

# GREEN FINANCE AND CARBON EMISSIONS IN EUROPEAN COUNTRIES: EVIDENCE FROM A QUANTILE APPROACH

Tran Phuoc<sup>1</sup>, Bui The Sang<sup>1\*</sup>, Trinh Chi Tam<sup>2</sup>

<sup>1</sup>*Ho Chi Minh City University of Industry and Trade*

<sup>2</sup>*Industrial University of Ho Chi Minh City*

\*Email: 6023250004@huit.edu.vn

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## ABSTRACT

This study examines the impact of green finance on carbon emissions in eleven European countries over the period 2003–2023, using consumption-based CO<sub>2</sub> emissions as the empirical proxy. To capture distributional heterogeneity beyond mean effects, the Method of Moments Quantile Regression (MMQR) is employed, while bootstrap quantile (BSQ) estimation is used as a robustness check. The results indicate that green finance significantly reduces emissions across all quantiles, with stronger mitigation effects observed at higher emission levels, suggesting a nonlinear and heterogeneous impact. This pattern can be explained by efficiency gains, capital reallocation, and innovation-led decarbonization mechanisms, through which green finance facilitates structural transformation toward low-carbon production systems. The study contributes to the literature by providing new evidence on the distributional environmental effects of green finance and highlighting its greater relevance in carbon-intensive contexts. Policy efforts should prioritize green finance development in high-emission economies and promote targeted financial and regulatory frameworks that account for cross-country heterogeneity to enhance decarbonization effectiveness.

*Keywords:* Green finance, carbon emissions, quantile regression, Europe.

## 1. INTRODUCTION

Climate change has emerged as one of the most pressing global challenges, driven largely by the continuous rise in carbon dioxide (CO<sub>2</sub>) emissions despite intensified international climate commitments. Global energy-related CO<sub>2</sub> emissions reached approximately 37.4 gigatonnes in 2023, and rose to about 37.8 gigatonnes in 2024 [1]. Although the European Union (EU) has adopted ambitious climate policies under the European Green Deal, achieving carbon neutrality by 2050 requires substantial structural transformation. Due to Europe's deep integration into global value chains, a substantial share of emissions is embodied in trade and final consumption. Therefore, consumption-based CO<sub>2</sub> emissions provide a more comprehensive indicator of environmental pressure than traditional production-based measures [2-3].

Green finance has increasingly been recognized as a key instrument for aligning financial systems with sustainability goals. Global green bond issuance exceeded USD 580 billion in 2023 and increased further to around USD 670 billion in 2024, highlighting the growing role of green finance in supporting sustainability transitions [4]. Regulatory frameworks such as the EU Taxonomy and the Sustainable Finance Disclosure Regulation (SFDR) further strengthen incentives to channel capital toward low-carbon activities. Theoretically, green

finance reduces emissions by reallocating resources to sustainable sectors and promoting technological innovation, thereby facilitating the transition to a low-carbon economy [5].

Empirical evidence increasingly supports the environmental benefits of green finance. Guo et al. identify direct and indirect channels linking green finance to improved carbon performance [6], while Umar & Safi show that higher levels of green financial development are associated with lower emissions across OECD countries [7]. Ran et al. demonstrate that green finance enhances carbon emission efficiency [8], and Obobisa & Ahakwa confirm its emission-reducing role in European economies [9].

Despite these advances, several important research gaps remain. First, most prior studies rely on production-based CO<sub>2</sub> emissions, overlooking consumption-based measures that better capture environmental pressure in globally integrated economies. Second, existing research predominantly employs mean-based estimation methods, which may mask heterogeneous effects across different emission levels. Third, empirical evidence focusing specifically on European countries using distributional approaches remains limited.

To address these gaps, this study investigates the impact of green finance on consumption-based CO<sub>2</sub> emissions in selected European countries over the period 2003-2023. In particular, it examines whether the environmental effects of green finance vary across different emission levels. Accordingly, this study seeks to answer two key research questions: (i) Does green finance reduce consumption-based CO<sub>2</sub> emissions? and (ii) Does this effect differ across the emission distribution?

This study contributes to the literature by adopting a consumption-based perspective and employing a distributional framework to capture heterogeneous environmental effects. It also provides policy-relevant insights into the role of green finance in supporting Europe's low-carbon transition.

