Original Article

The impact of economic, social, and political globalization with economic complexity on economic vitality: the case of the UK

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ABSTRACT: This paper explores the effects of economic complexity and globalization in different economic, social, and political development aspects on ecosystem vitality within the United Kingdom, covering 1995-2023. The study used FMOLS cointegration regression and Impulse Response Function analyses on two empirical models composed of linear and nonlinear components. The analysis shows a positive impact of growth complexity and ecosystem vitality. This relationship may be driven by technological innovation and improved resource efficiency. Economic globalization has a negative impact on ecosystems, while social and political globalization has a positive effect. In addition, we examine how GDP per capita, population density, education level, energy consumption, and renewable energy influence ecosystem vitality. An early rise in GDP per capita positively affects ecosystem vitality, but this effect turns negative after reaching a certain threshold. Population density and energy use have adverse effects on ecosystem vitality, while renewable energy, together with higher levels of education, have positive impacts on ecosystem vitality. These findings suggest that integrated policies aimed at reconciling such aspects as economic complexity, globalization, and other socio-economic factors are required to ensure that the ecology remains sustainable despite development processes occurring in the economy. They stress the significance of continuous interventions for maintaining environmental benefits.

KEYWORDS: ecosystem vitality, economic complexity, globalization, renewable energy, economic growth

INTRODUCTION

The interplay between economic complexity, globalization, and ecological vitality becomes increasingly relevant in light of current environmental conditions worldwide. Economic complexity refers to the capacity of an economy to produce goods and adopt technology that can influence the environment through innovation, efficiency, and resource use (Hidalgo & Hausmann, 2009). Likewise, globalization, including its social and political aspects, can affect ecosystems, changing trade patterns, cultural dynamics, and governance frameworks (Kochtcheeva, 2022). For this reason, understanding how these factors impact ecosystem health is crucial for formulating policies that balance economic development and environmental sustainability.

According to Hidalgo and Hausmann (2009), one such fundamental determinant of a nation's economic growth is associated with economic complexity as opposed to traditional growth theories. In essence, this implies that any country can grow economically if it expands its productive capabilities based on what it knows how to do best. The Economic Complexity Index (ECI) calculates this by evaluating an economy's export portfolio of diversity. An increase in ECI means that the economy is complex, indicating that it has higher abilities to produce sophisticated goods, whereas a decrease suggests lower abilities. It indicates that the country's products have a high level of technological knowhow or knowledge intensity; for instance, value-added products could be classified into several categories.

However, if unsustainable practices take over, this might lead to increased resource consumption (Baranowski, Jabkowski, & Kammen, 2025) and waste generation while simultaneously causing negative consequences on resources that may cause depletion of natural resources due to excessive exploitation (Randhir, 2016). On top of leading to improvements in resource efficiency, technological advances often reduce their adverse impacts on the environment. Still, very complex levels, if not sustainably managed, could also result in greater utilization of resources and increased waste production.

Theories of globalization highlight the interdependence among countries' economies, societies, cultures as well as political systems when considering economic complexity. Economic globalization combines national markets via international trade, foreign direct investment, and capital flows. For example, it can cause environmental degradation through increased industrial activity and resource extraction. Additionally, it may facilitate the diffusion of green technologies and promote sustainable practices globally (Kochtcheeva, 2022). Social globalization refers to the cross-border spread of ideas, information, and cultures. This means it may create environmental awareness, leading to global initiatives to conserve nature (Randhir, 2016). Political globalization means the increasing influence of international organizations and agreements on domestic policies. It encourages cooperation on worldwide environmental problems (Randhir, 2016). As such, political globalization could act as a catalyst toward collective action in addressing environmental challenges.

The Environmental Kuznets Curve (EKC) hypothesis suggests an inverted-U-shaped relationship between economic growth and environmental degradation. At the beginning of a country's development, increased industrial activity and resource utilization are expected to cause environmental deterioration. Grossman & Krueger (1995) discovered that as countries reach certain levels of wealth, they invest in cleaner technologies and establish stronger environmental rules, which improve or enhance the state of the environment. An especially pertinent use of this idea is examining how economic complexity and globalization influence the environmental outcomes at different stages in development. As per the Brundtland Commission's definition, the concept of sustainable development means meeting the needs of present generations without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987). It blends conservation of the environment with inclusion of the social community. This article highlights the need to balance economic activities, environmental management, and social welfare.

Another approach in our work involves ecosystem services. These involve what individuals derive from clean air, water, food, and other things. These are good indicators for human well-being as well as healthy progress in economic activities. In this regard, any disturbances within ecosystems can reduce the benefits we receive from them, leading to ill health and poverty at the individual level (Kochtcheeva, 2022; Sarmah & Mahanta, 2025). Therefore, it can be said that understanding factors influencing ecosystem vitality is essential to maintain these services because they are crucial aspects of the global environment.

In addition to the above, complexity science examines how unexpected behaviors arise from system interactions and produce results. In other words, it explores the consequences and effects of different factors, such as technological innovations, policy interventions, and global trade, regarding the economy or the environment (Aerni, 2021). From this perspective, economic complexity helps to understand the relationships between globalization and ecosystem vitality. The UK was chosen as a case study because, in addition to being a developed economy, it exhibits a high level of participation in globalization and the progressive environmental policies it implements. In addition, since the UK economy consists of developed industries, it stands out as a suitable example in terms of the comprehensiveness and accuracy of the economic complexity index. (Kovács, 2022). In this context, economic complexity provides a framework for looking at environmental effects, such as technological progress and production capabilities. Additionally, extensive trading relationships, cultural exchanges, and participation in global policy frameworks make the UK a suitable case for examining economic, social, and political globalization. To this end, the UK has demonstrated its commitment to environmental sustainability through strong policies such as the 2008 Climate Change Act, which aims to achieve net zero emissions by 2050. Such policies reveal a proactive stance on environmental management and offer insights into the effects of economic complexity and globalization on ecosystem health.

So far, we have touched on some approaches we will employ as we build our empirical model. Despite this, the research will primarily focus on economic complexity and globalization with their economic, social, and political dimensions concerning the well-being of ecosystems, besides other parameters such as economic growth, energy consumption, renewable energy, education, and population. We apply Fully Modified Ordinary Least Squares (FMOLS) cointegration regression to assess long-term connections between variables. Moreover, impulse-response function (IRF) analysis is adopted to determine the paths through which one variable within the system causes changes in other variables at different times. These will be used to study how economic complexity, globalization, and other socio-economic factors affect the United Kingdom's ecosystem vitality. This paper will include a discussion of the literature review on these issues, as well as criteria for selecting specific variables, methods employed in this undertaking, and models run empirically

LITERATURE REVIEW

In this section, we examine empirical research on the impact of globalization on ecosystem vitality, including its economic, social, and political dimensions and its economic complexity. More generally, we aim to determine how economic, social, and political factors impact the environment and contribute to the ecosystem's overall health.

