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Does country-level eco-innovation help reduce corporate CO_2 emissions? Evidence from Europe

Muhammad Azeem Qureshi [a,*], Tanveer Ahsan [b], Ammar Ali Gull [c,d]

[a] Oslo Business School, Oslo Metropolitan University, Norway
[b] Department of Finance, Rennes School of Business, Rennes, France
[c] Ecole Superieure des Sciences Commerciales d'Angers (ESSCA), Lyon, France
[d] International School, Vietnam National University Hanoi, Hanoi, Viet Nam

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Climate change and CO_2 emissions intertwine corporations and society in current political, social, environmental, and economic debates, specifically in Europe. The climate action plan formulated by the European Commission aims to achieve net zero emissions through eco-innovation by 2050. The objective of this study is to investigate the impact of the European eco-innovation index on CO_2 emissions produced by European firms. Using a dataset of 735 firms from 17 European countries listed during 2010–2018, we found a significant negative association between the country-level eco-innovation index and CO_2 emissions directly produced by the European firms. We also found a significant negative association between the eco-innovation index and indirect CO_2 emissions produced by the value chain of these firms. The results provide evidence that via eco-innovation, supportive steps taken by European countries provide a conducive environment for the European firms to adopt eco-innovative strategies that significantly reduce their direct and indirect CO_2 emissions per dollar of their corporate assets and make their value chains eco-friendly. The results also reveal that financial development brings in some environmental monitoring that cultivates a supportive culture for the corporations to promote corporate efforts to reduce CO_2 emissions.

1. Introduction

Society and its institutions have mediated and steered the debate about corporate social responsibility (Bakker et al., 2005) and climate change over time evolving into two meta-constructs: "sustainable development" (Hopwood, Mellor and O'Brien, 2005) and "Environmental, Social, and Governance performance" (ESG) (Orlitzky et al., 2003). The perceived consequences of climate change have created a social demand in societies to mitigate climate change risk, especially focusing on reduction in CO_2 emissions resulting in institutional changes (Cao, 2016), their regulatory frameworks (Grove-White, 1997), and investments in financial, human, and technical resources. Corporate CO_2 emissions are largely driven by corporate production capacity and technology (Cadez and Czerny, 2016; Cadez and Guilding, 2017). The regulatory intervention by the governments, and the institutions along with the stakeholders' pressure can push corporations to reduce CO_2 emissions through eco-innovation (Cadez et al., 2019; Jiménez-Parra, Alonso-Martínez and Godos-Díez, 2018; Rashid Khan et al., 2021; Többelmann and Wendler, 2020).

Corporate climate change mitigation efforts entail a reduction in corporate CO_2 emissions (Cadez and Czerny, 2016; Weinhofer and Busch, 2013). In Europe, corporations are motivated to make such decisions, including a reduction in corporate CO_2 emissions that add to their value and a concerted effort by the European Commission (EC) are systematically fostering the ecosystem to strategically promote eco-innovation and green technologies (Többelmann and Wendler, 2020). We observe an increasing frequency of empirical literature dealing with eco-innovation and its potential impact on environmental and financial performance, and sustainability (Ahmad and Wu, 2022; Cadez and Guilding, 2017; Naeem and Welford, 2009; Qureshi et al., 2020; Többelmann and Wendler, 2020). However, conspicuously, these studies ignore the eco-innovation index, which provides the multidimensional measure of the extent to which a country's ecosystem promotes eco-innovation. For example, a few studies investigated the

Abbreviations: EC, European Commission; RBT, Resource-based theory.

* Corresponding author. 0130 Oslo, Norway.
E-mail addresses: muhaqu@oslomet.no (M.A. Qureshi), tanveer.ahsan@rennes-sb.com (T. Ahsan), ammarshaukit@gmail.com (A.A. Gull).

