8. Balancing Progress and Sustainability: Industrial Innovation's Impact on Europe's Emission Management, Economic Expansion, and Financial Growth

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Abstract

Europe has entered an era of environmental consciousness that is accelerating the transition toward more sustainable economic and financial growth. This study investigates the effects of industrial innovation (INV) on production-based emissions (PBE), Gross Domestic Product (GDP), and financial development (FD) in European countries between 1994 to 2021. The study employed CIPS and CADF tests to assess unit roots, while second-generation tests were used to evaluate cross-sectional dependence. The Westerlund (2007) test assesses panel cointegration. The pooled mean grouped (PMG)-ARDL estimates short and long-run parameters. Additionally, the D-H (2012) causality test examines varied causal links while the System Generalized Method of Moment Regression (SGMM) is used for robustness check. The research affirms that INV significantly influences all models, yielding consistent outcomes in both short and long run. The findings show innovative technologies fuelled with renewable energy play critical roles in reducing PBE by 14.6% and 67.1%, respectively, in the long run and increasing GDP by 10.9% and FD by 14.2%, highlighting the significance of INV for sustainable development. Additionally, individual model analyses emphasize the critical role of environmental policy, research and development, renewable energy use, and the challenges posed by energy consumption and economic globalization in shaping emissions. The findings support strategic policies encouraging innovation-driven methods, creating a harmonic alignment of economic growth and environmental preservation in Europe.

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Keywords: *Industrial Innovation; Production-Based Emissions; Gross Domestic Product; Financial Development; Environmental Preservation; Europe.*

JEL Classification: *Q55, O33, O44, O16*

1. Introduction

Europe is currently experiencing a significant phase of transformation, driven by a strong dedication to sustainability (Shetty & Bhat, 2022). According to Usman *et al.* (2022), this dedication is altering the parameters of economic and financial advancement and establishing fresh pathways for societal development (Khurshid *et al.,* 2020). Against this contextual backdrop, the convergence of industrial innovation and its diverse effects on emission control, economic development, and financial development assumes the utmost importance. The need to achieve a harmonious equilibrium between progress and sustainability is currently paramount. As Europe adopts more sustainable practices, there is a growing interest in investigating the significance of industrial innovation in promoting economic progress and environmental conservation (Li *et al.,* 2023). In light of the significant impact of the industrial production chain on the degradation of the environment in Europe, the European Union (EU) acknowledges the necessity of expanding the focus of the Sustainable Development Goals (SDGs). The European Commission has officially implemented the Sustainable Consumption and Production and the Sustainable Industrial Policy Action Plan, which supports European sustainable product policies (Lélé, 1991). The European Union member countries have demonstrated significant dedication to attaining the SDGs (Khurshid *et al.*, 2023). However, it has been observed that the region, on average, has not met expectations in terms of effectively promoting sustainable production and consumption (Usman *et al.*, 2022).

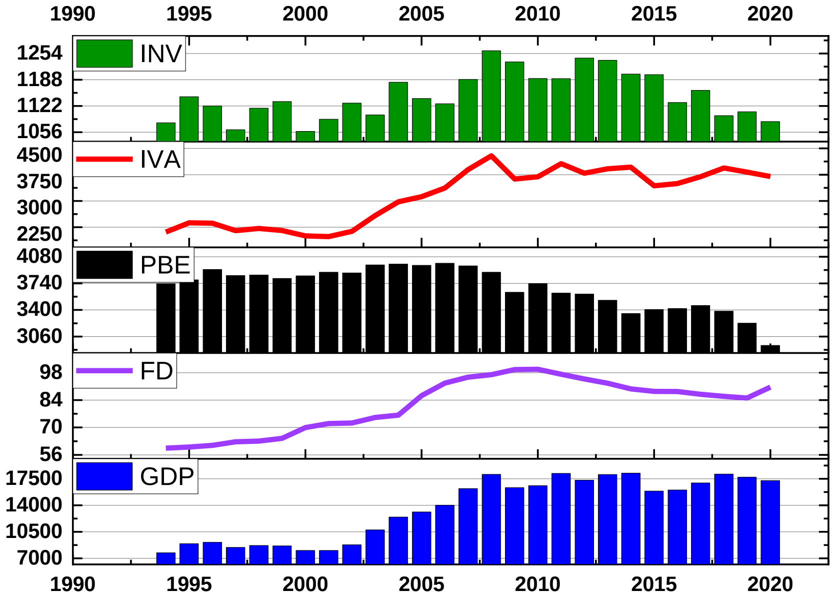
The current state of affairs has significantly focused on the attention garnered by technological advancements to reduce environmental pollution (Khurshid & Khan, 2021). The scholarly investigation of the influence of technological advancements on pollution has exhibited a lack of progress over an extended period. Nevertheless, a body of recent empirical research has provided evidence for the significant impact of eco-innovation in mitigating carbon dioxide (CO2) emissions (Khan *et al.*, 2022). According to Ojekemi *et al.* (2022), innovation, which plays a major role in the evolution of technology, is seen as a significant indicator by the United Nations about the SDGs. Governments are reforming their industrial sectors to achieve the SDGs' targets, emphasizing upgrading energy-efficient technologies (Xie *et al.*, 2022). Certain nations, like Denmark, Norway, and Sweden, have made partial progress in attaining these significant accomplishments (Chen *et al.*, 2023). Nevertheless, a significant proportion of nations around the globe have not successfully enacted measures to effectively facilitate the process of adapting to the impacts of climate change (Cheng *et al.*, 2021). Implementing environmentally sustainable technology in the industrial sector, including grid modernization, carbon storage systems, and renewable energy sources, has significant and far-reaching environmental consequences (Ulucak & Khan, 2020).

