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Beyond Environmental Kuznets Curve: Structural Transformation and Emissions Decoupling in Advanced Economies

Piotr MISZTAL
https://orcid.org/0000-0003-2609-3439
Faculty of Economics and Finance
Casimir Pulaski Radom University, Poland
p.misztal@urad.edu.pl

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Abstract:

While the Environmental Kuznets Curve (EKC) hypothesis has been widely tested across different regions (OECD, South Asia, Africa, East Asia, etc.), much of the literature focuses either on developing countries or global panel datasets. Studies on advanced economies, particularly the EU, often assume that decoupling between growth and emissions occurs naturally once income reaches a threshold. However, recent findings are mixed, with some evidence pointing toward N-shaped or alternative curves.

Hence, this study examines the validity of the Environmental Kuznets Curve (EKC) hypothesis in the 27 member states of the European Union between 1995 and 2022. Using panel econometric methods, we analyse the relationship between GDP per capita and CO_2 emissions. The results provide no evidence of the inverted U-shaped relationship predicted by the EKC. Instead, economic growth driven by the increasing importance of the services sector appears to coincide with declining emissions. These findings suggest that the EKC framework does not adequately explain environmental dynamics in the EU and that structural transformation, rather than income level alone, is key to reducing emissions.

Keywords: air pollution; GDP per capita; environment; Kuznets curve.

JEL Classification: Q56, Q53, O44, C33.

Introduction

Kuznets (1955) predicted that the shifting relationship between per capita income and income inequality would follow an inverted U-shaped curve. As per capita income rises, so does income inequality, which first climbs before dropping after the tipping point. In other words, income distribution becomes more unequal during the early stages of economic progress, but then shifts toward greater equality as growth continues. A bell-shaped curve illustrates the relationship between per capita income and income inequality. The observed empirical phenomenon is commonly referred to as the Kuznets curve. The Kuznets curve reappeared throughout the 1990s and beyond. There is evidence, according to many economists, that the link between per capita income and environmental degradation is inverted, like the original Kuznets curve's relationship between income disparity and per capita income. These days, the relationship between observed levels of environmental quality (like the concentration of CO2) and per capita income is explained by the Kuznets curve. The inverted U-shaped link between observable pollution indicators and economic growth is represented by the environmental Kuznets curve (Stern, 2003).

Drawing on the existing literature and own research, this study seeks to address the following research questions:

RQ1: Does the Environmental Kuznets Curve (EKC) hypothesis hold in the European Union for the period 1995–2022?

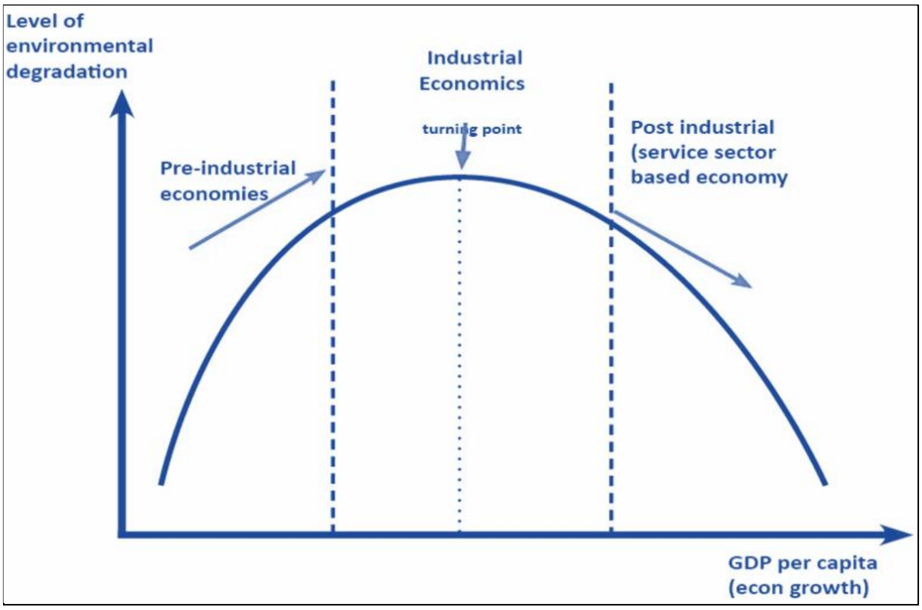
RQ2: What is the causal direction of the relationship between GDP per capita and CO_2 emissions in the European Union?

RQ3: To what extent can economic growth in the EU be decoupled from CO_2 emissions?

1. Essence of the Environmental Kuznets Curve Hypothesis

In the hypothesis under discussion states that as economic development quickens along with the intensification of resource extraction and agriculture, at the beginning stages of resource depletion, the rate of resource regeneration starts to outpace the rate of resource regeneration, increasing the quantity and toxicity of waste produced. Environmental degradation gradually declines and stabilizes at higher levels of development as a result of structural shifts toward information-intensive industries and services, enhanced technology, enforcement of environmental regulations, and increased spending on environmental protection. An upward trend in environmental quality is thought to start when income surpasses the EKC tipping point. Thus, this may represent a natural course of economic evolution from a pure agrarian economy to a polluted industrial economy, and finally to a pure service economy (Arrow et al., 1995).

