DOI: 10.20472/IAC.2026.070.012

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GREEN FINANCE AND CARBON INTENSITY: EVIDENCE FROM SELECTED EUROPEAN ECONOMIES INCLUDING TURKEY

Abstract:

This study examines the determinants of carbon intensity in selected European economies, including Germany, France, Italy, Spain, the Netherlands, Poland, and Türkiye, over the period 1990-2024. The analysis focuses on the roles of financial development, renewable energy consumption, energy intensity, inflation, tax revenue, and GDP per capita. Considering cross-sectional dependence and structural heterogeneity across countries, the Dynamic Common Correlated Effects Mean Group (DDCEMG) estimator is employed. The empirical results indicate that renewable energy consumption is the only variable with a statistically significant long-run effect on carbon intensity at the panel level. Other macroeconomic variables do not show robust average effects. Overall, the findings suggest that structural transformation in the energy mix plays a more decisive role in reducing carbon intensity than general macro-financial expansion.

Keywords:

Carbon intensity; renewable energy; financial development; DCCE; European economies.

JEL Classification: C33, O44, Q56

1. Introduction

Climate change has become one of the most pressing global challenges, driven largely by rising greenhouse gas emissions associated with economic growth, industrialization, and energy consumption. Carbon intensity, defined as the amount of carbon emissions per unit of economic output, is widely used as an indicator to evaluate the environmental efficiency of economic systems. Reducing carbon intensity is a key objective of global climate agreements, including the Paris Agreement and the European Green Deal, which aim to achieve sustainable economic growth while minimizing environmental degradation.

In this context, financial development has emerged as a critical factor influencing environmental outcomes. A well-developed financial system can facilitate investments in clean technologies, renewable energy projects, and environmentally friendly innovations. By improving access to capital and reducing financing constraints, financial development may accelerate the transition toward low-carbon economies. However, financial development may also increase carbon emissions by supporting industrial expansion, energy consumption, and economic activities that rely on fossil fuels. Therefore, the relationship between financial development and environmental sustainability remains theoretically ambiguous and requires empirical investigation.

At the same time, renewable energy consumption plays a crucial role in reducing carbon intensity. The transition from fossil fuels to renewable energy sources such as wind, solar, and hydropower contributes significantly to lowering carbon emissions and improving environmental quality. Many European countries have implemented policies promoting renewable energy adoption to achieve their decarbonization targets. However, the effectiveness of these policies may vary depending on countries' financial structures, economic conditions, and energy dependence.

The relationship between financial development, renewable energy consumption, and carbon intensity has attracted increasing attention in the empirical literature. Previous studies have examined the environmental effects of financial development and energy consumption using various econometric approaches. However, many of these studies rely on conventional panel data estimators that assume cross-sectional independence and parameter homogeneity. These assumptions may not hold in macroeconomic panels consisting of interconnected countries exposed to common shocks such as global financial crises, energy price volatility, and international environmental policies. Ignoring cross-sectional dependence may lead to biased and inconsistent estimates.

Unlike previous studies that focus solely on financial development and renewable energy, this study incorporates additional macroeconomic controls such as energy intensity, inflation, tax revenue, and GDP per capita to capture structural, fiscal, and scale effects on carbon intensity. The selected European economies, including both advanced and emerging countries such as Germany, France, Italy, Spain, the Netherlands, Poland, and Turkey. This heterogeneous sample provides a suitable framework to analyze how macro economic indicatords influence environmental outcomes across different stages of economic and financial development. Also, this study employs the Dynamic Common Correlated Effects (DCCE) estimator developed by Chudik and Pesaran (2015), which accounts for cross-sectional dependence, unobserved common factors, and heterogeneity across countries. By using this advanced econometric approach, the study provides more reliable and robust empirical evidence compared to conventional panel data methods. The last, this study focuses on carbon intensity rather than

total carbon emissions, allowing for a more accurate assessment of environmental efficiency in relation to economic output. The remainder of the paper is organized as follows. Section 2 reviews the relevant literature. Section 3 presents the data and methodologyand the empirical results. Section 4 discusses the policy implications. Finally, Section 5 concludes the study.

