its main determinants. The (Westerlund, 2005) statistics are statistically significant for all models without interaction terms, which indicates the existence of a long-run equilibrium relationship between ecological survival and the explanatory variables. Given these outcomes, the study continues with the LMUQ estimation. Fig. 7 and Table 7 present the main results, while Fig. 8 summarizes the pattern across the selected quantiles.

According to the LMUQ outcomes as reported in Table 7 at odd quantiles and Fig. 8 at even quantiles of ESE, economic upturn has a positive and statistically significant effect on ecological survival proxied by ESE in all models without moderation (Model 1, Model 2, and Model 3). The size of the coefficient of LUP is higher in the higher quantiles in Model 1 that uses the baseline indicator of financial enrichment (LFED) implicating the statistically significant outcomes across all, odd and even quantiles. By comparison, Model 2, which uses LFEI to measure financial enrichment, shows a positive coefficient for LUP, although this effect becomes smaller when moving from higher to lower quantiles. Similarly, Model 3 also shows a positive and statistically significant coefficient of LUP, with the most visible influence in less ecologically intensive countries. The results presented in Table 7 and Fig. 8 uncover that the economic upturn squared yields statistically significant and negative impact on ESE, exerting a decreasing trend in Model 1 and Model 2 and an increasing trend in Model 3.

Accordingly, the relationship between economic upturn and ESE follows an inverted U-shaped pattern lending credence to the notion of EKC phenomenon in Model specifications 1–6. This means that in the case of European Union, ecological survival is weak in the early industrial phases impairing its ecological quality. However, after reaching a certain threshold of economic output, the harmful ecological impact of LUP begins to decline, improving the ecological outcomes of EU

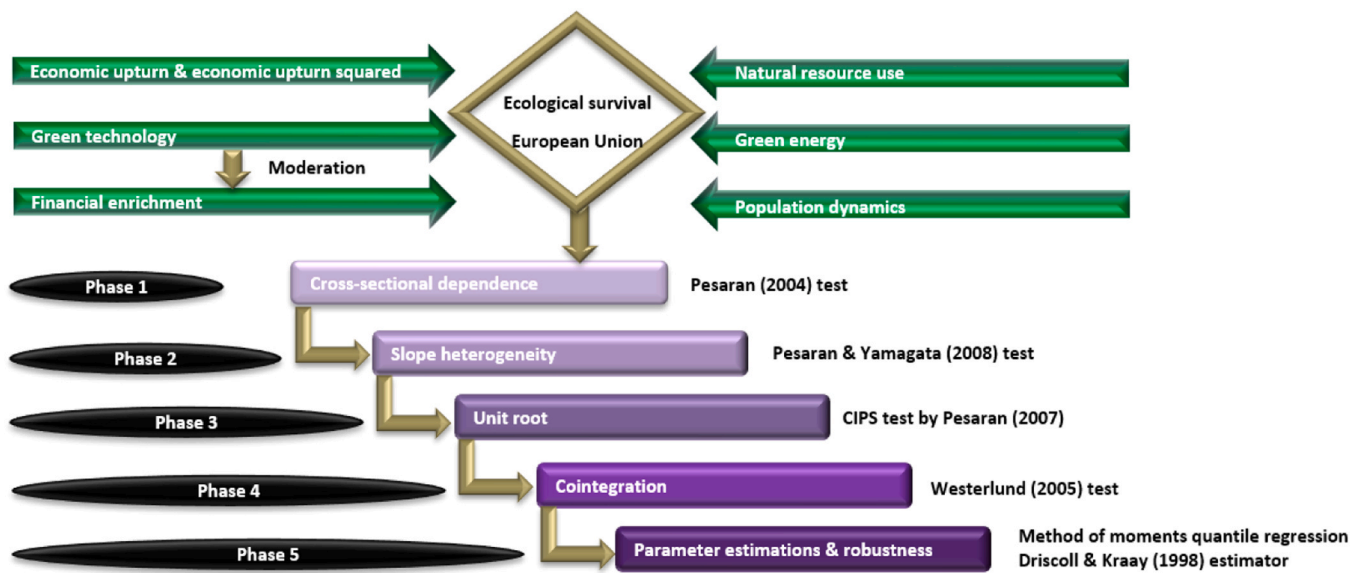


Fig. 6. Conceptual framework.

Table 3
ISCD analysis outcomes.

Analytical framework	Model 1	Model 2	Model 3	Model 7	Model 8	Model 9
ISCD test statistics	11.560a (0.000)	13.700a (0.000)	11.722a (0.000)	20.040a (0.000)	25.345a (0.000)	20.252a (0.000)

Notes: a, b, and c denote significance at the 1%, 5%, and 10% levels, respectively; p-values are underlined.

Table 4
SPHR analysis outcomes.

Statistic/ Model	Model 1	Model 2	Model 3	Model 7	Model 8	Model 9
SPHR Δ test	10.488a (0.000)	9.744a (0.000)	10.582a (0.000)	14.425a (0.000)	13.576a (0.000)	14.598a (0.000)
SPHR Δ adj. test	12.970a (0.000)	12.050a (0.000)	13.087a (0.000)	17.839a (0.000)	16.789a (0.000)	18.053a (0.000)

Notes: a, b, and c denote significance at the 1%, 5%, and 10% levels, respectively; p-values are underlined.

members (Satrovic et al., 2025). Feasible justifications for LUP's positive elasticity and LUP square's negative elasticity are twofold: (i) EU members are establishing themselves in service (tertiary) sectors of economy tending to phase out heavy polluting economic activities; (ii) rising income and standard of living increases ecological consciousness, and the citizens of advanced nations have enhanced eagerness to pay for

ecological resilience (Satrovic et al., 2025). Early stages of growth inhibit ecological survival as countries favor economic upturn and employment over air and water quality. The intensification of economic output goes hand in hand with growth in natural resources exploitation and anthropogenic emissions, which hamper the targets of ecological survival. However, as standard of living and income increase, people can afford to pay ecological implications of LUP to support ecological survival of EU members. Numerous researchers have rendered support to the inverted U-type nexus between ecology and economic activities (Naqvi et al., 2023; Qalati et al., 2023). These studies reach a consensus on the advantageous ecological impacts of LUP at the higher stages of growth.

Table 7 and Fig. 8 show that green technology helps mitigate ecological pressure and supports ecological survival in EU members. Our results show negative coefficients of LGRT in the lower, middle, and upper quantiles and indicate that green technology mitigates ecological destruction by exemplifying ecological survival effect. The strength of this effect renders a decreasing but statistically significant trend in

Table 5
SDST analysis outcomes (cases with constant and trend).

Test/Var.	LUP	LUP2	LGRT	LFED	LFEL	LFEM	LRU	LGRE	LDY	LESE	LESC
Log transformed series	-1.778	-1.704	-3.866	-3.031	-3.834	-3.135	-2.735	-3.394	-1.981	-3.317	-2.991
Differenced series	-3.190a	-3.164a	-5.731a	-5.426a	-5.625a	-5.040a	-5.081a	-5.469a	-4.411a	-6.047a	-5.672a

Notes: a, b, and c denote significance at the 1%, 5%, and 10% levels, respectively.

Table 6
Cointegration results.