Extensive research has been conducted on how economic complexity, globalization, and environmental quality are interconnected. In some studies, innovation and resource use drive the relationship between economic complexity and environmental sustainability, which has both positive and negative consequences. For example, He et al. (2021) argue that in leading energy transition economies, carbon emissions are reduced through sophisticated technology that increases efficiency and minimizes waste. Similarly, Aerni (2021) emphasizes decentralized economic complexity for sustainable practices and innovations that benefit the environment as well as the economy in Switzerland.

To comprehend the influence of economic growth and complexity on ecological outcomes, many scholars use the Environmental Kuznets Curve (EKC) framework. For example, Fan et al. (2024) explored the connection between financial development, energy consumption, and ecological footprint among BRICS-T countries. Their findings reveal that pollution initially rises with growing economic complexity, but its square reduces it significantly, proving the EKC hypothesis. The study also indicated that financial development and non-renewable energy consumption negatively impacted the environment, while renewable energy mitigated these adverse effects. Lee et al. (2022) and Qayyum et al. (2021) indicated that the growth of complexity might hurt ecological integrity, while effective regulations at the national level, coupled with efficient control of trade carbon emissions, could mitigate this situation. Thus, it appears that this system's intricacy can lead to eco-positive outcomes via inventiveness. Still, it also stresses proper risk management so that any negative impact does not happen again. Lee et al. (2022) present more evidence supporting these conclusions. A positive correlation exists between OECD member countries' economic complexity and their environmental performance, thus indicating how a nation's productive structure influences its ecological results.

Similarly, Arnaut and Dada (2023) studied the UAE's ecological footprint, showing that economic complexity and nonrenewable energy degradation affect environmental quality. On the other hand, an increase in renewable energy sources and urbanization improved the ecological footprint, indicating a sustainability path forward. These findings further emphasize the need to align manufacturing with environmental aspirations.

It must be noted that each aspect of globalization–economic, social, or political–has specific impacts on ecosystems' sustainability within given settings (Randhir, 2016). Economic globalization destroys nature due to increased industrialization activities concurrent with resource exploitation, yet it still promotes the adoption of sustainable practices along with environmentally friendly technologies. Social/cultural norms affecting policies influence ecosystem sustainability because they change when globalized, thereby creating awareness about environmental conservation among many people who may act towards protecting them. Moreover, international collaboration regarding such issues can be enhanced through political globalization among different nations.

Another good illustration of such complicated relations between globalization, productivity, and pollution is provided by research on newly industrialized countries (NICs). Karaduman (2022) found a strong negative association between economic globalization, human capital, and ecological footprint, supporting the pollution halo hypothesis. However, greater productivity led to more environmental degradation, which required stronger regulations for NICs. Tausch & Heshmati (2018) have also shown that some aspects of globalization, like the New International Division of Labour (NIDL), significantly contribute to increased CO2 emissions, thereby harming the environment. Aggarwal (2006) showed that globalization may affect local ecosystems through trade liberalization and technology transfer by reducing their resilience and increasing vulnerability. This affects people with low incomes who depend on these ecosystems. Therefore, it is evident that there is a need for all-encompassing policies addressing socioeconomic and ecological resilience (Randhir, 2016). Kochtcheeva (2022) studied how global economic integration affects the environment by looking at its positive and negative impacts on environmental policies as well as nature itself. The author contended that although global integration can boost productivity levels, this process must be carefully managed; otherwise, it will lead to even worse environmental degradation than before.

Neagu (2020), on the other hand, focused on highly complex economies, revealing a positive long-run relationship between economic complexity, fossil fuel energy consumption, and ecological footprints. This study underscores the critical role of economic complexity in environmental sustainability, especially in economies already in ecological deficit.

The health of an ecosystem is significantly influenced by various factors such as the gross domestic product per capita, population density, education level, energy consumption, and the proportion of renewable energy sources. However, a higher share of renewable energy sources may help mitigate the adverse effects of increased energy use, which tends to cause more environmental destruction. The introduction of renewable sources into the energy mix has been shown in research to lessen harm done to the environment significantly, thus providing grounds for implementing sustainable energy regulations (Raihan, 2023).

Education is vital in encouraging increased environmental consciousness and promoting sustainable programs. However, it is possible to deplete natural resources in densely populated regions, thereby adversely affecting the environment. The research by Xu et al. (2018) and Bezák & Lyytimäki (2011) draws attention to the importance of considering socio-economic factors in environmental governance. Through these studies, land use and population change are shown to have significant impacts on ecosystem services. Xu et al.'s (2018) study about the Yangtze River Economic Belt Area indicated spatial and temporal changes in carbon sequestration and water retention, for example. This varies with changing weather patterns as well as land use, according to their survey responses. According to Bezák & Lyytimäki (2011), urban green spaces are essential for economic growth and human welfare, requiring planning approaches that integrate these aspects fully. Gong et al. (2023) investigate the spatial-temporal dynamics of China's Lixiahe Plain regarding its vitality. They demonstrate apparent variation among different townships regarding spatial development trends, calling for targeted development schemes depending on the type of township selected. Karimzadeh et al. (2023) highlight that economic complexity significantly reduces CO2 emissions in the long run, highlighting the potential environmental benefits of transitioning to more sophisticated economic activities.

Satrovic and Adedoyin (2022) evaluated the relationship between electricity consumption and environmental degradation within complex economies. Their results validated the EKC assumption that trade openness and economic complexity influence performance over time along environmental dimensionality. The study also revealed bidirectional causality between economic growth, complexity, and ecological footprint.

The relationship between the vitality of ecosystems, economic complexity, and globalization is multifaceted and varies. Randhir (2016) investigated the effect of globalization on local commons. He stressed the need for multi-scale adaptation strategies that enhance sustainability and resilience. To address this effectively, he suggested a multi-scale ecosystem framework to handle global market pressures on local resources better.

Kovács (2022) has studied the link between environmental performance and economic complexity among OECD countries. This research establishes that economic complexity leads to better environmental results. Therefore, we infer that economic complexity predicts environmental performance. El-Massah & Hassanein (2023) reviewed whether the Gulf Cooperation Council economies conform to the Environmental Kuznets Curve (EKC). When there is a certain threshold at which economic growth becomes too complex in its composition, it will lead to decreased pollution associated with increased levels of human activity within areas where people live or work. This reveals how income level, openness to trade, connectedness to global markets, and economic diversity affect ecological footprints and CO2 emissions patterns across countries. This underscores the necessity of more widely harnessing technology and diversifying energy sources to enhance environmental sustainability.