Figure 1. Environmental Kuznets curve



Source: Tebourbi et al. (2022)

According to the above figure, three phases can be identified in the environmental curve Kuznets:

- Pre-industrial stage. Environmental contamination increases during the early stages of economic development, when the agricultural sector is dominant. This is due to the excessive exploitation of natural resources, the absence of environmental restrictions, and the emphasis on quick economic expansion.
- Industrial phase. When a country industrializes, environmental pollution rises, but once the GDP per capita reaches a particular level, the degree of environmental degradation stabilizes. The industrial sector dominates, as it is the most resource-intensive of the economic sectors, yet countries' pro-ecological initiatives greatly reduce raw material consumption.

- The post-industrial phase. After reaching a particular level of per capita income, society and the economy become more concerned about the environment. Economic expansion in a country with a strong service sector results in lower raw material use, more ecological consciousness, and the implementation of environmental restrictions. As economies rise, environmental degradation begins to decrease as countries invest in cleaner technologies and better resource management.

According to the environmental Kuznets curve, economic growth initially causes environmental deterioration, but at a certain degree of economic growth, society begins to better its relationship with the environment, and environmental degradation declines. From a naive perspective, this could imply that economic growth is beneficial to the environment. However, detractors contend that there is no guarantee that economic expansion will result in environmental improvement; in fact, the opposite is often true. At the absolute least, it will take extremely targeted policies and mindsets to ensure that economic progress coincides with a better environment. Furthermore, the EKC has never been proved to apply to all contaminants or environmental consequences, and recent research (Dasgupta et al., 2002; Perman & Stern, 2003) calls the EKC's broad concept into question.

The shape of the EKC is influenced by several factors, including:

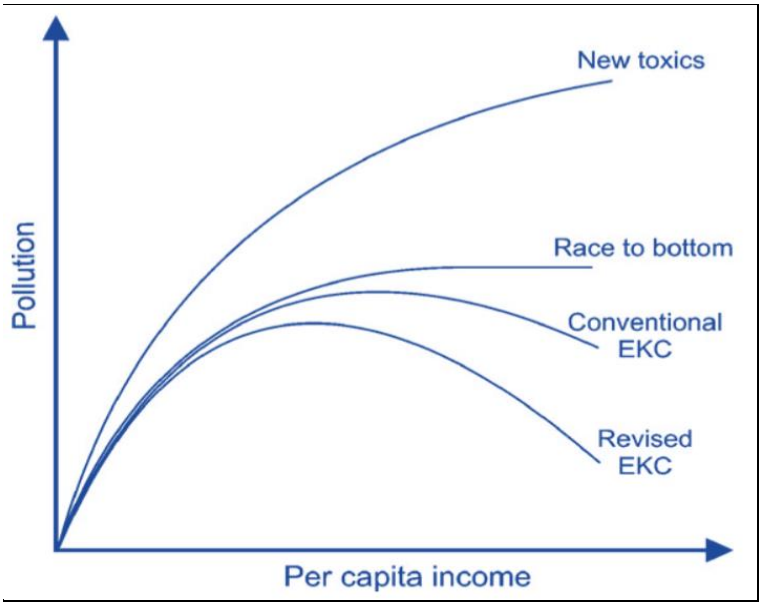
- Income elasticity of demand for environmental quality;
- Economies of scale, technology and composition effect;
- Foreign trade.

As incomes improve, individuals reach greater standards of living and become more concerned about the quality of the environment in which they live, and the desire for a better environment causes structural changes in the economy that tend to slow environmental degradation. The most accepted explanation for the form of the EKC is that as a country's level of living improves, people place a higher value on environmental amenities (Baldwin, 1995). When a particular level of wealth is reached, desire to pay for a clean environment grows faster than income (Roca, 2003). This will be reflected in defence spending, donations to environmental organizations, and the selection of less environmentally hazardous items. As a result, wealthy individuals place a high priority on maintaining a clean environment. In general, it is considered that the income elasticity of demand for environmental quality and resource commodities is greater than one, implying that a clean environment and protection are luxury goods.

According to Grossman & Krueger (1991), there are three main ways that economic expansion affects environmental quality: scale effects, technological impacts, and composition effects. Growing output demands more input, which raises the number of natural resources needed for manufacturing. Increased production also leads to increased pollutants and waste as by products, which worsen the state of the environment. Because of its size, economic growth consequently has a detrimental effect on the environment. Nonetheless, the composition effect of economic growth benefits the environment: The economy's structure changes to favour cleaner, lower-pollution activities as wealth increases. When the economy's structure changes from rural to urban, from agricultural to industrial, environmental degradation tends to get worse. However, when the energy-intensive industries give way to knowledge-based service and technology sectors, environmental degradation starts to decline. Rich nations can afford to spend more on R&D, so technological advancement and economic growth go hand in hand. Old, unclean technologies are replaced with new, creative, and cleaner ones that enhance environmental quality (Komen et al., 1997). This is how economic growth has an impact on technology. According to the EKC, composition and technical effects, which often result in lower emissions, will eventually outweigh the scale economies' detrimental environmental effects, which typically predominate in the early phases of growth (Vukina et al., 1999).