Model/Stat.	Model 1	Model 2	Model 3	Model 7	Model 8	Model 9
Vr. ratio	-2.267b	-2.003b	-2.321b	-1.871b	-1.541c	-1.951b
p-values	0.012	0.023	0.010	0.031	0.062	0.026

Notes: a, b, and c denote significance at the 1%, 5%, and 10% levels, respectively.

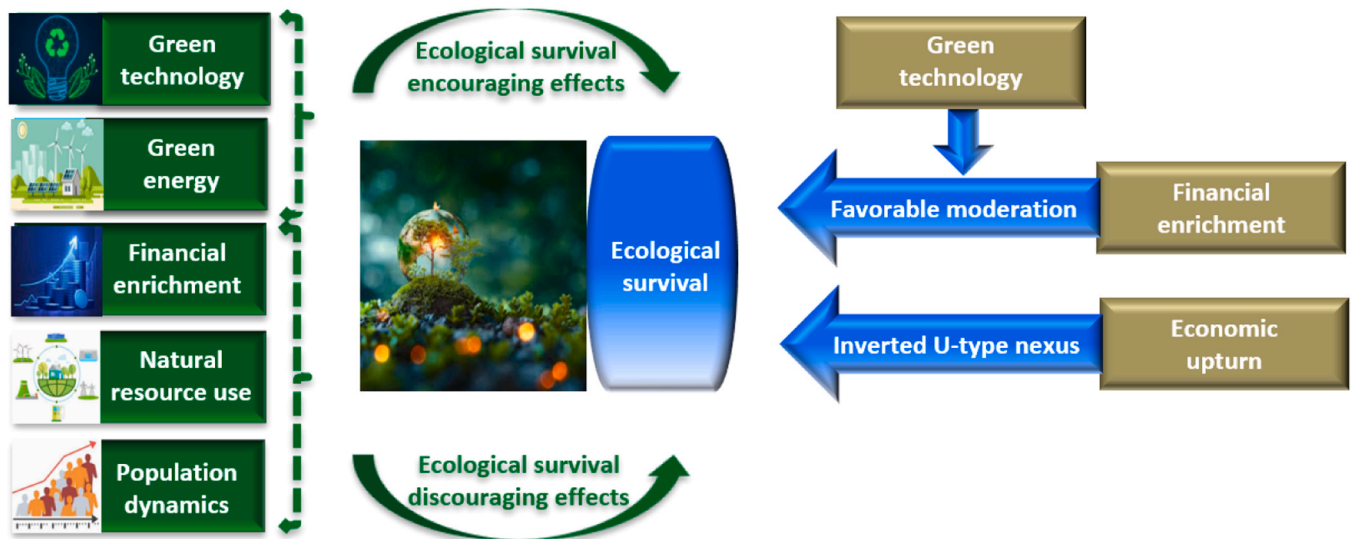


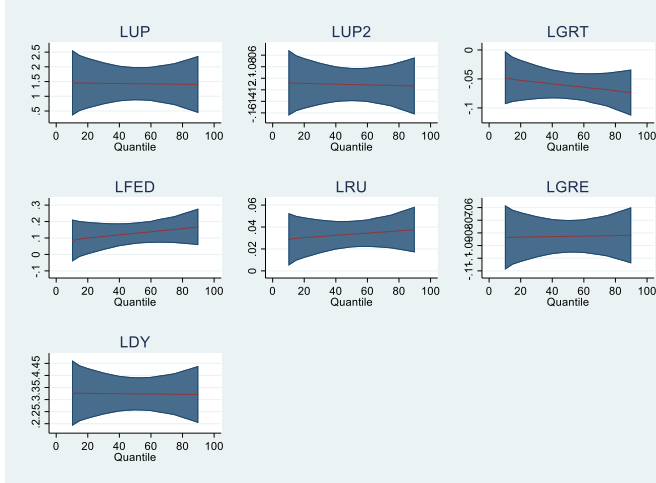
Fig. 7. The impact of core variables on ecological survival.

Table 7
LMUQ analysis outcomes (ESE- ecological indicator).

