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# LINKING ECONOMIC COMPLEXITY AND THE ENVIRONMENT: THE CASE OF THE EUROPEAN UNION

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## **Abstract**

*Environmental damage has been a topic of great importance to the European Union since the European Green Deal was approved in 2020, with the goal of Europe becoming the first continent with net-zero emissions by 2050. Economic complexity is a concept that has gained relevance because it explains the productive structure of countries. There is literature that links economic complexity with environmental degradation. There is a gap of knowledge regarding how the productive structure of the European Union member states affects the environment. The paper aims to quantify the effect of economic complexity on the environment at the European Union through a nonlinear function. To achieve this, a panel data model with fixed effects was used, as well as a nonlinear functional model to quantify the effect of the Economic Complexity Index on CO2 emissions. The results show that the relationship between the Economic Complexity Index and CO2 emissions is U-shaped, and the same holds whether fossil fuels or the energy intensity index are used as measures of environmental degradation.*

**Keywords:** *European Union, economic complexity, environmental damage*

## **1. INTRODUCTION**

The environment has become a very important issue in many of the European Union (EU)'s public policies. The European Green Deal was approved by European supranational institutions in 2020, with the goal of making Europe the first continent with net-zero CO2 emissions. This is a challenge that depends not only on environmental care but also on ensuring that the production process produces goods with a reduced impact on ecosystems. From a theoretical perspective, the Environmental Kuznets Curve (EKC) is the first analytical tool (Grossman and Krueger, 1991) to link economic development with environmental degradation. It is considered that there is an inverted



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U-shaped relationship between the previous two variables. Several papers estimate the EKC for various regions around the world and by regions of countries. Some papers find an inverted U-shaped curve, while others an N-shaped curve.

Most papers that estimate the EKC use Gross Domestic Product (GDP) as an indicator of a country's level of economic development; however, there is evidence that economic growth does not reflect the development of territories. Furthermore, GDP is a synthetic indicator that does not show a country's productive structure. Hidalgo & Hausmann (2009) estimate the Economic Complexity Index (ECI) as an indicator that shows the productive structure of a country's sectors and the relationships among them. According to Hartmann et al. (2017), countries with diversified productive structures have inputs that allow them to produce sophisticated goods and services that can be exported to multiple destinations. Diversified productive structures require the necessary conditions to attract human, physical, and social capital. This is possible due to the institutional design that has been built over a long period of time (Acemoglu, Johnson & Robinson, 2005). Thus, economic complexity is a concept that more closely approximates a country's level of development. Therefore, instead of using GDP the ECI can be used.

There is a large body of literature estimating the effect of economic complexity on CO<sub>2</sub> emissions, greenhouse gas emissions, ecological footprint, environmental damage, sustainable development, and nonrenewable resources. Some articles find that economic complexity reduces emissions, while others find the opposite. For the EU, studies are limited and do not consider nonlinear functional forms on the EKC. This paper aims to estimate the relationship between economic complexity and environmental degradation for EU member states using a nonlinear functional approach. This approach aims to fill the gap of knowledge the relationship between economic complexity and environmental degradation in the short and long term for the EU. The novelty of this article is that it uses environmental degradation variables, such as CO<sub>2</sub> emissions, renewable energy, fossil energy, and energy intensity, in addition to raising the possibility of nonlinear relationships.

The paper is structured as follows. After the introduction, the literature review is presented, followed by the methodology section. The following section presents the results, and finally the discussion and conclusions.

## **2. LITERATURE REVIEW**

The literature relating economic development and environmental deterioration dates back to the EKC. Grossman and Krueger (1991) estimate an inverted U-shaped relationship between GDP and environmental deterioration, such that at initial levels of GDP per capita, environmental deterioration increases until a certain point is reached, and from there increases in GDP per capita lead to environmental improvement. Since this paper, a large number of articles have been written estimating the effect of economic development on the environment. The vast majority of articles estimating the above relationship have focused on using GDP per capita as a proxy for economic development, which has been criticized (Kahneman et al., 2006; Bleys, 2012; Van den Bergh, 2009). On the other hand, a country's economic structure could be a closer proxy for its level of development, due to the goods that are made in a country require human, physical, and social capital, which implies the development of inclusive institutions.