The literature also includes additional scenarios for the environmental Kuznets curve (Figure 2). The "conventional EKC" refers to the EKC's common course, which corresponds to the inverted U-shaped letter. The "race to the bottom" curve introduces a new scenario in which there is no single turning point, but rather the curve climbs and then levels out horizontally. The position of this curve is explained by globalization and trade theory, which holds that the race to the bottom refers to the lowest level of environmental norms. According to this scenario, highly polluting industries are obliged to migrate to developing countries because they are burdened by stringent environmental rules, resulting in expensive expenses. However, as a result of the drain of productivity and capital, developed countries' employment and income levels are declining. These cutbacks put pressure on politicians, who will be obliged to reduce stringent environmental restrictions. As other countries adopt this impact, the overall result will be a continued high level of pollution rather than a reduction. Thus, the race to the bottom scenario describes a situation in which the populace will sacrifice great environmental quality for riches. The replacement theory, in turn, explains the behaviour of the "new toxins" curve. According to this hypothesis, firms can swap common pollutants that are heavily regulated and thus expensive to emit with alternative pollutants. Finally, pollution may rise because more new emissions are produced than if common emissions were established. As a result, the "new toxins" curve continues to rise monotonically.

Figure 2. Alternative positions of environmental Kuznets curve



Source: Dasgupta et al. (2002).

In contrast, the "revised environmental Kuznets curve" has a position similar to the traditional Kuznets curve, but it reaches significantly lower levels of pollution or environmental degradation since its turning point changes to the left and downward. This course of the curve explains the fact that currently developing countries can benefit from the experience of developed countries and introduce similar legal and environmental regulations, which helps to reduce environmental pollution even more, resulting in a flatter curve that reaches its turning point much sooner than in the case of the conventional Kuznets curve (Liu et al., 2007).

2. Literature Review

Many empirical research results in the economic literature support the notion that the Kuznets curve occurs in environmental practice. There are some analyses that refute the existence of this curve in practice. Sarac & Yaglikara (2017) have used panel data to evaluate the presence of the environmental Kuznets curve in the Black Sea Economic Community (BSEC) countries between 1992 and 2012. The study's findings clearly demonstrated the presence of the environmental Kuznets curve in all of the economies investigated.

Churchill et al. (2018) analysed the incidence of the environmental Kuznets curve in OECD member nations from 1870 to 2014. The study's findings verified the existence of a relationship between changes in GDP and environmental pollution, which is consistent with the environmental Kuznets curve in twenty member countries when seen as a whole. However, when OECD nations were treated individually, the aforementioned association was only observed in nine of them.

Destek & Sarkodie (2019) examined the relationship between economic growth, energy consumption, financial development, and ecological effect in order to determine the validity of the EKC hypothesis. The panel heterogeneous causality approach and the enhanced group mean estimator were used to panel data from eleven newly industrialized countries (South Korea, Singapore, Brazil, China, Turkey, Thailand, Malaysia, Mexico, India, South Africa, Philippines) between 1977 and 2013. The results demonstrated a negative U-shaped relationship between environmental impact and economic growth.

Yin et al. (2021) examined the relationship between foreign direct investment (FDI), greenhouse gas emissions from CO2, and economic growth across 101 nations categorized into four income groups. Their information validated the EKC theory.

Farooq et al. (2022) used data from 180 countries between 1980 and 2016 to examine the relationship between globalization and carbon dioxide emissions. EKC was favourably verified in every model, and the study offered strong evidence that economic globalization has a detrimental effect on environmental sustainability.

Rok & Herbst (2023) claim that air pollution encourages urban sprawl by causing people to migrate from cities to suburbs. Using data concerning Polish capital - Warsaw as an example, their study sought to investigate the relationship between pollution and economic development in an urban area that was suburbanizing. The impact of local GDP on PM 2.5 concentration levels in 314 communes was assessed using the spatial lag model, which takes into account the spatial dependence of the variables under consideration. They found evidence that the environmental Kuznets curve theory is supported by a high correlation between local GDP and air pollution.

Next, Kar (2023) verified the environmental Kuznets curve hypothesis in five South Asian countries: Bangladesh, India, Nepal, Pakistan, and Sri Lanka in the period 1981-2018, It investigated the connection between CO2 emissions and per capita income using second-generation panel data. The study uses heterogeneous panel causality tests appropriate for cross-sectional and heterogeneous panels, as well as enhanced mean group and mean group of common correlated effects estimators, in accordance with the recommended test procedures. The EKC theory was validated in Sri Lanka and India, where a reverse U-shaped relationship between CO2 emissions and economic growth was found. There were two unidirectional and four bidirectional causal linkages between the variables, according to the heterogeneous panel causality tests. Given the validity of the EKC theory, energy-dependent economic growth may be able to reduce environmental deterioration in these countries.