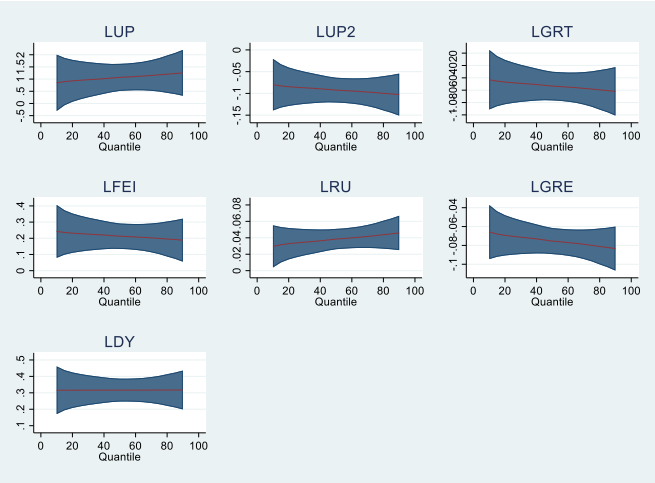
Mod	Expl. var.	KRDR		10th quantile		30th quantile		50th quantile		70th quantile		90th quantile	
		Elast.	p	Elast.	p	Elast.	p	Elast.	p	Elast.	p	Elast.	p
1	LUP	1.417a	<u>0.000</u>	1.439b	<u>0.011</u>	1.426a	<u>0.000</u>	1.416a	<u>0.000</u>	1.407a	<u>0.000</u>	1.396a	<u>0.005</u>
	LUP2	-0.110a	<u>0.000</u>	-0.107a	<u>0.000</u>	-0.109a	<u>0.000</u>	-0.110a	<u>0.000</u>	-0.112a	<u>0.000</u>	-0.113a	<u>0.000</u>
	LGRT	-0.061a	<u>0.003</u>	-0.048b	<u>0.041</u>	-0.055a	<u>0.000</u>	-0.062a	<u>0.000</u>	-0.067a	<u>0.000</u>	-0.074a	<u>0.000</u>
	LFED	0.127a	<u>0.001</u>	0.083	<u>0.204</u>	0.108b	<u>0.010</u>	0.128a	<u>0.000</u>	0.146a	<u>0.000</u>	0.168a	<u>0.003</u>
	LRU	0.033a	<u>0.000</u>	0.029b	<u>0.019</u>	0.031a	<u>0.000</u>	0.034a	<u>0.000</u>	0.036a	<u>0.000</u>	0.038a	<u>0.000</u>
	LGRE	-0.083a	<u>0.000</u>	-0.083a	<u>0.000</u>	-0.083a	<u>0.000</u>	-0.083a	<u>0.000</u>	-0.082a	<u>0.000</u>	-0.082a	<u>0.000</u>
2	LDY	0.323a	<u>0.000</u>	0.326a	<u>0.000</u>	0.324a	<u>0.000</u>	0.323a	<u>0.000</u>	0.322a	<u>0.000</u>	0.320a	<u>0.000</u>
	LUP	1.049a	<u>0.003</u>	0.831	<u>0.160</u>	0.962a	<u>0.009</u>	1.058a	<u>0.000</u>	1.139a	<u>0.000</u>	1.246a	<u>0.009</u>
	LUP2	-0.091a	<u>0.000</u>	-0.079a	<u>0.009</u>	-0.086a	<u>0.000</u>	-0.092a	<u>0.000</u>	-0.096a	<u>0.000</u>	-0.102a	<u>0.000</u>
	LGRT	-0.053a	<u>0.005</u>	-0.043c	<u>0.080</u>	-0.049a	<u>0.001</u>	-0.053a	<u>0.000</u>	-0.057a	<u>0.000</u>	-0.062a	<u>0.002</u>
	LFEI	0.214a	<u>0.000</u>	0.242a	<u>0.004</u>	0.225a	<u>0.000</u>	0.213a	<u>0.000</u>	0.202a	<u>0.000</u>	0.188a	<u>0.005</u>
	LRU	0.038a	<u>0.000</u>	0.029b	<u>0.026</u>	0.035a	<u>0.000</u>	0.038a	<u>0.000</u>	0.042a	<u>0.000</u>	0.046a	<u>0.000</u>
3	LGRE	-0.075a	<u>0.000</u>	-0.066a	<u>0.000</u>	-0.071a	<u>0.000</u>	-0.075a	<u>0.000</u>	-0.079a	<u>0.000</u>	-0.083a	<u>0.000</u>
	LDY	0.316a	<u>0.000</u>	0.314a	<u>0.000</u>	0.315a	<u>0.000</u>	0.316a	<u>0.000</u>	0.316a	<u>0.000</u>	0.317a	<u>0.000</u>
	LUP	1.807a	<u>0.000</u>	1.924a	<u>0.001</u>	1.855a	<u>0.000</u>	1.802a	<u>0.000</u>	1.757a	<u>0.000</u>	1.696a	<u>0.001</u>
	LUP2	-0.128a	<u>0.000</u>	-0.130a	<u>0.000</u>	-0.129a	<u>0.000</u>	-0.128a	<u>0.000</u>	-0.127a	<u>0.000</u>	-0.125a	<u>0.000</u>
	LGRT	-0.058a	<u>0.006</u>	-0.039	<u>0.102</u>	-0.050a	<u>0.001</u>	-0.059a	<u>0.000</u>	-0.067a	<u>0.000</u>	-0.077a	<u>0.000</u>
	LFEM	0.049a	<u>0.002</u>	0.033	<u>0.211</u>	0.043b	<u>0.012</u>	0.050a	<u>0.000</u>	0.056a	<u>0.000</u>	0.064a	<u>0.008</u>
4	LRU	0.035a	<u>0.000</u>	0.029b	<u>0.016</u>	0.032a	<u>0.000</u>	0.035a	<u>0.000</u>	0.038a	<u>0.000</u>	0.041a	<u>0.000</u>
	LGRE	-0.086a	<u>0.000</u>	-0.087a	<u>0.000</u>	-0.087a	<u>0.000</u>	-0.086a	<u>0.000</u>	-0.086a	<u>0.000</u>	-0.086a	<u>0.000</u>
	LDY	0.316a	<u>0.000</u>	0.323a	<u>0.000</u>	0.319a	<u>0.000</u>	0.316a	<u>0.000</u>	0.313a	<u>0.000</u>	0.309a	<u>0.000</u>
	LUP	1.417a	<u>0.000</u>	1.439b	<u>0.011</u>	1.426a	<u>0.000</u>	1.416a	<u>0.000</u>	1.407a	<u>0.000</u>	1.396a	<u>0.005</u>
	LUP2	-0.110a	<u>0.000</u>	-0.107a	<u>0.000</u>	-0.109a	<u>0.000</u>	-0.110a	<u>0.000</u>	-0.112a	<u>0.000</u>	-0.113a	<u>0.000</u>
	LMod1	-0.061a	<u>0.003</u>	-0.048b	<u>0.041</u>	-0.055a	<u>0.000</u>	-0.062a	<u>0.000</u>	-0.067a	<u>0.000</u>	-0.074a	<u>0.000</u>
5	LFED	0.188a	<u>0.000</u>	0.130c	<u>0.067</u>	0.163a	<u>0.000</u>	0.190a	<u>0.000</u>	0.214a	<u>0.000</u>	0.242a	<u>0.000</u>
	LRU	0.033a	<u>0.000</u>	0.029b	<u>0.019</u>	0.031a	<u>0.000</u>	0.034a	<u>0.000</u>	0.036a	<u>0.000</u>	0.038a	<u>0.000</u>
	LGRE	-0.083a	<u>0.000</u>	-0.083a	<u>0.000</u>	-0.083a	<u>0.000</u>	-0.083a	<u>0.000</u>	-0.082a	<u>0.000</u>	-0.082a	<u>0.000</u>
	LDY	0.323a	<u>0.000</u>	0.326a	<u>0.000</u>	0.324a	<u>0.000</u>	0.323a	<u>0.000</u>	0.322a	<u>0.000</u>	0.320a	<u>0.000</u>
	LUP	1.049a	<u>0.003</u>	0.831	<u>0.160</u>	0.962a	<u>0.009</u>	1.058a	<u>0.000</u>	1.139a	<u>0.000</u>	1.246a	<u>0.009</u>
	LUP2	-0.091a	<u>0.000</u>	-0.079a	<u>0.009</u>	-0.086a	<u>0.000</u>	-0.092a	<u>0.000</u>	-0.096a	<u>0.000</u>	-0.102a	<u>0.000</u>
6	LMod2	-0.053a	<u>0.005</u>	-0.043c	<u>0.080</u>	-0.049a	<u>0.001</u>	-0.053a	<u>0.000</u>	-0.057a	<u>0.000</u>	-0.062a	<u>0.002</u>
	LFEI	0.267a	<u>0.000</u>	0.286a	<u>0.001</u>	0.274a	<u>0.000</u>	0.266a	<u>0.000</u>	0.259a	<u>0.000</u>	0.250a	<u>0.000</u>
	LRU	0.038a	<u>0.000</u>	0.029b	<u>0.026</u>	0.035a	<u>0.000</u>	0.038a	<u>0.000</u>	0.042a	<u>0.000</u>	0.046a	<u>0.000</u>
	LGRE	-0.075a	<u>0.000</u>	-0.066a	<u>0.000</u>	-0.071a	<u>0.000</u>	-0.075a	<u>0.000</u>	-0.079a	<u>0.000</u>	-0.083a	<u>0.000</u>
	LDY	0.316a	<u>0.000</u>	0.314a	<u>0.000</u>	0.315a	<u>0.000</u>	0.316a	<u>0.000</u>	0.316a	<u>0.000</u>	0.317a	<u>0.000</u>
	LUP	1.807a	<u>0.000</u>	1.924a	<u>0.001</u>	1.855a	<u>0.000</u>	1.802a	<u>0.000</u>	1.757a	<u>0.000</u>	1.696a	<u>0.001</u>
	LUP2	-0.128a	<u>0.000</u>	-0.130	<u>0.000</u>	-0.129a	<u>0.000</u>	-0.128a	<u>0.000</u>	-0.127a	<u>0.000</u>	-0.125a	<u>0.000</u>
	LMod3	-0.058a	<u>0.006</u>	-0.039	<u>0.102</u>	-0.050a	<u>0.001</u>	-0.059a	<u>0.000</u>	-0.067a	<u>0.000</u>	-0.077a	<u>0.000</u>
	LFEM	0.107a	<u>0.001</u>	0.072b	<u>0.046</u>	0.093a	<u>0.000</u>	0.109a	<u>0.000</u>	0.122a	<u>0.000</u>	0.141a	<u>0.000</u>
	LRU	0.035a	<u>0.000</u>	0.029b	<u>0.016</u>	0.032a	<u>0.000</u>	0.035a	<u>0.000</u>	0.038a	<u>0.000</u>	0.041a	<u>0.000</u>
	LGRE	-0.086a	<u>0.000</u>	-0.087a	<u>0.000</u>	-0.087a	<u>0.000</u>	-0.086a	<u>0.000</u>	-0.086a	<u>0.000</u>	-0.086a	<u>0.000</u>
	LDY	0.316a	<u>0.000</u>	0.323a	<u>0.000</u>	0.319a	<u>0.000</u>	0.316a	<u>0.000</u>	0.313a	<u>0.000</u>	0.309a	<u>0.000</u>