Economic complexity measures how a country's productive structure produces sophisticated goods that require a large number of inputs. Hidalgo and Hausmann (2009)

and Hausmann and Hidalgo (2014) develop the previous concept to measure how countries with more complex productive structures produce goods that require a variety of capital. Based on the concept of economic complexity, the ECI (Hausmann and Hidalgo, 2014) was created for each country, which measures a country's capacity to export sophisticated products to the rest of the world. Economic complexity was initially linked to economic growth (Hidalgo, 2021; Mealy and Teytelboym, 2022), income inequality (Hartmann et al., 2017; Lee and Vu, 2020), and later to the environmental degradation. High levels of human, physical, and social capital require strong and inclusive institutions (Acemoglu, Johnson & Robinson, 2005) which in turn is more common in organized societies focused on the common good. Thus, the effect of economic complexity on the environment can be: (i) positive, due to inclusive institutions would lead society to demand a cleaner environment and greener production processes; (ii) negative, because when countries (with low levels of development) industrialize, they tend to pollute more.

The following tables (I, II, III) show a review of the impact of economic complexity on the environment. The studies are divided into three groups. The first group (table I) of articles estimates the effect of the ECI on CO<sub>2</sub> and greenhouse gas emissions. The second group (table II) quantifies the impact of the productive structure on the ecological footprint, and the third one (table III) calculates the relationship between ECI and environmental degradation, environmental damage, and other variables.

The table I shows papers that quantifies the effect of economy complexity on CO<sub>2</sub> and Greenhouse emissions. Some papers find a positive relationship between economic complexity and emissions (Mealy & Teytelboym, 2022; Khaliq & Mamkhezri, 2023; Khezri, Heshmati & Khodaei, 2022; Neagu, & Teodoru, 2019; Qayyum, Yu & Li, 2021), while others find a negative relationship (Romero & Gramkow, 2021; Mealy & Teytelboym, 2022; Can & Gozgor, 2017). There is an article that estimates a non-linear relationship between the above variables. Such paper, the inverted U and N shape between ECI and CO<sub>2</sub> emissions is calculated (Balsalobre-Lorente, Nur, Topaloglu & Evcimen, 2024).

The two most commonly used variables to measure the environmental impact of an economy's productive structure are CO<sub>2</sub> and greenhouse gas emissions. Some papers estimate long-term relationships (Khaliq & Mamkhezri, 2023; Can & Gozgor, 2017; Khezri, Heshmati & Khodaei, 2022; Neagu & Teodoru, 2019). One article (Mealy & Teytelboym, 2022) calculates the Green Complexity Index, an indicator of green complexity and its impact on CO<sub>2</sub> emissions. The result is a negative relationship with per capita CO<sub>2</sub> emissions, while a positive relationship with total CO<sub>2</sub> emissions. There are a wide variety of methodologies used, from static and dynamic panels to time-series models and the groups of countries range: G7, the WTO, South Asia, and OECD countries.

Table 1 Literature review on economic complexity and greenhouse gas and CO2 emissions