2. Emprical Literature

The recent literature largely confirms that green finance and financial development contribute to reducing carbon intensity through mechanisms such as green technological innovation, energy efficiency improvements, and structural transformation. However, many existing studies rely on conventional panel estimators that assume cross-sectional independence or focus on single-country settings, particularly China or region-specific cases. Although some recent works incorporate mediation or spatial dynamics, fewer studies explicitly address cross-sectional dependence and unobserved common shocks in multi-country European panels.

Table 1: Recent Empirical Studies Financial Development, Energy Structure, and Macroeconomic Determinants of Carbon Intensity

Authors	Region / Data Set	Key Variables	Methodology	Main Finding
Yang et al. (2026)	31 OECD countries (2003–2022)	Carbon intensity; Green finance; ISU; GTI	OLS, PCSE, System-GMM, IV	Green finance reduces carbon intensity directly and indirectly via industrial upgrading and green innovation.
Ocansey & Haywood-Dadzie (2025)	19 African countries (2014–2024)	CO_2 emissions; Environmental taxes; Tax design; Policy frameworks	Systematic review of 105 studies	Environmental taxes significantly reduce carbon emissions overall, but effectiveness varies by socio-economic context, tax design, implementation, and complementary policies. Revenue recycling and compensatory measures improve equity, while weak frameworks or political opposition limit success.
Jin et al. (2025)	China (30 provinces)	Carbon emission intensity; Digital economy; Green finance; Energy structure; Green innovation	Panel regression with threshold and moderating analysis	Digital economy significantly reduces carbon emission intensity by restructuring energy consumption and promoting green innovation; green finance moderates this effect with a nonlinear (strong initial, weak subsequent) threshold role, and the digital economy’s impact strengthens over time.

Authors	Region / Data Set	Key Variables	Methodology	Main Finding
Qin et al. (2024)	Guangzhou & 25 cities, China (2005-2019)	Carbon emission efficiency (CEE); Green Finance Pilot Policy (GFPP); Spatial spillovers; Energy efficiency; Green innovation	Synthetic control method; SDID model for spatial spillovers	GFPP increased Guangzhou's CEE by 25.3% on average and improved neighboring cities' CEE within a 100 km decaying boundary. Green technological innovation and energy efficiency were key mechanisms.
Zhang & Ke (2022)	China (regional, 2000s-2020s)	Carbon intensity; Green finance; Capital stock per capita	Threshold effect model Moderating effect model	A 1% increase in green finance reduces carbon intensity by 2%; capital stock per capita significantly moderates and strengthens this effect, with threshold effects showing stronger inhibition in regions with higher capital stock. Policy and financial structure optimization are recommended for enhancing green finance efficacy.
Belgacem et al. (2023)	UAE & Saudi Arabia (2010-2021)	Renewable energy; Financial innovation; Carbon emissions; Environmental protection	Panel data analysis	Renewable energy and financial innovation significantly improve environmental protection. Green finance amplifies the positive effects of innovation on renewable energy adoption, supporting carbon reduction and sustainable development.
Sun et al. (2022)	China (carbon market and energy markets)	Carbon market prices; Energy market (crude oil, coal, natural gas, new energy, new energy vehicles)	Time-varying parameter VAR (TVP-VAR); TVP-DY spillover indices	Dynamic spillover effects exist between China's carbon and energy markets; traditional fossil energy affects carbon prices most, while new energy markets provide hedging. The carbon-energy network exhibits fragile cycle spillovers, highlighting complex risk transmission.
Mohsin et al. (2023)	25 EU countries (2000-2021)	Green finance; Green Climate Fund (GCF)	Panel regression; Generalized	Green finance significantly influences quality economic growth and enhances the