Similarly, innovation is regarded as a critical economic growth and development catalyst. It encompasses generating and using novel concepts, methodologies, commodities, and technologies (Nihal *et al.*, 2023). In addition to driving economic progress, innovation is crucial in cultivating resilience within sectors, empowering them to respond and adapt to ever-changing circumstances effectively. Research and development (R&D) projects have been extensively recognized as crucial for fostering economic growth, prompting numerous nations to invest substantially in this domain. The primary objective behind such investments is to encourage innovation and fortify the overall economic landscape. Furthermore, the importance of innovation in job creation is significant, and policies that attempt to foster innovation can have favourable outcomes in terms of employment (Acharya *et al.*, 2022). The interdependent association among innovation and economic growth fosters a positive feedback loop that contributes to the consistent upward trajectory of growth indicators.

The interplay between industrial innovation and the financial sector is crucial, as the financial industry's growth is intricately linked to innovation (Mtar & Belazreg, 2023). The financial system is pivotal in supporting and advancing technological innovation efforts and improving their effectiveness (Qiang *et al.*, 2019). This is achieved through several activities, including collecting and analyzing information, distributing risks, and allocating credit (Lv *et al.*, 2021). Financial sectors that are effectively managed tend to be more appealing to investors since they can enhance the stock market's performance and stimulate overall economic activity. The financial industry is vital in fostering GDP growth by facilitating FDI, thereby contributing to a mutually reinforcing cycle for development (Khan *et al.*, 2023). The existing body of research examines the relationship between financial development and technological innovation within the theoretical structure for financial development and economic growth (Lv *et al.*, 2021). The financial system is crucial in facilitating and sustaining technical innovation efforts and improving technological innovation efficiency.

Researchers have examined alternative emission management, economic expansion, and financial growth aspects in addition to the three areas of investigation that are vulnerable to innovation in the subject under study. Foreign direct investment, energy efficiency, fiscal expenditure, demographic dynamics, globalization, energy consumption trends, R&D, environmental policy, and others are included. This study examined the variables above and their relationship to the study's core factors. Policymakers will have a comprehensive view, improving their efforts to build sustainable European nations.

Figure 1: Parameters trend in European countries



Note: Author computation using annual data

Figure 1 illustrates the temporal patterns of INV, IVA, PBE, FD, and GDP among European nations from 1990 to 2020. The image demonstrates a positive association between the FD and GDP with adopting innovative practices in European countries. Moreover, this trend showed a decrease in the PBE with an increase in INV despite a positive correlation between innovation and the upward trajectory of both FD and GDP. Nevertheless, the level of innovation falls short of expectations. Given the favorable effects of innovation on FD and GDP and its mitigating impact on PBE, there is a clear rationale for accelerating the rate of industrial creative practices within European nations.

Given the setting above, the primary goal of this research is to investigate the intricate relationships between industrial innovation, emission control, economic growth, and financial development in the European context. The research questions can be precisely articulated as follows:

- How does industrial innovation limit production-based emissions in Europe?
- Is the interaction of renewable energy and industrial optimization driving Europe towards a sustainable path?
- How are trade globalization, industrial value-added and fiscal expenditures adding to the financial development of European economies?
- How do industrial optimization, financial development, energy efficiency, and financial globalization contribute to Europe's economic development?

This study aims to enhance our understanding of fundamental aspects of sustainability and advancement by exploring relevant research inquiries. *Firstly*, this analysis examines how industrial innovation can lower production-related emissions, a key issue in global environmental discussions. The study's findings highlight the value of cutting-edge technologies in reducing emissions and establishing a balanced relationship between economic development and environmental conservation. This research also examines how integrating renewable energy sources and modernizing industry affects Europe's sustainability. This study also investigates the complex relationship between trade globalization and fiscal expenditures on European financial development. These findings help policymakers navigate globalization while promoting financial institutions that underpin economic growth and, l*astly*, by examining how industrial innovation affects financial and economic growth. This will give European nations a coherent plan for sustainable growth. The study holds collective importance in providing insights for policy development and strategic decision-making. The research shows that innovation-driven solutions can address environmental issues, boost economic growth, and boost European financial development. The study also uses rigorous analytical methods to strengthen and validate its findings and improve the reliability of its insights.

The study is divided into sections to achieve its goals systematically. Section 2 of this study review critically analyzes previous works. Section 3 describes the research methods. Next, empirical facts and discussion are presented. The study concludes with a full summary of its policy implications.

2. Literature Review

The dedication of Europe to achieving environmental sustainability has generated a keen interest in comprehending the complex dynamics among industrial innovation, emissions control, economic growth, and FD. This part critically examines the pertinent literature on the themes above and establishes the background for the current research.

