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Do Financial and Technological Innovations Enhance Environmental Quality? Empirical Evidence from the EU Countries

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Finansal ve Teknolojik İnovasyonlar Çevresel Kaliteyi İyileştirir mi? AB Ülkelerinden Ampirik Kanıtlar

Abstract

This paper aims to investigate the long-term effects of financial innovations (FI) and technological innovations (TI) on carbon dioxide emissions (CO_2) in the EU from 2001 to 2022. The ratio of the aggregate money supply to narrow money (M3/M1) is used as a proxy for FI, and the total number of patents is used as a measure of technological innovation. The research applies Westerlund cointegration, augmented mean group estimator (AMG), and Dumitrescu-Hurlin causality tests. The empirical results demonstrate that the variables are cointegrated, and FI and TI contribute to reducing CO_2 emissions. Additionally, the study finds that an increase in LGDP is associated with higher CO_2 emissions. At the same time, the square of LGDP is linked to a reduction in CO_2 emissions, supporting the Environmental Kuznets Curve (EKC) hypothesis. According to the Dumitrescu-Hurlin causality results, a unidirectional causality relationship exists between financial and technological innovations and CO_2 emissions. These findings stress the importance of increased funding and grants to align with the Union's 2030 targets. Financial incentives should promote investments in the next generation of low-carbon technologies, supporting Europe's shift towards climate neutrality.

Keywords : Financial Innovation, Technological Innovation, Environmental Quality, EU Countries.

JEL Classification Codes : Q53, C33, P28.

Öz

Bu çalışma, 2001-2022 dönemi için Avrupa Birliği ülkeleri bağlamında finansal yenilikler (FI) ve teknolojik yeniliklerin (TI) karbondioksit (CO_2) emisyonları üzerindeki uzun dönem etkilerini Westerlund eşbütünleşmesi, artırılmış ortalama grup tahmincisi (AMG) ve ardından Dumitrescu-Hurlin nedensellik testleri ile araştırmaktadır. Finansal inovasyon vekil değişken olarak geniş para arzının dar para arzına oranı (M3/M1) ve teknolojik inovasyon olarak toplam patent sayısı kullanılmıştır. Ampirik sonuçlar, değişkenlerin etkilerinin eşbütünleşik olduğunu göstermektedir. Finansal ve teknolojik inovasyonlar CO_2 emisyonlarını azaltmaktadır. Sonuçlar, LGDP'nin CO_2 emisyonlarındaki artışla ilişkili olduğunu, LGDP'nin karesinin ise CO_2 emisyonlarındaki azalmayla bağlantılı olduğunu göstermektedir. Bu bulgular, Çevresel Kuznets Eğrisi hipotezi ile uyumludur. Ayrıca Dumitrescu-Hurlin nedensellik sonuçlarına göre finansal ve teknolojik inovasyonlardan CO_2 emisyonlarına doğru tek yönlü nedensellik ilişkisi tespit edilmiştir. Bu sonuçlar ışığında, Avrupa Birliği'nin 2030 yılı hedefleri doğrultusunda fon ve hibeler artırılmalıdır. Şirketlerin ve kamu

otoritelerinin yeni nesil düşük karbonlu teknolojilere yatırım yapmaları ve Avrupa'nın iklim nötrlüğüne geçişini desteklemeleri için finansal teşvikler sağlanmalıdır.

Anahtar Sözcükler : Finansal İnovasyon, Teknolojik İnovasyon, Çevresel Kalite, AB Ülkeleri.

1. Introduction

Climate change is a major threat to our planet and global economic development, causing significant environmental degradation and jeopardising sustainability. The rise in temperatures due to greenhouse gas (GHG) emissions, mainly CO_2 from fossil fuels, is at the forefront of this crisis. Demographic and macroeconomic factors, such as income, population, and energy consumption, influence CO_2 emissions. The IPCC (2022) reports that human activities contribute about 95% of global warming. Without international cooperation on climate-friendly practices, global temperatures could rise by 2 degrees Celsius, resulting in severe consequences, including floods, droughts, and the melting of glaciers. To combat this, controlling greenhouse gas emissions and promoting environmental innovations is crucial. These innovations aim to reduce fossil fuel dependency while fostering economic growth and environmental sustainability through financial and technological advancements.

Financial innovation (FI) is essential for funding renewable energy initiatives. Access to low-cost and reliable finance, efficient financial markets, and regulations can encourage investment in energy-saving projects. For example, financial institutions and banks lending to green projects significantly improve areas such as clean energy, sustainable agriculture, and waste management (Zhan et al., 2023). Additionally, FI can drive economic growth and support emissions reduction by ensuring the optimal allocation of capital, facilitating foreign capital inflows, and speeding up capital accumulation. Environmental degradation and increased energy consumption are unintended consequences of more significant investment and economic growth. Higher-income levels and credit expansion increase demand for energy-intensive products, ultimately causing environmental degradation. Since the 1990s, there has been a growing emphasis on the role of financial development in the ecological economy. A robust financial system promotes green investments, contributing to sustainable development and environmental conservation. Numerous financial products are categorised as 'green finance' to achieve sustainable development goals (Kirikkaleli & Adebayo, 2024). From a consumption perspective, FI enhances financial education and awareness among individuals and businesses, promoting the adoption of environmentally friendly practices and reducing carbon emissions. However, FI does not always have positive effects on EQ. Rapid and uncontrolled financial expansion can lead to environmental degradation and overexploitation of natural resources (Omri et al., 2015).