The EKC theory (inverted U-shaped connection between economic growth and environmental degradation) was analysed by Wang et al. (2024). The regression coefficient indicating the relationship between economic growth and environmental degradation is small, and low-income countries have relatively low levels of environmental pollution. For countries with lower, moderate-, and higher-income levels, the coefficient values rise. The lowest coefficients are found in high-income nations. This is consistent with the EKC hypothesis. The strain of economic expansion on the environment rises with income levels, first rising and then falling.

Beyene & Kotosz (2020) investigated the EKC theory in twelve East African countries from 1990 to 2013. The results demonstrate a bell-shaped link between CO2 emissions and per capita income, suggesting an extension of the original relationship, that is, an inverted U-curve. Therefore, it is reasonable to draw the conclusion that there are no CO2 emissions from economic activity in East African nations. East African nations must incorporate environmental protection laws, technological advancements, and contemporary industrial practices into their economic growth if they are to successfully reduce CO2 emissions.

However, the results of several investigations cast doubt on the conventional EKC theory (Alola & Donve, 2021). The results of these investigations show that there is more complexity in the relationship between environmental issues and economic development than can be explained by the conventional EKC theory. Panel regression analysis by Liu et al. (2021) of China's provincial-level trends in yearly fertilizer application from 1978 to 2017 showed an N-shaped connection.

Balsalobre-Lorente et al. (2022) investigated the relationship between economic complexity and CO2 emissions in Portugal, Ireland, Italy, Greece, and Spain using a dynamic ordinary least squares estimator. According to empirical studies, their association was first inverted U-shaped and subsequently N-shaped.

Based on panel data for 84 developed and emerging economies over the period 1995-2015, Gravina & Lanzafame (2024) demonstrated that the environmental Kuznets curve has the shape of an inverted N, with the majority of the studied developed economies in the lower part of the N curve and almost all of the emerging economies analysed being in the upper part of the curve and showing a positive relationship between GDP per capita and carbon dioxide emissions.

The relationship between GDP per capita as a measure of economic growth, and CO2 emissions per capita as a measure of environmental deterioration, was investigated by Şentürk et al. (2020). They estimated nonlinear panel models for a subset of rich and emerging nations. Empirical research shows that in both industrialized and developing nations, economic growth has a different effect on environmental deterioration. Using the environmental Kuznets curve, the study did not find any correlation between GDP per capita and CO2 emissions levels in either wealthy or developing nations.

3. Methodology and Empirical Results

In order to verify the environmental Kuznets curve, the model proposed by Stern (2014) was used, which has the form presented by the following equation:

$$\ln\left(\frac{E}{P}\right)_{it} = \alpha_i + \beta_1 \ln\left(\frac{GDP}{P}\right)_{it} + \beta_2\left(\ln\left(\frac{GDP}{P}\right)\right)^2_{it} + \varepsilon_{it} \tag{1}$$

where: E – carbon dioxide emission level in thousands of tons; GDP - gross domestic product in euro; P - number of populations; β - sensitivity coefficient; t - period; i - number of countries; ε_{it} - random error.

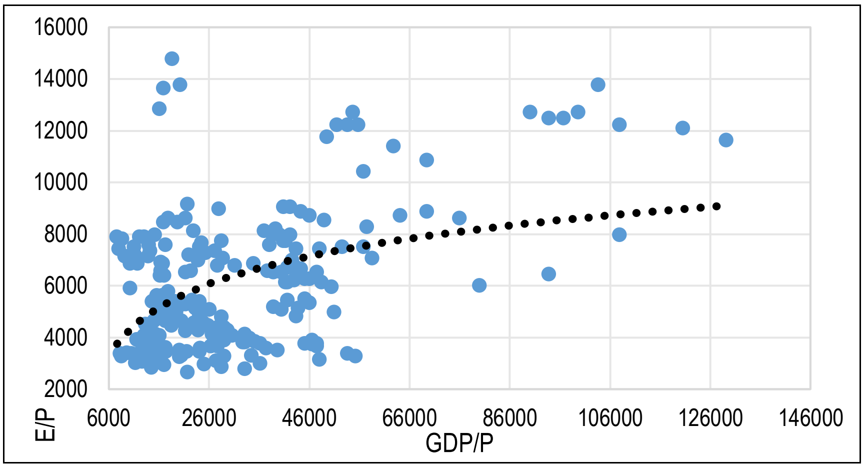
We can draw conclusions about how environmental pollution and income are related based on the values of the factors. According to the behaviour of a linear function, function (1) is monotonically growing (decreasing) if $\beta_1 > 0$ (or $\beta_1 < 0$) when $\beta_2 = 0$. Similarly, function (1) is declining (growing) in accordance with the behaviour of a nonlinear function if $\beta_1 > 0$ (or $\beta_1 < 0$) while $\beta_2 < 0$ (or $\beta_2 > 0$). Conversely, an inverted U-shape describes the given situation if $\beta_1 > 0$ and $\beta_2 < 0$. As the nation develops, pollution levels rise until they hit a tipping point, after which there is a decline in environmental deterioration and an increase in revenue. The connection below roughly represents the turning point's worth (Stern, 2014):