Authors	Country	Period	Methodology	Results
Romero & Gramkow	67 countries	1976-2012	Fixed effects, System GMM	1. EC $\Rightarrow$ $\Downarrow$ Greenhouse gas emission intensity. 2. EC $\Rightarrow$ $\Downarrow$ Greenhouse gas emissions per capita.
Mealy & Teytelboym	WTO countries	1995-2014	OLS	1. GCI (Green Complexity Index) $\Rightarrow$ $\Downarrow$ Log CO2/cap. 2. EC $\Rightarrow$ $\Uparrow$ CO2 emissions.
Khaliq & Mamkhezri	South Asian	1995 to 2019	Nonlinear ARDL	1. EC $\Rightarrow$ $\Uparrow$ CO2 emissions (long term).
Can & Gozgor	France	1964 to 2014.	Dynamic OLS (DOLS)	1. EC $\Rightarrow$ $\Downarrow$ CO2 emissions (long term).
Dogan et al.	28 OECD countries	1990-2014	Panel cointegration and panel regression techniques	1. ECI $\Rightarrow$ $\Downarrow$ CO2 emissions.
Khezri, Heshmati & Khodaei	29 Asia-Pacific countries	2000-2018	Fixed effect, DOLS, FMOLS and ARDL	1. EC $\Rightarrow$ $\Uparrow$ CO2 emissions (long term).
Neagu & Teodoru	EU countries	1995-2016	FMOLS, DOLS	1. EC $\Rightarrow$ $\Uparrow$ Greenhouse emissions (long term)
Murshed et al.	G7 countries	1995 and 2016	GMM	1. EC $\Rightarrow$ $\Downarrow$ CO2 emissions; 2. EC $\Rightarrow$ $\Downarrow$ Carbon footprint
Sun et al.	BRICS countries	1995 to 2018	GMM and Quantile regression	1. EC $\Rightarrow$ $\Downarrow$ Carbon emissions
Qayyum, Yu & Li	34 OECD countries and 24 non-OECD countries	1995 to 2015	GMM	1. EC $\Rightarrow$ $\Uparrow$ domestic carbon emission.
Balsalobre-Lorente et al.	PIIGS countries	1990-2019	DOLS	1. EC $\Rightarrow$ inverted- U and N-shaped CO2 emissions.

Source: Mealy & Teytelboym (2022); Khaliq & Mamkhezri (2023); Khezri, Heshmati & Khodaei (2022); Neagu, & Teodoru (2019); Qayyum, Yu & Li (2021); Romero & Gramkow (2021); Mealy & Teytelboym (2022); Can & Gozgor (2017); Balsalobre-Lorente, Nur, Topaloglu & Evcimen (2024); Khaliq & Mamkhezri (2023); Can & Gozgor (2017); Khezri, Heshmati & Khodaei (2022); Neagu & Teodoru (2019); Mealy & Teytelboym (2022).

Regional Comprehensive Economic Partnership (RCEP); Generalized Method of Moments (GMM); Ordinary Least Squares (OLS); Autoregressive Distributed Lag (ARDL); Dynamic OLS (DOLS); Fully Modified OLS (FMOLS); Kernel-based Regularized Least Squares (KRLS); Quantile autoregressive distributed lag (QARDL); Quantile-on-quantile (QQ); Cross sectional autoregressive distributed lags (CS-ARDL); Augmented mean group (AMG); Pooled Mean Group (PMG).

The table II includes papers that relate economic complexity with ecological footprint. Three articles use the Quantile Regression methodology, which allows estimating differentiated effects of percentiles (Shahzad, Fareed, Shahzad, & Shahzad, 2021; Alvarado, Tillaguango, Dagar, Ahmad, Işık, Méndez, & Toledo, 2021; Akadiri, Adebayo, Asuzu, Onuogu, & Oji-Okoro, 2023). Some papers find a positive relationship between ECI and ecological footprint (Hassan, Wang, Khan, &

Zhu, 2023; Shahzad, Fareed, Shahzad, & Shahzad, 2021; Akadiri, Adebayo, Asuzu, Onuogu, & Oji-Okoro, 2023; Rafei, Esmaili, & Balsalobre-Lorente, 2022), with the exception of one study that finds a negative relationship (Balsalobre-Lorente, Nur, Topaloglu, & Evcimen, 2024) and another paper that estimates an asymmetric impact (Alvarado, Tillaguango, Dagar, Ahmad, Işık, Méndez, & Toledo, 2021). The groups are: The United States, the G-7 economies, Latin American countries, China, and a group of 117 countries.