Notes: a, b, and c denote significance at the 1%, 5%, and 10% levels, respectively; p-values are underlined. Mod1 = GRT×FED; Mod2 = GRT×FEI; Mod3 = GRT×FEM.

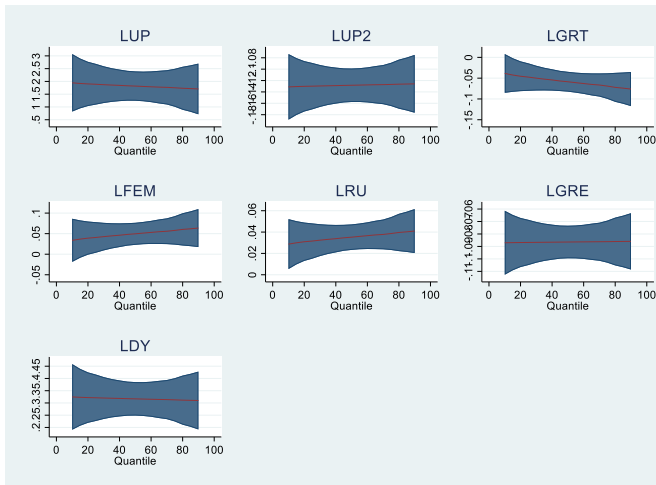
Model 1



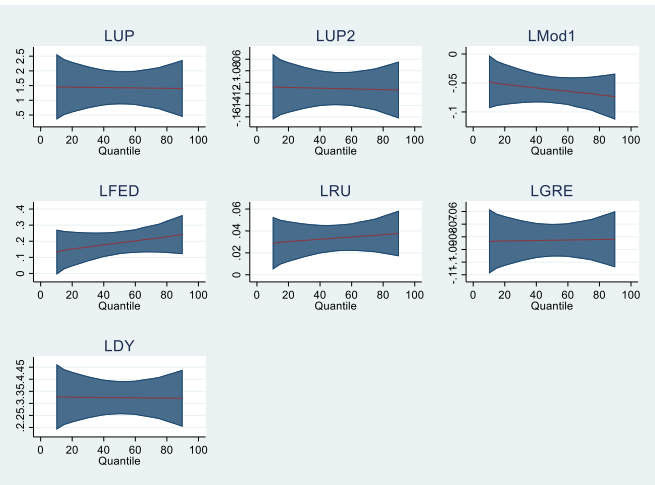
Model 2



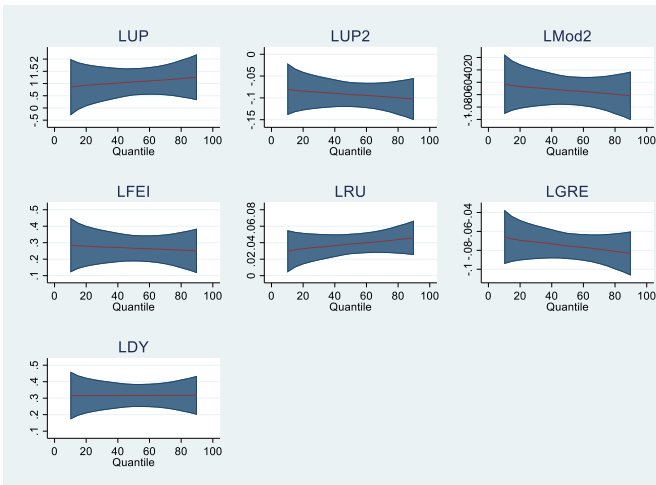
Model 3



Model 4



Model 5



Model 6

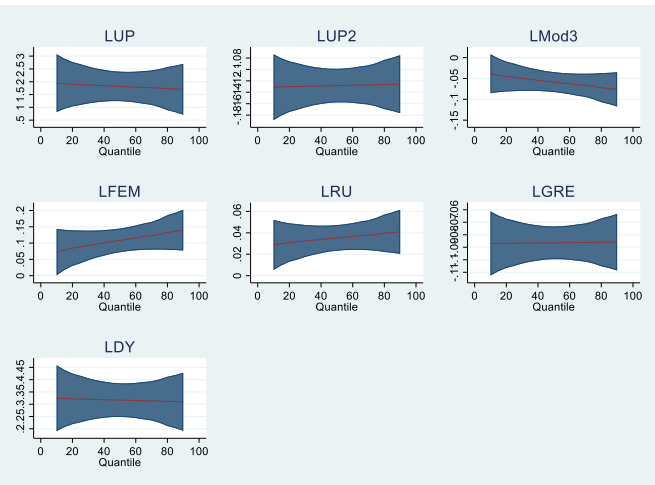


Fig. 8. Visualizing quantile coefficients (ESE- ecological indicator).

models without moderation (Model specifications 1–3). It is suitable to infer from these findings that at 10th–90th quantiles, green technology hampers ecological destruction, but this influence vanishes from lower to higher quantiles. This beneficial ecological effect of LGRT can be linked to the technique effect such that advanced nations are more

prepared to adopt green technologies and replace machines powered by dirty energy sources with clean technologies for ecological survival. In other words, the adoption of modern green technologies that are dedicated towards energy efficiency and conservation of resources from Earth is assigned to technique effect which is likely to tackle ecological

challenges.

Several mechanisms help explain the link between green technology and ecological survival: (i) green technology advances the introduction of green energy sources advocating decarbonization; (ii) ecological survival capitalizes on green technology as it focuses on supply chain innovations to curtail the overutilization of natural resources and foster green manufacturing; (iii) green technology is a vital catalyst in global movement to green energy sources, as improved technologies work to augment traditional machinery's efficiency and to introduce modern energy efficient facilities that will generate cleaner products (Satrovic et al., 2025). This beneficial ecological impact is consistent with (Xu et al., 2024), who show that LGRT is among the critical tools in strengthening the environmental quality of next rising economies. In a similar fashion, (Ahmad and Jabeen, 2024) found that innovative technologies encourage EU members to increase funding for research and development to maintain eco-efficiency. By transforming the traditional high-pollution methods into cleaner production methods, green technologies are accountable for net zero objectives in South Asian countries as discovered by (Amin et al., 2023). Considering these findings, EU members should intensively engage in green technologies to attain the targets of ecological survival against ecological destruction.