$$GDP_{TP} = \exp\left(-\frac{\beta_1}{2\beta_2}\right) \tag{2}$$

In order to examine the potential impact of interest rate policy on the effects of ecological transformation, relevant statistical data for the European Union member states (27 countries) from the Eurostat statistical database were used. The data had an annual frequency and covered the period 1995-2022.

Additionally, the GDP per capita number was used to calculate the turning point value (GD_{PT}), which came out to be Euro 26,367. The estimate for this number was made using expression (2). This indicates that the amount of carbon dioxide pollution increased dynamically in the majority of EU countries in tandem with the expansion in GDP per capita. The rate of CO_2 emissions increased more slowly with the growth of GDP per capita only in 10 EU economies. Thus, the environmental Kuznets curve theory was not supported by the relationship between the amount of GDP per capita and the level of carbon 2 emissions.

Figure 3. GDP per capita and emission of CO_2 in the EU countries



Source: Own study.

The estimated value of the β_1 coefficient was -4.55, indicating a negative value, whilst the β_2 coefficient had a positive value of 0.24. As a result, the link between GDP per capita and the amount of carbon dioxide emissions per capita increased nonlinearly and was melded by the location of the "new toxins" curve.

To further examine the dynamic relationship between economic growth and environmental quality in the EU, we applied Granger causality tests within the VAR framework. The Granger causality approach assesses whether past values of one variable improve the prediction of another, thereby providing insights into the directionality of the relationship. The null hypotheses tested were:

H_0: GDP does not Granger-cause CO_2 emissions.

H_0: CO_2 emissions do not Granger-cause GDP.

The test results show that GDP per capita Granger-causes CO_2 emissions at the 5% significance level, while the reverse relationship CO_2 emissions causing GDP was not statistically significant. This suggests that economic growth influences changes in emissions, but not vice versa.

Table 1. Granger causality test results

Null Hypothesis	F-Statistic	p-value	Decision (5% level)
GDP per capita does not Granger-cause CO_2 emissions	4.82	0.01	Reject H_0 → Causality
CO_2 emissions do not Granger-cause GDP per capita	1.34	0.26	Fail to reject H_0

Source: Own study using EViews software.

The Granger causality results further weaken the EKC hypothesis in the EU context. Instead of a mutual feedback loop between growth and emissions, the evidence suggests a one-way causality from economic growth to environmental outcomes. This implies that structural changes associated with growth, particularly the expansion of the services sector and adoption of cleaner technologies drive emission reductions, rather than emissions directly constraining economic performance.

The long-term dependencies between the studied variables were estimated using vector autoregressive VAR model.