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impact of eco-innovation on environmental pollution, such as Jiménez-Parra et al. (2018) measured eco-innovation using an output indicator (percentage of patents related to emissions reduction) and found the significant role of eco-innovation in reducing air pollution in 31 countries. Töbelmann and Wendler (2020) measured eco-innovation as the total number of patent applications and found a negative association between eco-innovation and country-level CO_2 emissions across 27 European countries. Mongo, Belaïd, and Ramdani (2021) also measured eco-innovation using output indicator (patents related to environmental innovation) and found a negative association between eco-innovation and country-level CO_2 emissions across 15 European countries. Some provide empirical evidence from Europe that stakeholders' pressure enhances corporate environmental performance (Cadez et al., 2019) while others study the impact of regulations to conclude that effective regulations can encourage eco-innovation adoption (Dewick et al., 2019). We observed the following limitations related to eco-innovation and CO_2 emissions in the existing studies. *First*, these studies measure eco-innovation solely using the output indicator (number of patents), which is only one of the 16 indicators of eco-innovation as described by the EC.[1] *Second*, existing studies used the country-level data of periodic stock of CO_2 emissions and not the data of corporate CO_2 emissions, specifically the CO_2 emissions directly produced by the firms and the CO_2 emissions indirectly produced by the value chain partners of these firms. Therefore, it is difficult to determine the potential impact of the strategic promotion of eco-innovative ecosystem in Europe that will systemically help reduce corporate CO_2 emissions, and whether the corporations actually reduce their own CO_2 emissions or transfer responsibility of CO_2 emissions reduction to their value chain partners in response to environmental regulations and social demand. This study is an attempt to overcome the shortcomings of these existing studies. Grounded in the stakeholders' theory which articulates corporations' right to operate as a social contract granted by stakeholders in a society that requires continuous renewal through corporate ESG practices (Carroll, 1979; Scherer and Palazzo, 2007), and the product stewardship theory that advocates corporations' engagement with each stakeholder along their entire value chain to achieve the objectives of sustainable development (Hart and Dowell, 2011; Rehman et al., 2021), this study aims to investigate the impact of country level eco-innovation on direct CO_2 emissions of European firms as well as indirect CO_2 emissions produced by their value chain partners.

The study makes the following significant contributions to the literature. *First*, to the best of the authors' knowledge, this is the first study that uses a comprehensive index-based measure of eco-innovation and investigates its impact on corporate CO_2 emissions. The eco-innovation index used in this study is developed by the EC that incorporates policies and initiatives taken by the European countries to drive an eco-supportive environment. This index includes 16 factors grouped into 5 dimensions (eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency, and socio-economic outcomes). *Second*, using a dataset of 735 non-financial firms listed in 17 European countries, we calculated two proxies to measure the change in corporate CO_2 emissions to investigate the impact of country-level eco-innovation on direct corporate CO_2 emissions (produced by the corporations), and indirect CO_2 emissions (produced by their value chain partners). The results of the system generalized method of moments (GMM) regression analysis explain a significant negative association between eco-innovation and change in direct as well as indirect CO_2 emissions, indicating that country-level eco-innovation helps European firms not only in reducing the direct CO_2 emissions of their own operations, but it also supports these firms to reduce CO_2 emissions in their value chains. *Third*, we included Hofstede's cultural dimensions in our econometric models and the results of the additional analysis reveal the significant impact of different cultural attributes of European countries on CO_2 emissions directly and indirectly produced by the European firms. *Fourth*, we found that developed stock markets effectively channel social demand and regulations to adopt eco-innovation that pushes European firms to reduce their direct CO_2 emissions.

There are six sections in our study. Section 1 being the introduction, section 2 presents the theoretical framework and develops the hypotheses for the study. Section 3 describes the data and the methodology. Section 4 presents the empirical results. Section 5 provides discussion and implications. Section 6 provides the conclusions and future research directions. The references are listed at the end of the manuscript.

2. Theoretical framework

Five decades ago, profit maximization was the only corporate objective, and using corporate resources other than this was a "form of theft" (Friedman, 1962). The push for unlimited growth to maximize wealth was challenged by many, notably by *"The Limits to Growth"* which integrates the environment as well as stakeholders using a system dynamics approach (Meadows et al., 1972). The ensuing public discourse created a social demand leading to sustainable development, ESG, and the gradual evolution of a set of regulations to mitigate climate change, but the enormity and complexity of the environmental challenge quickly revealed the impotence of the existing technologies to adequately address the environmental problems (Töbelmann and Wendler, 2020). This motivated many countries to bring in institutional changes (Cao, 2016) by investing in financial, human, and technical resources to innovate (Gao et al., 2021) and improve the products and services, and their value chain processes (Fethi and Rahuma, 2020; Popp, 2010). It also motivated many countries to build regulatory frameworks (Grove-White, 1997), and the societal pressure on firms to develop and adopt alternate technologies (Rashid Khan et al., 2021; Töbelmann and Wendler, 2020) to help increase their eco-efficiency (Henri and Journeault, 2010; Michelon et al., 2020). Researchers observe that social demand and regulations (Choi and Luo, 2021; Grove-White, 1997; Jeppesen, 2021) foster the adoption of environmental technologies (Popp, 2010) to provide a competitive advantage to the firms through product and process innovation to enhance their environmental and financial performance (Porter and Kramer, 2006; Porter and Kramer, 2011). As such, eco-innovative solutions help integrate economic, social, and environmental benefits (Hopwood et al., 2005). The results of recent empirical evidence indicate a positive impact of eco-innovation on environmental performance (Fethi and Rahuma, 2020; Galbreath et al., 2021; Mongo et al., 2021; Puertas and Marti, 2021; Sun et al., 2021; Tao et al., 2021; Töbelmann and Wendler, 2020). We use change in corporate CO_2 emissions to proxy corporate efforts in response to climate change, and based on the above discussion, we expect a negative association between country-level eco-innovation and change in direct CO_2 emissions of European firms. Accordingly, we develop our first hypothesis as follows:

H1. There is a negative association between the eco-innovation index and the change in direct CO_2 emissions of European firms.