2.1. Industrial Innovation and Emission Management

The investigation of the impact of technology progress on harmful emissions has remained stagnant for a number of years. Nevertheless, a substantial body of contemporary research has provided empirical evidence supporting the significance of eco-innovation in mitigating harmful emissions (Khan & Khurshid, 2022; Cheng *et al.,* 2021). Significant scholarly research has been conducted in recent years on the effect of industrial innovation on lowering ecological effects. Ren *et al.* (2022) underscored the need to examine the impact of INV on carbon intensity in China. The findings revealed that implementing INV decreased the ecological consequences, contributing to sustainable development. Shang *et al.* (2023) discovered a correlation between green innovation and reduced carbon emissions, specifically when environmentally friendly technology was implemented as a substitute for carbon-intensive alternatives. Moreover, several studies conducted by scholars such as Cao (2023) on E-7 countries, Hailiang *et al.* (2023) on BRICS, and Jian and Afshan (2023) on G-10 countries, have provided evidence to support the notion that INV significantly contributes to promoting ecological sustainability through the reduction of carbon emissions (Wang *et al.,* 2023). Nevertheless, there is a notable deficiency in the existing body of literature regarding the explicit focus on industrial innovation and the comprehensive analysis of its ramifications on emissions derived from production activities. This rationale similarly applies to European countries, classified as industrialized nations whose pollution concerns predominantly stem from an industrial source.

2.2. Industrial Innovation and Economic Growth

Extensive study has been carried out to investigate the relationship between industrial innovation and economic growth. Studies such as Romer (1990) and Aghion and Howitt (2009), which contributed to the development of endogenous growth theory, have proven the link between innovation and sustained economic development. Jaffe (1986) discovered in a prior study that innovation plays a substantial role in aiding economic growth and that policies promoting R&D expenditure can yield sound economic effects (Khurshid *et al.,* 2023). The goal of recent scholarly research undertaken by Nihal *et al.* (2023) has been to analyze the relationship between technological advances and economic expansion across the G8 nations from 1996 to 2020. The results suggest a robust relationship between innovation and GDP growth. Undoubtedly, innovation is pivotal in fostering prospects for augmenting economic progress. After reaching a particular growth stage, European nations pursue innovation-led growth to facilitate environmentally conscious and sustainable economic expansion (Khurshid *et al.,* 2022). This statement provides the rationale for incorporating an econometric model that assesses the influence of industrial innovation on the economic growth of European economies.

2.3. Industrial Innovation and Financial Development

The transformative influence of innovation on financial services, intermediation, and access has been emphasized in the studies conducted by Popov and Rocholl (2015) and Claessens *et al.* (2018), which focused on examining financial technology and digitalization advancements. Moreover, the scholarly investigation conducted by Scholtens (2019) has demonstrated that inventive financial instruments can effectively promote investments in ecologically friendly initiatives. In a similar vein, Lv *et al.* (2021) conducted a study from 2003 to 2017 to analyze the efficiency of INV in over 30 provinces in China. The authors defined the level of FD using the notions of financial structure, scale, and financial efficiency. The study observes the positive relationship between the parameters. They then looked into the relationship and the development of green technology (Khurshid *et al.,* 2021). Similarly, Mtar and Belazreg (2023) used the panel-VAR approach to explore the links among INV, trade openness, FD, and economic development for 11 European countries from 2001 to 2016. They found a positive association between INV and FD. However, a dearth of research investigates the reciprocal relationship, specifically evaluating the impact of innovation on financial development. The absence of research examining the relationship between industrial innovation and financial development in the existing literature justifies the inclusion of this topic in the present study.

3. Data and Method

3.1. Data

The empirical relationship of industrial innovation (INV) with production-based emissions (PBE), economic growth (GDP), and financial development (FD), along with other relevant independent variables, is tested for the 25 European countries. The selected time frame is from 1994 to 2021, as this range was chosen based on data availability and consistency considerations. The data has been taken from a range of sources, including the International Energy Agency (IEA) (https://www.iea.org/statistics/) and the Organisation for Economic Co-operation and Development (OECD) statistics (OECD-ilibrary.org/statistics). Table I provides details.

Table 1: Description of variables

Variable	*Description*	*Variable*	*Description*
PBE	Production-based emissions	*FDI*	Foreign direct investment
GDP	Gross national product	*EEFC*	Energy efficiency (Energy consumption/GDP)
FD	Financial development (Domestic credit to the private sector	*INV*	Sum of innovation related to industries, energy, and water and water technologies
FE	Fiscal expenditure	*POP*	Total population
EGOB	Economic globalization	*TGOB*	Trade globalization
FGOB	Financial globalization	*ECI*	Energy consumption in industries
EPY	Environmental Policy	*RD*	Research and development
RINV	Interaction of renewable energy with industrial innovations		

3.2. Theoretical Modeling

The relationship between industrial innovation, carbon emissions, economic expansion, and financial growth can be described theoretically using a set of equations and concepts from economics (Qayyum *et al.,* 2021). Previously, Zakaria and Bibi (2019) established the theoretical relationship between the aforementioned variables in their study addressing environmental sustainability.

The Environmental Kuznets Curve suggests an inverted U-shaped relationship between income (economic expansion) and environmental degradation (carbon emissions) (Grossman & Krueger, 1991). Initially, as income and economic activity increase, so do emissions. However, emissions begin to decline beyond a certain income threshold due to increased environmental awareness. The EKC can be represented as:

$$E= f\,(Y) \tag{1}$$

Where E represents carbon emissions, Y represents income or economic expansion, and f is a function that describes the relationship.

Furthermore, industrial innovation can reduce carbon emissions through adoption of cleaner technologies and processes (Wang *et al.,* 2022). This can be represented as:

$$E= g\,(I) \tag{2}$$

Where, I represent the level of industrial innovation, g is a function that describes the impact of innovation on emissions.