## **2. THEORETICAL BACKGROUND AND LITERATURE REVIEW**

### **2.1. Theoretical background**

Green finance refers to financial activities and instruments aimed at supporting environmental protection, climate change mitigation, and efficient resource use [10]. From a systemic perspective, it encompasses the allocation of capital to environmentally beneficial investments within a long-term sustainable development framework, highlighting the role of financial systems and public policies in steering capital flows toward green activities [11-12]. In empirical research, green finance is commonly proxied by the issuance of green bonds or the volume of green credit [13]. However, data constraints and cross-country differences in economic size limit the comparability of these measures. Recent studies therefore emphasize the structure of public expenditure on clean energy R&D as a forward-looking indicator of green policy orientation [14-15]. Following Safi et al, this study measures green finance by the share of public expenditure on renewable energy R&D in total energy R&D spending [16], which captures governments' strategic commitment to sustainable energy transition while mitigating scale-related biases.

Carbon emissions refer to the release of carbon-containing gases, primarily carbon dioxide (CO<sub>2</sub>), into the atmosphere as a result of human activities such as fossil fuel combustion, industrial production, and land-use change [17-18]. In environmental and energy economics, carbon emissions are widely employed as an indicator of environmental pressure and the sustainability of economic growth processes [19]. Empirically, they are commonly measured using total CO<sub>2</sub> emissions, CO<sub>2</sub> emissions per capita, or carbon intensity (CO<sub>2</sub> emissions per unit of GDP) [20]. Beyond the conventional production-based approach, recent studies emphasize consumption-based CO<sub>2</sub> emissions, which allocate emissions according to

final consumption and incorporate carbon embodied in international trade [21-22]. This measure provides a more comprehensive assessment of a country's carbon footprint in the context of globalization. Accordingly, this study employs consumption-based CO<sub>2</sub> emissions as the proxy for carbon emissions to better capture the environmental impacts associated with domestic consumption patterns and global value chain integration.

Drawing on Sustainable Development Theory and the Porter Hypothesis, green finance is theoretically expected to reduce carbon emissions through two primary mechanisms: resource reallocation and innovation-driven decarbonization. Sustainable Development Theory posits that economic growth must be pursued in tandem with environmental protection and the preservation of natural capital for future generations [23-24]. Within this framework, green finance serves as a financial instrument that directs capital toward environmentally beneficial activities, including renewable energy development, clean technologies, and energy efficiency improvements [5]. By reallocating financial resources away from carbon-intensive sectors, green finance facilitates structural transformation toward a low-carbon economy, thereby contributing to long-term reductions in CO<sub>2</sub> emissions.

Complementing this perspective, the Porter Hypothesis [25] argues that well-designed environmental policies and incentive mechanisms can stimulate technological innovation, generating both environmental and economic gains. In this context, green finance provides financial support for green R&D and cleaner production processes, fostering improvements in energy efficiency and reductions in carbon intensity. Taken together, these theoretical foundations suggest that green finance can mitigate carbon emissions by promoting structural shifts and innovation-led decarbonization in the long run.

## **2.2. Literature review**

Recent empirical evidence consistently supports the emission-reducing role of green finance across different institutional and geographical contexts. Using a multidimensional index of green finance and a Spatial Dynamic Panel Model (SDPM) for Chinese provinces, Chen & Chen document that green finance significantly reduces carbon emissions and generates spatial spillover effects, indicating that regional green financial development can also curb emissions in neighboring areas [26]. Extending the analysis to advanced economies, Meo & Karim, using a quantile-on-quantile regression framework, find that green finance has a robust negative impact on CO<sub>2</sub> emissions across most emission levels, with stronger effects in countries undergoing energy transition [27]. Focusing on innovation channels, Sharif et al. show for G7 economies that both green finance and green technological innovation significantly mitigate CO<sub>2</sub> emissions, highlighting the importance of innovation-driven decarbonization [28]. Similarly, Li et al. report a long-run negative relationship between green finance and carbon emissions in N-11 economies using Cup-FM and Cup-BC estimators [29]. From an efficiency and structural perspective, Ran et al. demonstrate that higher levels of green financial development improve carbon emission efficiency across Chinese provinces [8], while Wei et al. confirm, through panel quantile regression, that green finance consistently reduces CO<sub>2</sub> emissions across different emission quantiles and exhibits bidirectional causality with carbon emissions [30]. Overall, the literature shows that green finance reduces emissions through capital reallocation, technological innovation, structural upgrading, and spillover effects, thereby supporting its central role in the transition toward low-carbon development.

3. METHODOLOGY

3.1. Econometric model, Variable Description and Data

3.1.1. Econometric model

To analyze and quantify the impact of green finance on carbon emissions, this study specifies carbon emissions as the dependent variable and green finance as the main independent variable. In addition, several control variables are incorporated, including economic growth, trade openness, financial development, and innovation. Drawing on prior empirical studies, particularly Meo & Karim [27] and Sharif et al. [28], the model is specified as follows:

$$CBE_{it} = \beta_0 + \beta_1 GF_{it} + \beta_2 EG_{it} + \beta_3 OPE_{it} + \beta_4 FD_{it} + \beta_5 R\&D_{it} + \varepsilon_{it}$$

The coefficients  $\beta_1$  to  $\beta_5$  represent the marginal effects of the explanatory variables on carbon emissions, while  $\beta_0$  is the constant term. The error term  $\varepsilon_{it}$  captures unobserved factors affecting carbon emissions across countries and over time.