A literature review found a substantial nexus between economic complexity, globalization, and ecosystem well-being. The intricacies of economies and interconnectedness among states imply that promoting sustainable practices can be challenging, but it provides an opportunity through innovative approaches and global collaborations. Policies can be developed if such dynamics are well understood to promote economic growth while maintaining optimal health status for ecosystems. Therefore, in our empirical study involving the United Kingdom, it is necessary to include socio-economic factors in the model, economic complexity, and globalization on the environment to explain their impact on the ecosystem's vitality.

COMPONENTS OF ECOSYSTEM VITALITY

To better understand the composition and influencing factors of ecosystem vitality, it is crucial to examine its components in detail. Figure 1 provides a breakdown of ecosystem vitality. This illustrates the main indicator categories and their sub-components determining the overall score. It also shows the weights of these main indicator categories within the ecosystem vitality. For a more detailed view of each sub-component's contribution, please refer to the table in the Appendix.

In Figure 1, the largest category, Biodiversity & Habitat, contributes 42.9% to the Ecosystem Vitality score. Within this category, Terrestrial Biome Protection, both national and global, along with Marine Protected Areas, each contribute 22.2%. Other significant contributions come from the Protected Areas Representation Index at 14.0%, Species Habitat Index and Species Protection Index at 8.3%, and the Biodiversity Habitat Index at 3.0%. Ecosystem Services account for 19.1% of the Ecosystem Vitality score. This category is primarily driven by Tree Cover Loss, which contributes 75.0%, while Grassland Loss and Wetland Loss each contribute 12.5%. The Fisheries category, contributing 11.5%, includes sub-components such as Fish Stock Status and Marine Trophic Index, each contributing 36.0%, and Fish Caught by Trawling, which contributes

28.0%. Acid Rain, contributing 9.6% to the overall score, is divided equally between SO2 and NOX Growth rates, each contributing 50.0%. Similarly, agriculture, which also contributes 9.6%, is equally split between the Sustainable Nitrogen Management Index and Sustainable Pesticide Use, with each sub-component contributing 50.0%. Finally, Water Resources, contributing 7.2%, is represented solely by Wastewater Treatment, which accounts for 100.0% of this category's contribution.

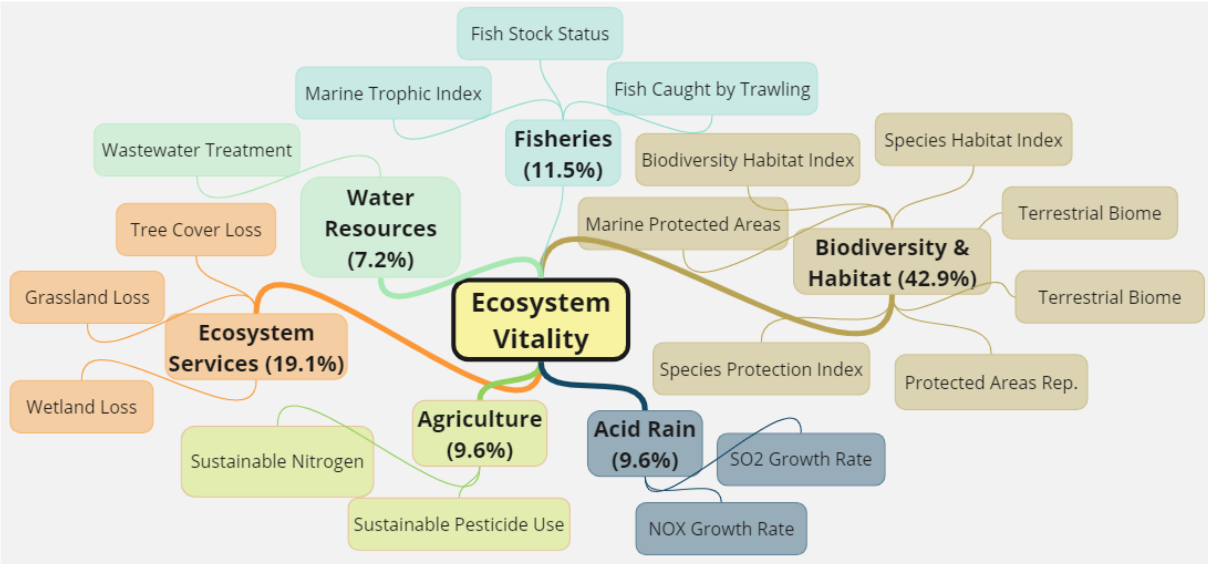


Figure 1. Components of ecosystem vitality

Source: Plotted by the author using the KOF Swiss Economic Institute data set

VARIABLES AND 3D VISUALIZATION OF KEY FACTORS

Table 1 summarizes the key variables used in the empirical model. It also includes their notations and indicators. The variables are as follows: The Yale Center for Environmental Law and Policy provides ecosystem vitality (ECO) data. The World Bank's World Development Indicators offer data on GDP per capita (GDPpc), population density (POP), and education (EDU). The KOF Swiss Economic Institute is the source of economic globalization (EcG), social globalization (SoG), and political globalization (PoG). We obtain Economic Complexity (ECI) from the Harvard Growth Lab. Our World in Data provides information on energy consumption (ENC) and renewable energy share (REN).

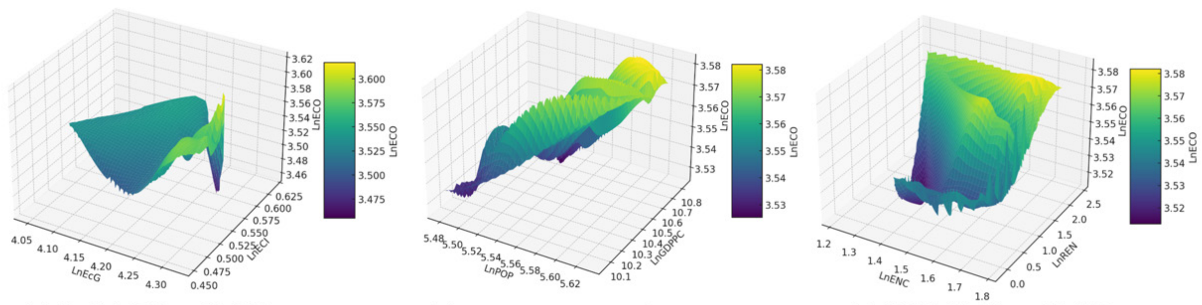
Figure 1 illustrates a three-dimensional surface map to clarify the probable complex connections between ecosystem vitality and the factors that influence it.