Moreover, industrial innovation can also drive economic expansion through increased productivity and competitiveness (Surya *et al.,* 2021). The relationship can be represented as:

$$Y=h\ (I) \tag{3}$$

Here, h is a function that describes the impact of innovation on economic expansion.

Lastly, financial growth can be linked to economic expansion through various economic indicators such as GDP or GNI (Hsu *et al.,* 2023). This relationship can be represented as:

$$G= k\ (Y) \tag{4}$$

Where G represents financial growth and k is a function that describes the relationship between economic expansion and financial growth.

3.3. Empirical Modeling

On the basis of a general theoretical base, we construct specific empirical models while taking PBE, GDP, and FD as dependent variables in three separate models:

$$\mathbf{PBE_{it}} = \boldsymbol{\sigma_0} + \boldsymbol{\gamma_1}\mathbf{INV_{it}} + \boldsymbol{\gamma_2}\mathbf{EPY_{it}} + \boldsymbol{\gamma_3}\mathbf{ECI_{it}} + \boldsymbol{\gamma_4}\mathbf{RD_{it}} + \boldsymbol{\gamma_5}\mathbf{EGOB_{it}} + \boldsymbol{\gamma_6}\mathbf{RINV_{it}} + \\ + \mathbf{u_{it}} + \boldsymbol{\epsilon_{it}} \tag{5}$$

for t = 1……..,*T* and *i* = 1………, *N*

In Equation 5, PBE_{it} is the dependent variable that is observed for individual *i* at *t* time.

INV, EPY, ECI, RD, EGOB, and RINV are time-varying parameters. The γs reflect the parameter values, u_{it} represents all of the time-invariant indistinct factors which can affect PBE, and ϵ_{it} is the model's error term. The second and third models, which encompass economic growth and FD, can be written as follows:

$$\mathbf{GDP_{it}} = \boldsymbol{\sigma_0} + \boldsymbol{\gamma_1}\mathbf{INV_{it}} + \boldsymbol{\gamma_2}\mathbf{FDI_{it}} + \boldsymbol{\gamma_3}\mathbf{FD_{it}} + \boldsymbol{\gamma_4}\mathbf{EEFC_{it}} + \boldsymbol{\gamma_5}\mathbf{POP_{it}} + \\ + \boldsymbol{\gamma_6}\mathbf{FGOB_{it}} + \mathbf{u_{it}} + \boldsymbol{\epsilon_{it}} \tag{6}$$

$$\mathbf{FD_{it}} = \boldsymbol{\sigma_0} + \boldsymbol{\gamma_1}\mathbf{INV_{it}} + \boldsymbol{\gamma_2}\mathbf{GDP_{it}} + \boldsymbol{\gamma_3}\mathbf{EEFC_{it}} + \boldsymbol{\gamma_4}\mathbf{FE_{it}} + \boldsymbol{\gamma_5}\mathbf{TGOB_{it}} + \\ + \boldsymbol{\gamma_6}\mathbf{FDI_{it}} + \mathbf{u_{it}} + \boldsymbol{\epsilon_{it}} \tag{7}$$

Whereas, GDP_{it} is the dependent variable, with *INV, FDI, FD, EEFC, POP*, and *FGOB*, independent variables in Equation 6. Whereas *FD* is a dependent variable with *INV, FDI, EEFC, GDP, FE, TGOB,* and *FDI* as independent variables in Equation 7.

In our study, we considered various aspects of globalization and factors that influence environmental conditions, as highlighted in the existing literature. We allocated these independent variables across three separate equations to ensure a comprehensive analysis. This approach allowed us to estimate their specific impacts on the dependent variables that are most closely related to them, drawing from the insights provided by prior research. By distributing the variables this way, we aimed to avoid potential econometric issues arising when variables overlap or are repeated within the same equation. This structured approach enhances the robustness and interpretability of our findings. Importantly, each independent variable we included in our analysis is expected to yield outcomes that policymakers can effectively utilize to inform their decision-making processes.

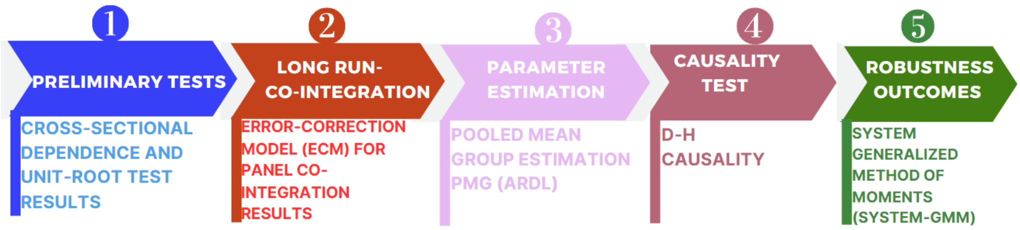
3.4. Methodology

The methodological flow chart is illustrated in Figure 2. Following the computation of descriptive statistics, the study began with the cross-section dependence (CRSD) examination, as is necessary for studying panel data due to its potential impact on prevailing shocks (Wang *et al.,* 2022). The omission of cross-section dependence in an analysis might lead to inaccurate findings, as shown by Tao *et al.* (2021). The CRSD test suggested by Khurshid and Deng (2021) and

Khurshid *et al.* (2022) is used. Once the presence of the CRSD in the panel data has been confirmed, first-generation stationary analyses are not deemed accurate. This study employs second-generation stationary tests, specifically the cross-sectional augmented IPS (CIPS) and cross-sectional augmented Dickey-Fuller (CADF) tests established by Pesaran (2007), to determine the existence of a unit root. After examining the variable's integration order, the next step is to conduct tests to determine the evidence of cointegration among the variables. The Westerlund (2007) panel cointegration test is used for that purpose. This method addresses structural break, autocorrelation, and CRSD issues. The null hypothesis asserts that no significant long-term relationship exists among the examined parameters. As Pedroni (2004) and Khurshid *et al.* (2022) state, this strategy is useful in limiting estimation bias if parameters are integrated at the level and first difference.