Similarly, technological innovations (TI) can reduce reliance on fossil fuels. Examples of such innovations include solar energy, wind power, energy storage, and smart grids, which can transform the energy landscape and expedite the adoption of clean energy sources. Additionally, TI supports the development of environmentally friendly products and services, thereby helping to increase environmental awareness among consumers and businesses. TI is transforming its manufacturing process and techniques. It is an essential tool for achieving sustainable development goals and combating environmental degradation. In particular, empirical studies have consistently shown that TI enables the efficient use of natural resources and slows the depletion rate, thereby limiting the increase in emissions (Zhang et al., 2016; Yu & Hu, 2019; Khan et al., 2021; Raihan et al., 2022; Adebayo et al., 2023). Hence, acquiring and implementing TI effectively promotes sustainable development globally. TI involves generating new ideas, developing and implementing new patents and technologies, and adjusting production structures. It is widely acknowledged as a critical solution to environmental challenges and sustainability.

As the urgency to reduce GHG emissions increases, low-carbon technology is crucial for meeting future targets and minimising costs. The EU aims for carbon neutrality by 2050, aligning with the goal of the Paris Agreement to limit the global temperature rise to below 2°C. It aims to reduce primary energy consumption by 26% and final energy consumption by 20% by 2030 compared to 2005, with a focus on improving energy efficiency and increasing the use of renewable sources (European Commission, 2018). The EU Emissions Trading System (EU ETS), a crucial component in decarbonising the economy, has contributed to reducing fossil fuel use, increasing the share of renewable energy from approximately 10% in 2005 to 23% in 2022 (European Commission, 2023). To meet the 2030 target of 42.5%, a significant transformation of the energy system is necessary. Given these challenges, energy transformation and conservation are critical for developed countries, especially EU countries, to combat environmental degradation. The EU's role as a significant greenhouse gas emitter highlights the need for effective climate and energy policies to reduce emissions, promote renewable energy sources, and enhance energy efficiency. This study will investigate the long-term impact of financial and technological innovations on carbon emissions, considering primary energy consumption and economic growth within the European Union context.

The rest of the paper is organised as follows: Section 2 summarises the relevant literature, Section 3 describes the data and empirical model, Section 4 presents the results, and Section 5 provides a concluding remark.

2. Literature

The literature is presented briefly in two subsections: (i) the link between TI and the environment, and (ii) FI and the environment.

2.1. Financial Innovation and Environmental Quality

Financial innovation creates new products that manage risks and improve credit and liquidity efficiency. It is vital for addressing adverse economic conditions and impacting ecological quality. FI facilitates large-scale investments in sustainable development, particularly in the transition to renewable energy, by promoting clean energy projects (Kirikkaleli et al., 2023). It enhances opportunities for companies to invest in clean energy R&D, thereby advancing renewable technologies (Jiang & Ma, 2019). Moreover, FI can stimulate economic growth and broaden financial access. However, this expansion may lead to higher energy consumption and environmental pollution in the early stages of development, as noted in the EKC theory (Piracha & Chaudhary, 2022).

There is no consensus in the empirical literature on the impact of FI on EQ. Al Mamun et al. (2018) conducted a study using a sample of 25 OECD countries from 1980 to 2015. They found that financial markets increase green energy through high innovation, using the FMOLS and DOLS methods. However, the widespread use of fossil fuel technology is seen as a barrier to realising this relationship. Charfeddine and Kahia (2019) employed the PVAR method from 1980 to 2015 for MENA countries and concluded that financial development is associated with reduced CO_2 emissions. Tian et al. (2020) demonstrated the significant contribution of carbon finance to China's innovative financial macroenvironment and its role in reducing carbon intensity. Similarly, Zhan et al. (2023) found that long-term CO_2 emissions and greenhouse gas estimates have a significant negative impact on green finance. In other words, green finance and FI reduce China's CO_2 and greenhouse gas emissions. When environmental laws are stricter and banking competition is low, Huo et al. (2022) have found that FI promotes green innovation. Green bonds, which have emerged as an FI in recent years, support sustainable projects that aim to improve EQ. The issuance of green bonds leads to substantial investments in renewable energy, energy efficiency, and other environmentally friendly initiatives. For example, Flammer (2021) found that green bonds were associated with a substantial increase in environmental performance among firms that issued them. The study suggests that green bonds provide financial resources for sustainable projects, thereby increasing the issuer's ecological reputation and commitment. Additionally, studies have examined the link between sustainable investment funds, another indicator of FI, and EQ. For instance, Friede et al. (2015) discovered a positive association between environmental, social, and governance criteria and firms' financial performance in a meta-analysis study. The findings indicate that financial markets reward firms that adopt sustainable practices and promote better EQ. Microfinance has also been explored as a means to support environmental sustainability, particularly in developing countries. By providing small loans to individuals and communities, microfinance institutions can enable investments in environmentally friendly practices and technologies at a grassroots level. Studies by Jabin et al. (2015) demonstrate that microfinance can promote sustainable agricultural practices, improve water management, and support renewable energy projects in rural areas, thereby contributing to EQ. The rise of digital financial services, including mobile banking and fintech platforms, has also influenced EQ. Digital financial services can reduce the need for physical infrastructure and paper-based transactions, lowering carbon footprints. Moreover, fintech innovations can facilitate the efficient flow of funds to green projects. Research by Zhang et al. (2020) suggests that fintech solutions can improve the transparency and traceability of green investments, ensuring that funds are utilised effectively for environmental purposes.