This visual representation enables a deeper understanding of how key economic variables interact to influence ecosystem vitality. Given the three-dimensional nature of the graphs, we will analyze how pairs of independent variables affect changes in the dependent variable, ecosystem vitality. While the parameter estimates suggest that interactions between independent variables can influence or even alter their relationship with the dependent variable, this visual analysis will provide a general overview. Accordingly, we will interpret how economic globalization (EcG) and economic complexity (ECI) together affect ecosystem vitality (ECO) in panel (a) of Figure 2, how population density and GDP per capita together affect ECO in panel (b), and how energy consumption energy consumption (ENC) and renewable energy share (REN) together affect ECO in panel (c).

Variable	Abrev.	Indicators
Ecosystem vitality	ECO	Environmental performance index
GDP per capita	GDPpc	GDP per capita (constant 2015 US$)
Economic globalization	EcG	Economic globalization, de facto
Social globalization	SoG	Social globalization, de facto
Political globalization	PoG	Political globalization, de facto
Economic complexity	ECI	Economic complexity index
Population	POP	Population density—the number of people per km² of land area
Education	EDU	School enrolment, tertiary (% gross)
Energy consumption	ENC	Primary energy consumption per capita (kWh/person)
Renewable energy	REN	Renewable energy share

Table 1. Variables

Source: ECO: Yale Center for Environmental Law & Policy; GDPpc, POP, EDU: World Bank—World Development Indicators; EcG, SoG, PoG: KOF Swiss Economic Institute; ECI: the Harvard Growth Lab; ENC, REN: Our World in Data



(a) EcG, ECI, and ECO (b) POP, GDPpc, and ECO (c) ENC, REN, and ECO

Figure 2. 3D surface plots among the key variables

Source: Author's graph

Figure 2 (a) demonstrates that higher values of ecosystem vitality (LnECO) are associated with certain combinations of economic globalization (LnEcG) and economic complexity (LnECI). For lower levels of LnEcG, an increase in LnECI is associated with a modest rise in LnECO. The progression of colors from darker to lighter shades demonstrates this. As LnEcG continues to expand, the story uncovers a noticeable increase in LnECO that corresponds with the growth of LnECI. The surface plot also shows some curvature and peaks. The relationship between LnECO, LnEcG, and LnECI is not straightforward. Areas with strong LnECO are typically found in regions characterized by high levels of LnEcG and LnECI, as evidenced by the peaks on the surface. It appears that increased levels of LnEcG and LnECI positively impact LnECO.

On the other hand, the plot's valleys or darker regions, where LnEcG and LnECI are lower, indicate a decrease in LnECO. These findings suggest that when LnEcG and LnECI are at lower levels, there is a decrease in LnECO. The plot clearly shows a positive relationship between LnEcG and LnECO, as well as between LnECI and LnECO. The interaction effect is remarkable, as the combined rise in LnEcG and LnECI significantly boosts LnECO.

Figure 2(b) illustrates the relationship between LnPOP (logarithm of population density), LnGDPpc (logarithm of GDP per capita), and LnECO (logarithm of ecosystem vitality). The color gradient represents LnECO's values. The darker shades indicate lower LnECO values, whereas the lighter shades indicate higher values. The presence of higher levels of LnPOP can have varying effects on LnECO. This shows a complex association. Similarly, as LnGDPpc rises from approximately 10.0 to 10.8, LnECO exhibits variations. At different levels of LnGDPpc, we observe both increases and decreases in LnECO. Therefore, we may conclude that the relationship between LnGDPpc and LnECO is non-linear. Specific combinations of LnPOP and LnGDPpc achieve the highest levels of LnECO. On the surface, there are noticeable peaks where both LnPOP and LnGDPpc are high. This indicates regions of higher LnECO. The peaks and troughs suggest that the relationship between LnECO, LnPOP, and LnGDPpc is complex and may involve interaction effects.

Figure 2 (c) demonstrates that when LnENC rises from about 1.2 to 1.8, there is a corresponding alteration in LnECO (logarithm of ecological vitality). LnECO reaches its peak when LnENC is at the upper limit of this range, indicating a potential positive correlation between increasing LnENC and LnECO under certain circumstances. Changes in the renewable energy share (LnREN) also affect the LnECO. As the natural logarithm of the relative efficiency (LnREN) climbs from about 0 to 2.5, there is a clear enhancement in the natural logarithm of the economic output (LnECO), as seen by the shift from darker to lighter hues. This indicates a direct correlation between the natural logarithm of renewable energy consumption (LnREN) and environmental quality (LnECO), emphasizing the potential advantages of growing LnREN for the environment's well-being. The interaction between LnENC and LnREN is noteworthy. The most prominent peaks in LnECO are observed when there is a particular combination of high LnENC and high LnREN. This can be interpreted as the synergistic effect of high LnENC and significant LnREN, which can result in improved LnECO.

As a result, the relationships among ecosystem vitality, energy consumption, renewable energy share, economic globalization, economic complexity, population density, and GDP per capita are complex and nonlinear. Both energy consumption and renewable energy share have significant effects on ecosystem vitality. From this graphical analysis, we can conclude that encouraging renewable energy while controlling energy consumption can help improve ecosystem vitality. Similarly, there is a positive relationship between economic globalization, economic complexity, and ecosystem vitality. Increasing both factors provides significant benefits to ecosystem vitality. Accordingly, it shows that in order to increase or sustain ecosystem vitality, integration with the global economy and increasing the complexity of economic activities can be effective. The relationship between ecosystem vitality, population density, and GDP per capita is complex. Because each component has different effects on ecosystem vitality, it is seen that there is a non-linear relationship between GDP per capita and ecosystem vitality. This non-linear structure related to economic growth is parallel to the environmental Kuznets Curve thesis. In this context, this situation will be considered while creating the empirical model, and estimates will be made for the non-linear model.

MODEL SPECIFICATION

In light of the pattern provided by 3D surface plots, we found complex and non-linear relationships between ecosystem vitality (LnECO) and various economic, demographic, and energy-related variables. These plots depict the interaction between economic globalization, economic complexity, population density, GDP per capita, energy consumption, renewable energy, and ecosystem vitality. Accordingly, they emphasize the importance of integrating global financial activities, managing population density, and balancing energy consumption with renewable energy share to increase ecosystem vitality. However, it should be noted that these visualizations only give us a preliminary idea before parameter estimations. In other words, the observed relationships between variables may differ due to the interactions of independent variables within a model. According to the theoretical background and the opinion obtained from the visualizations, two models will be created to analyze the relationships between variables. The first model addresses the linear relationships between ecosystem vitality and independent variables. The second model extends this by including the quadratic term of GDP per capita in the model to capture non-linear effects. The empirical models are formulated as follows:

Model 1

In the first model, we may specify ecosystem vitality (ECO) as a linear function of GDP per capita (GDPpc), economic globalization (EcG), social globalization (SoG), political globalization (PoG), economic complexity (ECI), population density (POP), education (ED), energy consumption (ENC), and renewable energy share (REN). Eq.1 represents the functional form of the model, while Eq.2 provides the econometric specification with the inclusion of the beta coefficients and error term:

$ECO = f(GDPpc, EcG, SoG, PoG, ECI, POP, ED, ENC, REN)$	(1)
$LnECO_t = \beta_0 + \beta_1.GDPpc_t + \beta_2.LnEcG + \beta_3.LnSoG_t + \beta_4.LnPoG_t + \beta_5.LnPOP_t + \beta_6.LnED_t + \beta_7.LnENC_t + \beta_7.LnREN_t + \varepsilon_t$	(2)

Model 2

The second model has been extended from Model 1 by including the quadratic relationship observed between GDP per capita and ecosystem vitality, both in the three-dimensional surface graphs and the Environmental Kuznets Curve context. Accordingly, Model 2 includes the quadratic term of GDP per capita (GDPpcS). In this context, ecosystem vitality (ECO) is expressed as a function of GDP per capita (GDPpc), GDP per capita squared (GDPpcS), economic globalization (EcG), social globalization (SoG), political globalization (PoG), economic complexity (ECI), population density (POP), education (ED), energy consumption (ENC), and renewable energy share (REN). Similarly, Eq.3 represents the functional form of Model 2, while Eq.4 provides the econometric specification with the inclusion of the beta coefficients and error term:

$ECO = f(GDPpc, (GDPpcS, EcG, SoG, PoG, ECI, POP, ED, ENC, REN)$	(3)
$LnECO_t = \beta_0 + \beta_1 . GDPpc_t + \beta_2 . GDPpcS_t + \beta_3 . LnEcG + \beta_4 . LnSoG_t + \beta_5 . LnPoG_t + \beta_6 . LnPOP_t + \beta_7 . LnED_t + \beta_7 . LnENC_t + \beta_8 . LnREN_t + \varepsilon_t$	(4)

METHODOLOGY AND ESTIMATIONS

In this research, we employ Impulse Response Function (IRF) analysis and Fully Modified Ordinary Least Squares (FMOLS) cointegration regression to examine how economic complexity and its three dimensions impact ecosystem health over time. FMOLS assesses the long-run relationship between ecosystem vitality and the chosen independent variables. It effectively addresses possible endogeneity as well as serial correlation in cointegrated systems, thus giving consistent estimates for long-run parameters. IRF analysis is then utilized to study the short-term impacts of shocks on independent variables on ecosystem vitality. IRFs trace a one-time shock's influence through a system's present and future values, which enables understanding of short-term responses and temporal causality among variables. By observing GDP per capita, social, political and economic dimensions of globalization, energy consumption, population density, education as well as share of renewable energy where they react to shocks; we gain insight into these factors' immediate yet fleeting effects on ecosystem vitality more broadly within an integrated methodological framework provided by combining FMOLS cointegration regression with impulse response function analysis. Our dual approach allows us to study long-term dynamics influencing ecosystem vitality comprehensively across different timescales that impact sustainability within ecosystems, while also helping understand interactions between economic, social, and environmental factors involved in this process.

To obtain unbiased estimations, it is vital to determine the appropriate lag length before proceeding to the series' stationarity tests. Table 2 displays the results of selecting the optimum lag length.

Table 2 shows the results of the optimum lag length selection based on statistical criteria. Each row corresponds to a different lag length (0, 1, and 2); the columns present the associated statistics. For lag 0, the log-likelihood (LL) is 485.024, with a final prediction error (FPE) of 1.10E-32. The information criteria values are -45.2404 (AIC), -45.1324 (HQIC), and -44.743 (SBIC), indicating a relatively poor model fit. Lag 1 shows a significant improvement with an LL of 766.251.

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	485.024				1.10E-32	-45.2404	-45.1324	-44.743
1	766.251	562.45	100	0.00	1.1e-39*	-62.5001	-61.3127	-57.0288
2	6469.38	11406*	100	0.00	.	-596.131*	-593.864*	-585.686*

Table 2. Optimum lag-length selection
Source: Author's calculation

The likelihood ratio (LR) test statistic is 562.45, with 100 degrees of freedom (df) and a p-value of 0. The FPE is 1.1e-39, marked as optimal. The AIC, HQIC, and SBIC values are -62.5001, -61.3127, and -57.0288, respectively, indicating a better model fit than lag 0. Lag 2 has the highest LL at 6469.38 and an LR test statistic of 11406, which is highly significant with a p-value of 0. Although FPE is unavailable, the AIC, HQIC, and SBIC values are -596.131, -593.864, and -585.686, respectively, all optimal. These values are significantly lower than those for lags 0 and 1, indicating the best model fit. Therefore, given the AIC, HQIC, and SBIC criteria, the model with lag 2 is the optimal choice.

	ADF test stat.		PP test stat.		KPSS test stat.		ZA test stat.	
Variable	Level	1st diff.	Level	1st diff.	Level	1st diff.	Level	1st diff.
ECO	-1.113	-5.163*	-.971	-5.191*	.219*	.052	-2.737	-5.157*
GDPpc	1.805	-4.254*	-1.804	-4.196*	.445*	.0559	-3.217	-4.651**
EcG	-2.815	-3.810*	2.856	-3.813*	.51*	.0327	-2.579	-5.359*
SoG	-2.048	-3.521*	-1.916	-3.503*	.557*	.0671	-3.559	-6.454*
PoG	-8.435*	.	-7.202*	.	.23*	.0857	-5.382*	.
ECI	-1.667	-5.248*	-1.869	-5.26*1	.163**	.0609	-4.726**	.
POP	0.022	-3.023**	-.632	-2.983**	.535*	.0731	-1.123	-7.074*
ED	-2.050	-4.322*	-2.068	-4.315*	.322*	.0434	-3.915	-4.722**
ENC	.807	-6.878*	1.216	-6.899*	.448*	.0682	-4.684**	.
REN	1.828	-5.154*	2.303	-5.166*	.671*	.0443	-4.885**	.
Residual	-6.354*		-6.792*		0274		-6.134*	

Note: * p<0.01, ** p<0.05. Critical values are as follows: ADF and PP (%1: -3.730, %5: -2.992), KPSS (%1: 0.146, %5: 0.216), Zivot-Andrews ZA (%1: -4.93, %5: -4.42). For KPSS, the null hypothesis (H0) is that the series is stationary. For ADF, PP, and ZA, the null hypothesis (H0) is that the series contains a unit root.

Table 3. Unit root test
Source: Author's graph

Table 3 presents the results of various unit root tests (ADF, PP, KPSS, and ZA) for the variables in the model, both at the level and first difference, including a row for the residuals to determine long-term relationships.