The panel dataset examines the enduring association between the investigated variables. The pooled MG model estimates robust estimates (Pesaran *et al.*, 2001, 1999). According to (Johnsen, 1988; Phillips & Hansen, 1990), long run relationships can only be seen when variables are co-integrated in the same integration sequence. However, the ARDL method described by Pesaran & Shin (1995) is applicable when the variables are stationary at the level or first difference. Despite the likelihood of endogeneity, the PMG-ARDL method provides reliable coefficients because it includes reaction slacks and descriptive features (Pesaran *et al.,* 1999).Furthermore, The System Generalized Method of Moment Regression (*SGMM*), proposed by Arellano and Bover (1991), is utilized rouburtness of results obtained from the PMG-ARDL approach. The SGMM is advantageous for panel data analysis. It effectively controls for endogeneity, requires no strict exogeneity, and is well-suited for dynamic models with lagged dependent variables (Fan *et al.,* 2015). Finally, Dumitrescu and Hurlin (2012) are utilized to ascertain the causality among the parameters. This is significant as it allows for formulating policy implications specific to the region being investigated.

Figure 2: Research Flow Chart



4. Result and discussion

4.1. Preliminary Testing Results

Table 1 shows the variables' descriptive statistics before the findings and analysis for quantitative analysis. The data analysis reveals that the variable RINV exhibits the highest average value compared to the other variables representing distinct aspects of globalization. In contrast, the variable EPY indicates the lowest mean value. Furthermore, it is worth noting that the most significant standard deviation value is observed in the PBE method, with RINV showing the second-highest value. This implies that both the PBE and RINV exhibit a considerable degree of volatility. Nevertheless, most variables exhibit low standard deviation values, suggesting that these variables possess limited variability and that their mean values accurately reflect the actual values. The detailed descriptive statistics are shown in Table 2.

The outputs of the CSRD test results support the alternative hypothesis for all variables at a significance level of 1%. The findings of this study confirm the presence of CRSD within the dataset encompassing all 25 European countries, thereby highlighting the interconnectedness among them. Additionally, the CIPS and CADF test outcomes are presented in Table 1A (Appendix). Based on the findings from the test results, it can be observed that all of the variables exhibit stationarity at the first difference and few at the level. Therefore, as per Baloch *et al.* (2021), using error correction-based panel cointegration approaches is more appropriate when there is cross-sectional dependency and when the importance of data is observed at both the level and the first difference.

Table 2: Descriptive Statistics, Cross-Sectional Dependence, and Unit Root Result

Variable	Mean	Std.Dev.	Min	Max	CSRD-Test	CIPS		CADF	
						I(0)	I(I)	I(0)	I(I)
ECI	15.33	19.15	0.564	85.906	13.88^{***}	-2.133	-4.881^{***}	-2.019	-3.396^{***}
EEFC	8.972	1.865	4.648	12.566	66.49^{***}	-3.581^{***}	-5.792^{***}	-2.940^{**}	-4.577^{***}
EGOB	75.77	9.383	37.95	92.852	65.55^{***}	-2.189	-4.921^{***}	-2.111	-3.624^{***}
EPY	2.150	1.061	0.000	4.222	-2.39^{***}	-5.475^{***}	-6.190^{***}	-4.911	-5.660^{***}
FD	84.57	40.93	12.86	304.57	24.55^{***}	-1.008	-3.689^{***}	-1.531	-2.997^{***}
FDI	19.24	11.57	-26.56	27.322	3.68^{***}	-4.182^{***}	-6.070^{***}	-2.520^{**}	-4.808^{***}
FE	25.70	2.629	21.02	34.403	66.68^{***}	-2.516^{**}	-4.176^{***}	-1.915	-2.689^{***}
FGOB	77.19	11.96	33.68	98.033	60.89^{***}	-2.438^{**}	-5.002^{***}	-2.394^{*}	-3.562^{***}
GDP	25.90	1.668	22.22	29.011	75.26^{***}	-1.999	-4.520^{***}	-2.143	-3.717^{***}
INV	46.08	12.15	17.48	130.52	5.62^{***}	-3.695^{***}	-5.922^{***}	-2.735^{**}	-4.126^{***}
PBE	133.0	180.7	1.470	887.06	45.58^{***}	-2.451^{**}	-4.901^{***}	-1.909	-3.846^{***}
POP	15.83	1.457	12.49	18.236	17.27^{***}	-1.476	-2.761^{***}	-2.617^{**}	-2.274^{***}
RD	7.911	1.737	3.576	11.895	74.27^{***}	-1.837	-3.884^{***}	-2.066	-2.861^{***}
RINV	87.28	100.6	0.150	707.71	20.57^{***}	-3.238^{***}	-6.003^{***}	-2.211^{**}	-4.292^{***}
TGOB	74.39	9.104	37.81	90.061	51.88^{***}	-2.106	-4.684^{***}	-2.280^{**}	-3.626^{***}

Note: *** *p < .01,* ** *p < .05,* * *p < .10 and SD means standard deviation*

4.2. Westerlund Panel Cointegration Results

The present study utilizes the Westerlund panel cointegration method to identify relationships among the variables. The results are reported in Table 3. This methodology's test results depend on the group variables (Gs, Ga) and the panel statistics (Pt, Pa). The findings are summarized in Table 3, and in our particular example, the results indicate the rejection of the null hypothesis that there is no cointegration and, therefore, confirm the long-run cointegration among variables in all three models.