In a study conducted in EU countries, Jamshidi et al. (2023) examined the effects of M3/M1 and M2/M1 ratios on CO_2 emissions. The results showed a negative and significant relationship. In addition, there are studies examining the effects of digitalisation in line with the climate neutrality targets of the European Green Deal. Digitalisation improves interaction between investors and financial markets, helping to address new needs (Di Febo et al., 2024). Banelienė & Strazdas (2023) noted that while green innovation in Europe supports economic growth, the impact of digitalisation on GDP is uncertain and relies on its qualitative implementation. Tran et al. (2023) found that all digital skills except basic ones positively affect European economic development. Similarly, Imran et al. (2022) found that financial digitalisation has positive effects on the environmental quality of Europe.

Studies with varying findings examine the relationship between financial development and innovation, on the one hand, and carbon emissions, on the other. To illustrate, Al-Mulali (2015) found that financial development, trade openness, and economic growth lead to increased carbon emissions over the long term in European countries. Similarly, Shahbaz (2016) found that financial development and innovation lead to increased carbon emissions, with unidirectional causality from economic growth to carbon emissions. Guliyev (2024) examined the determinants of ecological footprint in European countries from 1992 to 2020 using the Bayesian Model Averaging approach. According to the results, FI and developments positively affect EQ.

2.2. Technological Innovation and Environmental Quality

TI is a key driver of economic growth. Therefore, TI can have positive or negative externalities on the environment, depending on the attitudes and policies of policymakers. TI can affect EQ through several channels. The first is the Foreign Direct Investment (FDI) channel. FDI can facilitate the transfer of new technologies and business models through technology spillovers, which can affect EQ. While high-tech FDI can promote environmentally friendly practices by increasing energy efficiency, low-tech FDI can increase pollution. Another channel is TI, which can contribute to the growth of the digital economy, the optimisation of business processes, and the efficient use of energy. Cloud computing, remote working, and digitalisation can improve EQ by reducing the use of physical resources. TI can enhance productivity by optimising production processes (Karimli et al., 2024). For instance, using automation, data analytics, and artificial intelligence can improve labour productivity. Furthermore, it can facilitate the implementation of more effective methods for pollution control, such as filtration systems, recycling technologies, and cleaner production practices. In this context, empirical studies have shown that TI has a positive impact on EQ. Apergis et al. (2013) investigated the effects of TI on carbon emissions in Germany, France, and the UK from 1998 to 2011, finding that TI reduces CO_2 emissions. Ahmed et al. (2016) found that technological innovation promotes biomass energy consumption, resulting in lower emissions across 24 European countries from 1980 to 2010. Cho and Sohn (2018) found that R&D improvements drive the issuance of green tech patents and enhanced energy efficiency in Germany, Italy, and the UK from 2004 to 2012. Shahbaz et al. (2018) highlighted that R&D expenditures in energy significantly lower CO_2 emissions in France while noting the connection to financial system development. Chen and Lei (2018) emphasised the impact of TI on countries with higher CO_2 emissions from 1980 to 2014, advocating for increased energy efficiency and renewable energy initiatives. Bindi (2019) reported that innovation in developed countries, as measured by climate patents, reduced emissions from 1976 to 2012. Churchill et al. (2019) found that technological innovation led to a decrease in CO_2 emissions among G-7 countries from 1970 to 2014. Zameer et al. (2020) concluded that TI lowered emissions in India from 1985 to 2017, while Cheng et al. (2021) observed a dual effect of technological innovation on emissions across 35 OECD countries from 1996 to 2015. Zhang (2021) found a one-way causality between patents and emissions in BRICS nations from 1990 to 2019. Lastly, Rout et al. (2022) noted that TI reduced the ecological footprint in BRICS countries between 1990 and 2018.

Some studies have found that TI does not significantly affect EQ in the long run. For example, Yii and Geetha (2017) employed VECM and TYDL methods for the period 1971-2013 in Malaysia. They found that TI has an adverse effect on CO_2 emissions in the short run but has no significant impact in the long run. Using dynamic panel data analysis, Koçak and Ulucak (2019) examined 19 high-income OECD countries from 2003 to 2015. According to the study results, no significant relationship was found between TI and CO_2 emissions. Similarly, Villanthenkodath and Mahalik (2022) employed the ARDL cointegration technique to investigate the impact of TI on the ecological footprint in India from 1980 to 2018. The study's findings, which utilised patent applications as a proxy variable for TI, indicated that TI has a positive effect on EQ in the short term, although this effect dissipates over time.