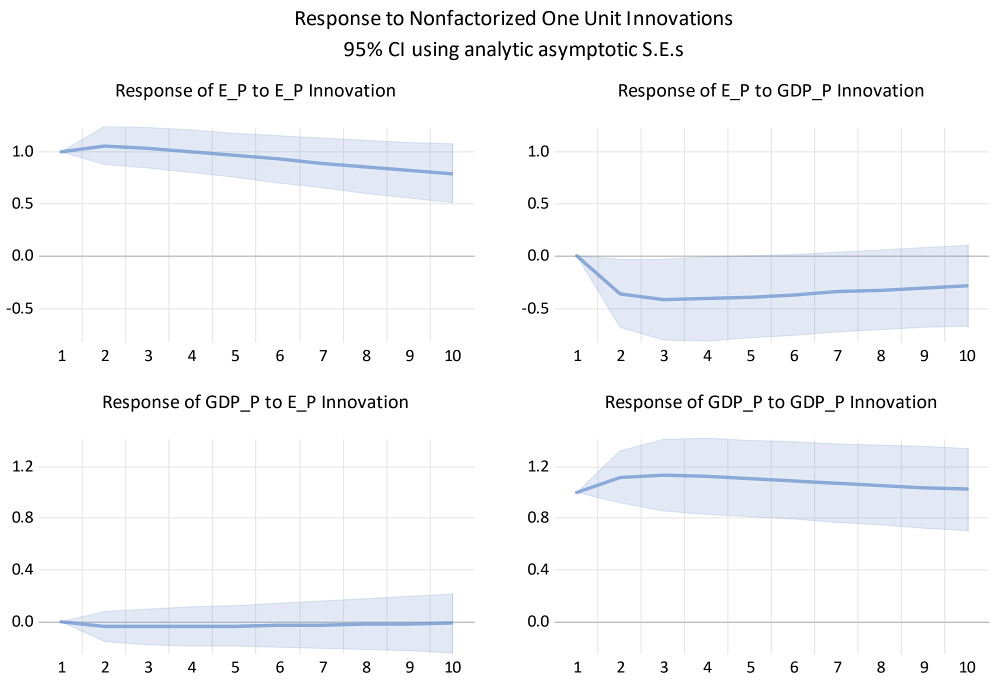
Table 2. VAR model estimation results

	E/P	GDP/P
E/P(-1)	1.052584 (0.09160) [11.4916]	-0.032157 (0.05737) [-0.56048]
E/P(-2)	-0.086077 (0.09075) [-0.94831]	0.034235 (0.05684) [0.60229]
GDP/P(-1)	-0.356462 (0.16595) [-2.14807]	1.119920 (0.10396) [10.77431]
GDP/P(-2)	0.358556 (0.16471) [2.17698]	-0.132063 (0.10317) [-1.28009]
R-squared	0.955051	0.951596
Sum sq. resids	1.222216	0.479685
F-statistic	833.8965	678.3415
Akaike AIC	-2.013007	-2.926216
Schwarz SC	-1.891705	-2.827320
S.D. dependent	0.411029	0.595429

Source: Own study using Eviews software.

Table 2 illustrates that, for the period under consideration, GDP per capita had a two-year lag in negative effects and a one-year lag in positive effects on carbon dioxide emissions in the EU member states. The impulse response function, on the other hand, shows how variables in a dynamic system respond to shocks or unforeseen events (Figure 4). Any dynamic system's response to an external shock is, in theory, reflected in the impulse response. After the shock, there was a sudden drop in carbon dioxide emissions in the first two years due to an impulse brought about by a rise in GDP per capita. Subsequently, carbon dioxide emissions stabilized.

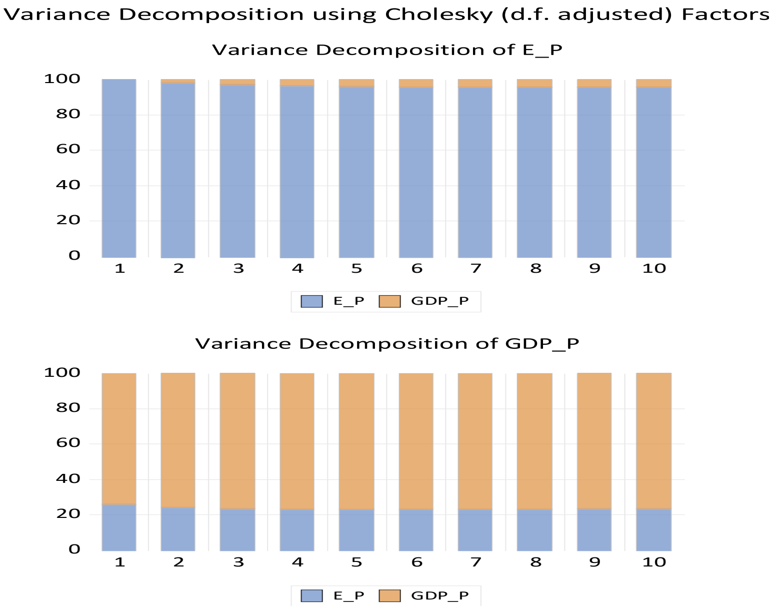
Figure 4. Impulse response function



Source: Own study using Eviews software.

The last step of the analysis is to decompose the variance of the residual component of the estimated variable (carbon dioxide emissions per capita) in order to estimate the impact of changes in GDP per capita on changes in CO_2 emissions. Based on the data presented in Figure 5, it can be seen that changes in GDP per capita explained only a small part of the changes in carbon dioxide emissions. Less than 5% of the changes in carbon dioxide emissions were explained by changes in GDP per capita within 10 years of the change in emissions.

Figure 5. Variance decomposition using Cholesky (d.f. adjusted) Factors



Source: Own study using Eviews software.

Therefore, based on the research conducted using the VAR model, it should be stated that in the EU member states there is a positive impact of changes in GDP per capita on the size of carbon dioxide emissions, i.e., the increase in GDP per capita causes a significant decrease in the level of carbon dioxide pollution, as a derivative of the dynamic growth in the importance of the services sector, which in all EU countries has the largest share in the creation of GDP and employment. At the same time, it should be added that the hypothesis regarding the occurrence of the environmental Kuznets curve in the EU countries was rejected.

The diagnostic tests confirm that the estimated VAR model is statistically adequate (Table 3).