Table 3: Westerlund Panel Cointegration Test Results

	Model 1		Model 2		Model 3	
Statistic	**Value**	**Z-value**	**Value**	**Z-value**	**Value**	**Z-value**
Gt	-2.281***	-1.664	-2.444***	-1.783	-2.723*	-2.28
Ga	-11.474***	-6.203	-11.137***	-5.413	-13.427**	-7.038
Pt	-16.453***	-5.42	-15.795***	-6.112	-15.214***	-6.736
Pa	-14.263***	-4.868	-12.371***	-5.033	-14.021***	-5.017

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

4.3. Short and long-run estimation using PMG-ARDL

This study examines the effects of industrial innovation (INV) on PBE, GDP, and FD in a panel setting through PMG-ARDL approach. The empirical results are summarized in Table 4. The results obtained demonstrate consistent outcomes across all models. The outcomes indicate that INV effectively reduces PBE in model 1 in both the short and long-run, while in models 2 and 3, it positively influences GDP and FD in both European countries in the short and long run. The findings demonstrate an apparent decrease in the PBE by 14.6% and 10.1% in long and short run, respectively, as a result of INV practices. These findings are corroborated by previous studies conducted by Cao (2023), Hailiang *et al.* (2023), and Jian and Afshan (2023). Additionally, INV is found to have a positive impact on GDP, as supported by Nihal *et al.* (2023). Furthermore, INV is shown to significantly affect GDP and FD, with an increase of 10.9% and 14.2%, respectively, in long-run and 11.2% and 8.7%, respectively, in short-run. This aligns with the findings of Lv *et al.* (2021) and Mtar and Belazreg (2023). The results of this study indicate that the INV has a substantial impact on the aspects of environmental sustainability, revenue growth, and financial prosperity within European nations. The observed decrease in PBE resulting from INV fits with anticipated environmental outcomes, underscoring the significance of inventive methods and technology in mitigating emissions. Simultaneously, the recorded growth in GDP and the notable surge in FD emphasize the favorable impact of industrial innovation on the economy's expansion and the financial sector's advancement. The findings of this study indicate that promoting industrial innovation has the potential to not only enhance environmental sustainability but also yield a twofold advantage of economic growth and financial advancement in European nations. The findings of this research propose endorsement for the prioritizing of policies centered on innovation as a strategy to attain a future that is both sustainable and affluent in the region under investigation.

The findings of empirical model 1 indicate that environmental policy (EPY), research and development (RD), and the interaction of renewable energy with industrial innovations (RINV) have a significant mitigating influence on PBE. These results align with the conclusions of Wang *et al.* (2022) and Li *et al.* (2023). It has been observed that the consumption of energy in industrial sectors (ECI) and the process of economic globalization (EGOB) play a significant role in contributing to the PBE in both short and long-run. The implications of the study's findings are substantial in terms of understanding the factors that influence PBE and devising effective strategies to alleviate its consequences. The importance of EPY, RD, and RINV in reducing PBE highlights the crucial role of proactive governmental interventions and technological developments. The RINV causes a significant reduction of 67.1% in the PBE in long-run. Similarly, in short-run, the RINV technique exhibits a noteworthy decrease of 18.2% in PBE. This demonstrates that integrating renewable energy with industrial innovation can significantly contribute to achieving European countries' environmentally sustainable production objectives. On the other hand, the significant impact of ECI and EGOB on PBE underscores the difficulties presented by energy-intensive industrial processes and the potential environmental compromises linked to globalization in European countries. The aforementioned results emphasize the necessity of implementing specific policies that facilitate the integration of renewable energy, adopting strategies driven by innovation, and implementing environmental legislation. These measures should also consider the ecological consequences of energy consumption and the impact of globalization trends in the area under investigation.

For empirical Model 2, results further reveal that all the independent variables, i.e., FDI, FD, EEFC, POP, and FGOB, are helpful in the economic expansion of European nations. All variables significantly increase GDP by more than 10% and EEFC and EGOB by nearly 30% in short-run. In short-run variables exhibit the same direction as depicted in the long-run. These findings highlight the need for integrative plans for economic expansion, in which not only traditional drivers such as FDI and FD play important roles but also energy efficiency measures and economic/financial globalization. Energy efficiency (EEFC) and economic globalization (EGOB) contributed to GDP growth by nearly 30%. These findings emphasize the need for policies that promote sustainable energy practices and facilitate international financial integration alongside strategies to attract foreign investment, enhance financial systems, and manage the population dynamics of the European countries.