3. Data and Methodology

3.1. Data

To achieve the objectives of this study, we collected data on the proposed variables from various sources covering the period from 2001 to 2022 for EU countries. The data for the dependent variable, CO_2 emissions per capita, as well as the control variable, PEC, were sourced from Our World in Data (ourworldindata.org). We utilised the M3/M1 ratio—representing the aggregate and narrow money supply—as a measure of financial innovation. M3 data were obtained from the Eurostat and Trading Economics databases, while the narrow money supply (M1) data were sourced from the OECD database. This ratio shows the sophistication of the financial system. Additionally, the M3/M1 ratio indicates the rate at which illiquid assets are converted into liquid assets. Some of the studies use the M3/M1 ratio as an indicator of financial innovation. They are Dunne and Kasekende, 2018; Jia et al., 2021; Jamshidi et al., 2023; Kirikkaleli, 2023; Naseem et al., 2023; Ursavas et al., 2024. TI, another independent variable in this study, is represented by the total number of patents. This variable indicates the level of invention of a country. Patent data for EU countries were obtained from the OECD database. Some studies used this variable as TI. They are Kogan et al., 2017; Kihombo et al., 2021; Sun et al., 2021. The model includes GDP per capita and

PEC as control variables. This model aligns with the theory of economic modernisation (EMT), which is based on environmental innovation in improving EQ and the argument that such innovations should be encouraged.

The model specification of the current study is:

$$CO_2 = f\,(\text{FI, TI, PEC, GDP}) \tag{1}$$

Variable log transformation represents a crucial step in enhancing the reliability of analysis and smoothing the data (Zafar et al., 2019). Consequently, variables are converted into logarithmic form. The following equation represents the regression form of the model, which is employed for the empirical analysis:

$$LCO_2 = \alpha_0 + \alpha_1 LFI_{it} + \alpha_2 LTI_{it} + \alpha_3 LGDP_{it} + \alpha 4 LGDP^2{}_{it} + \alpha_5 LPEC_{it} + \epsilon_{it} \tag{2}$$

Table: 1
Definitions

Variable	Definition
LCO_2	The natural logarithm of production-based carbon dioxide emissions per capita in metric tons
LFI	The natural logarithm of the ratio of the aggregate money supply to narrow money (M3/M1)
LTI	The natural logarithm of the total number of patents
LGDP	The natural logarithm of GDP per capita in constant 2010 US dollars
$LGDP^2$	Square of the LGDP
LPEC	The natural logarithm of primary energy consumption (% of total final energy consumption)

The central hypothesis of this paper is that FI and TI reduce CO_2 emissions.

H1: Financial and technological innovations significantly and negatively impact CO_2 emissions in EU countries.

Our expectation for GDP per capita and its square variables, added to the study as control variables, are positive and negative, respectively.

H2: $LGDP^2$ significantly and negatively impacts CO_2 emissions in the EU countries.

The primary hypothesis is that economic growth will lead to environmental degradation by increasing resource demand and waste production. The EKC shows an inverted U-shape, indicating that ecological pollution increases in the early stages of economic growth. EQ deteriorates due to the increased use of fossil fuels and the generation of environmental waste with the expansion of production. In the later stages of economic growth, structural transformation and the development of machinery and equipment will reduce environmental pollution by focusing on R&D studies in prosperous countries. In other words, introducing green technologies plays a role in reducing environmental pollution. Research on EU countries by Lee and Brahmasrene (2013), Onofrei et al. (2022), and Deka et al. (2023) concludes that economic growth often leads to long-term environmental degradation.

Another control variable in the study is PEC.

H3: PEC significantly and positively impacts EU countries' CO_2 emissions.

PEC refers to the total energy demand of a country, encompassing the energy sector's consumption, energy lost during conversion (e.g., from oil or gas to electricity), and final consumption by end-users through energy distribution. Primary energy sources encompass a variety of inputs, including fossil fuels (such as coal, oil, and natural gas) and renewable energy sources (such as solar, wind, and hydropower). It is essential to recognise that the combustion of fossil fuels contributes to greenhouse gas emissions, and consequently, the sources utilised in energy production influence total emissions. Several studies, including Kasman and Duman (2015), Bianco et al. (2019), and Liu et al. (2023), have concluded that PEC leads to long-term environmental degradation in EU countries.

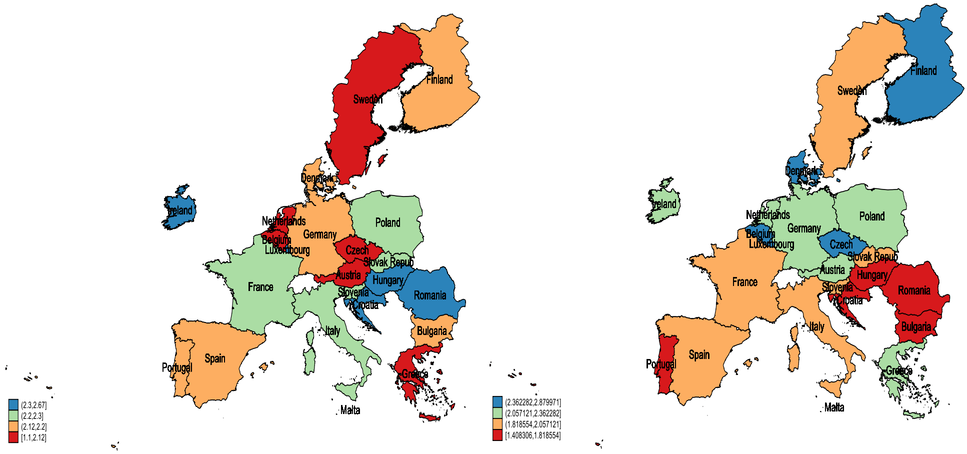
Table: 2
Descriptive Statistics (After Logarithm)