For the variable ECO, the ADF and PP tests at the level do not reject the null hypothesis of a unit root, as indicated by test statistics that are not significant. However, at the first difference, both tests show significant values (ADF: -5.163, PP: -5.191), leading to rejecting the null hypothesis at the 1% significance level, indicating that ECO is stationary in its first difference. The KPSS test at the level is significant, supporting the presence of a unit root, but the first difference is not substantial, confirming stationarity. The ZA test shows similar results, indicating a unit root at the level and stationarity at the first difference.

For GDPpc, the ADF and PP tests do not reject the null hypothesis of a unit root at the level but reject it at the first difference (ADF: -4.254, PP: -4.196) at the 1% significance level, indicating stationarity in the first difference. The KPSS test at the level is significant, supporting the presence of a unit root, but the first difference is not significant. The ZA test confirms these findings.

The variable EcG shows similar patterns with ADF and PP tests, not rejecting the null hypothesis at the level but rejecting it at the first difference (ADF: -3.810, PP: -3.813). The KPSS and ZA tests indicate the presence of a unit root at the level but stationarity in the first difference.

SoG follows the same trend, with ADF and PP tests indicating non-stationarity at the level but stationarity at the first difference (ADF: -3.521, PP: -3.503). The KPSS and ZA tests support these results.

For PoG, both ADF and PP tests reject the null hypothesis of a unit root at the level, indicating stationarity (ADF: -8.435, PP: -7.202). The KPSS and ZA tests confirm these results.

ECI and POP show non-stationarity at the level but stationarity at the first difference, supported by significant first-difference ADF and PP test statistics. The KPSS and ZA tests are consistent with these findings. ED, ENC, and REN also follow the same pattern, showing non-stationarity at the level but stationarity at the first difference, confirmed by ADF, PP, KPSS, and ZA tests.

The row for Residuals is particularly important for assessing long-term relationships. The ADF and PP test statistics for residuals are -6.354 and -6.792, respectively, both significant at the 1% level, indicating stationarity of the residuals. The KPSS test shows that the residuals are stationary at the level. Similarly, the ZA test confirms that the residuals are stationary at the 1% level.

According to the ADF, PP, KPSS, and ZA tests, the residuals are stationary at the level. These results indicate a long-run cointegrating relationship among the variables; i.e., despite short-term fluctuations, all the variables move together in a long-run equilibrium state.

	Model 1- Linear				Model 2- Non-linear			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
LnECO	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
LnGDPpc	-.058*	-.060*	-.038*	-.045*	-.420	.723	.792**	1.001*
LnGDPpcS					.017	-.037	-.040**	-.049*
LnEcG	.179*	.013	-.042**	-.065**	.221*	-.051	-.131*	-.079**
LnSoG		.262*	.235*	.261*		.327*	.281*	.279*
LnPoG		1.116*	.343*	.379*		1.417*	.255**	.513*
LnECI	-.107*	-.035	.070*	.055*	-.092**	-.022	.068*	.067**
LnENC			-.044**	-.036***			-.0443**	-.061**
LnREN			.011*	.028*			.016*	.026*
LnPOP				-0.388**				-.429**
_cons	3.466*	-2.085	1.953	3.931*	5.213	-7.613		-1.663*
R2	.693	.694	.866	.888	.682	.682	.823	.846
Adj. R2	.652	.618	.810	.825	.621	.581	.734	.744

Note: * p<.01, ** p<.05, ** p<.10

Table 4. FMOLS cointegration regression estimations
Source: Author's calculation

FMOLS results are presented in Table 4. In this regard, we will examine how environmental vitality (LnECO) is influenced by economic complexity and multidimensional globalization in the United Kingdom. Two main models are described: Model 1, Linear, and Model 2, Non-linear Quadratic. Additionally, each model was assessed using different specifications. This section concentrates on the largest forms of Model 1 and Model 2, which are respectively denoted as Model 1(4) and Model 2(4)

The linear model's coefficient for GDP per capita (LnGDPpc) is -0.045. This indicates a negative relationship with ecosystem vitality, with a significance level of 1%. This suggests that, in the linear model, an increase in GDP per capita is associated with a decrease in ecosystem vitality. The economic globalization variable (LnEcG) has a coefficient of -0.065. It shows a negative relationship with ecosystem vitality. Social globalization (LnSoG), with a coefficient of 0.221, demonstrates a significant positive impact, indicating that higher social globalization benefits ecosystem vitality. Political globalization (LnPoG) has a significant positive coefficient of 1.417, the largest among the globalization variables, suggesting a strong positive effect on ecosystem vitality.

Economic complexity (LnECI) shows a coefficient of 0.055 with a positive sign and is statistically significant at 1% significance level in this linear specification. Primary energy consumption per capita (LnENC) has a negative and significant coefficient of -0.036, indicating that higher energy consumption per capita harms ecosystem vitality. Renewable energy share (LnREN) with a coefficient of 0.016 is positive, statistically significant at the 1% level. Population density (LnPOP) has a negative coefficient of -0.388 with a statistically significant result at 1% level, suggesting that higher population density negatively impacts ecosystem vitality. The adjusted R-squared value of 0.825 indicates that this model explains 82.5% of the variance in ecosystem vitality.

In the non-linear quadratic specification, the coefficient for GDP per capita (LnGDPpc) is positive and significant at 1% level, while the coefficient for GDP per capita squared (LnGDPpcS) is negative, and similarly significant at 1% level. This pattern suggests an inverted U-shaped relationship between GDP per capita and ecosystem vitality, contrasting with the traditional Environmental Kuznets Curve hypothesis. Initially, increases in GDP per capita improve ecosystem vitality up to a turning point, beyond which further increases in GDP per capita lead to declines in ecosystem vitality. This deviation from the EKC hypothesis indicates that higher economic growth may not always result in better environmental outcomes. It underscores the need for continuous policy interventions to sustain environmental benefits.

Economic globalization (LnEcG) in the non-linear model has a coefficient of -0.079, indicating a significant negative impact on ecosystem vitality, similar to the linear model. Social globalization (LnSoG) remains positive and significant, with a coefficient of 0.513, supporting the beneficial role of social globalization. Political globalization (LnPoG) also retains a significant positive impact, with a coefficient of 0.513, though slightly smaller than the linear model.

Economic complexity (LnECI) shows a positive and significant coefficient of 0.067, suggesting that economic complexity positively influences ecosystem vitality in the quadratic model. Primary energy consumption per capita (LnENC) has a more pronounced negative impact in the quadratic model, with a coefficient of -0.061, reinforcing the detrimental effects of higher energy consumption. Renewable energy share (LnREN) remains positive and significant with a coefficient of 0.026, indicating that increasing renewable energy share benefits ecosystem vitality. Population density (LnPOP) has a negative and significant coefficient of -0.429, suggesting that higher population density negatively impacts ecosystem vitality in this specification. The adjusted R-squared value of 0.744 for the quadratic model indicates that it explains 74.4% of the variance in ecosystem vitality.