Using different indicators of financial enrichment allows us to test the robustness of the baseline findings from the perspective of alternative explanatory variables. Model 1 shows that the adverse ecological effect of the financial development index is statistically significant from the 20th to the 90th quantile, and the effect is larger in more ecologically intensive EU members. Model 2 yields a similar pattern, with a statistically significant positive coefficient for the financial institutions efficiency index across most quantiles. Model 3 also shows a positive association between the financial markets index, used here as a measure of financial enrichment, and ecological destruction. At the 20th to 90th quantiles, LFEM reduces ecological survival, and the magnitude of the effect increases across the distribution. These results suggest that the financial development index and the financial markets index have stronger adverse ecological effects in EU members with higher ecological intensity, whereas Model 2 indicates that the adverse ecological effect of financial enrichment is more pronounced in countries with lower ecological intensity. Likewise, the models with the interaction term show that the direct effect of financial enrichment impairs ecological survival in EU members.

The disadvantageous ecological impact of financial enrichment can be supported by the fact that it can provide households and individuals with high-quality and affordable loans capable to foster their production, consumption, and investment levels (Satrovic et al., 2025). With this in place, individuals may easily afford expensive energy consuming gadgets that are accountable for ecological destruction. In line with these findings, (Naqvi et al., 2023) showed a direct relationship between financial development and environmental pressure. In line with the positive coefficient of financial development, it is pertinent to note that financial system is not practical catalyst for environmental survival. Thereby, Asia-Pacific Economic Cooperation is advised to reform financial systems to facilitate the flow of funds toward green technologies. Analogously, financial enrichment is fostering ecological destruction of EU countries as divulged by (Satrovic et al., 2025). Notwithstanding these findings, (Qalati et al., 2023) reported that the risk of ecological destruction increases with financial enrichment. Herein, the outcomes highlighted that both developed and developing countries need to design financial systems to encourage not only economic but also ecological benefits of society. Thus, the advancement of financial system should be incorporated into sustainability objectives by fostering green energy and green technology innovations.

Our findings show negative and statistically significant coefficients for LGRE in models without moderation (Models 1–3) and with moderation (Models 4–6). To avoid passing 1.5°C threshold of global warming, a paramount amount of carbon must be eradicated from atmosphere forcing an entire change of energy picture. Greener practices

in energy generation and transportation need to be adopted to limit ecological pressure. A pathway to green energy is of vital importance in driving utilization of fewer RU, supporting the waste mitigation, and sustaining biodiversity. As such, green energy protects and conserves RU for future generations and works towards energy cost reduction. The consumption of green energy is underway to energy security. (Hassan et al., 2024) give credence to our findings, discovering that green energy tackles the greenhouse gasses emissions of emerging countries in the time span from 1993 to 2020. Analogously, (Ma et al., 2024) unveiled that the utilization of LGRE is a vigorous tool in easing ecological destruction.

According to Table 7 and Fig. 8, it is witnessed that natural resources are positively linked with ecological destruction in all models. Thereby, natural resource use is likely to hinder the ecological survival of EU members. The outcomes of the models presented an increasing trend showcasing the ecological hindering impact of natural resources, especially for EU countries with more ESE. It is justifiable on the ground that energy is playing a vigorous driver of EU members' economic growth, and as such accelerates the demand for natural resources. Excessive exploitation and usage of natural resources generate substantial amounts of waste and anthropogenic emissions intensifying ecological pressure. This outcome corroborates the positive natural resources-ecological deterioration impact witnessed by (Tang and Jiang, 2024) considering the emerging countries. Equivalently, (Lv et al., 2024) unveiled that the strong reliance of natural resources is likely to reduce the environmental quality of developing and emerging economies. (Mohsin and Jamaani, 2023) evidenced that resources from nature are a vigorous catalyst of greenhouse gasses emissions in Asian economies.

Similarly, DY is positively related to ESE in all models uncovering that population dynamics provoke energy consumption impairing the ecological survival of observed countries. To be able to provide enough food for rising population, countries are fostered to transform even more forest areas into agricultural land. Such practice may deepen soil degradation, reduce soil quality, and diminish soil fertility. In addition, intensified energy consumption will magnify the utilization of natural resources coupled with ecological challenges. This outcome is consistent with (Xaisongkham and Liu, 2024; Ng et al., 2023) as they postulated the positive association between population and anthropogenic emissions in developing and OECD members, respectively.

With reference to joint effect of green technology and financial enrichment, this study examines whether LGRT undermines the adverse ecological impact of LFE. Models with moderation (Model specifications 4–6) revealed that green technology negatively moderates the financial enrichment-ESE nexus. This impact remains significant across all quantiles in Model 4 and Model 5, divulging a decreasing trend. Analogously, Model 6 observes a declining trend of LMod3 coefficients that are negative but statistically significant across 20th–80th quantiles. These findings corroborate that European Union's green technology growth instigates ecological survival betterment impact of financial enrichment, especially for EU members with lower ESE. Therefore, green technology vigorously participates in curtailing the destructive ecological impacts of triplet indicators of financial enrichment by motivating financial institutions to support eco-friendly industrial activities dedicated towards energy conservation and pollutant emissions mitigation. Green technology may ease the adoption of green financial products like green savings, bonds, and loans specifically designed to encourage eco-friendly business activities. By the means of green technology, financial systems can direct more funds to support decarbonization and energy efficiency priorities. In this context, green technology is an important tool for EU members as they work to align their financial systems with ecological objectives. As such, green technologies are driving the transformation of financial systems by accelerating access to both traditional and green financial products and services. In addition, green technologies are of paramount importance in mobilizing funds and innovative financial mechanisms to actualize the systematic changes ought to mitigate ecological destruction and support the

utilization of green energy. Notably, the finding that LGRT is tackling the harmful ecological impact of financial enrichment lent credence to the outcomes of (Fareed et al., 2022) portraying that LGRT yields an underway to ecological survival of Eurozone.

As a robustness check, we use carbon footprint (gha per person/UP) as an alternative dependent variable. The results for LESC at the odd quantiles are reported in Table A1 (Appendix 1), while Fig. A1 shows the differences in elasticities across the even quantiles. The purpose of using LESC is to assess whether the ecological indicator responds consistently to the selected explanatory variables. The results from the alternative models without moderation (Models 7–9) and with moderation (Models 10–12) are consistent with the baseline findings. Economic upturn has a positive effect on LESC, whereas its squared term has a negative effect. Green technology and green energy reduce ecological destruction in EU members, while financial enrichment, natural resource use, and population dynamics weaken ecological survival. The moderation results also confirm that green technology helps reduce the harmful ecological effect of financial enrichment. The KRDR estimates further support the robustness of these findings. Tables 7 and A1 show an inverted U-shaped relationship between LUP and both indicators of ecological destruction.

In addition, green energy and green technology significantly reduce ecological pressure in EU members. More specifically, a 1% increase in LGRE reduces LESE by 0.083% in Models 1 and 4, 0.075% in Models 2 and 5, and 0.086% in Models 3 and 6. Similarly, a 1% increase in LGRE reduces LESC by 0.108% in Models 7 and 10, 0.100% in Models 8 and 11, and 0.114% in Models 9 and 12. By contrast, financial enrichment, natural resource use, and population increase both LESE and LESC across all models. The interaction terms in Models 4–6 and 10–12 are also statistically significant, which confirms that green technology weakens the adverse ecological effect of financial enrichment. Since Models 7–12 produce signs and significance levels like those in Table 7, the main results can be considered robust. These findings also offer useful guidance for policymakers and think tanks.