Authors	Region / Data Set	Key Variables	Methodology	Main Finding
		portfolio structure; Economic growth	two-step moment method (GMM)	capacity to channel climatic funding; GCF portfolio structure supports de-risking and scaling up climate finance.
Jóźwik et al. (2025)	13 countries with advanced green finance (1994–2020)	Green finance; Ecological footprint; Green growth; Financial globalization; Capital formation	Panel econometrics (AMG, FMOLS, DOLS); Causality tests	Green finance and green growth significantly reduce ecological footprint, while economic growth, financial globalization, and capital formation increase environmental pressure.
Hasan & Hoque	11 EU countries (2001-2019)	CO_2 emissions; Green finance; Biofuel consumption; Technological progress	Panel cointegration & panel regression (FMOLS, DOLS)	Green finance alone shows no significant direct effect on CO_2 emissions, but when combined with biofuel consumption and technological progress it significantly reduces emissions, highlighting the importance of energy transition and technology in achieving EU 2050 carbon goals.
Yardımcı & Oskay (2025)	Turkey (2001-2021)	Green finance; Financial globalization; Load capacity factor (LCF)	ARDL, FMOLS, DOLS, CCR estimators	Green finance positively influences environmental sustainability in the long term in Turkey and exhibits a U-shaped relationship with ecological pressure (supporting the load capacity curve hypothesis). Financial globalization shows mixed effects.

In this context, the present study contributes to the literature by employing the Dynamic Common Correlated Effects (DCCE) estimator, which explicitly controls for cross-sectional dependence, global shocks, and parameter heterogeneity across countries. Given the high degree of financial and economic integration among European economies, ignoring such interdependencies may lead to biased conclusions. By focusing on selected European economies including Turkey and using carbon intensity as an environmental efficiency indicator, this study provides more robust and policy-relevant evidence on the role of macro-economic indicators in the decarbonization process.

3. Methodology

This study examines the determinants of carbon intensity by focusing on financial development (proxied by domestic credit), renewable energy consumption, energy intensity, inflation, tax revenue, and GDP per capita in selected European economies.

Since macroeconomic panels consisting of multiple countries are likely to be affected by common shocks such as global financial crises, energy price fluctuations, and environmental policies, conventional panel data estimators assuming cross-sectional independence may produce biased and inconsistent results. In such cases, unobserved common factors can lead to cross-sectional dependence across countries, which must be properly addressed to obtain reliable estimates.

To account for these issues, this study employs the Dynamic Common Correlated Effects (DCCE) estimator developed by Chudik and Pesaran (2015), which extends the Common Correlated Effects (CCE) approach proposed by Pesaran (2006). The DCCE estimator controls for cross-sectional dependence by incorporating cross-sectional averages of the dependent and independent variables into the model, thereby capturing unobserved common factors and global shocks affecting all countries in the panel. Furthermore, this method allows for heterogeneity in slope coefficients across countries, making it particularly suitable for panels consisting of economies with different levels of economic and financial development.

The use of the DCCE estimator is especially appropriate in the context of environmental and macroeconomic panel data, where countries are interconnected through financial markets, trade linkages, and global environmental policies. By controlling for cross-sectional dependence and parameter heterogeneity, the DCCE estimator provides consistent and efficient estimates even in the presence of multifactor error structures. Therefore, this approach ensures robust empirical results regarding the relationship between financial development, renewable energy consumption, and carbon intensity.

Our question is; How do financial development, energy intensity, renewable energy consumption, and macroeconomic factors affect carbon intensity in European economies under cross-sectional dependence?

This study focuses on selected European economies including both advanced and emerging countries such as Germany, France, Italy, Spain, the Netherlands, Poland, and Turkey. These countries were selected due to their heterogeneous economic structures, varying levels of financial development, and different stages of energy transition. While advanced European economies have made significant progress in renewable energy adoption, emerging economies such as Turkey and Poland are still undergoing structural transformation toward low-carbon systems. This heterogeneity provides a suitable framework to examine the role of financial development in facilitating decarbonization. The data is gathered from World Bank Development Indicators databank for the period between 1990-2024. Augmented Dickey-Fuller (ADF) unit root test. The tests were performed for carbon intensity (CI), domestic credit to the private sector (CRDT), GDP per capita (GDPper), energy intensity (EI), renewable energy consumption (RE), tax revenue (TAX), and inflation (INF) at both level and first-difference forms. The results indicated that the variables were either stationary at level, I(0), or became stationary after first differencing, I(1), satisfying the prerequisite for the subsequent panel cointegration analysis.