Table 2 Literature review on economic complexity and ecological footprint

Authors	Country	Period	Methodology	Results
Hassan et al.	United States	1985 to 2016	DARDL and KRLS	1. $EC \Rightarrow \hat{\uparrow}$ Ecological footprint.
Shahzad et al.	United States	1965Q1 to 2017Q4	Quantile unit root test, QARDL and Quantile Granger causality tests	1. $EC \Rightarrow \hat{\uparrow}$ Ecological footprint.
Balsalobre-Lorente et al.	G-7 economies	1991-2018	Cup-FMOLS, Konya panel bootstrap causality and panel VAR analyses	1. $EC \Rightarrow \hat{\downarrow}$ Ecological footprint.
Alvarado et al.	17 Latin America countries	1980-2016	Quantile regression approach	1. $EC \Rightarrow$ Asymmetric impact on Ecological footprint.
Akadiri et al.	China	1985Q1-2019Q4	QQ regression and non-parametric techniques	1. $EC \Rightarrow \hat{\uparrow}$ Ecological footprint.
Rafei et al.	118 countries	1995 to 2017	Panel vector autoregressive model	1. $EC \Rightarrow \hat{\uparrow}$ Ecological footprint.

Source: Shahzad, Fareed, Shahzad, & Shahzad (2021); Alvarado, Tillaguango, Dagar, Ahmad, Işık, Méndez, & Toledo (2021); Akadiri, Adebayo, Asuzu, Onuogu, & Oji-Okoro (2023), Hassan, Wang, Khan, & Zhu (2023); Shahzad, Fareed, Shahzad, & Shahzad (2021); Akadiri, Adebayo, Asuzu, Onuogu, & Oji-Okoro (2023); Rafei, Esmaili, & Balsalobre-Lorente (2022), Balsalobre-Lorente, Nur, Topaloglu, & Evcimen (2024); Alvarado, Tillaguango, Dagar, Ahmad, Işık, Méndez, & Toledo (2021).

Regional Comprehensive Economic Partnership (RCEP); Generalized Method of Moments (GMM); Ordinary Least Squares (OLS); Autoregressive Distributed Lag (ARDL); Dynamic OLS (DOLS); Fully Modified OLS (FMOLS); Kernel-based Regularized Least Squares (KRLS); Quantile autoregressive distributed lag (QARDL); Quantile-on-quantile (QQ); Cross sectional autoregressive distributed lags (CS-ARDL); Augmented mean group (AMG); Pooled Mean Group (PMG).

The table III includes papers that relate economic complexity with environmental degradation. There are a wide variety of dependent variables: environmental degradation, environmental quality, environmental damage, environmental pollution, sustainable development, and non-renewable energy. Some studies show that economic complexity is beneficial to the environment (Caglar, Zafar, Bekun & Mert, 2022; Bashir, Benjiang, Hussain, Shahbaz, Koca & Shahzadi, 2022; Saud, Haseeb, Zaidi, Khan & Li, 2024; Can & Ahmed, 2023), while others find the opposite (Ahmad, Ahmed, Majeed, & Huang, 2021; Caglar, Zafar, Bekun & Mert, 2022; Feng, Usman, Saqib, & Mentel, 2024). A paper uses quantile regression methodology, which shows the quantile effects of ECI on energy-related environmental risks (Ozkan, Haruna, Alola, Ghardallou, & Usman, 2023). This group of studies uses a wide variety of methodologies: ARDL, FMOLS, DOLS, VEC, and quantile regression.