5. Conclusion and policy implications

The present study evaluates the impact of green technology, green energy, financial enrichment, economic upturn, natural resource use, and population dynamics on ecological survival. Financial enrichment is found to jeopardize the ecological survival in 21 EU members from 1995 to 2020. Moreover, natural resources use and population are found to support ecological pressure of the observed countries. In contrast, green energy and green technology are encouraging ecological survival, bringing about favorable ecological impact. Economic upturn authenticates the inverted U-shaped relationship with ecological survival. Green technology is efficient in transforming the adverse ecological impact of financial enrichment into a beneficial one.

In quantitative terms, the LMUQ estimates show that a 1% increase in financial enrichment is associated with roughly a 0.03–0.3% increase in ecological intensity, while a 1% increase in green technology accounts for a 0.04–0.2% reduction in ecological intensity across quantiles. It is plausible to note that environmental patents used to quantify green technology account for 10.77% of the total patents, while green energy quantified by electricity generated from renewables constitutes 25.09% of the total electricity, on average. Natural resource use and population dynamics also exhibit positive elasticities, around 0.02–0.07% and 0.2–0.6% respectively, corroborating their contribution to ecological pressure. These results confirm our main research hypothesis: financial enrichment on its own tends to exacerbate ecological pressure, whereas its adverse effects are reduced or even reversed when it operates through green technology and is accompanied by green energy.

These outcomes serve to propose several policy implications for the

European Union. The member states differ in structural change patterns; therefore, the design of policies should follow this heterogeneity. Notably, EU members that underperform in the utilization of green technologies may need enhanced assistance and support in comparison to members with well-established green technology in enabling financial enrichment to support its ecological survival objectives. The empirical findings outlined that an intrinsic change of green technology, green energy, financial enrichment, economic upturn, natural resource use, or population dynamics may bring about sizable changes in ecological survival. Thereby, it is of vital importance for EU decision makers to impose more stringent environmental standards and integrate environmental risks into creditworthiness assessment. In addition, the favorable financial enrichment-green technology ecological impact reinvigorates public funding for green technologies by means of grants, tax incentives, and subsidies to instigate more affordable funding for eco-friendly activities. Policies should also penalize resource-intensive while incentivizing resource-efficient economic practices by easing access to green financial mechanisms like sustainability-linked products, green bonds, and green loans. These mechanisms should also support the utilization of renewable energy, especially in energy- and carbon-intensive economic sectors.

Despite its vital theoretical and practical implications, there are certain limitations of this study that can be addressed in future research. First, the study hinges on twin indicators of ecological survival that focus on demand side of the environment and may overlook the holistic perspective of sustainability. Second, since there is the sole focus on EU nations, the generalizability of the study may be contested. These limitations also contribute to future research. Future studies could apply the same framework to emerging economies to test whether green technology plays a similar moderating role under less developed financial systems. They could also include ecological indicators that capture both the demand side and the supply side of nature, which is especially relevant for regions with biocapacity deficits such as the European Union.

Ethical approval

Throughout the drafting process, all ethical practices were followed.

Consent to publish

All authors have reviewed and approved the final version of the manuscript and consent to its publication.

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CRediT authorship contribution statement

Elma Satrovic: Writing – original draft, Data curation, Conceptualization. **Manuel A. Zambrano-Monserrate:** Writing – original draft, Software, Writing – review & editing. **Magdalena Radulescu:** Writing – original draft, Writing – review & editing. **Cristina Micu:** Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

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

Appendix 1

Table A1
LMUQ analysis outcomes (ESC- ecological indicator)