H_0**:** $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6$=0

H_1: At least one $\beta_k \neq 0$

The null hypothesis states that energy intensity, domestic credit, inflation, renewable energy consumption, tax revenue, and GDP per capita have no statistically significant impact on carbon intensity in the selected European economies. In other words, variations in these macroeconomic and financial variables do not systematically explain changes in carbon intensity once cross-sectional dependence and unobserved common factors are controlled for.

The alternative hypothesis posits that at least one of the explanatory variables significantly affects carbon intensity. Rejecting the null hypothesis would imply that carbon intensity is influenced by macroeconomic, financial, and energy-related factors, suggesting that policy instruments such as renewable energy promotion, financial development, fiscal policy, and energy efficiency improvements play a measurable role in the decarbonization process.

To investigate the impact of independent variables on carbon intensity, the following empirical model is specified: where i and t denote country and time period, respectively. CI represents carbon intensity, $CRDT$ denotes domestic credt, RE refers to renewable energy consumption, INF refers to inflation and TAX refers to tax revenue, $GDPper$ represents economic growth, and EIindicates energy intenstiy. a_i captures country-specific fixed effects, and ε_{it} is the error term. All variables are transformed into natural logarithms to reduce heteroskedasticity, improve normality, and allow interpretation of the estimated coefficients as elasticities. This transformation also helps mitigate the influence of extreme values commonly observed in macroeconomic data.

To account for cross-sectional dependence and unobserved common factors, the Dynamic Common Correlated Effects (DCCE) estimator incorporates cross-sectional averages of both dependent and independent variables. The DCCE model can be expressed as follows:

$$InCI_{it} = a_i + \beta_1 InCRDT_{it} + \beta_2 InRE_{it} + \beta_3 InGDPper_{it} + \beta_4 InEI_{it} + \beta_5 InTAX_{it} + \beta_6 InINF_{it} + \varepsilon_{it} \quad (1)$$

$$InCI_{it} = a_i + \sum_{k=6}^{6} \beta_k InX_{it} + \gamma_0 \overline{\ln \mathrm{CI}_t} + \sum_{k=6}^{6} \gamma_k \overline{\ln \mathrm{X}_k} + u_{it} \quad (2)$$

where $\overline{\ln \mathrm{CI}_t}$ and $\overline{\ln \mathrm{X}_k}$ represent the cross-sectional averages of the dependent and independent variables, respectively. These averages serve as proxies for unobserved common factors and global shocks affecting all countries in the panel. The DCCE estimator allows for heterogeneity in slope coefficients and provides consistent estimates even in the presence of multifactor error structures and strong cross-sectional dependence. This makes it particularly appropriate for European macro panels characterized by financial integration, trade linkages, and shared environmental policies.

The Delta and Delta-adjusted tests examine whether slope coefficients are homogeneous across countries.

Table 2: Delta Test Results

Dependent Variable: CI	***CRDT***	***GDPper***	***EI***	***RE***	***TAX***	***INF***
Δ prob.	0.373	0.920	0.430	0.000	0.033*	0.935
Δ-adj. prob.	0.376	0.929	0.427	0.000	0.027*	0.943

In the table 2 for CRDT, GDPper, EI, and INF, the probability values are above 0.05 → fail to reject the null of slope homogeneity. For RE (Renewable Energy) and TAX, the probability values are statistically significant; RE: p = 0.000 and. TAX: p ≈ 0.03.Thus, the impact of renewable energy consumption and tax revenue on carbon intensity differs significantly across countries. The effects of financial development, energy intensity, GDP per capita, and inflation appear statistically homogeneous. This result is economically meaningful and The heterogeneous effect of renewable energy suggests that the carbon-reducing impact of renewables depends on energy mix structure, technological capacity, policy efficiency, stage of energy transition. For example, the elasticity of RE in Germany may differ substantially from that in Turkey or Poland, given coal dependence and structural differences. The heterogeneous tax effect implies fiscal structure and environmental taxation effectiveness vary across countries. This supports our methodological choice of DCCE, which allows for slope heterogeneity.