The resource-based theory (RBT) emphasizes the role of two key elements for the firms to create competitive advantage, that is, resources and capabilities (Wernerfelt, 1984). A *resource* is defined as something possessed by firms that may include financial, physical, and human assets, among others. *Capability* is the ability of a firm to exploit its resources to create a competitive advantage (Hart, 1995). The operating environment may either provide the firms with a supportive ecosystem to achieve a competitive advantage or may restrict firms from using their capabilities to exploit their resources (Hart, 1995; Hart and Dowell,

[1] *The eco-innovation index developed by the European Commission integrates significant elements of supportive ecosystem at country level by capturing 16 different indicators of eco-innovation grouped into 5 dimensions: eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency, and socio-economic outcomes*. https://ec.europa.eu/environment/ecoap/indicators/index_en.

2011). To achieve the objectives of sustainable development, corporations may adopt pollution prevention or the product stewardship strategy. The firms following pollution prevention strategy do not primarily aim to reduce the emissions but instead focus on transferring emissions reduction targets to their value chain partners. The examples of pollution prevention strategies may include the use of emission or waste reduction technologies developed by other firms, transfer of high-emission producing operations to remote locations, or subcontracting high emission activities to other firms (Hart and Dowell, 2011; Kolk and Pinkse, 2005). Alternatively, under the product stewardship strategy, corporations engage with the stakeholders in their value chains to reduce emissions by improving their production and process efficiency and developing energy-efficient technologies through innovation (Hart and Dowell, 2011; Kolk and Pinkse, 2005; Rehman et al., 2021). Previous empirical studies measured eco-innovation using country-level patents or R&D investments among others (Ahmad and Wu, 2022; Galbreath et al., 2021; Mongo et al., 2021; Sun et al., 2021; Többelmann and Wendler, 2020) that we believe are not sufficient to investigate the impact of country-level eco-innovation on the environmental performance of corporate value chains. We argue that the eco-innovation index developed by the EC integrates significant elements of a country-level supportive ecosystem that may help value chain partners of the European firms to reduce CO_2 emissions of their operations. Therefore, to explore whether European firms are transferring CO_2 emissions reduction responsibility to their partners in the value chain or collaborating with them to actually reduce the CO_2 emissions, we aim to investigate the impact of European eco-innovation index on the indirect CO_2 emissions produced by the value chain partners of these firms. Accordingly, we develop our second hypothesis as follows:

H2. There is a negative association between the eco-innovation index and the change in indirect CO_2 emissions of European firms.

3. Data and methodology

3.1. Data and variables

Eco-innovation of a country is our main explanatory variable. We use a country-level eco-innovation index developed by the EC as a proxy to measure the eco-innovation performance of our sampled countries. A higher number of this eco-innovation index represents a higher eco-innovation performance. We retrieve the data on the eco-innovation index (Eco_Index) published by the EC[2] for the 2010–2018 period. The EC calculates the Eco-Index separately for different European countries capturing 16 indicators and grouping them into five dimensions, that is, eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency, and socio-economic outcomes. Change in corporate CO_2 emissions is our dependent variable, and we measure it using the difference between the current and the previous year's volume of CO_2 emissions (direct, indirect) scaled by the average of two years' total assets to indicate the change in CO_2 emissions per dollar of assets/resources managed by the firm. In this, direct CO_2 emissions are the emissions (in tons) from the sources owned or controlled by the firms, and indirect CO_2 emissions are the emissions (in tons) from the value chain of the firms such as from the consumption of purchased electricity, steam, or heat, which occur at the facility where it is generated. A potential negative relationship of Eco_Index with change in corporate CO_2 emissions would suggest that higher eco-innovation in the country has resulted in reduced corporate CO_2 emissions per dollar of assets managed by the firm. We retrieve all firm-level data, that is, CO_2 emissions and other firm-level explanatory variables from the Thomson Reuters (EIKON) database which is one of the leading databases providing firm-level financial and non-financial data. We restrict our dataset according to the following criteria: headquarters based in Europe,[3] eco-innovation index availability, and availability of corporate CO_2 emissions data. Our final dataset consists of 735 firms and 4078 firm-year observations from 17 European countries during 2010–2018.