Mod	Expl. var.	KRDR		10th quantile		30th quantile		50th quantile		70th quantile		90th quantile	
		Elast.	p	Elast.	p	Elast.	p			Elast.	p	Elast.	p
7	LUP	1.520a	<u>0.000</u>	2.286a	<u>0.000</u>	1.890a	<u>0.000</u>	1.489a	<u>0.000</u>	1.160a	<u>0.004</u>	0.810	<u>0.154</u>
	LUP2	−0.117a	<u>0.000</u>	−0.157a	<u>0.000</u>	−0.136a	<u>0.000</u>	−0.116a	<u>0.000</u>	−0.099a	<u>0.000</u>	−0.081a	<u>0.005</u>
	LGRT	−0.058b	<u>0.010</u>	−0.068b	<u>0.015</u>	−0.063a	<u>0.001</u>	−0.058a	<u>0.000</u>	−0.054a	<u>0.001</u>	−0.049b	<u>0.042</u>
	LFED	0.217a	<u>0.002</u>	0.155b	<u>0.048</u>	0.187a	<u>0.000</u>	0.219a	<u>0.000</u>	0.246a	<u>0.000</u>	0.274a	<u>0.000</u>
	LRU	0.048a	<u>0.005</u>	0.068a	<u>0.000</u>	0.058a	<u>0.000</u>	0.048a	<u>0.000</u>	0.039a	<u>0.000</u>	0.030b	<u>0.036</u>
	LGRE	−0.108a	<u>0.000</u>	−0.093a	<u>0.000</u>	−0.100a	<u>0.000</u>	−0.108a	<u>0.000</u>	−0.115a	<u>0.000</u>	−0.122a	<u>0.000</u>
	LDY	0.508a	<u>0.000</u>	0.493a	<u>0.000</u>	0.501a	<u>0.000</u>	0.508a	<u>0.000</u>	0.514a	<u>0.000</u>	0.521a	<u>0.000</u>
8	LUP	1.190a	<u>0.003</u>	1.779b	<u>0.012</u>	1.472a	<u>0.002</u>	1.174a	<u>0.001</u>	0.899b	<u>0.032</u>	0.651	<u>0.264</u>
	LUP2	−0.099a	<u>0.000</u>	−0.132a	<u>0.000</u>	−0.115a	<u>0.000</u>	−0.098a	<u>0.000</u>	−0.082a	<u>0.000</u>	−0.068b	<u>0.022</u>
	LGRT	−0.046b	<u>0.048</u>	−0.065b	<u>0.022</u>	−0.055a	<u>0.004</u>	−0.046a	<u>0.001</u>	−0.037b	<u>0.028</u>	−0.029	<u>0.218</u>
	LFEI	0.249a	<u>0.000</u>	0.244b	<u>0.011</u>	0.246a	<u>0.000</u>	0.249a	<u>0.000</u>	0.251a	<u>0.000</u>	0.253a	<u>0.001</u>
	LRU	0.056a	<u>0.002</u>	0.066a	<u>0.000</u>	0.061a	<u>0.000</u>	0.055a	<u>0.000</u>	0.050a	<u>0.000</u>	0.046a	<u>0.001</u>
	LGRE	−0.100a	<u>0.000</u>	−0.075a	<u>0.000</u>	−0.088a	<u>0.000</u>	−0.100a	<u>0.000</u>	−0.112a	<u>0.000</u>	−0.122a	<u>0.000</u>
	LDY	0.493a	<u>0.000</u>	0.486a	<u>0.000</u>	0.490a	<u>0.000</u>	0.494a	<u>0.000</u>	0.497a	<u>0.000</u>	0.501a	<u>0.000</u>
9	LUP	2.186a	<u>0.000</u>	3.226a	<u>0.000</u>	2.641a	<u>0.000</u>	2.135a	<u>0.000</u>	1.705a	<u>0.000</u>	1.258b	<u>0.033</u>
	LUP2	−0.147a	<u>0.000</u>	−0.201a	<u>0.000</u>	−0.171a	<u>0.000</u>	−0.144a	<u>0.000</u>	−0.122a	<u>0.000</u>	−0.099a	<u>0.001</u>
	LGRT	−0.053b	<u>0.022</u>	−0.054c	<u>0.060</u>	−0.054a	<u>0.004</u>	−0.053a	<u>0.000</u>	−0.053a	<u>0.003</u>	−0.052b	<u>0.035</u>
	LFEM	0.084a	<u>0.002</u>	0.070b	<u>0.026</u>	0.078a	<u>0.000</u>	0.084a	<u>0.000</u>	0.090a	<u>0.000</u>	0.096a	<u>0.000</u>
	LRU	0.051a	<u>0.003</u>	0.067a	<u>0.000</u>	0.058a	<u>0.000</u>	0.051a	<u>0.000</u>	0.044a	<u>0.000</u>	0.037a	<u>0.009</u>
	LGRE	−0.114a	<u>0.000</u>	−0.100a	<u>0.000</u>	−0.108a	<u>0.000</u>	−0.115a	<u>0.000</u>	−0.120a	<u>0.000</u>	−0.126a	<u>0.000</u>
	LDY	0.496a	<u>0.000</u>	0.491a	<u>0.000</u>	0.494a	<u>0.000</u>	0.496a	<u>0.000</u>	0.498a	<u>0.000</u>	0.500a	<u>0.000</u>
10	LUP	1.520a	<u>0.000</u>	2.286a	<u>0.000</u>	1.890a	<u>0.000</u>	1.489a	<u>0.000</u>	1.160a	<u>0.004</u>	0.810	<u>0.154</u>
	LUP2	−0.117a	<u>0.000</u>	−0.157a	<u>0.000</u>	−0.136a	<u>0.000</u>	−0.116a	<u>0.000</u>	−0.099a	<u>0.000</u>	−0.081a	<u>0.005</u>
	LMod1	−0.058b	<u>0.010</u>	−0.068b	<u>0.015</u>	−0.063a	<u>0.001</u>	−0.058a	<u>0.000</u>	−0.054a	<u>0.001</u>	−0.049b	<u>0.042</u>
	LFED	0.275a	<u>0.000</u>	0.223a	<u>0.009</u>	0.250a	<u>0.000</u>	0.277a	<u>0.000</u>	0.300a	<u>0.000</u>	0.323a	<u>0.000</u>
	LRU	0.048a	<u>0.005</u>	0.068a	<u>0.000</u>	0.058a	<u>0.000</u>	0.048a	<u>0.000</u>	0.039a	<u>0.000</u>	0.030b	<u>0.036</u>
	LGRE	−0.108a	<u>0.000</u>	−0.093a	<u>0.000</u>	−0.100a	<u>0.000</u>	−0.108a	<u>0.000</u>	−0.115a	<u>0.000</u>	−0.122a	<u>0.000</u>
	LDY	0.508a	<u>0.000</u>	0.493a	<u>0.000</u>	0.501a	<u>0.000</u>	0.508a	<u>0.000</u>	0.514a	<u>0.000</u>	0.521a	<u>0.000</u>
11	LUP	1.190a	<u>0.003</u>	1.779b	<u>0.012</u>	1.472a	<u>0.002</u>	1.174a	<u>0.001</u>	0.899b	<u>0.032</u>	0.651	<u>0.264</u>
	LUP2	−0.099a	<u>0.000</u>	−0.132a	<u>0.000</u>	−0.115a	<u>0.000</u>	−0.098a	<u>0.000</u>	−0.082a	<u>0.000</u>	−0.068b	<u>0.022</u>
	LMod2	−0.046b	<u>0.048</u>	−0.065b	<u>0.022</u>	−0.055a	<u>0.004</u>	−0.046a	<u>0.001</u>	−0.037b	<u>0.028</u>	−0.029	<u>0.218</u>
	LFEI	0.295a	<u>0.000</u>	0.309a	<u>0.002</u>	0.301a	<u>0.000</u>	0.294a	<u>0.000</u>	0.287a	<u>0.000</u>	0.281a	<u>0.000</u>
	LRU	0.056a	<u>0.002</u>	0.066a	<u>0.000</u>	0.061a	<u>0.000</u>	0.055a	<u>0.000</u>	0.050a	<u>0.000</u>	0.046a	<u>0.001</u>
	LGRE	−0.100a	<u>0.000</u>	−0.075a	<u>0.000</u>	−0.088a	<u>0.000</u>	−0.100a	<u>0.000</u>	−0.112a	<u>0.000</u>	−0.122a	<u>0.000</u>
	LDY	0.493a	<u>0.000</u>	0.486a	<u>0.000</u>	0.490a	<u>0.000</u>	0.494a	<u>0.000</u>	0.497a	<u>0.000</u>	0.501a	<u>0.000</u>