Table 3 Literature review on economic complexity and environmental degradation

Authors	Country	Period	Methodology	Results
Ahmad et al.	Emerging countries	1984 to 2017	Cross-sectional autoregressive distributed lags (CS-ARDL)	1. $EC \Rightarrow \uparrow$ Environmental degradation.
Caglar et al.	BRICS countries	1990 to 2018	Second-generational panel methods	1. $EC \Rightarrow \uparrow$ Environmental quality.
Feng et al.	BRICS countries	1990-2020.	CS-ARDL	1. $EC \Rightarrow \uparrow$ Environmental damage (long term).
Bashir et al.	RCEP	1990 to 2019	CS-ARDL, AMG, PMG, FMOLS, and DOLS	1. $EC \Rightarrow \downarrow$ Environmental degradation.
Pata	United States	1980 to 2016.	Bayer- Hanck cointegrations test, Vector error correction model	1. $EC \Rightarrow$ inverted U-shaped environmental pollution.
Ozkan et al.	United States	1995: Q1-2020: Q4	Bivariate multivariate QQ regression	1. $EC \Rightarrow \downarrow$ (weak) lower quantiles (energy-related environmental risks). 2. $EC \Rightarrow \uparrow$ (strong) middle and higher quantiles (energy-related environmental risks).
Saud et al.	EU 27	1990-2019	PMG-ARDL	1. $EC \Rightarrow \uparrow$ Sustainable development.
Can & Ahmed	EU 14	1990 to 2017	Random or fixed effect models and GMM	1. $EC \Rightarrow \downarrow$ Non-renewable.

Source: Caglar, Zafar, Bekun & Mert (2022); Bashir, Benjiang, Hussain, Shahbaz, Koca & Shahzadi (2022); Saud, Haseeb, Zaidi, Khan & Li (2024); Can & Ahmed (2023), Ahmad, Ahmed, Majeed, & Huang (2021); Caglar, Zafar, Bekun & Mert (2022); Feng, Usman, Saqib, & Mentel (2024); Ozkan, Haruna, Alola, Ghardallou, & Usman (2023).

Regional Comprehensive Economic Partnership (RCEP); Generalized Method of Moments (GMM); Ordinary Least Squares (OLS); Autoregressive Distributed Lag (ARDL); Dynamic OLS (DOLS); Fully Modified OLS (FMOLS); Kernel-based Regularized Least Squares (KRLS); Quantile autoregressive distributed lag (QARDL); Quantile-on-quantile (QQ); Cross sectional autoregressive distributed lags (CS-ARDL); Augmented mean group (AMG); Pooled Mean Group (PMG).

The literature review includes three studies for the EU. Neagu & Teodoru (2019) show that economic complexity leads to and increase on greenhouse gas emissions over the long term. The authors used the FMOLS and DOLS models for the period 1995–2016. In the second paper, Saud, Haseeb, Zaidi, Khan & Li (2024) find that complexity drives sustainable development. Such authors used the EU 27 for the period 1990–2019 with a Pooled Mean Group and Autoregressive Distributed Lag methodology. In the third study, Can & Ahmed (2023) showed that economic complexity has a negative effect on the use of nonrenewable resources. The authors used a fixed and random effects panel data model and a Generalized Methods of Moments model.

### 3. METHODOLOGY

The paper aims to quantify the relationship between ECI and environment damage in the EU. We argue that the relationship between economic complexity and environmental degradation is dynamic; meaning that it initially presents a negative relationship that later becomes positive. It is suggested that there is a U-shaped relationship between the above variables in the case of the EU. To assess this, panel data models were used to examine how changes in economic complexity impact CO<sub>2</sub> emissions, renewable energy use, fossil fuel dependence, and energy intensity.

The dataset includes the EU 27 over the period 1990–2020. The main sources of information include the World Bank, the Observatory of Economic Complexity, and the Worldwide Governance Indicators (WGI), providing data on CO<sub>2</sub> emissions, energy consumption, GDP per capita, trade openness, R&D investment, and institutional quality. The dependent variables are CO<sub>2</sub> emissions per capita, renewable energy use, fossil fuel dependence and energy intensity. Independent variables include the ECI and its quadratic term, ECI<sup>2</sup>, which capture nonlinear relationships between complexity and environmental performance.