Similarly, for empirical model 3, having FD as a dependent variable, results further reveal that all the independent variables, i.e., FDI, EEFC, GDP, Fiscal expenditures (FE), and trade globalization (TGOB), are significantly increasing FD in the European countries in both short and long-run. This validates the selected variables' importance in defining the European countries' financial development status moreover, identifying the potential areas to be targeted by the policymakers to enhance the FD of the European nations. The exact relationship between INV and FD is validated by Mtar and Belazreg (2023). This validation underscores these variables' pivotal role in shaping European countries' financial development landscape. Policymakers can enhance the financial sector and contribute to the economic well-being of European nations through various strategies. These include directing efforts towards attracting and nurturing FDI to stimulate capital inflows, promoting energy efficiency to support sustainable economic growth, optimizing fiscal expenditures to ensure responsible financial management, and facilitating trade globalization to foster cross-border economic integration.

The findings imply that European governments are committed to boosting economic growth by recognizing financial development's importance. A balanced and mutually beneficial link between development and ecological conservation is needed to safeguard the environment while advancing. To navigate such a system, prioritize industrial innovation and be forward-thinking. European nations may boost economic growth and manage environmental issues using creative techniques and clean technologies. The change in outlook means that expansion no longer relies on finite resources but thrives on green strategies. These nations can set up environmentally friendly industries by investing in renewable energy, resource-efficient sectors, and progressive research.

Table 4: PMG-ARDL Results

	Model 1: PBE		**Model 2: GDP**		**Model 3: FD**	
Variables	**LR**	**SR**	**LR**	**SR**	**LR**	**SR**
_ec		-0.087***				
		(0.025)				
INV	-0.146*	-0.101*	0.109***	0.112***	0.142***	0.087**
	(0.092)	(0.084)	(0.007)	(0.072)	(0.062)	(0.044)
EPY	-0.305***	0.169***				

	Model 1: PBE		Model 2: GDP		Model 3: FD	
Variables	**LR**	**SR**	**LR**	**SR**	**LR**	**SR**
	(1.978)	(0.226)				
ECI	0.428***	0.253*				
	(0.085)	(0.167)				
RD	-0.165***	0.054				
	(0.090)	(1.048)				
EGOB	0.830***	0.045				
	(0.373)	(0.265)				
RINV	-0.671***	-0.182***				
	(0.023)	(0.033)				
FDI			0.153***	0.141***	0.160**	0.142*
			(0.001)	(0.012)	(0.092)	(0.102)
FD			0.133***	0.086**		
			(0.025)	(0.010)		
EEFC			0.280***	0.197***	0.166***	0.140**
			(0.022)	(0.026)	(0.045)	(0.051)
POP			0.168***	0.157		
			(0.019)	(1.850)		
FGOB			0.326***	0.2490**		
			(0.013)	(0.021)		
GDP					0.282**	0.165***
					(0.123)	(0.105)
FE					0.117***	0.036
					(0.009)	(0.561)
TGOB					0.195***	0.175***
					(0.095)	(0.049)
Constant	131.5***	20.32***		11.45***	-318.1***	-595.0***
	(27.01)	(7.430)		(2.703)	(111.1)	(186.7)
No. of ids	25	25	25	25	25	25

*Note: Standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$*
Where LR and SR are long and short-run effect.

4.4. Robustness Outcomes

The System Generalized Method of Moment Regression (*SGMM*), proposed by Arellano and Bover (1995), is used for robustness check when T is considered fixed, and the results are summarized in Table 5. The findings suggest that INV lowered PBE by 9.2%. However, it positively affects GDP by increasing it by 8.2% and FD by 32.8%. The PMG-ARDL estimate supports these findings, and previous research confirms the independent factors' direction and relevance. Finally, the panel Granger causality test proposed by Dumitrescu and Hurlin (2012) determines the causative relationship between the variables under investigation. Results are presented in Table 1A (see Appendix) and Figure 3.

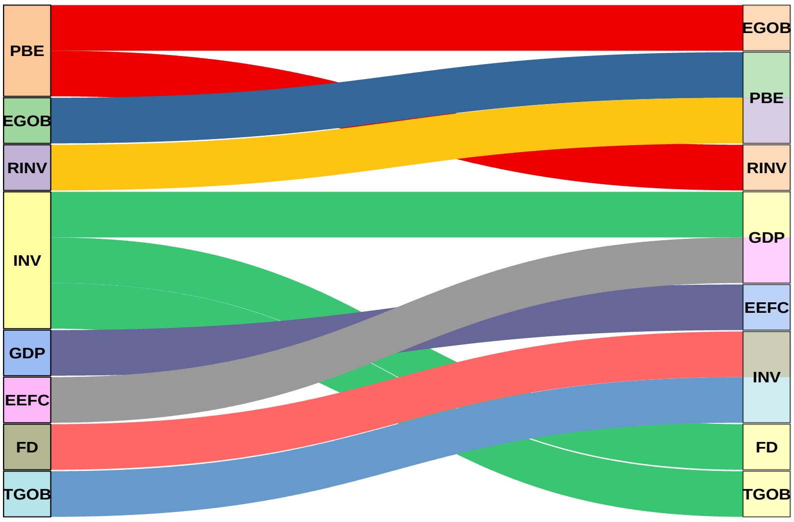
The causality results indicate evidence of a bidirectional causal relationship between INV, GDP, and FD. Similarly, the RINV exhibits a bidirectional causal association with PBE. The observed bidirectional causal relationship of industrial innovation with GDP and financial development underscores the dynamic nature of these interactions. This implies that the augmentation of industrial innovation not only fosters economic expansion but also exerts a favorable influence on the advancement of the financial sector, hence emphasizing the potential synergy between technical progress and financial development. Furthermore, the intricate relationship between RINV (Interaction of renewable energy and industrial innovation) and PBE highlights the reciprocal cause-and-effect link, stressing the nuanced connection between innovative endeavors and their environmental impacts. This suggests that adding renewable energy technologies into industrial innovation programs could reduce emissions and improve cleaner production. This study shows that comprehensive and coordinated methods that use innovation to achieve positive outcomes are needed. This also emphasizes the importance of innovation in affecting Europe's three core areas. It also verifies our past PMG-ARDL model results. Moreover, most remaining variables have shown unidirectional or bidirectional causal links.