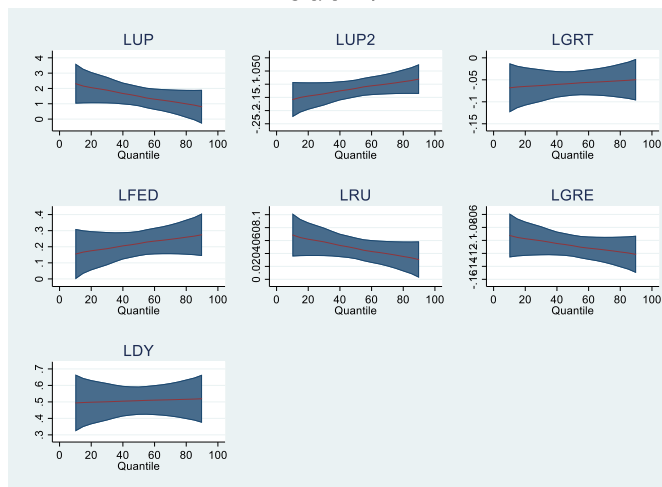
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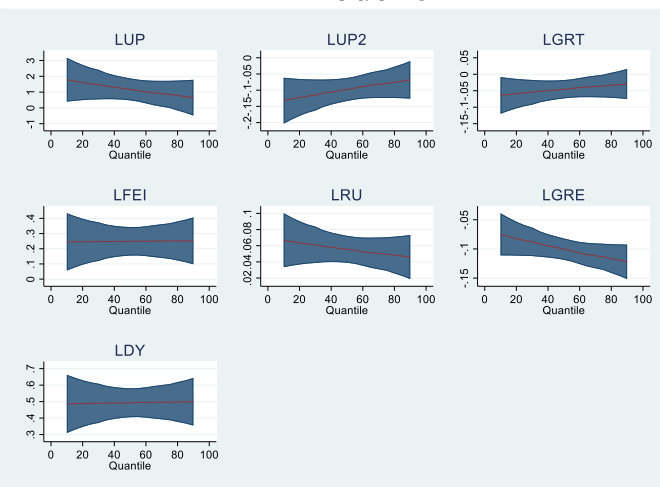
Mod	Expl. var.	KRDR		10th quantile		30th quantile		50th quantile		70th quantile		90th quantile	
		Elast.	p	Elast.	p	Elast.	p			Elast.	p	Elast.	p
12	LUP	2.186a	<u>0.000</u>	3.226a	<u>0.000</u>	2.641a	<u>0.000</u>	2.135a	<u>0.000</u>	1.705a	<u>0.000</u>	1.258b	<u>0.033</u>
	LUP2	−0.147a	<u>0.000</u>	−0.201a	<u>0.000</u>	−0.171a	<u>0.000</u>	−0.144a	<u>0.000</u>	−0.122a	<u>0.000</u>	−0.099a	<u>0.001</u>
	LMod3	−0.053b	<u>0.022</u>	−0.054c	<u>0.060</u>	−0.054a	<u>0.004</u>	−0.053a	<u>0.000</u>	−0.053a	<u>0.003</u>	−0.052b	<u>0.035</u>
	LFEM	0.137a	<u>0.000</u>	0.125a	<u>0.003</u>	0.132a	<u>0.000</u>	0.138a	<u>0.000</u>	0.143a	<u>0.000</u>	0.148a	<u>0.000</u>
	LRU	0.051a	<u>0.003</u>	0.067a	<u>0.000</u>	0.058a	<u>0.000</u>	0.051a	<u>0.000</u>	0.044a	<u>0.000</u>	0.037a	<u>0.009</u>
	LGRE	−0.114a	<u>0.000</u>	−0.100a	<u>0.000</u>	−0.108a	<u>0.000</u>	−0.115a	<u>0.000</u>	−0.120a	<u>0.000</u>	−0.126a	<u>0.000</u>
	LDY	0.496a	<u>0.000</u>	0.491a	<u>0.000</u>	0.494a	<u>0.000</u>	0.496a	<u>0.000</u>	0.498a	<u>0.000</u>	0.500a	<u>0.000</u>

Notes: a, b, and c denote significance at the 1%, 5%, and 10% levels, respectively; p-values are underlined. Mod1 = GRT×FED; Mod2 = GRT×FEI; Mod3 = GRT×FEM.

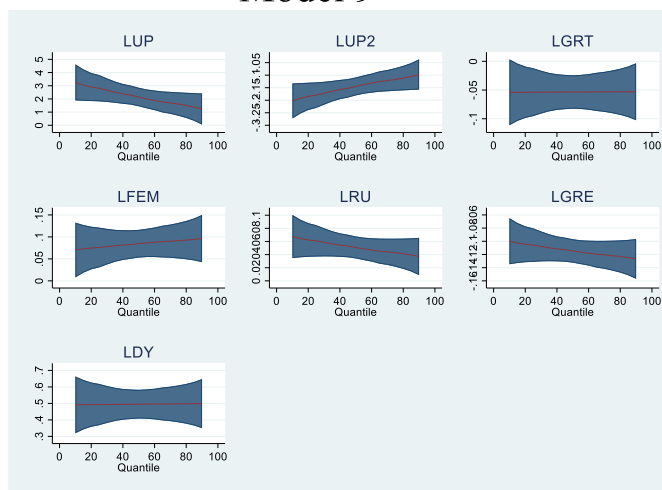
Model 7



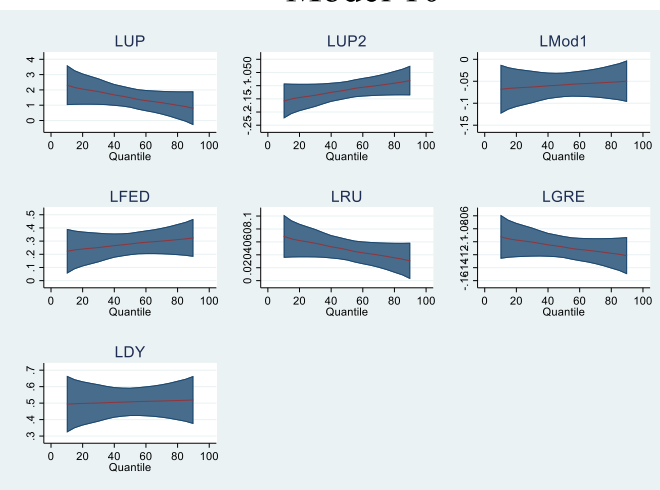
Model 8



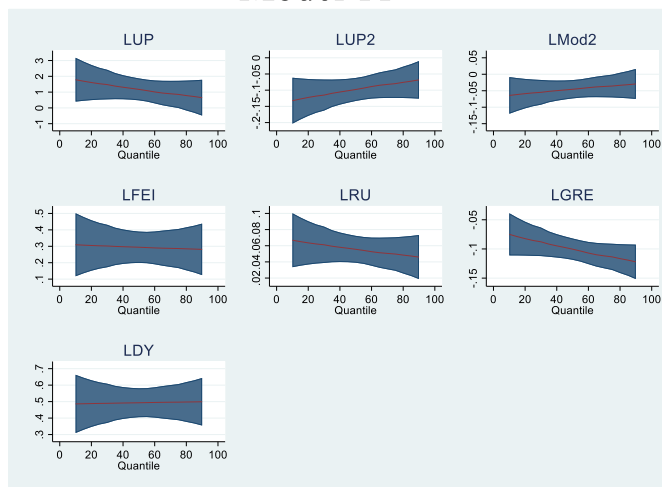
Model 9



Model 10



Model 11



Model 12

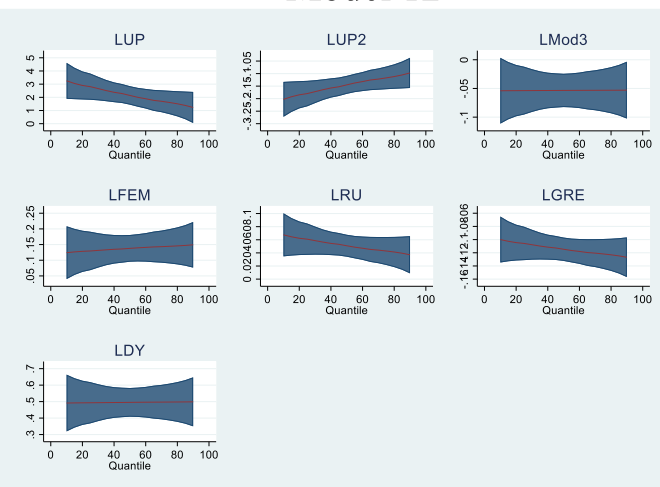


Fig. A1. Visualizing quantile coefficients (ESC- ecological indicator).

Appendix 2

Table A2
List of countries

Austria	France	Netherlands
Belgium	Germany	Poland
Bulgaria	Greece	Portugal
Croatia	Hungary	Slovakia
Czech Republic	Ireland	Slovenia
Denmark	Italy	Spain
Finland	Luxembourg	Sweden

Data availability

Data will be made available on request.

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