To improve the validity of the analysis, several control variables were incorporated to isolate the impact of the ECI on environmental variables. These variables were selected based on the empirical literature. GDP per capita reflects a country's production level and its capacity to adopt more efficient and sustainable technologies. Economies with higher GDP per capita are expected to have better regulatory capacities and greater investment in clean energy. Trade liberalization impacts the availability of clean technologies, and greater levels of liberalization can facilitate the transfer of low-environmental-impact technologies. Control of corruption is a proxy for institutional quality and effectiveness in the implementation of environmental policies. Countries with less corruption tend to implement stricter and more efficient environmental policies. Investment in technological innovation can facilitate the transition to more sustainable production models that are less dependent on polluting energy sources. Population density captures the effects of urbanization and population concentration on energy demand and emissions. Denser cities can reduce emissions through economies of scale in transportation and housing, but may also face challenges in local pollution. Finally, total population controls for country size, ensuring that the effects are not influenced by demographic differences.

This paper follows the methodology of Aluko et al. (2023), who analyzed the nonlinear relationship between economic complexity and emissions in OECD countries. It seeks to replicate and extend their methodology, applying it to EU and considering the inclusion of additional variables such as population density and corruption control. This paper incorporates a panel data approach with fixed effects, which allows for capturing differences between countries and more accurately assessing the impact of economic complexity on emissions and energy efficiency. Additionally, robustness tests such as multicollinearity, heteroskedasticity, and autocorrelation are included, ensuring that the results are statistically robust.

Table 4 Description of variables

Variable	ID	Source	Description
CO <sub>2</sub> emissions	CO2	World Bank	Carbon dioxide (CO <sub>2</sub> ) emissions per capita, excluding land use, land-use change, and forestry (LULUCF), measured in metric tons of CO <sub>2</sub> equivalent per capita (t CO <sub>2</sub> e/capita).
Renewable Energy	RE	World Bank	Energy consumption from renewable sources as a percentage of total final energy consumption.
Fossil Energy	FE	World Bank	Energy consumption from fossil sources (coal, oil and natural gas) as a percentage of total energy consumption.
Energy Intensity Level	EIL	World Bank	The ratio of total primary energy supply to gross domestic product (GDP) adjusted for purchasing power parity (PPP), measured in megajoules per dollar of GDP PPP.
Economic Complexity Index	ECI	The Observatory of Economic Complexity	Measure of the complexity of a country's productive structure, based on the diversity and ubiquity of the exports.
Control of Corruption	CC	Worldwide Governance Indicators (World Bank)	An indicator that measures the perception of the degree to which public power is used for private gain, including corruption in its various forms, as well as the effectiveness of anti-corruption policies and governance institutions.
Rule of Law	RL	Worldwide Governance Indicators (World Bank)	Rule of Law captures perceptions of the extent to which agents have confidence in and abide by rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence.
Trade openness	TO	World Bank	Foreign trade as a percentage of GDP, calculated as the sum of exports and imports in relation to GDP.
Total Population	TP	World Bank	Inhabitants in a country in a given year.
Population Density	PD	World Bank	Population density is the number of people per square kilometer of land area.
GDP per capita	GDPpc	World Bank	Gross Domestic Product per capita at constant 2015 prices (USD), reflecting economic output adjusted for population.
Research and Development	R&D	World Bank	Research and development (R&D) expenditure as a percentage of GDP, reflecting investment in innovation and technological development.

Source: World Bank, Worldwide Governance Indicators (World Bank) and the Observatory of Economic Complexity.

To assess the relationship between economic complexity and environmental variables, fixed effects models were estimated using the following equation:

$$Y_{it} = \beta_0 + \beta_1 ECI_{it} + \beta_2 ECI_{it}^2 + \beta_3 X_{it} + \gamma_i + \delta_t + \varepsilon_{it}$$

Where:

- $Y_{it}$  represents CO<sub>2</sub> emissions, renewable energy, fossil energy and energy intensity.
- $CE_{it}$  is the economic complexity index.