Comparing the two models, the linear model explains a higher proportion of the variance in ecosystem vitality (adjusted R-squared of 0.825) compared to the non-linear quadratic model (adjusted R-squared of 0.744). However, the quadratic model provides a nuanced understanding of the relationship between GDP per capita and ecosystem vitality, highlighting an inverted U-shaped curve. This suggests that while economic growth initially benefits Ecosystem vitality, beyond a certain point, further growth can lead to environmental degradation.

Social and political globalization positively impacts ecosystem vitality in both linear and nonlinear models. In this sense, these results support each other and are consistent. Economic globalization and per capita energy consumption negatively impact ecosystem vitality. According to this result, we can say that policy interventions may be necessary to reduce these negative effects. The positive effect of the renewable energy share on ecosystem vitality shows that it is important to encourage sustainable energy practices.

IMPULSE RESPONSE ANALYSIS

Figure 3 shows the impulse response functions (IRFs). These graphs illustrate how ecosystem vitality (LnECO) reacts to one standard deviation shocks in GDP per capita (LnGDPpc), economic globalization (LnEcG), political globalization (LnPoG), social globalization (LnSoG), economic complexity (LnECI), primary energy consumption per capita (LnENC), and renewable energy share (LnREN). The shaded areas represent the 95% confidence intervals, which show the uncertainty around the estimated responses. Each graph highlights the impact of these shocks on ecosystem vitality. Thus, we may see how the model's variables affect the ecosystem over time.

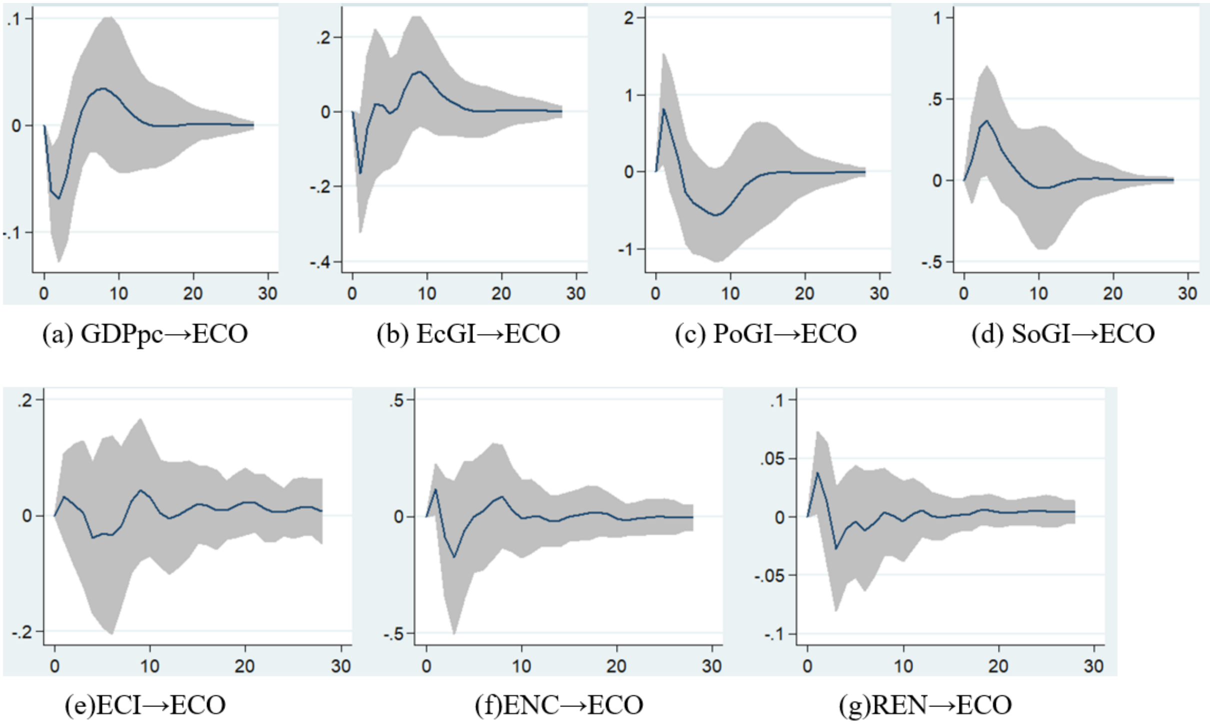


Figure 3. Impulse response analysis
Source: Author's graph

The first reaction of ecosystem vitality to a shock in GDP per capita (LnGDPpc) is negative, as shown in Figure 3(a). This suggests that the first rise in GDP per capita might negatively impact ecosystem vitality. This negative impact is short-lived, as the response quickly shifts to positive, peaking around step 10. This suggests that, over the medium term, increases in GDP per capita enhance Ecosystem vitality. However, the response stabilizes around zero towards the end of the horizon, indicating that the long-term effect of GDP per capita on Ecosystem vitality balances out.

Figure 3 (b) shows the response of Ecosystem vitality to a shock in Economic Globalization (LnEcG). The initial impact is positive, suggesting that an increase in economic globalization initially boosts Ecosystem vitality. This positive effect peaks early, around step 5, but then gradually declines and fluctuates around zero, indicating that the benefits of economic globalization are significant in the short term but do not sustain over the long term.

Figure 3 (c) illustrates the response of Ecosystem vitality to a shock in Political Globalization (LnPoG). The initial response is highly positive, reaching its peak almost immediately. This substantial initial positive impact indicates that political globalization significantly enhances Ecosystem vitality in the short run. However, similar to the other variables, the effect diminishes over time and stabilizes around zero, suggesting that the initial benefits of political globalization are not sustained indefinitely.

Figure 3 (d) depicts the response of Ecosystem vitality to a shock in Social Globalization (LnSoG). The initial negative impact suggests that increased social globalization might initially harm Ecosystem vitality. However, this negative impact quickly reverses, turning positive around step 5, and peaking shortly after. This positive response then gradually declines, stabilizing around zero towards the horizon's end. This pattern indicates that while social globalization may initially pose challenges to Ecosystem vitality, it eventually contributes positively, although these benefits are not maintained over the long term.

Figure 3 (e) shows the response of Ecosystem vitality to a shock in Economic Complexity (LnECI). Initially, there is a positive response, suggesting that an increase in economic complexity leads to a short-term improvement in Ecosystem vitality. This positive impact peaks around the 5th step but then oscillates and stabilizes around zero, indicating that the initial benefits of increased economic complexity are not sustained in the long term.