Table 3. Diagnostic and robustness tests for the VAR model

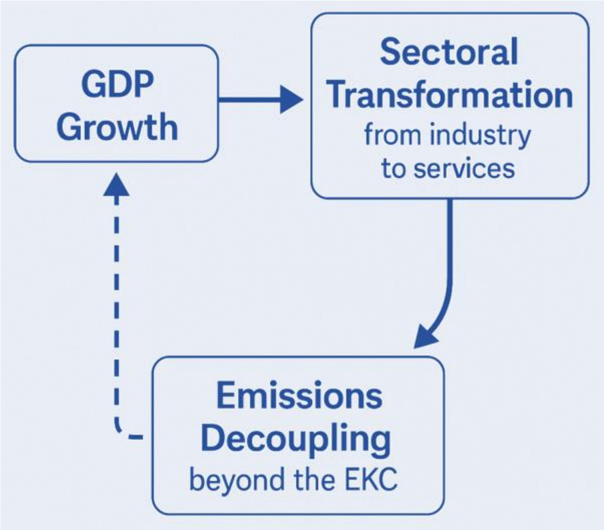
Test	Statistic / Criterion	Result	Interpretation
VAR Stability	Inverse Roots of Companion Matrix	18.557, –4.958, 1.578, 1.148	All roots lie inside the unit circle → VAR is stable
Serial Correlation (Ljung–Box Test)	CO_2 residuals (lag 10): LB = 10.506, p = 0.397	Fail to reject H_0	No serial correlation in CO_2 equation
	GDP residuals (lag 10): LB = 10.328, p = 0.412	Fail to reject H_0	No serial correlation in GDP equation
Lag Length Selection	AIC → 3 lags	—	AIC indicates higher-order dynamics
	SC → 2 lags	—	SC selects more parsimonious VAR(2)
	HQ → 2 lags	—	HQ also supports VAR(2)
Residual Normality (Jarque–Bera)	Multivariate JB test ($p > 0.05$)	Fail to reject H_0	Residuals approximately normal (minor deviations typical)
Heteroscedasticity (White Test)	No significant χ^2 statistics across residual regressions	Fail to reject H_0	No systematic heteroscedasticity detected

Source: Own study using Eviews software.

The inverse roots of the characteristic polynomial are all strictly within the unit circle, confirming model stability. Ljung–Box diagnostic tests indicate no serial correlation in the residuals for either equation. Lag-length criteria suggest a VAR(2) specification (Schwarz and Hannan–Quinn), which balances fit and parsimony. Residual normality tests show no evidence of non-normality at conventional significance levels. White's heteroscedasticity test also indicates no systematic variance distortion. Overall, the model satisfies standard robustness requirements for reliable interpretation of VAR-based impulse responses and variance decompositions.

The diagram below (Figure 6) illustrates the structural mechanism through which advanced economies move beyond the traditional Environmental Kuznets Curve framework. Rather than following an inverted U-shaped pattern driven solely by rising income, the EU experience suggests that economic growth initiates structural shifts in the composition of output, particularly through the transition from industry-dominated production toward a service-oriented economy. This process plays a pivotal role in reducing the carbon intensity of economic activity. As the share of services and knowledge-based activities increases, overall emissions tend to decline even as GDP continues to rise, generating a form of progressive emissions decoupling.

Figure 6. Sectoral transformation



Source: Own study.

The bottom part of the diagram emphasizes that this decoupling is not an automatic consequence of income levels, as posited by the EKC, but a result of changes in economic structure, technology, and policy incentives. The dotted feedback arrow suggests that lower emissions may, in turn, support more sustainable long-term growth by alleviating environmental constraints and lowering energy costs. Environmental improvement in advanced economies is driven not by income thresholds, but by deliberate structural transformation supported by institutional and technological change.

4. Discussion

The empirical results for EU member states challenge the traditional Environmental Kuznets Curve framework and instead point to a pattern of long-term structural decoupling between economic growth and CO_2 emissions. The negative linear coefficient and positive quadratic term indicate that the EU follows a trajectory closer to the "new toxins" curve rather than the inverted U-shaped EKC. Combined with the Granger causality results, which show a one-way causal effect from GDP per capita to emissions, the findings emphasize that economic expansion in the EU has been accompanied by declining carbon intensity but not due to income-driven environmental improvements. Rather, reductions in emissions have coincided with deep structural transformations within EU economies.

Recent global evidence by Freire-González & Gòmez (2024) shows that many world economies exhibit various forms of decoupling between GDP and CO_2 emissions, although the underlying mechanisms differ across income groups. Our findings for the EU align with this broader trend but suggest that decoupling in advanced European economies is structurally driven rather than income-driven, thereby moving beyond the conventional EKC interpretation. By contrast, some earlier analyses of the EU-27 identified partial evidence supporting the EKC, such as Mohammed et al. (2023), who documented an inverted U-shaped pattern for earlier time periods. The divergence between their findings and ours likely reflects differences in methodological approaches and, importantly, the strengthening of EU climate and energy policies after 2010, which have accelerated structural decarbonization beyond what a simple income–pollution relationship can capture.

Further support for the structural interpretation comes from Balsalobre-Lorente et al. (2022), who show that economic complexity and shifts in production structure significantly affect EKC dynamics in Southern European economies. Their results reinforce our finding that sectoral change, particularly the expansion of services and clean technological capabilities, plays a more decisive role than income thresholds in explaining emissions trajectories.