Table 5: SGMM outcomes for robustness check

	PBE	**GDP**	**FD**
PBE(-1)	0.843^{**} (0.317)		
GDP(-1)		0.695^{***} (0.019)	
FD (-1)			0.873^{***} (0.017)
INV	-0.092^{*} (0.021)	0.082^{**} (0.011)	0.328^{***} (0.106)
EPY	-0.459^{**} (0.117)		
ECI	0.623^{***} (0.120)		
RD	-0.266^{***} (0.019)		
EGOB	0.898^{***} (0.221)		
RINV	-0.716^{***} (0.189)		
FDI		0.121^{**} (0.013)	0.117^{***} (0.019)
FD		0.135^{***} (0.019)	
EEFC		0.227^{***} (0.106)	
POP		0.162^{*} (0.100)	0.103^{***} (0.016)
FGOB		0.331^{***} (0.017)	
GDP			0.281^{***} (0.102)
FE			0.093^{*} (0.011)
TGOB			0.141^{***} (0.026)
_cons	35.99^{***} (9.832)	12.48^{***} (1.427)	-198.3^{*} (107.2)
Observations	700	700	700
Countries	25	25	25
AR(2)	0.214	0.139	0.263
Hansan (P-values)	0.117	0.316	0.462

Note: Standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure 3: Visual evidence by Granger causality from EU25 countries



5. Conclusion and Policy Implications

The widespread ecological consciousness in Europe has driven a shift toward sustainable economic and financial progress. This research proposes to analyze the influence of INV on PBE, GDP, and FD across 25 European nations from 1994 to 2021. The study also employs PMG-ARDL models to estimate parameters. Additionally, the D-H (2012) causality approach is applied to unveil potential causal connections between the variables. The study also utilizes the System Generalized Method of Moment Regression (*SGMM*) for the robustness check of the outcomes. The study concludes that industrial innovation emerged as a potential determinant of European sustainable development.

The policy implications of this study are significant. Environmental policy should build on the positive association between industrial innovation (INV) and reduction of production-based emissions (PBE). Incentivizing enterprises to embrace innovative technologies and sustainable practices can improve emissions mitigation measures, meeting global environmental goals. INV and GDP development are linked, emphasizing the need for innovation ecosystems. INV's significant impact on financial development (FD) suggests financial policies that promote capital access and innovation-driven investment are necessary. Supporting innovation clusters, venture capital networks, and technology transfer platforms improves financial services and diversifies the economy. These findings highlight the need for integrated policies that leverage innovation, sustainability, economic growth, and financial sector resilience.

Furthermore, the findings have important policy implications for PBE mitigation. Strong regulatory frameworks and focused innovation investment are needed because environmental policy (EPY) and research and development (RD) are beneficial. Promoting renewable energy and industrial innovations (RINV) can reduce emissions effectively. The high estimations suggest that renewable energy and industrial innovation can help European countries achieve their ecologically friendly output goals. Energy efficiency programs are needed due to industrial energy consumption (ECI), but economic globalization (EGOB) requires environmentally friendly trade and economic strategies.

The positive effects of FDI, EEFC, GDP, Fiscal Expenditures (FE), and Trade Globalization (TGOB) demonstrate the complexity of financial development determinants. For FDI to bring cash and knowledge into local financial markets, policymakers should prioritize an appealing investment environment. The focus on energy efficiency promotes measures that encourage sustainable economic growth and reduce resource use. Optimization of fiscal expenditures is crucial to ensure government spending supports the financial sector. Trade globalization can boost cross-border financial flows with proper risk management. By addressing these elements, policymakers may deliberately promote financial development to boost European economic stability and resilience.

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Appendix:

Table 1A: Dumitrescu & Hurlin Panel Granger Causality Results

	W-bar	*Z-bar*	*Z-bar t*		*W-bar*	*Z-bar*	*Z-bar t*
PBE to EGOB	2.609	5.338***	4.261***	***GDP to EEFC***	3.127	2.644***	1.709*
EGOB to PBE	2.760	1.784*	1.215*	***EEFC to GDP***	7.748	13.480***	10.431***
PBE to RINV	4.489	5.838***	4.280***	***FD to INV***	1.913	-0.203	-0.583
RINV to PBE	3.295	3.037***	2.025**	***INV to FD***	4.130	4.997***	3.603***
GDP to INV	1.453	-1.281	-1.451	***INV to TGOB***	3.474	1.876*	1.476*
INV to GDP	4.215	5.196***	3.763***	***TGOB to INV***	3.621	3.802***	2.641***

*Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$*