Table 3: CD_{LM} *Model Test Results*

Dependent Variable: CI	***Statistic***	***Prob. Value***
CD_{LM1} (Breusch, Pagan 1980)	14.617	0.147
CD_{LM2}(Pesaran 2004 CD_{LM})	1.032	0.151
CD_{LM} (Pesaran 2004 CD)	-1.175	0.120
Bias-adjusted	38.780	0.000*

According to Table 3 standard LM and CD tests are statistically insignificant but bias-adjusted LM test is significant (p = 0.000). In macro panels with large T (1990–2024) and for financially integrated economies with common global shocks the bias-adjusted LM test is more reliable. There is strong cross-sectional dependence in the panel. This is expected for interconnected European economies with common shocks (financial crises, energy price shocks), EU environmental regulations, global climate agreements, trade integration. Countries such as France, Italy, and Netherlands are financially and economically integrated. Ignoring cross-sectional dependence would produce: biased coefficients, Overstated significance and Spurious inference. Therefore, using the Dynamic Common Correlated Effects (DCCE) estimator (Chudik & Pesaran, 2015) is justified.

Table 4: ECM Bootstrap Test Results

Dependent Variable: CI	***Mod 1 (None)***		***Mod 2 (Constant)***		***Mod 3 (Constant & Trend)***	
g_{-tau}	-9.626	0.000*	0.000	0.000*	-14.546	0.000*
g_{-alpha}	-7.599	0.000*	0.000	0.000*	-7.585	0.000*
p_{-tau}	-9.608	0.000*	0.000	0.000*	-15.202	0.000*
p_{-alpha}	-5.395	0.000*	0.000	0.000*	-8.589	0.000*

Table 4 indicates that all models (None, Constant, Constant & Trend) show strongly significant negative statistics and bootstrap p-value are 0.000. We reject the null of no cointegration. There exists a long-run equilibrium relationship between all variables. This means carbon intensity is not drifting randomly relative to macroeconomic variables. Instead independent variables jointly determine environmental efficiency in the long run.

The Mean Group (MG) estimator should be reported as the primary specification because the diagnostic tests indicate the presence of slope heterogeneity across countries. The Delta test results reject the null hypothesis of homogeneous slopes for key variables, particularly renewable energy and tax revenue. This implies that the environmental effects of these macroeconomic variables differ structurally across the sample economies. Under such conditions, pooled estimators impose a restrictive assumption of identical coefficients for all countries, which may lead to biased and economically misleading conclusions. In contrast, the Mean Group estimator allows each country to have its own slope coefficients and then computes the average of these heterogeneous effects, thereby preserving cross-country structural differences.

Moreover, the existence of cross-sectional dependence further strengthens the case for using the Dynamic Common Correlated Effects Mean Group (DCCEMG) estimator. European economies are highly interconnected through trade, financial markets, and common environmental policies, which generates unobserved common shocks. The DCCEMG framework explicitly controls for these common factors while allowing for heterogeneous slope coefficients. Given the structural diversity among countries such as France, Germany, Italy, Spain, Netherlands, Poland, and Türkiye, imposing common elasticities would obscure meaningful differences in energy transition paths and financial-environmental linkages. Therefore, reporting the Mean Group results ensures econometric consistency and more credible policy interpretation.

Table 5. DCCE Mean Group (Long-run avarage elasticities)

Variables	Coefficient	Std. Error	t-stat	Significance
GDPper	-0.00020	0.000685	-0.304	Not significant
INF	-0.00001	0.001083	-0.009	Not significant
EI	0.06391	0.09429	0.678	Not significant
CRDT	0.01257	0.03352	0.375	Not significant
TAX	0.10100	0.06806	1.484	Not significant
RE	-0.00832	0.00265	-3.146	*Significant (1%)*

According to Table 5, only renewable energy consumption demonstrates a statistically significant long-run effect on carbon intensity in the panel. All other macroeconomic variables are statistically insignificant at conventional significance levels (10%, 5%, 1%). This implies that, at the European average level, decarbonization is primarily driven by energy structure rather than financial or macroeconomic conditions.