Following similar empirical studies (Al-Tuwaijri et al., 2004; Pan et al., 2021; Qureshi and Ahsan, 2022), we included firm size (SIZE), performance (ROA), and financial leverage (EM) as control variables in our regression models. Bigger and highly profitable firms may have more incentive and funds available to invest in eco-innovation related technologies. Financial leverage, on the one hand, may provide access to external resources; on the other hand, it may bring in increased monitoring by the creditors (Al-Tuwaijri et al., 2004; Pan et al., 2021; Qureshi and Ahsan, 2022). Further, the stakeholders' theory postulates a firm's right to operate as a social contract with society, which requires continuous renewal through the firm's ESG practices across different cultural contexts (Carroll, 1979; Qureshi and Ahsan, 2022). The literature also demonstrates that cultural diversity has different implications not only for innovation but also for corporations' environmental performance (Hofstede, 1983, 1984; Jones and Davis, 2000; Qureshi and Ahsan, 2022). Therefore, we included cultural values in our econometric models by using the Hofstede's cultural dimensions (Hofstede, 1984) that differentiate sample countries based on cultural values (Table 2) and postulate that cultural differences among European countries may have implications for the association between country-level eco-innovation and reduction in corporate CO_2 emissions.

We also included banking development (BD) and stock market development (SMD) to represent the development of financial markets (Cao, 2016), which may bring in increased institutional monitoring by the stakeholders (Cherchye and Verriest, 2016). We retrieve the data on Hofstede's cultural dimensions published by Hofstede Insights[4] and financial development variables from the World Bank database.[5] Table 1 explains the measurement proxies and model names of all the variables included in the study.

3.2. Methodology

First, to investigate the impact of eco-innovation on change in corporate CO_2 emissions (H1 and H2), we employed a dynamic panel data approach as corporate CO_2 emissions are expected to be dependent on last year's corporate CO_2 emissions (Ibrahim and Law, 2014) and developed our baseline regression model as follows:

$$CO_{it} = \beta_0 + \beta_1 CO_{it-1} + \beta_2 ECO_{jt} + \beta_3 SIZE_{it} + \beta_4 EM_{it} + \beta_5 FP_{it} + ind_i + \varepsilon_{it} \tag{1}$$

Where CO_{it} is one of the two (direct, indirect) measures of CO_2 emissions (CO_2_Dir, CO_2_Ind) of firm i at time t. ECO_{jt} is the eco-innovation index of country j at time t. $SIZE_{it}$ is the size of firm i at time t. EM_{it} is the equity-multiplier ratio of firm i at time t. FP_{it} is performance (ROA) of firm i at time t. ind_i controls for industry fixed effects, and ε_{it} are standard errors.

Second, we investigated the impact of eco-innovation on change in CO_2 emissions after controlling our models for Hofstede's cultural dimensions and financial development. We extended our baseline regression model as follows:

$$CO_{it} = \beta_0 + \beta_1 CO_{it-1} + \beta_2 ECO_{jt} + \beta_3 SIZE_{it} + \beta_4 EM_{it} + \beta_5 FP_{it} + \beta_6 cul_j + \beta_7 CNT_{jt} + ind_i + \varepsilon_{it} \tag{2}$$

Where cul_j represents six of Hofstede's cultural dimensions (power distance – PDI, individualism – IDV, masculinity – MAS, uncertainty

[2] https://ec.europa.eu/environment/ecoap/indicators/index_en.

[3] *The eco-innovation index used in this study is available only for the European countries.*

[4] https://www.hofstede-insights.com/.

[5] https://www.worldbank.org/.

Table 1
Variables.

Variable		Model Name	Proxy
Dependent	CO_2 Emissions	CO_2_Dir	(Direct CO_2 emissions$_t$ - Direct CO_2 emissions$_{t-1}$) over average assets. Direct CO_2 emissions are the emissions in tons from the sources owned or controlled by the firms. Average assets are two years' average assets (in thousand dollars).
		CO_2_Ind	(Indirect CO_2 emissions$_t$ - Indirect CO_2 emissions$_{t-1}$) over average assets. Indirect CO_2 emissions are the emissions (in tons) from the value chain of the firms such as from the consumption of purchased electricity, steam, or heat which occur at the facility where it is generated. Average assets are two years' average assets (in thousand dollars).
Independent	Eco-Innovation	Eco_Index	Eco-Innovation Index developed by the European Commission. The index illustrates the eco-innovation performance of a country across 16 indicators grouped into five dimensions: eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency, and socio-economic outcomes.
Control Firm level	Firm Size	SIZE	Natural logarithm of total assets
	Leverage	EM	Total assets over total equity.
	Firm Performance	ROA	Net income before tax over total assets.
Control Cultural Dimensions	Power Distance Index	PDI	Hofstede's country-level Power Distance Index score
	Individualism Index	IDV	Hofstede's country-level Individualism Index score
	Masculinity Index	MAS	Hofstede's country-level Masculinity Index score
	Uncertainty Avoidance Index	UAI	Hofstede's country-level Uncertainty Avoidance Index score
	Long-term Orientation Index	LTO	Hofstede's country-level Long-term Orientation Index score
	Indulgence Index	IVR	Hofstede's country-level Indulgence Index score
Control Financial Development	Banking development	BD	The ratio of domestic credit to the private sector to GDP.
	Stock market development	SMD	The ratio of the market capitalization of listed domestic companies to GDP.

avoidance – UAI, long-term orientation – LTO, and indulgence – IVR) of country *j*. CNT_{jt} represents two variables of financial development (BD and SMD) of country *j* at time *t*. Other variables are the same as explained in model 1.