- $|CE_{it}^2$  captures non-linear effects of economic complexity.
- $\beta_3 X_{it}$  represents the control variables.
- $\gamma_i$  are country fixed effects.
- $\delta_t$  are time fixed effects.
- $\varepsilon_{it}$  is the error term.

The first model estimated was a pooled Ordinary Least Squares (OLS) model. However, the Breusch-Pagan test yielded a  $\text{Chi}^2(1) = 7.32$ ,  $p = 0.0068$  ( $< 0.05$ ), indicating the presence of uncaptured heterogeneity, suggesting that this model is not adequate. Because of this, models with individual effects were estimated: fixed effects (FE) and random effects (RE). To determine the best specification, the Hausman test was applied, which rejected the null hypothesis ( $\text{Chi}^2(9) = 56.97$ ,  $p = 0.0000$  ( $< 0.05$ )), indicating that the individual effects are correlated with the explanatory variables. This justified the choice of the FE model.

Additionally, tests were applied to verify the validity of the models. The Breusch-Pagan test indicated the presence of heteroskedasticity, which led to estimation with robust standard errors. The Wooldridge test for autocorrelation in panel data also rejected the hypothesis of no autocorrelation, justifying the use of standard robust errors to autocorrelation and heteroskedasticity. To ensure that the explanatory variables are not highly correlated with each other, a Variance Inflation Factor (VIF) test was performed. Overall, the tests performed confirm that the estimates obtained are statistically reliable and robust.

## 4. RESULTS

The results show that a higher level of economic complexity is associated with a significant reduction in CO<sub>2</sub> emissions. However, this effect is not linear; the squared index suggests that, at high levels of economic complexity, the impact on emissions increases. Regarding the use of renewable energy, it is found that economic complexity drives the use of these sources. The coefficient of the quadratic term is negative, indicating that the positive relationship diminishes. On the other hand, fossil fuel dependence and energy intensity exhibit inverse relationships with ECI, confirming that more diversified economies tend to reduce their fossil fuel consumption and improve energy efficiency. In both cases, the positive quadratic term suggests that, at advanced stages of economic complexity, these effects may be reversed. In addition to the impact of economic complexity, the control variables included in the model provide insight into the factors affecting environmental sustainability. Population density shows a negative relationship with CO<sub>2</sub> emissions, fossil fuel dependence, and energy intensity, suggesting that denser cities can operate with greater energy efficiency and lower environmental impact.

Regarding institutional variables, in the estimated models, control of corruption is paradoxically associated with increased emissions and fossil fuel use. The rule of law has a significant impact on energy intensity, suggesting that economies with stronger institutions tend to improve energy efficiency. This result is consistent with the idea that strong regulatory frameworks favor the implementation of effective environmental policies and the adoption of more efficient technologies. The GDP per capita is associated with a reduction in energy intensity and dependence on fossil fuels, but also with an increase in CO<sub>2</sub> emissions. This is consistent with the EKC, which suggests that, in the early stages of economic development, growth generates greater emissions, but as economies move toward more sophisticated, environmental regulations and technological innovations reduce this impact. Trade liberalization also has a positive effect on the adoption of renewable energy and a reduction in fossil fuel consumption. Investment in research and development is also a key factor, as it reduces CO<sub>2</sub> emissions, promotes the use of

renewable energy, and improves energy efficiency, reinforcing the importance of designing public policies that incentivize innovation in strategic sectors.