Variable	Obs	Mean	Std. Dev.	Min	Max
LCO_2	572	0,8276	0.94639	0.4662	2.725
LFI	572	0,3988	0.13728	-0,9212	1.2884
LTI	572	0,4652	0.1163	0.1385	2.8194
LGDP	572	2.4877	0.77092	0.2466	5.1272
LPEC	572	15.282	0.13342	0.03	52.88

As shown in Table 2, the average CO_2 emission for the EU countries from 2001 to 2022 is 0.8276. While Latvia had the lowest CO_2 emissions among EU countries in 2002, Luxembourg had the highest CO_2 emissions in 2005. Denmark was the leader among EU countries in terms of the TI in 2019. Luxembourg had the highest M3/M1 ratio in 2018. LGDP has an average value of 2.4877 across EU countries. The variable's highest and lowest values are associated with Luxembourg (2014) and Bulgaria (2001), respectively. Among EU countries, Germany had the highest LPEC in 2002, while Austria had the lowest number of observations in 2005.

In Figure 1, the average values of FI and TI for 2001-2020 are visualised on the map.

Figure: 1
Spatial Distribution of Financial Innovation and Technological Innovation across EU Countries, Respectively (Average 2001-2020)

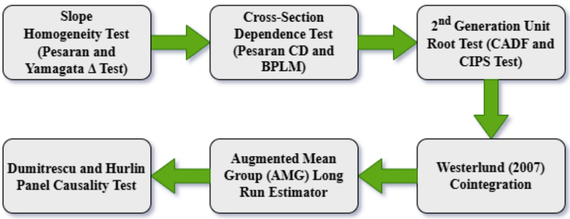


Note: Visualisations were created by the authors using STATA 18.

3.2. Methodology

Figure 2 illustrates the stages involved in the study's methodology.

Figure: 2
Methodological Flowchart



In the first step, the homogeneity or heterogeneity of the variables changes the form of the unit root and cointegration tests to be applied. In the study, the homogeneity of the variables was investigated using the delta test. The Δ and Δadj tests are calculated as specified in the equations below (Pesaran & Yamagata, 2008).

$$\widetilde{\Delta} = \sqrt{\frac{N \cdot N^{-1} \cdot S^{-k}}{\sqrt{2k}}} \tag{3}$$

$$\widetilde{\Delta}_{adj} = \sqrt{N} \cdot \frac{\hat{S} - B(\bar{Z}_{it})}{\sqrt{\mathrm{Var}(\bar{Z}_{it})}} \tag{4}$$

Testing the series' cross-sectional dependence (CSD) in panel data analysis is essential in the second stage. It should be examined whether the cross-sectional units are dependent on each other and whether they are affected by a shock to the series to the same degree. In this study, cross-sectional dependence is analysed using the Pesaran CD test.

Pesaran (2015) CD test is applied;

$$CD_{L,M} = \sqrt{\frac{1}{N(N-1)}\sum_{i=1}^{N} \sum_{j=i+1}^{N}(T_{0,ij}^{2} - 1)} \sim N(0,1) \quad (5)$$

Based on the findings obtained from the above equations, CD_{LM} test statistic values are obtained. Here, the simultaneous correlation between residuals is expected.

The statistical significance of the correlations is assessed using the LM test proposed by Breusch and Pagan (1980) and further discussed by Pesaran (2004). The LM statistic can be computed as follows:

$$LM = T\sum_{i=1}^{N} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^{2} \sim \chi^{2}(\frac{N(N-1)}{2}) \quad (6)$$

p_{ij} is the simple correlation coefficient between the residuals from each equation in the least squares (LM) estimation. Under the null hypothesis of no correlation between the residuals, LM shows a chi-square distribution with N constant and T going to infinity.

Table: 3
CSD and Heterogeneity Tests

	PCD	BPLM
LCO_2	51.89 (0.98) [0.000]	32.56 [0.000]
FI	60.48 (1.01) [0.000]	44.11 [0.000]
TI	42.23 (0.88) [0.000]	39.92 [0.000]
LGDP	53.96 (0.99) [0.000]	36.61 [0.000]
$LGDP^2$	76.181 (0.87) [0.000]	42.56 [0.000]
LPEC	41.16 (0.84) [0.000]	37.08 [0.000]
Slope Heterogeneity Test	$\bar{\Delta}$	$\bar{\Delta}_{adj}$
	16.067*** [0.000]	18.840*** [0.000]

The results in Table 3 indicate that the panel data set variables are heterogeneous. The CD and BPLM tests reveal cross-sectional dependence (CSD). Thus, unit root tests accounting for horizontal CSD are necessary before conducting the panel cointegration test (Nazlıoğlu, 2010). Second-generation panel unit root tests, such as the Cross-Sectionally

Augmented Dickey-Fuller (CADF) test developed by Pesaran (2007), should be used for accurate estimations.

$$\Delta Y_{it} = \alpha_i + \beta_i Y_{i,t-1} + \sum_{j=1}^{P} \gamma_{ij}\, \Delta y_{i,t-j} + \delta_t + \lambda_t M_{i,t-1} + \sum_{j=0}^{P} \pi_{ij}\, \Delta \tilde{y}_{ij,t-j} + \epsilon_{it} \qquad (7)$$