3.3. Robustness and endogeneity issues

Due to the use of the lagged dependent variable and expected endogeneity as a result of a potential bidirectional relationship between corporate financial performance and change in corporate CO_2 emissions, we applied the GMM (GMM-System) that controls for these issues (Roodman, 2009). First, we considered firm performance, size, and lagged dependent variable (current year's CO_2 emissions minus last year's CO_2 emissions over two years' average total assets) as endogenous variables in our dynamic regression models to control for potential endogeneity issues (Lin et al., 2019; Roodman, 2009). The number of instruments across all the regression models remained less than the number of groups (firms). The results of the Hansen and Arellano-Bond test for AR-2 showed that our models do not suffer from the over-identification problem and the problem of second-order autocorrelation (Roodman, 2009). Second, we controlled our regression models for industry fixed effects to eliminate their impact on the regression results. Third, we controlled for country-level institutional development (BD and SMD) and cultural differences to ensure that our results do not suffer from country bias.

Table 2
Summary statistics.

Panel A

Variable	Mean	STD	Median	Min.	Max.
CO_2_Dir	0.280	11.634	0.000	−31.345	41.863
CO_2_Ind	0.077	4.742	−0.025	−12.353	15.129
Eco_Index	112.599	16.902	112	30	149
SIZE	9.156	1.810	8.956	4.073	13.662
EM	4.878	6.552	2.722	−7.538	39.009
ROA	0.062	0.078	0.053	−0.266	0.374
BD	117.429	32.725	124.287	32.808	193.040
SMD	84.895	32.334	96.010	10.325	190.047

Panel B: Hofstede's cultural dimensions by country

	Country	PDI	IDV	MAS	UAI	LTO	IVR
1	Austria	11	55	79	70	60	63
2	Belgium	65	75	54	94	82	57
3	Denmark	18	74	16	23	35	70
4	Finland	33	63	26	59	38	57
5	France	68	71	43	86	63	48
6	Germany	35	67	66	65	83	40
7	Greece	60	35	57	112	45	50
8	Hungary	46	80	88	82	58	31
9	Ireland	28	70	68	35	24	65
10	Italy	50	76	70	75	61	30
11	Luxembourg	40	60	50	70	64	56
12	Netherlands	38	80	14	53	67	68
13	Poland	68	60	64	93	38	29
14	Portugal	63	27	31	104	28	33
15	Spain	57	51	42	86	48	44
16	Sweden	31	71	5	29	53	78
17	United Kingdom	35	89	66	35	51	69

Note: Panel A of the table presents the summary statistics of the dependent and explanatory variables included in our sample dataset. The variables are explained in Table 1.

4. Results

4.1. Descriptive statistics and correlation matrix

Table 2 (Panel A) presents the summary statistics for our sample dataset. The mean value of 0.280 for CO_2_Dir shows that on average, the European firms produce 0.280 tons of CO_2 emissions per thousand dollars of their average assets. The mean value of 0.077 for CO_2_Ind as compared to the mean value of 0.280 for CO_2_Dir indicates that on an average, the CO_2 emissions directly produced by the European firms are greater than the CO_2 emissions indirectly produced by the value chain of these firms. The mean value of 112.599 (Eco_Index) with a median of 112 explains that almost half of the sample countries have average eco-innovation performance according to the criteria developed by the EC. However, the minimum (30) and maximum (149) values of the Eco_Index indicate that some of the sample European countries have a very high performance, while others have a lower eco-innovation performance. The mean value of 9.156 for SIZE with a median of 8.956 explains that half of the firms in our sample are of average size. The mean value of 0.062 with a standard deviation of 0.078 for ROA explains high variations in the accounting performance of the sampled European firms.

Table 3 presents the results of the pairwise correlations. We observed a significant negative correlation of Eco_Index with direct CO_2 emissions indicating that higher eco-innovation performance of a country leads to lower direct corporate CO_2 emissions. However, this correlation becomes insignificant with indirect corporate CO_2 emissions, suggesting a need for further investigation.