Figure 3 (f) depicts the response of Ecosystem vitality to a shock in Primary Energy Consumption per capita (LnENC). The initial response is negative, suggesting that an increase in energy consumption per capita has an adverse short-term effect on Ecosystem vitality. This negative impact intensifies and peaks around the 3rd step before gradually diminishing. The response fluctuates around zero after the 10th step, indicating that the negative effects of increased energy consumption are significant in the short run but tend to neutralize in the long term.

Figure 3 (g) shows the response of Ecosystem vitality to a shock in Renewable Energy Share (LnREN). The initial response is positive, indicating that an increase in the share of renewable energy improves Ecosystem vitality. This positive impact peaks immediately and remains positive for the initial steps, suggesting that renewable energy contributes to better ecosystem health in the short term. However, the effect fluctuates and stabilizes around zero towards the end of the horizon, implying that while renewable energy has a beneficial short-term impact, its long-term effects are less specific.

CONCLUSION

This research investigates the relationship between economic complexity, different aspects of globalization, and ecosystem vitality. The analysis covers the period from 1995 to 2023 within the context of the United Kingdom. This study concentrates on the UK due to its developed economy, high economic complexity, extensive integration within globalization, and environmentally proactive policies. The model used included the primary dependent variables measured by the Economic Complexity Index (ECI). Higher economic complexity can lead to technological innovations that improve efficiency and minimize environmental impacts.

Nevertheless, unsustainable management of this process could entail risks that must be avoided. The analysis findings indicate that such an improvement in economic conditions positively affects ecosystem health; thus, it suggests that sophisticated economic actions may support environmental preservation if followed by proper policies. He et al. (2021) established this when they noted that carbon emissions reduce with increasing economic complexity in leading energy transition economies. It also agrees with Aerni (2021), who put forward decentralized economic complexity to promote sustainable development.

Another variable affecting ecosystem vitality is globalization, which has been captured in this work using its economic, social, and political dichotomy. Our empirical results show that while social and political globalization positively affect ecosystem vitality, economic globalization has a negative effect. In this case, we can argue that there is a negative impact on the economy. At the same time, social and political dimensions positively influence the environment, perhaps because these two categories facilitate international cooperation among countries, leading to policy harmonization in issues concerning ecological protection and spreading awareness about sustainable practices and mitigation strategies towards environmental friendliness. This argument supports Randhir (2016) and Kochtcheeva (2022), who investigated this duality within the framework of environmental outcomes associated with globally integrated systems.

Other variables such as population density, education, energy consumption, and renewable energy share play crucial roles in determining ecosystem vitality. Our empirical analysis reveals that energy consumption and population density have a negative impact on ecosystem vitality, while education and renewable energy share have a positive impact. We may say that rising energy consumption typically leads to higher environmental degradation, while a higher renewable energy share can help mitigate these effects. Similarly, higher population density can strain natural resources, whereas higher education levels are often associated with greater environmental awareness and more sustainable practices. These observations are supported by the studies of Xu et al. (2018) and Raihan (2023), who highlighted the importance of energy policies and education in promoting environmental sustainability.

Our analysis indicates an inverted U-shaped relationship between ecosystem vitality and GDP per capita. Initially, higher GDP per capita is beneficial for ecosystem vitality until it reaches a tipping point, after which the effect becomes negative again. However, this relationship between GDP per capita and ecosystem vitality differs from the traditional environmental Kuznets curve. In the Environmental Kuznets Curve, the vertical axis illustrates the level of environmental degradation. As the graph moves away from the origin, the extent of environmental degradation intensifies.

On the other hand, in our analysis, the vertical axis represents ecosystem vitality. Moving away from the origin indicates an enhancement in environmental conditions. Therefore, although the visual forms may seem alike, their meanings are fundamentally contradictory. Such deviation from the Kuznets Curve may be caused by the index comprising 6 components, which stem from 18 indicators measuring ecosystem vitality used in this research.

The impulse response function (IRF) analysis shows that GDP per capita, economic globalization, and energy consumption significantly affect ecosystem vitality in the short term. However, their long-term effects tend to stabilize. Initially, increases in GDP per capita slightly reduce ecosystem vitality, but later, they enhance it. This effect levels off around zero in the long term. Economic globalization initially boosts ecosystem vitality, but this benefit peaks early and declines. Political globalization also has a substantial initial positive impact, fades, and stabilizes around zero over time. Social globalization starts with a negative effect, but eventually contributes positively. However, these benefits do not persist in the long term. Economic complexity improves ecosystem vitality in the short term. However, these gains are not sustained as the effect fluctuates and stabilizes. Energy consumption has a negative short-term impact on ecosystem vitality, peaking quickly before diminishing. In the long term, its effects stabilize around zero.

In contrast, higher renewable energy usage initially enhances ecosystem vitality. This positive effect fluctuates and then stabilizes over time. These results suggest that economic growth and globalization significantly impact ecosystem vitality in the short term. However, their long-term effects tend to balance out. Continuous management and consideration of both short- and long-term impacts are necessary to ensure lasting improvements.

While these elements may significantly impact ecological health in the short term, their longer-term effects tend to be neutral, suggesting that continuous management of globalization and eco-growth is necessary for achieving lasting improvements in ecosystem resilience. Therefore, we argue that looking at both short-term and long-term effects is essential when determining how much EC affects EP policies. This includes different socio-political factors that affect sustainability outcomes, such as efforts to protect ecosystems made possible by investments in green technologies that can help reach the SDG targets set out at the post-2020 Agenda launch event in New York City on September 25, 2015, where world leaders promised to work together to reach all fifteen goals by 2030.

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BIOGRAPHICAL NOTE

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APPENDIX

Ecosystem Vitality	Biodiversity & Habitat 42.9%	Terrestrial Biome Protection (national) 22.2%
		Terrestrial Biome Protection (global) 22.2%
		Marine Protected Areas 22.2%
		Protected Areas Rep. Index 14.0%
		Species Habitat Index 8.3%
		Species Protection Index 8.3%
		Biodiversity Habitat Index 3.0%
	Ecosystem Services 19.1%	Tree Cover Loss 75.0%
		Grassland Loss 12.5%
		Wetland Loss 12.5%
	Fisheries 11.5%	Fish Stock Status 36.0%
		Marine Trophic Index 36.0%
		Fish Caught by Trawling 28.0%
	Acid Rain 9.6%	SO2 Growth Rate 50.0%
		NOX Growth Rate 50.0%
	Agriculture 9.6%	Sustainable Nitrogen Mgmt. Index50.0%
		Sustainable Pesticide Use50.0%
	Water Resources 7.2%	Wastewater Treatment100.0%

Table A1. Ecosystem Vitality Components
Source: Yale Center for Environmental Law & Policy