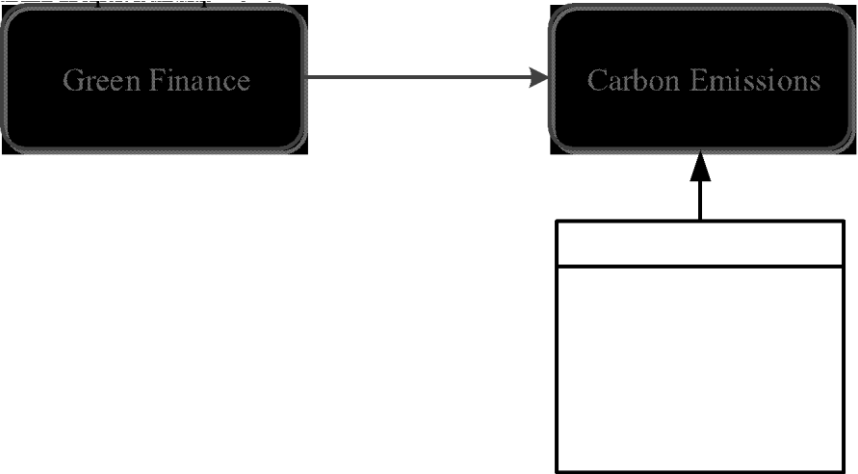


Figure 1. Econometric model

Based on the theoretical framework and prior empirical evidence, green finance is expected to affect carbon emissions through efficiency improvements, capital reallocation, and innovation-related decarbonization mechanisms. Accordingly, the following hypotheses are proposed:

H1: Green finance has a negative effect on carbon emissions.

H2: The emission-reducing effect of green finance is stronger at higher quantiles of carbon emissions.

3.1.2. Variable Description and Data

This study uses panel data from multiple international databases to ensure reliability and cross-country comparability. The dependent variable is consumption-based CO<sub>2</sub> emissions (CBE), measured in metric tons of CO<sub>2</sub> (MtCO<sub>2</sub>) and transformed into natural logarithms to reduce skewness and potential heteroskedasticity, following previous studies [16, 28]. The data are obtained from the Global Carbon Atlas database. The primary independent variable is green finance (GF), proxied by the share of public budget allocation for renewable energy research and development in total public energy R&D expenditure, reflecting an innovation-based dimension of green finance consistent with prior studies [7,16]. This indicator reflects the extent to which governments prioritize renewable energy

innovation within their overall energy research framework. Data for this variable are sourced from the Organisation for Economic Co-operation and Development (OECD). To enhance the robustness of the empirical specification, several control variables are incorporated. Economic growth (EG) is measured as the natural logarithm of GDP per capita, following previous studies [31,34]. Trade openness (OPE) is calculated as the ratio of total exports and imports to GDP, consistent with the approach adopted in earlier studies [35, 37]. Financial development (FD) is proxied by domestic credit to the private sector as a percentage of GDP, capturing the depth of financial intermediation, as widely used in the literature [39,40]. Innovation (R&D) is measured by research and development expenditure as a percentage of GDP, reflecting national technological effort, in line with prior studies [41,42]. All control variables are retrieved from the World Development Indicators (World Bank). Overall, the constructed dataset provides a comprehensive analytical framework for assessing the impact of green finance and macroeconomic factors on carbon emissions in Europe over the period 2003-2023.

### 3.1.3. Expected Effects of Explanatory Variables

Based on theoretical arguments and prior empirical evidence, the expected effects of the explanatory variables on consumption-based CO<sub>2</sub> emissions are summarized in Table 1.

Table 1. Expected effects of explanatory variables

| Variable | Expected sign | Supporting studies    |
|----------|---------------|-----------------------|
| GF       | -             | [28], [7], [16], [30] |
| EG       | +             | [31-34]               |
| OPE      | -             | [35-37]               |
| FD       | -             | [38-40]               |
| R&D      | -             | [41-43]               |

Note: “-” indicates an emission-reducing effect, while “+” indicates an emission-increasing effect.