4.2. Regression analysis

Table 4 presents the results of regression analysis investigating the impact of the eco-innovation index on change in direct and indirect corporate CO_2 emissions per dollar of average corporate assets. We observed a significant negative association between Eco_Index and change in direct corporate CO_2 emissions (columns 1 and 2) favoring H1. This negative association explains that macro-level activities and investments in eco-innovation in the sampled European countries create and sustain eco-innovative capital that promotes an eco-innovative operating environment initiating eco-friendly corporate processes to help improve the production process of the European firms and consequently reduce corporate CO_2 emissions. These findings confirm the results of earlier studies (Mongo et al., 2021; Többelmann and Wendler, 2020), explaining that environmental innovation in European countries contribute to the reduction of country-level CO_2 emissions. We also observed a highly significant negative association between Eco_Index and change in indirect corporate CO_2 emissions per dollar of corporate assets (columns 3 and 4) favoring H2. This negative association indicates that due to European countries' eco-innovative activities, the firms operating in these countries are collaborating with their partners in the value chain to reduce CO_2 emissions. These findings indicate that macro-level activities and investments in people and processes initiating and sustaining eco-innovative corporate ecosystem also helps the value chain partners of the European firms to improve the eco-efficiency of their products and services as well as the value chain processes and consequently reduce their CO_2 emissions (change in indirect corporate CO_2 emissions per dollar of corporate assets).

Further, significant positive association of firm size (SIZE) and profitability (ROA) with change in direct and indirect corporate CO_2 emissions per dollar of corporate assets suggests an increase in CO_2 emissions of European firms as well as their value chain partners as the firms become bigger and more profitable. We also observed a negative association between financial leverage (EM) of the sampled firms and change in direct and indirect corporate CO_2 emissions indicating that high use of debt financing brings in increased monitoring by the creditors and restrict firms from producing more CO_2 emissions per dollar of corporate assets.

Columns 2 and 4 (Table 4) present the results of regression analysis investigating the impact of the eco-innovation index on direct and indirect corporate CO_2 emissions after controlling for Hofstede's cultural dimensions. We observed a significant negative association of Eco_Index with direct and indirect CO_2 emissions even after controlling for Hofstede's cultural dimensions. We also observed a significant positive association of PDI and MAS with direct and indirect CO_2 emissions, indicating that the European firms operating in cultures with high power distance and masculinity produce more CO_2 emissions per dollar of their corporate assets. The plausible reasons may be that the cultures with high PDI are more likely to tolerate questionable business practices due to high acceptance of societal inequalities. Further, the emphasis of a strongly masculine culture on self-orientation and material success makes them less sensitive to collective issue such as environmental pollution (Ho et al., 2012; Qureshi and Ahsan, 2022). We also observed a significant negative association of IDV and UAI with direct and indirect

Table 3
Pairwise correlations.

Variables	CO_2_Dir	CO_2_Ind	Eco_Index	SIZE	EM	ROA	PDI	IDV	MAS	UAI	LTO	IVR	BD	SMD
CO_2_Dir	1.000													
CO_2_Ind	0.166*	1.000												
Eco_Index	−0.009*	−0.003	1.000											
SIZE	−0.016	0.001	−0.036*	1.000										
EM	−0.010	0.010	−0.015	0.508*	1.000									
ROA	−0.006	0.048*	0.084*	−0.311*	−0.246*	1.000								
PDI	−0.024	0.045*	−0.420*	0.221*	0.050*	−0.132*	1.000							
IDV	−0.017	−0.064*	0.087*	−0.251*	−0.048*	0.124*	−0.355*	1.000						
MAS	−0.011	0.004	−0.203*	−0.067*	0.034*	−0.045*	−0.068*	0.329*	1.000					
UAI	−0.013	0.063*	−0.339*	0.308*	0.073*	−0.187*	0.813*	−0.714*	−0.009	1.000				
LTO	−0.010	0.011	0.225*	0.181*	0.032*	−0.091*	0.220*	−0.020	0.123*	0.362*	1.000			
IVR	0.009	−0.060*	0.198*	−0.310*	−0.097*	0.182*	−0.596*	0.586*	−0.217*	−0.827*	−0.396*	1.000		
BD	0.026	−0.034*	0.199*	−0.211*	0.013	0.146*	−0.366*	0.445*	−0.077*	−0.615*	−0.433*	0.633*	1.000	
SMD	−0.006	−0.056*	0.249*	−0.267*	−0.081*	0.175*	−0.289*	0.616*	−0.256*	−0.671*	−0.240*	0.795*	0.676*	1.000

Note: The table presents the results of pairwise correlation between the variables. The variables are explained in Table 1. * shows significance at the 0.05 level.

Table 4
The impact of eco-innovation on direct and indirect CO_2 emissions.