Pesaran (2007) showed that the common element could be approximated by the values of y_t and y_{t-1} when the lagged mean of the series is different from zero and N goes to infinity. To consider the potential autocorrelation for each cross-section, the yt can approximate the common element, and the Δyt lagged values. In his Monte Carlo simulations, Pesaran has demonstrated that the CADF test is valid in both cases where N > T and T > N. The t-statistic value of the CADF test is calculated as follows.

$$t_i(N,T) = \frac{\Delta Y_i \bar{M}_w Y_{i-1}}{\delta (Y_{i-1,} \bar{M}_w Y_{i-1})^{1/2}} \qquad (8)$$

The CIPS statistic is calculated for each horizontal cross-section of the t-statistic values. It is the average.

$$\bar{t} = \frac{1}{N} \sum_{i=1}^{N} t_i\,(N,T) \qquad (9)$$

Table: 4
Unit Root Tests

Test	LCO_2	LFI	LTI	LGDP	$LGDP^2$	LPEC
CADF						
I(0)	-2.650	-1.548	-2.691	-2.078	-1.018	-1.339
I(1)	-5.306***	-13.862***	-4.099***	-5.027***	-4.773***	-2.798***
CIPS						
I(0)	-1.259	-2.1491	-2.430	-0.7451	-1.9624	-1.647
I(1)	-4.229***	-4.5333***	-5.141***	-4.051***	-3.866***	-4.4263***

****< 0,01*

In Table 4, all variable t-statistic values compared with the critical values proposed by Pesaran (2007) indicate a statistically significant result at the 5% level, rejecting the null hypothesis. The calculated CADF t-statistic values for all variables exceed -3.87 at the 5% level, as indicated by the Pesaran (2007) critical value table. Furthermore, the CIPS values calculated for all variables are more significant than -2.86 at the 5% significance level, as indicated in the critical value table by Pesaran (2007). Thus, all series contain a unit root and are not stationary at the level. The series displays I(1) characteristics.

After assessing the series' homogeneity and stationarity, we chose a cointegration test based on our findings. The type of panel cointegration test varies depending on the stationarity of the variables. Given that the series are heterogeneous and cross-sectionally dependent, we employ the Westerlund panel cointegration test. Westerlund (2007) developed four tests based on the error correction model, with two categorised as group average statistics and two as panel statistics. The test assumes the series is stationary to the same degree and I(1) at first difference.

$$\Delta Y_{it} = \delta d_t + \alpha_i + \gamma(Y_{i,t-1} - \beta X_{i,t-1}) + \sum_{j=1}^{p} \lambda_j \, \Delta Y_{i,t-j} + \sum_{j=0}^{q} \theta_j \, \Delta X_{i,t-j} + \epsilon_{it} \tag{10}$$

$$\Delta Y_{it-1} = \delta d_t + \alpha Y_{i,t-1} + \gamma_1 X_{1i} + \cdots + \sum_{j=1}^{p_i} \phi_j \, \Delta X_{j,i,t-1} - \sum_{j=0}^{p_i} \lambda_j \, \Delta X_{j,i,t-j} + \epsilon_{it} \tag{11}$$

d_t is a vector of deterministic elements (constant and trend).

Then, the error correction coefficient for the whole panel and its standard deviation are calculated:

$$a_i = (\textstyle\sum_{s=1}^{N} T_s \sum_{t=2}^{T_s} (Y_{it} - Y_{i,t-1})^2)^{-\frac{1}{2}} \sum_{s=1}^{N} T_s \frac{(Y_{i,t-2} - Y_{i,t-1})}{a_{i(t-1)}} (Y_{it} - \hat{Y}_{it}) \tag{12}$$

$$S.E.(a_i) = \sqrt{\frac{\sum_{s=1}^{N} \hat{Y}^2}{\sum_{s=1}^{N} T_s - 2}} \tag{13}$$

Finally, panel cointegration statistics are calculated as follows:

$$P_t = \frac{a}{SE(a)} \sim N(0,1) \tag{14}$$

$$P_a = T_a \sim N(0,1) \tag{15}$$

4. Results and Discussion

When all series are stationary in a first order, the existence of a cointegration relationship between the series can be examined. The WCT test is applied to determine the cointegration relationship. This test is preferred because it allows significant heterogeneity in long-run dynamics. Additionally, this test yields more accurate results in conjunction with CSD. When the results of the Gt and Ga tests are analysed in Table 5, it is seen that H0 is rejected at a 1% significance level for Gt and a 5% significance level for Ga. In other words, a cointegration relationship exists between the FI, TI, and carbon emissions variables in at least one cross-sectional unit. When the Pt and Pa test results are analysed, it is seen that H_0 is rejected at the 1% level. According to the Pt test, the entire panel has a 1% significance level cointegration relationship.