### 3.2. Methods of analysis

The empirical analysis proceeds in several stages. First, descriptive statistics are reported to provide an initial characterization of the dataset. The normality of the variables is assessed using the Jarque-Bera [44] test. To evaluate parameter heterogeneity across cross-sectional units, the slope homogeneity test proposed by Pesaran & Yamagata [45] is implemented. Cross-sectional dependence is then examined employing the Pesaran [46] CD test to account for potential interdependencies among panel units.

Subsequently, the stationarity properties of the series are investigated using the Im–Pesaran–Shin (IPS) panel unit root test [47]. To determine whether a long-run equilibrium relationship exists among the variables, panel cointegration tests developed by Pedroni [48] and Kao [49] are conducted.

Following the pre-estimation diagnostics, the MMQR is applied to the balanced panel dataset to capture heterogeneous effects of the explanatory variables across different points of the conditional distribution of the dependent variable. This approach allows for a more comprehensive assessment beyond mean-based estimators. As a robustness check, BSQ regression is employed. The BSQ procedure utilizes resampling techniques to generate reliable estimates of the sampling distribution of the parameters, thereby enhancing the robustness and statistical inference of the results.

## 4. RESULTS AND DISCUSSION

### 4.1. Results and discussion

Table 2. Descriptive Statistics

|             | CBE    | GF    | EG     | OPE     | FD      | R&D    |
|-------------|--------|-------|--------|---------|---------|--------|
| Mean        | 18.508 | 0.261 | 10.590 | 103.258 | 99.508  | 2.212  |
| Std. Dev.   | 1.106  | 0.141 | 0.456  | 44.763  | 35.946  | 0.826  |
| Min         | 17.372 | 0.001 | 9.037  | 45.141  | 25.223  | 0.698  |
| Max         | 20.778 | 0.816 | 11.564 | 250.109 | 200.399 | 3.734  |
| p1          | 17.397 | 0.048 | 9.325  | 47.266  | 26.483  | 0.758  |
| p99         | 20.768 | 0.642 | 11.551 | 237.216 | 190.317 | 3.618  |
| Skew.       | 0.875  | 0.769 | -1.102 | 1.184   | 0.334   | -0.016 |
| Kurt.       | 2.087  | 3.313 | 3.991  | 3.854   | 3.140   | 1.636  |
| J-B         | 37.51  | 23.2  | 56.18  | 60.99   | 4.479   | 17.92  |
| J-B P-Value | 0.000  | 0.000 | 0.000  | 0.000   | 0.107   | 0.000  |

Table 2 reports the descriptive statistics of the key variables, including consumption-based CO<sub>2</sub> emissions (CBE), green finance (GF), economic growth (EG), trade openness (OPE), financial development (FD), and innovation (R&D). CBE has a mean value of 18.508 with a standard deviation of 1.106, indicating noticeable variation across countries. GF records an average of 0.261, reflecting disparities in the level of green financial development within the sample. EG and OPE exhibit relatively high mean values (10.590 and 103.258, respectively), while FD and R&D also display substantial dispersion, as evidenced by their wide ranges between minimum and maximum values.

The skewness and kurtosis statistics indicate departures from normality for most variables. The Jarque-Bera test further confirms non-normal distributions at the 1% significance level for all variables except FD (p-value = 0.107). These distributional characteristics suggest considerable heterogeneity across cross-sectional units and justify the application of advanced panel econometric techniques in the subsequent empirical analysis.

Table 3. Slope Heterogeneity Test

|       |     |    |    |     |    |     | Stat     | p-value |
|-------|-----|----|----|-----|----|-----|----------|---------|
| Model | CBE | GF | EG | OPE | FD | R&D | 4.638*** | 0.000   |
|       |     |    |    |     |    |     | 5.712*** | 0.000   |

Asterisks \*\*\* show significance levels at 1%

Table 3 reports the results of the slope heterogeneity test. The test statistics are statistically significant at the 1% level (p-values = 0.000), indicating the rejection of the null hypothesis of slope homogeneity. These findings suggest that the estimated coefficients are not identical across cross-sectional units, implying that the effects of green finance, economic growth, trade openness, financial development, and innovation on consumption-based CO<sub>2</sub> emissions vary across countries. Overall, the presence of slope heterogeneity justifies the adoption of econometric approaches that explicitly account for cross-country heterogeneity in the subsequent analysis.