	(1)	(2)	(3)	(4)
	CO_2_Dir	CO_2_Dir	CO_2_Ind	CO_2_Ind
Lag_CO_2_Dir	−0.067***	−0.063***		
	(0.006)	(0.002)		
Lag_CO_2_Ind			0.037***	0.033***
			(0.003)	(0.002)
Eco_Index	−1.941***	−0.588**	−0.839***	−1.412***
	(0.294)	(0.253)	(0.097)	(0.251)
SIZE	1.451***	1.847***	0.884***	0.963***
	(0.227)	(0.221)	(0.102)	(0.047)
EM	−0.089***	−0.023	−0.059***	−0.058***
	(0.028)	(0.040)	(0.013)	(0.011)
ROA	19.932***	16.962***	9.735***	9.665***
	(0.561)	(0.439)	(0.360)	(0.331)
PDI		0.307**		0.119**
		(0.120)		(0.060)
IDV		−0.343***		−0.171***
		(0.101)		(0.043)
MAS		0.164***		0.071***
		(0.039)		(0.021)
UAI		−0.266***		−0.105**
		(0.103)		(0.049)
LTO		0.044		0.020
		(0.035)		(0.014)
IVR		0.100		0.056
		(0.049)		(0.031)
Constant	−5.072*	−4.313	−5.318***	2.330
	(2.847)	(6.942)	(1.165)	(3.422)
Observations	4078	4078	4038	4038
Firms	735	735	728	728
Hansen	156.652	224.339	164.710	232.138
Hansen-P	0.318	0.425	0.179	0.290
AR1	−5.260	−5.277	−7.637	−7.629
AR1-P	0.000	0.000	0.000	0.000
AR2	−1.275	−1.243	−0.743	−0.779
AR2-P	0.202	0.214	0.457	0.436
Industry Effect	Yes	Yes	Yes	Yes

Note: The table presents the results of regression analysis (GMM-System) to investigate the impact of eco-innovation on direct and indirect carbon emissions in 17 European countries. The variables are explained in Table 1. Standard errors are in parenthesis, ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

CO_2 emissions, indicating that the European firms operating in cultures with high individualism and uncertainty avoidance produce lesser CO_2 emissions per dollar of their corporate assets. The plausible reason for this may be that the attributes of individualistic cultures such as freedom, independence, and autonomy are considered favorable for innovation (Jones and Davis, 2000). Contrarily, high-UAI cultures being intolerant to ambiguity become highly regulated and try to follow the policies and guidelines provided by the regulatory institutions in an effort to reduce CO_2 emissions (Jones and Davis, 2000; Qureshi and Ahsan, 2022).

4.3. Additional analysis

Table 5 presents the results of regression analysis investigating the impact of financial development (BD and SMD) on two proxies of corporate CO_2 emissions. We observed that even after controlling for these country-level factors, the results of the main variable (Eco_Index) remain consistent. We observed a significant negative association of SMD with direct CO_2 emissions only explaining that the development of the stock market improves institutional, structured, skilled, and multi-dimensional oversight of only direct CO_2 emissions of European firms overlooking the indirect CO_2 emissions of the value chain partners of these firms. Quite intriguingly, BD does not show any sensitivity to direct and indirect CO_2 emissions of the European firms. These findings plausibly suggest that European stock markets partially channel social demand for balanced growth and sustainable development and there is a clear need to sensitize the financial markets about their institutional power to reduce corporate CO_2 emissions through a multi-dimensional institutional oversight of direct and indirect corporate CO_2 emissions in Europe.

Table 5
The impact of institutional development on direct and indirect CO_2 emissions.

	(1)	(2)
	CO_2_Dir	CO_2_Ind
Lag_CO_2_Dir	−0.064***	
	(0.003)	
Lag_CO_2_Ind		0.032***
		(0.005)
Eco_Index	−1.387***	−1.378***
	(0.442)	(0.335)
SIZE	2.103***	0.857***
	(0.145)	(0.066)
ROA	17.469***	9.342***
	(0.456)	(0.376)
EM	−0.146***	−0.056***
	(0.021)	(0.009)
PDI	0.223***	0.079**
	(0.081)	(0.039)
IDV	−0.238***	−0.125***
	(0.091)	(0.042)
MAS	0.108***	0.059***
	(0.031)	(0.016)
UAI	−0.205***	−0.069*
	(0.076)	(0.035)
LTO	0.018	0.025
	(0.030)	(0.019)
IVR	0.044	0.043
	(0.026)	(0.017)
BD	0.009	0.000
	(0.006)	(0.003)
SMD	−0.005**	0.005
	(0.002)	(0.003)
Constant	−2.984	−0.165
	(6.192)	(3.701)
Observations	4078	4038
Firms	735	728
Hansen	219.488	230.511
Hansen-P	0.535	0.300
AR1	−5.271	−7.581
AR1-P	0.000	0.000
AR2	−1.105	−0.820
AR2-P	0.269	0.412
Industry Effect	Yes	Yes