Table: 5
Westerlund Cointegration Analysis

Statistics	Value	Z-value	P-value
Gt	-2.522	-3.934	0.000
Ga	-9.575	-2.1	0.018
Pt	-10.814	-3.694	0.000
Pa	-7.582	-3.372	0.000

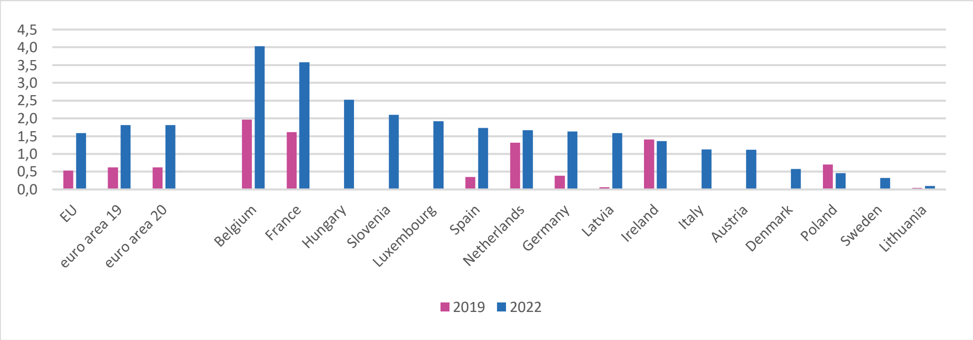
The results in Table 6 indicate that the coefficient values of all variables are statistically significant. The FI and TI variables have a negative coefficient. In contrast, the LGDP and LPEC variables have positive coefficients, which supports the view that innovations have a remedial effect on EQ. In comparison, LGDP and LPEC variables have a detrimental impact. In other words, a 1% increase in FI reduces CO_2 emissions by about 0.46%. A 1% increase in TI, ceteris paribus, reduces CO_2 emissions by 0.21%. A 1% increase in LPEC results in a 0.26% increase in CO_2 emissions. The results indicate that as LGDP increases, CO_2 emissions also increase, while the square of LGDP is linked to a decrease in CO_2 emissions. These findings support the EKC hypothesis.

Table: 6
The Estimates of AMG (Long-Run Estimation)

Variable	Coefficient	Std. Err	P	P>|z|
LTI	-0.4599	0..4343936	3.11	0.035**
LFI	-0.2147	0..0497355	4.46	0.004***
LGDP	0.2114	0.1539074	3.03	0.012**
$LGDP^2$	-0.0473	0.1864432	3.18	0.037**
LPEC	0.2602	0..0762360	3.63	0.032**

One of the possible reasons why FI hurts CO_2 emissions is the promotion of investments in green technologies and the improvement of risk management. With the EU-ETS, which entered into force in the EU in 2005, annual carbon dioxide (tCO2-eq) emissions decreased from 200 million tons to approximately 110 million tons in 2023 (European Environment Agency, 2024). Another reason for FI to reduce carbon emissions in EU countries is the increasing issuance of green bonds by central and local governments over time. Figure 3 shows that the issuance of green bonds, which accounted for 0.5% of the national income in member countries in 2019, increased threefold by 2022, reaching a level of 1.5% of the national income. Additionally, the European Investment Bank has issued approximately €1.5 trillion of climate awareness bonds cumulatively from 2006 to 2022. Thanks to Climate Awareness Bonds, renewable energy is allocated to projects that significantly contribute to climate change mitigation in energy efficiency, low-carbon transportation and innovative low-carbon technologies. A recent study by Jamshidi et al. (2023) confirms this finding. This result also implies that energy-intensive products, which individuals can purchase with easy access to credit thanks to financial innovations, reduce environmental pollution by becoming less energy-intensive and less carbon-emitting, thanks to the adoption of green technology.

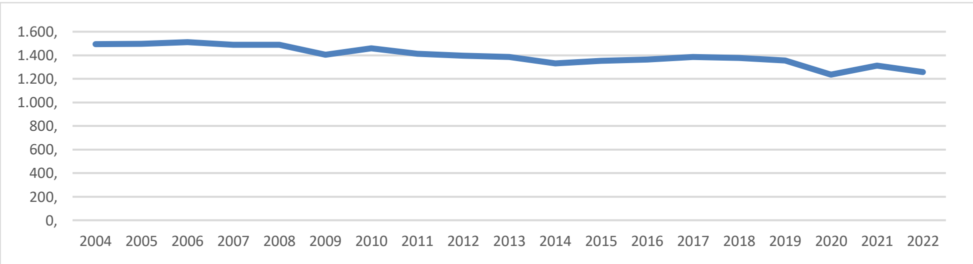
Figure: 3
Stocks of Green Bonds Issued by Member States, End of 2019 and 2022 (%GDP)



Source: Eurostat (online data code: gov_gb)

One of our study's main findings is the significant negative coefficient of TI. This is likely due to the advancements in energy efficiency technologies in EU countries. Figure 3 illustrates a decrease in energy wastage in EU countries. The 2004 PEC was 1,493 million tonnes of oil equivalent (Mtoe), which decreased to 1,257 million tonnes in 2022. In other words, the EU energy efficiency target has achieved approximately 14% of energy savings.

Figure: 4
Energy Efficiency in European Union Countries by Years (2004-2022)



Source: Eurostat (online data code: nrg_ind_eff)

The EU actively promotes smart building technologies to enhance energy efficiency, reduce GHG, and foster more sustainable urban environments. The construction sector accounts for 40% of Europe's energy demand, with 80% of this coming from fossil fuels. Technology and innovation are vital in securing the sector's short- and long-term energy needs. The Horizon Europe project, which began in 2020, has a budget of 95.5 billion USD allocated for this purpose. Furthermore, the European Green Deal seeks to address the climate crisis. It has invested over €1 billion in 73 projects in the private sector to develop solutions that reduce CO_2 emissions, protect Europe's biodiversity, and drive an inclusive, sustainable socio-economic recovery.