Table 4. Cross-sectional dependency analysis

| Variable | Pesaran's CD Stat | p-value | abs(corr) |
|----------|-------------------|---------|-----------|
| CBE      | -0.21             | 0.837   | 0.199     |
| GF       | 2.21              | 0.027   | 0.257     |
| EG       | -1.10             | 0.270   | 0.302     |
| OPE      | -0.35             | 0.727   | 0.277     |
| FD       | 7.39              | 0.000   | 0.541     |
| R&D      | -1.84             | 0.066   | 0.265     |

Table 4 reports the results of Pesaran's [46] cross-sectional dependence (CD) test. The findings reveal significant cross-sectional dependence for several variables. Specifically, green finance (GF) is statistically significant at the 5% level (p-value < 0.05), financial development (FD) at the 1% level (p-value < 0.01), and innovation (R&D) at the 10% (p-value < 0.1) level, indicating the presence of cross-country interdependencies and potential spillover effects in these variables. In contrast, consumption-based CO<sub>2</sub> emissions (CBE), economic growth (EG), and trade openness (OPE) do not exhibit statistically significant cross-sectional dependence at conventional significance levels.

These results suggest that certain variables are influenced by common shocks or regional spillovers across countries. Accordingly, the presence of cross-sectional dependence warrants the use of econometric techniques that explicitly account for such interdependencies in the subsequent empirical analysis.

Table 5. Unit Root Analysis

|           | At Level   | At I (1)   |
|-----------|------------|------------|
| Variables | T-bar Stat | t-bar Stat |
| CBE       | -3.3601*** |            |
| GF        | -3.7283*** |            |
| EG        | -2.7204*** |            |
| OPE       | -2.6166*** |            |
| FD        | -0.9476    | -2.7406*** |
| R&D       | -4.7056*** |            |

Asterisks \*\*\* show significance levels at 1%.

Table 5 reports the results of the IPS panel unit root test. The findings indicate that consumption-based CO<sub>2</sub> emissions (CBE), green finance (GF), economic growth (EG), trade openness (OPE), and innovation (R&D) are stationary at levels, as their test statistics are statistically significant at the 1% level. In contrast, financial development (FD) is non-stationary at levels but becomes stationary after first differencing, implying that it is integrated of order one, I(1).

Overall, the results reveal a mixed order of integration among the variables. Accordingly, the application of panel cointegration techniques is appropriate to examine the existence of long-run equilibrium relationships in the subsequent empirical analysis.

Table 6. Cointegration Analysis

| Pedroni (2004) Analysis             |          |         |
|-------------------------------------|----------|---------|
|                                     | Stat     | P-Value |
| Modified Phillips-Perron t          | 1.8735   | 0.0305  |
| Phillips-Perron t                   | -5.4758  | 0.0000  |
| Augmented Dickey-Fuller t           | -5.1123  | 0.0000  |
| Kao (1999) Analysis                 |          |         |
|                                     | Stat     | P-Value |
| Modified Dickey-Fuller t            | -2.8331  | 0.0023  |
| Dickey-Fuller t                     | -4.7464  | 0.0000  |
| Augmented Dickey-Fuller t           | -3.0561  | 0.0011  |
| Unadjusted modified Dickey-Fuller t | -12.6256 | 0.0000  |
| Unadjusted Dickey-Fuller t          | -8.4784  | 0.0000  |

Table 6 reports the panel cointegration results based on the methodologies of Pedroni [48] and Kao [49]. Under the Pedroni framework, the Phillips-Perron t and Augmented Dickey-Fuller t statistics are statistically significant at the 1% level (p-values = 0.0000), while the Modified Phillips-Perron t statistic is significant at the 5% level (p-value = 0.0305), leading to the rejection of the null hypothesis of no cointegration. Similarly, all Kao test statistics are statistically significant at the 1% level (p-values < 0.01).

Overall, the results from both tests provide strong evidence of a long-run equilibrium relationship among the variables, indicating that they move together over time despite short-run fluctuations.

Table 7. MMQR

| Variables | Location             | Scale               | 25Q                  | 50Q                  | 75Q                  | 90Q                  |
|-----------|----------------------|---------------------|----------------------|----------------------|----------------------|----------------------|
| GF        | -2.143***<br>(0.358) | -0.064<br>(0.222)   | -2.088***<br>(0.438) | -2.149***<br>(0.354) | -2.195***<br>(0.367) | -2.253***<br>(0.467) |
| EG        | 0.731***<br>(0.133)  | 0.081<br>(0.083)    | 0.661**<br>(0.163)   | 0.738***<br>(0.132)  | 0.796***<br>(0.137)  | 0.870***<br>(0.174)  |
| OPE       | -0.018***<br>(0.001) | -0.001<br>(0.001)   | -0.017***<br>(0.001) | -0.018***<br>(0.001) | -0.019***<br>(0.001) | -0.020***<br>(0.002) |
| FD        | -0.002*<br>(0.001)   | -0.002**<br>(0.001) | -0.001<br>(0.002)    | -0.003*<br>(0.001)   | -0.004***<br>(0.001) | -0.006***<br>(0.002) |
| R&D       | -0.873***<br>(0.071) | -0.059<br>(0.044)   | -0.822***<br>(0.087) | -0.879***<br>(0.070) | -0.921***<br>(0.073) | -0.975***<br>(0.093) |
| Constant  | 15.361***<br>(1.227) | 0.083<br>(0.761)    | 15.290***<br>(1.501) | 15.369***<br>(1.215) | 15.427***<br>(1.257) | 15.503***<br>(1.601) |

Note: The parentheses “()” show the standard errors. Asterisks \*\*\*, \*\* and \* show significance levels at 1%, 5% and 10%.