Although the Mean Group estimator provides the average long-run effect across countries, country-specific coefficient estimates are essential for identifying structural asymmetries. The environmental impact of financial development, energy intensity, or fiscal variables may differ substantially depending on a country's energy mix, regulatory framework, and stage of economic development. Panel averages alone may conceal these differences and potentially lead to overgeneralized conclusions. By examining country-level coefficients, the analysis reveals whether the estimated relationships are uniform, divergent, or even opposing across economies, thereby offering a more nuanced understanding of carbon intensity dynamics.

In addition, environmental and financial policies are implemented at the national level, making country-specific elasticities directly relevant for policy design. A statistically significant panel-

average effect does not necessarily imply identical responses across all countries. Conversely, insignificant individual coefficients do not invalidate a consistent directional pattern across the panel. Reporting country-level results helps avoid ecological fallacy, improves transparency, and strengthens the credibility of the empirical findings. Therefore, combining Mean Group averages with country-specific estimates provides both generalizable insights and country-tailored policy implications within the European context.

Table 6: Country-specific CCE Long-run Coefficients

Countries	*GDPper*	*INF*	*EI*	*CRDT*	*TAX*	*RE*
France	0.003	-0.001	0.091	0.011	-0.010	-0.011
Germany	0.000	-0.002	-0.247	-0.012	-0.098	-0.001
Italy	-0.003	0.005	0.482	0.077	0.116	-0.006
Spain	0.001	-0.003	0.099	0.064	-0.095	-0.021
Netherland	-0.002	-0.003	-0.238	-0.035	0.390	-0.002
Poland	0.001	-0.001	0.116	0.127	0.200	-0.013
Turkey	-0.001	-0.000	0.144	-0.144	0.205	-0.005

Table 6 shows that at the country-specific level, none of the regressors consistently achieve statistical significance individually. However, when heterogeneity is averaged across countries using the Mean Group estimator, renewable energy consumption becomes statistically significant. This indicates that the decarbonization effect of renewable energy is systematic but modest at the country level. Statistical power increases when averaging heterogeneous slopes. Macroeconomic variables exhibit high cross-country heterogeneity and lack robust individual significance.

Results and Policy Implications

The results reported in the tables 5 and 6 show that renewable energy consumption is the only variable exerting a statistically significant long-run effect on carbon intensity at the panel level. The negative elasticity indicates that improvements in the energy mix contribute, albeit modestly, to enhancing environmental efficiency across the selected European economies. In contrast, financial development, energy intensity, tax revenue, and income do not display statistically robust average effects, although their country-specific coefficients vary considerably. This heterogeneity suggests that macroeconomic and financial variables influence carbon intensity in structurally different ways depending on national energy dependence, regulatory frameworks, and stages of transition. In economic terms, the findings imply that decarbonization in Europe is more closely associated with structural energy transformation than with general macro-financial expansion.

From a policy perspective, the evidence supports the view that sustained progress in renewable energy deployment remains central to reducing carbon intensity, while acknowledging that the magnitude of its impact differs across countries. The country-level estimates indicate that uniform policy prescriptions may not be equally effective, and that national energy structures and institutional capacities should be taken into account. At the same time, the absence of a statistically significant average effect for domestic credit suggests that financial deepening alone does not automatically translate into environmental gains. Strengthening the allocation of

financial resources toward low-carbon sectors, rather than expanding aggregate credit, may therefore be more consistent with long-run decarbonization objectives.

Overall, the findings are broadly in line with recent empirical studies emphasizing the environmental benefits of renewable energy expansion, while offering more cautious evidence regarding the independent role of financial development. Unlike some contributions that report a uniformly strong finance environment nexus, the present results indicate that such effects are context-dependent within the European setting. Future research may benefit from distinguishing between conventional and green finance instruments, incorporating sectoral carbon intensity indicators, or exploring potential nonlinearities in the finance, energy, environment relationship. Such extensions could provide a clearer understanding of the channels through which financial systems interact with structural energy transformation.

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