Table 5 Estimated coefficients and statistical significance in static regression models

	Model 1	Model 2	Model 3	Model 4
	CO2	RE	FE	EIL
CEI	-0.6673***	13.7150***	-7.0616***	-1.9918***
CEI2	0.3597***	-8.8673***	3.3146***	0.7027***
PD	-0.0040***		-0.0456***	-0.0073*
CC	0.1768***	-6.8051***	4.5333***	0.3929***
RL				-0.2274***
GDPpc	0.2563***	5.9912***	-9.2933***	-3.0416***
TO	-0.0037***	0.0699***	-0.0282***	-0.0070***
TP	-3.77e-08***	7.82e-07***	-9.80e-07***	-1.08e-07***
R&D	-0.1085***	0.6595***	-2.9179***	-0.2115***
CONST	1.3097**	-70.69***	199.6112***	39.9395***
R <sup>2</sup>	0.5379	0.5830	0.7836	0.8324

Note: \* significant at 10% (p-value < 0.10), \*\* significant at 5% (p-value < 0.05) and \*\*\* significant at 1% (p-value < 0.01).

The results show that economic complexity has a negative impact on environmental degradation, suggesting that a diverse productive structure improves the environment. However, in the long term, this relationship becomes positive, demonstrating that within the EU, some countries have varying levels of economic complexity and environmental degradation.

## 5. DISCUSSION AND CONCLUSIONS

The paper aims to estimate the relationship between economic complexity and environmental degradation for the EU. In all models, it was found that the relationship between the above variables is initially negative; that is, as economic complexity increases, it has a negative impact on environmental degradation (environmental improvement) until reaching a certain level where the relationship becomes positive. Regarding the studies on the EU, the results obtained are similar to those of Neagu and Teodoru (2019), as these authors find a positive long-term relationship between economic complexity and greenhouse gas emissions. On the other hand, Saud et al. (2024) find a positive relationship between economic complexity and sustainable development (less environmental degradation), which is similar to the short-term results obtained. If we include studies beyond of the EU, the short-term results obtained are similar to those of Romero and Gramkow, C. (2021), Mealy and Teytelboym (2022), Can and Gozgor (2017), Doğan et al. (2021), Murshed et al. (2022), Bashir et al. (2022), and Ozkan et al. (2023). In the long term, the findings obtained coincide with Khaliq and Mamkhezri (2023).

The results obtained are similar to those of Neagu and Teodoru (2019), as these authors find a positive relationship between economic complexity and greenhouse gas emissions in the long term. However, our results also include CO2 emissions, the use of renewable energy, fossil fuels, and energy intensity. Based on the results, future research could be focusing on the relationship between economic complexity and environmental degradation at the subnational

level in the EU, either by country or by NUTS. Furthermore, the quantile regression methodology could be used to analyze the impact of EU. One limitation of this paper is that static panel data models (fixed and random effects) were used, rather than dynamic ones. The model was not considered the endogeneity among variables, which is considerably feasible given that the ECI can be persistent over time and some independent variables may be interrelated. An interesting extension would be the use of GMM models to estimate dynamic panels and address potential endogeneity issues. Based on the results obtained, it can be concluded that if national and supranational governments in the EU promote economic complexity, they could achieve environmental improvements. A productive structure with sophisticated products could improve environmental indicators in countries with a low levels of development. If the European Green Deal continues, economic complexity can be a means to achieve the goals established in that pact. The findings show that economic complexity can positively affect the environment. Thus, improvements in the productive structure of EU countries toward more sophisticated products can contribute to achieving the objectives of the European Pact. An increase in economic complexity requires inclusive institutions that allow for a continuous increase in social, human, and physical capital, which are unevenly distributed across EU member states. In this sense, increases in economic complexity will have greater effects on the environment in countries with a GDP below the European average.

The supranational authorities of the EU should consider that, in order to achieve the target of Europe becoming the first continent with net-zero CO<sub>2</sub> emissions by 2025, the national authorities should focus on the production of sophisticated products, that is, goods or services that combine valuable inputs in their production processes that are only available in partnership with functioning institutions. Finally, the text found that institutions have a positive impact on environmental improvement, which indicates that sustainable institutional arrangements can have permanent effects on the environment.

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