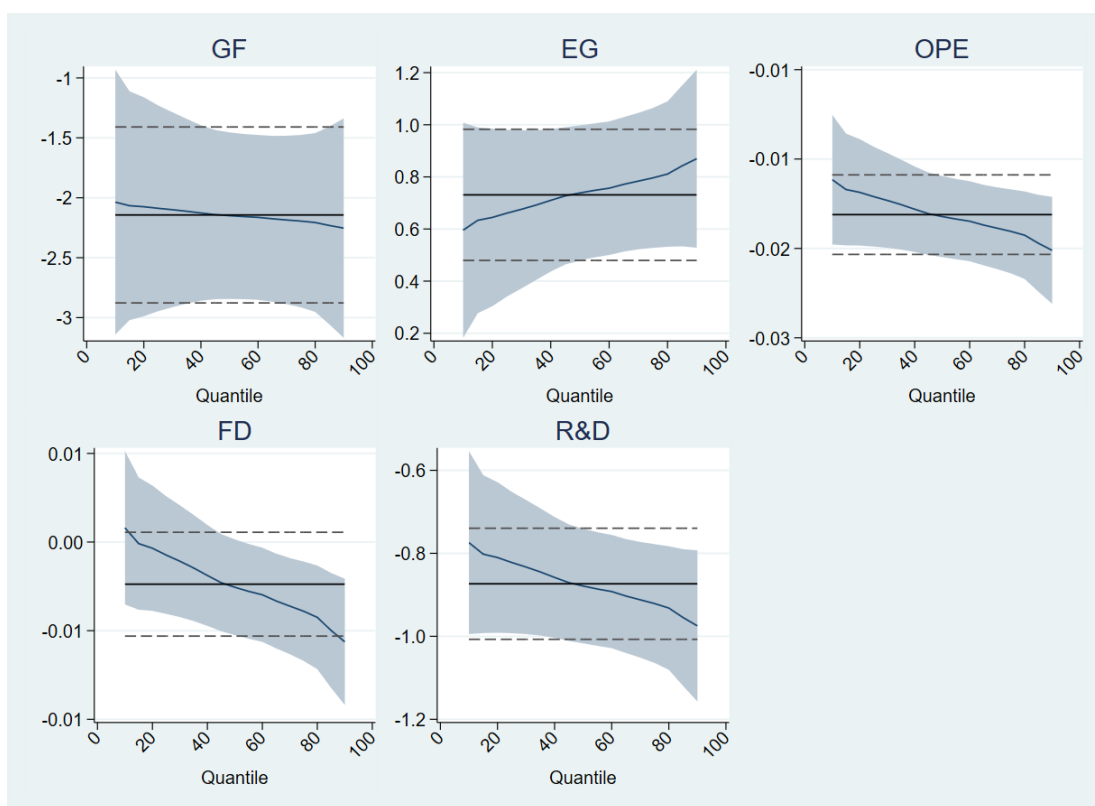


Figure 2. MMQR

Based on the MMQR estimates reported in Table 7 and illustrated in Figure 2, green finance (GF) exerts a negative and statistically significant effect at the 1% level on consumption-based CO<sub>2</sub> emissions across all quantiles. The estimated coefficients are -2.088 (Q25), -2.149 (Q50), -2.195 (Q75), and -2.253 (Q90), indicating that the emission-mitigating effect of green finance becomes progressively stronger toward the upper tail of the distribution. This pattern indicates distributional heterogeneity, with stronger effects in high-emission economies.

This result is consistent with Sustainable Development Theory and the Porter Hypothesis. Green finance reduces emissions by reallocating capital to low-carbon activities and promoting green innovation. In carbon-intensive economies - where the scope for efficiency gains and technological upgrading is greater - the marginal impact of green finance is expected to be stronger, consistent with the increasing coefficient magnitudes observed across quantiles.

The empirical results are consistent with prior evidence showing that green finance reduces emissions through capital reallocation, innovation channels, and stronger effects in high-emission or energy-transition contexts [26-28], [30].