Table: 7
Dumitrescu and Hurlin Panel Causality Test

Null Hypothesis	Test	Test Statistics	Probability	Decision
$LCO_2 \rightarrow LFI$	W-bar	1.0868		
	Z-bar	1.1462	0.1135	No causal relationship
	Z-bar tilde	1.6492	0.1097	
$LFI \rightarrow LCO_2$	W-bar	14.0493		
	Z-bar	44.2523	0.0000	FI causes CO_2
	Z-bar tilde	35.3544	0.0000	
$LCO_2 \rightarrow LTI$	W-bar	0.6631		
	Z-bar	1.0911	0.1792	No causal relationship
	Z-bar tilde	1.5408	0.1941	
$LTI \rightarrow LCO_2$	W-bar	13.1482		
	Z-bar	37.5429	0.0000	TI causes LCO_2
	Z-bar tilde	21.4773	0.0000	
$LCO_2 \rightarrow LGDP$	W-bar	2.3783		
	Z-bar	4.6740	0.0000	LCO_2 causes LGDP
	Z-bar tilde	3.4284	0.0006	
$LGDP \rightarrow LCO_2$	W-bar	2.0273		
	Z-bar	3.4837	0.0005	LGDP causes LCO_2
	Z-bar tilde	2.4682	0.0136	
$LCO_2 \rightarrow LPEC$	W-bar	5.1212		
	Z-bar	13.9755	0.0000	LCO_2 causes LPEC
	Z-bar tilde	10.9314	0.0000	
$LPEC \rightarrow LCO_2$	W-bar	3.5452		
	Z-bar	8.6313	0.0000	LPEC causes LCO_2
	Z-bar tilde	6.6205	0.0000	

Table 7 displays the results of Dumitrescu and Hurlin's panel causality analysis, indicating a one-way causal relationship between the FI and TI indicators and CO_2 emissions. The findings align with Zhang (2021). A bidirectional causality relationship was also found between economic growth, PEC variables, and CO_2 emissions.

5. Conclusion

This study is based on data from EU countries for 2001-2022, and the impact of FI, TI, and economic growth on CO_2 emissions is analysed using second-generation panel data methods. The application model includes the M3/M1 ratio representing FI, the total number of patents representing TI, CO2 emissions in metric tonnes per capita, GDP per capita in 2015, and GDP per capita squared. CSD is detected in the model. According to the AMG estimation results, FI and TI are found to reduce emissions. The coefficient of the LGDP variable is positive and statistically significant. In addition, the coefficient of the $LGDP^2$, which is included in the empirical model to observe a possible parabolic relationship between economic growth and carbon emissions, has a negative sign and is statistically significant. This finding confirms the existence of an inverted U-shaped relationship between economic growth and environmental pollution in EU countries. In other words, EKC is valid for EU countries. This result suggests that environmental deterioration accelerates in tandem with economic growth in EU countries. This deterioration continues until a certain optimum level of economic growth is reached, and thereafter, the increase in national income starts to affect EQ positively. In addition, the fact that $LGDP^2$ reduces emissions in the long run and the coefficients of TI and FI provide evidence that innovations contribute to environmentally friendly economic growth. Dumitrescu-Hurlin causality tests uncovered a unidirectional causality relationship from FI and TI to CO_2 emissions, emphasising their critical role in environmental sustainability.

Based on these findings, increasing funding and grants aligned with the Union's 2030 targets is crucial. This initiative offers crucial financial incentives for companies and public authorities to invest in the development of advanced, low-carbon technologies. However, it is essential to acknowledge that while green technologies are encouraged, new technologies may increase energy demand and have a negative impact on environmental quality. Therefore, while funding environmentally friendly projects, it is vital to facilitate households' access to energy-efficient products through appropriate financial support. This will be key in enabling Europe’s transition towards climate neutrality. Industries should receive financial and subsidy support to promote environmentally friendly clean technologies. Efforts must focus on enhancing renewable energy and energy storage facilities within energy-intensive sectors. Additionally, revenues from the EU Emissions Trading System could be allocated to promote the dissemination of innovative low-carbon technologies. This approach would allow businesses to scale up without compromising environmental quality. Furthermore, adequate financial support should be provided for the research, development, and patenting necessary for green technologies. Regulations should encourage banks to consider environmental criteria when providing funding. Investment incentives for sustainable projects must be established, and financing for environmentally harmful activities should face penalties. Responsible lending practices prioritising investments in sustainable projects and technologies should be encouraged. Developing guidelines for financial institutions to assess the environmental impact of their loan portfolios is essential. Financial products and mechanisms that support environmentally friendly initiatives, such as green bonds and loans, should be introduced to promote sustainable development. Partnerships between financial institutions, technology companies, and environmental organisations should be encouraged to drive the adoption of green technologies. Standards for environmental performance that businesses must meet to access financing should be established. Imposing penalties will help deter unsustainable practices that harm the environment. Providing financial support to households for accessing products with lower energy consumption, rather than energy-intensive alternatives, is crucial. Although EU countries have made progress in this regard, it is essential to utilise educational programmes, campaigns, and various media tools to increase public awareness about carbon emissions and climate change. This can enable individuals to make informed choices about reducing their carbon footprint. Lastly, comprehensive environmental impact assessments should be made mandatory for significant infrastructure projects.

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