Similar to our findings, research published by Aguir Bargaoui (2021) shows that the adoption of renewable energy and energy efficiency technologies significantly improves environmental quality in MENA countries, underscoring the broader relevance of clean-energy transitions for decoupling processes.

This aligns with the broader trajectory of EU climate and energy transition policy over the past two decades. The European Green Deal, the 2030 Climate Target Plan, and the "Fit for 55" legislative package have collectively sought to decouple growth from emissions by accelerating shifts toward clean energy, phasing out coal, raising energy efficiency standards, and stimulating large-scale investment in low-carbon technologies. Structural changes driven by these policies, including the rise of service-based economic activity, modernization of manufacturing, and increased deployment of renewable energy appear consistent with the results obtained here.

Additionally, the emerging composition effect detected in the VAR estimations and impulse response functions is in line with EU efforts to promote sectoral transformation. The services sector's expanding share in GDP and employment has coincided with declining emissions intensity. Similarly, policy instruments such as the EU Emissions Trading System (EU ETS), carbon pricing, and industrial decarbonization strategies have created incentives to shift away from carbon-intensive production processes. These mechanisms help explain why emissions reductions do not appear to be driven by income levels alone, but by deliberate regulatory and structural interventions.

The relevance of policy interventions for emissions reduction has also been highlighted in recent studies. Sarawagi et al. (2025) demonstrate how green-bond financing mechanisms across G20 economies accelerate progress toward sustainable development and emissions mitigation, reinforcing our argument that policy frameworks, such as the EU ETS and the Green Deal play a central role in shaping structural decarbonization pathways rather than income effects alone.

Furthermore, the finding that GDP growth leads emissions, but not vice versa reflects the success of EU policies to prevent environmental constraints from hindering economic performance. Heavy investment in renewable energy (wind, solar, hydro), cross-border electricity market integration, and green innovation programs under Horizon Europe have lowered the economic cost of decarbonization, allowing growth to continue alongside emissions reductions. In this sense, the EU experience supports the hypothesis that targeted institutional and technological changes are prerequisites for sustained decoupling.

Overall, the analysis confirms a shift away from pollution-intensive development patterns toward a cleaner, service-oriented and technologically advanced economic structure. These transformations, reinforced by ambitious EU climate policy frameworks, represent the primary mechanisms through which decoupling has taken place, rather than an endogenous EKC-type adjustment driven solely by rising incomes.

Conclusion

The study analysed the relationship between GDP per capita and CO_2 emissions in the EU-27 from 1995 to 2022 using panel econometric methods. The results reject the Environmental Kuznets Curve hypothesis, showing no evidence of an inverted U-shaped relationship between economic growth and environmental quality. Instead, the findings indicate a nonlinear pattern consistent with persistent structural transformation rather than income-driven environmental improvement.

The evidence points to sustained decoupling driven by the transition toward a service-based economy and the adoption of cleaner production technologies. Granger causality tests show that economic growth influences emissions, but emissions do not affect economic growth suggesting that EU economies have successfully reduced the carbon intensity of growth. This pattern aligns with the broader strategic objectives of EU climate policy, particularly the European Green Deal, the 2030 Climate Target Plan, and the Fit for 55 Package, all of which are designed to achieve climate neutrality by 2050 while supporting economic competitiveness.

The results underscore the importance of targeted policy instruments, such as carbon pricing under the EU ETS, energy efficiency standards, renewable energy promotion, and incentives for green innovation in driving emissions reductions independently of income levels. This highlights the critical role of deliberate institutional, regulatory, and technological interventions in shaping environmental outcomes.

For policymakers, the findings reinforce the need to continue supporting structural shifts toward low-carbon sectors, accelerating investment in clean energy, and strengthening innovation ecosystems. These measures are essential to maintaining and enhancing the decoupling trend, especially as the EU enters the next phase of its Green Deal Industrial Plan and the Net-Zero Industry Act. Limitations of the study include the exclusive focus on CO_2 emissions and the omission of other environmental indicators such as methane, particulate matter, or ecological footprint. Future research should integrate a wider range of pollutants, consider sector-level dynamics, and explore long-term nonlinearities beyond the 1995–2022 period.

In conclusion, the EU experience demonstrates that environmental improvements arise not automatically with rising income, but through structural change supported by coherent climate and energy transition policies. This reinforces the view that sustainable economic growth requires proactive environmental governance and strategic transformation, rather than relying on the self-correcting dynamics suggested by the traditional EKC hypothesis.

Credit Authorship Contribution Statement

The author was responsible for Conceptualization, Methodology, Data Curation, Formal Analysis, Investigation, Visualisation, Writing – Original Draft, and Writing – Review & Editing.

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Conflict of Interest Statement

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Data Availability Statement

All data used in this study are derived from publicly accessible sources. Macroeconomic and environmental indicators, including GDP per capita and CO_2 emissions, were obtained from the Eurostat database. All datasets can be accessed freely and replicated by other researchers.

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