Regarding the control variables, economic growth (EG) shows a positive and statistically significant effect across all quantiles, with larger coefficients at higher emission levels, reflecting the scale effect of economic expansion on carbon emissions. In contrast, trade openness (OPE) exhibits a negative and significant effect at the 1% level, suggesting that greater integration into international markets may enhance production efficiency and facilitate clean technology diffusion. Financial development (FD) and innovation (R&D) both display negative and statistically significant coefficients, with stronger effects in the upper quantiles, indicating that more advanced financial systems and technological progress contribute more substantially to decarbonization in high-emission economies.

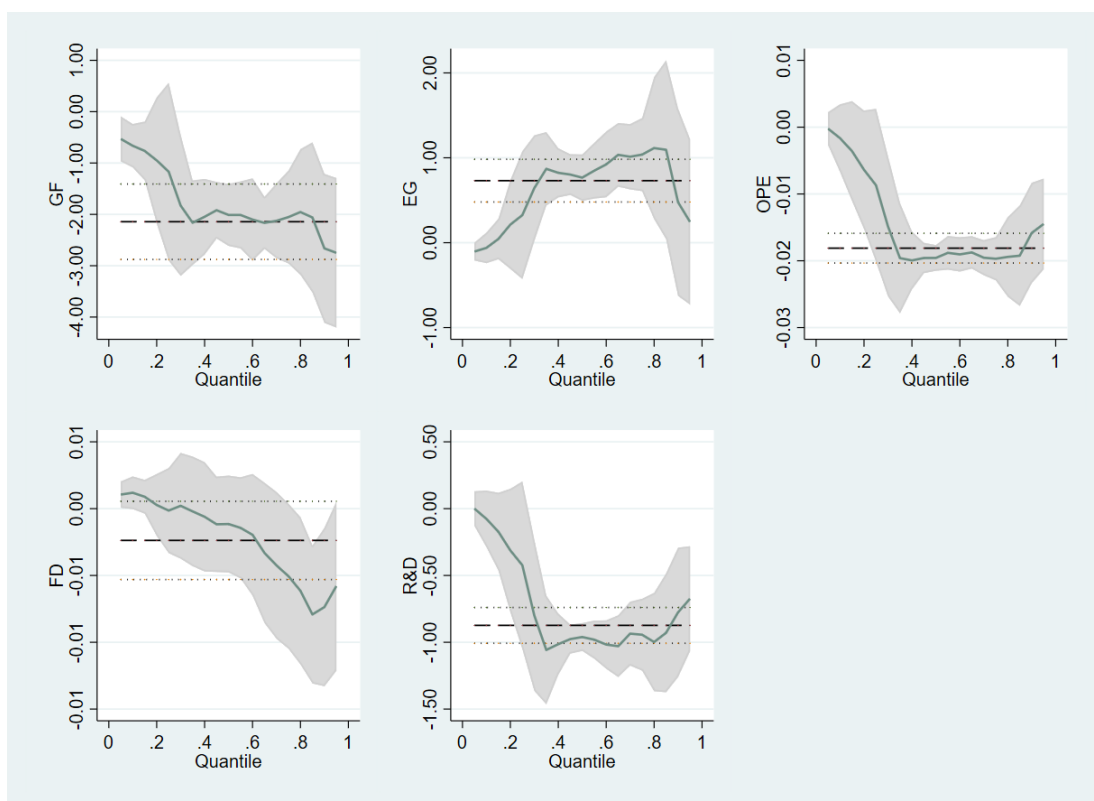
Collectively, these results underscore the importance of accounting for distributional heterogeneity and highlight the strategic role of green finance in advancing the transition toward a low-carbon growth trajectory.

#### 4.2. Robustness analysis

*Table 8. BSQ Regression*

| Variables | 25Q                  | 50Q                  | 75Q                  | 90Q                  |
|-----------|----------------------|----------------------|----------------------|----------------------|
| GF        | -1.169<br>(0.889)    | -2.011***<br>(0.300) | -2.053***<br>(0.460) | -2.662***<br>(0.663) |
| EG        | 0.325<br>(0.370)     | 0.766***<br>(0.135)  | 1.038***<br>(0.298)  | 0.477<br>(0.457)     |
| OPE       | -0.009<br>(0.006)    | -0.120***<br>(0.001) | -0.020***<br>(0.002) | -0.016***<br>(0.004) |
| FD        | -0.001<br>(0.002)    | -0.001<br>(0.002)    | -0.005***<br>(0.002) | -0.007***<br>(0.003) |
| R&D       | -0.424<br>(0.305)    | -0.960***<br>(0.053) | -0.943***<br>(0.109) | -0.776***<br>(0.185) |
| Constant  | 16.656***<br>(2.608) | 15.216***<br>(1.291) | 13.051***<br>(2.928) | 19.096***<br>(4.310) |

*Note: The parentheses “()” show the standard errors. Asterisks \*\*\* show significance levels at 1%.*



*Figure 3. BSQ regression*

To assess robustness, this study applies BSQ regression. The results reported in Table 8 and illustrated in Figure 3 are broadly consistent with the MMQR estimates. Green finance

(GF) continues to exhibit a negative and statistically significant effect at the median and upper quantiles (Q50, Q75, and Q90), with coefficient magnitudes increasing toward the upper tail. This pattern confirms that the emission-reducing effect of green finance is more pronounced in high-emission economies. Although the coefficient at Q25 is not statistically significant, the overall quantile pattern remains consistent with the baseline findings.

Regarding the control variables, economic growth (EG) maintains a positive and significant impact at the middle and upper quantiles, reflecting the scale effect of economic expansion on emissions. In contrast, trade openness (OPE), financial development (FD), and innovation (R&D) generally display negative effects, with R&D showing stronger mitigation effects at higher quantiles. Overall, the BSQ results corroborate the stability and reliability of the MMQR findings.

## **5. CONCLUSION AND RECOMMENDATIONS**

The empirical results provide robust evidence that green finance plays a significant role in mitigating consumption-based CO<sub>2</sub> emissions in European countries over the period 2003–2023. Consistent with prior empirical studies (e.g., Chen & Chen [26]; Meo & Karim [27]; Li et al. [29]), the MMQR results confirm a negative and significant effect of green finance across all quantiles, with stronger mitigation effects observed at higher quantiles. This finding aligns with the growing body of literature emphasizing the heterogeneous environmental impacts of financial development and green investment, particularly in high-emission contexts where the marginal benefits of decarbonization policies are more pronounced.

However, the existing literature also highlights that the impact of green finance on carbon emissions is not always uniformly beneficial. For instance, Zhu & Rastelli [50] demonstrate that the relationship between green finance and carbon emissions follows a nonlinear inverted U-shaped pattern, implying that green finance may initially increase carbon emission intensity before contributing to emission reduction after a certain threshold. Similarly, evidence from Wang & Ma [51] suggests that green finance can indirectly increase emissions through economic expansion and scale effects when financial resources stimulate industrial activity and energy consumption.

However, the results also contribute to the literature by extending beyond mean-based analyses and revealing distributional heterogeneity that conventional estimators may overlook. While most prior studies report average emission-reducing effects of green finance, our findings demonstrate that these effects are significantly stronger in carbon-intensive economies. This is consistent with innovation-driven and capital reallocation mechanisms highlighted in the literature (Sharif et al. [28]), suggesting that green finance is more effective where structural transformation and technological upgrading are more urgent.

At the same time, the results offer a nuanced perspective compared to some conflicting findings in the literature, where the impact of financial development on emissions is found to be positive due to scale effects or increased industrial activity. In our study, although economic growth continues to exert a positive scale effect on emissions, trade openness, financial development, and innovation jointly contribute to emission reduction, particularly at higher emission levels. This suggests that the environmental outcomes of financial development depend critically on its orientation toward green and sustainable investments.

Importantly, the findings should be interpreted within the specific institutional context of the European Union. The EU has developed one of the most comprehensive sustainable finance frameworks globally, including the EU Taxonomy for Sustainable Activities and the Sustainable Finance Disclosure Regulation (SFDR). These regulatory mechanisms play a crucial role in directing financial flows toward environmentally sustainable projects, enhancing transparency, and reducing greenwashing risks. Stronger effects at higher quantiles

may reflect the effectiveness of these policy instruments in channeling green finance toward sectors and countries with greater decarbonization needs.

From a policy perspective, the results highlight the strategic importance of strengthening climate-oriented financial regulations and aligning green finance with innovation and structural transformation policies. The quantile-based evidence further suggests that policy design should account for cross-country heterogeneity rather than adopting uniform approaches. Tailored strategies that integrate financial, technological, and regulatory dimensions are essential to improve the effectiveness of decarbonization efforts across European countries.

Despite its contributions, this study has several limitations. First, the analysis is limited to a sample of European countries, which may constrain the generalizability of the findings to other regions. Second, green finance is proxied by an innovation-based indicator, which may not fully capture the multidimensional nature of green financial development. Third, although the quantile-based approach accounts for distributional heterogeneity, potential endogeneity concerns cannot be entirely ruled out.

Future research may address these limitations by employing alternative measures of green finance, expanding the geographical scope, and applying econometric techniques that better account for endogeneity. Further studies could also explore the energy implications of financial and technological systems to better assess potential rebound effects.

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