Note: The table presents the results of regression analysis (GMM-System) to investigate the impact of institutional development on direct and indirect carbon emissions in 17 European countries. The variables are explained in Table 1. Standard errors are in parenthesis, ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

5. Discussion and implications

We theorized the eco-innovation index of 17 European countries, during the 2010–2018 period assigned by EC, as an outcome of eco-innovation inputs, activities, outputs, resource and process efficiency, and socio-economic outcomes within an economy. We found a generally negative significant association of the sampled European country's Eco_Index with the CO_2 emissions of European firms. These findings are in line with the results of earlier studies in European context where Töbelmann and Wendler (2020) as well as Mongo et al. (2021) observed a negative impact of eco-innovation on country-level CO_2 emissions. These findings also confirm the results of Hashmi and Alam (2019) and Sun et al. (2021) where they found a significant role of eco-innovation in reducing carbon emissions in the OECD countries and the USA respectively. A deeper analysis revealed that at a macro level, the eco-innovation performance by a country has a generally significant negative impact on corporate CO_2 emissions (direct as well as indirect). These interesting findings suggest that macro-level investments and resultant eco-innovations, and consequent "policy generated environmental imperatives" (Broadstock et al., 2018) provide a conducive ecosystem that helps European firms, and their value chain partners to reduce their CO_2 emissions. This clearly explains the significance of integrating macro-level eco-innovation, inputs, activities, and outputs with the value chains of the European firms for optimal attainment of targeted reduction of CO_2 emissions. We explain this significant role of eco-innovation in reducing corporate CO_2 emissions because of market pull by the stakeholders and regulatory push by the European countries (Fernández et al., 2021). The increased awareness about the climate change issue in Europe and appropriate policy actions taken by the EC are encouraging, supporting, and pushing European firms to combat climate change to achieve sustainable development. These findings also demand the attention of policymakers of non-European countries to follow the example set by these European countries to reduce CO_2 emissions and mitigate climate change risk.

We observed the universality of CO_2 emissions behavior of the European firms, and their value chain partners to emit more CO_2 as they become bigger and more profitable. There are two plausible policy implications of this conclusion. One, the European regulators need to focus their attention on bigger firms to ensure better compliance. Two, even though larger firms are generally more visible in the public eye, yet they are able to evade higher public scrutiny probably due to greenwashing (Mateo-Márquez et al., 2022) to improve their public image. We advocate increasing the scope and depth of the operational and public scrutiny of European firms, especially the bigger firms, by the European regulators and the civil society motivating them to not only invest resources to reduce their direct CO_2 emissions but also ensure that their partners in the value chains also ensure reduction in their CO_2 emissions.

We demonstrated the significance of country culture by including Hofstede's cultural dimensions in our econometric models. We found that the European firms operating in cultures with high power distance and high masculinity produce more CO_2 emissions while the European firms operating in cultures with high individualism and uncertainty avoidance produce lower CO_2 emissions (direct as well as indirect). We also find a generally significant negative impact of SMD on only direct CO_2 emissions of European firms. A plausible explanation is that European stock markets focus their attention only toward direct CO_2 emissions, failing to ensure a structured, skilled, and multi-dimensional monitoring. Thus, we advocate multi-dimensional institutional monitoring by the financial market (stock market as well as banking sector) of corporations' CO_2 emissions to cultivate a supportive and resilient corporate culture that responds not only to the regulatory frameworks but also to the social demand channeled through the financial market to ensure a broad-based and comprehensive reduction in corporate CO_2 emissions. The policy implication of this conclusion is that the regulators of the capital market can improve the regulatory framework requirements from the firms and monitoring of the compliance that ensures breadth in their shareholders, bondholders, and other capital providers increasing the scope and depth of social demand and operational scrutiny that shall help improve their financial as well as environmental performance.

6. Conclusion

The sustainable development goals (SDGs) are a collection of 17 interconnected goals designed by the United Nations (UN) to achieve a sustainable future for all.[6] The 13th goal is climate action that emphasizes accelerating the decarbonization of our economies. The evidence in this paper suggests that eco-innovation initiatives taken by the European countries in response to UN's climate action plan are helping European firms in reducing their CO_2 emissions. The evidence also suggests that these eco-supportive initiatives help European firms to reduce CO_2 emissions in their value chains. These results explain how macro-level investments in these European countries initiate and sustain eco-innovative systems that integrate social value systems, organizations, and institutions in their endeavors to sustainable development through reduced CO_2 emissions to mitigate climate change risk.

The significant negative association of SMD (Table 5) with change in direct CO_2 emissions suggests that effective social demand channeled through the developed stock markets persuade the European firms to reduce their direct CO_2 emissions. We argue that the European stock market and banking sector should adopt a broad-based multi-dimensional institutional monitoring of corporate CO_2 emissions along their entire value chain to effectively mitigate climate change risk. A generally positive significant association of firm size and profitability (ROA) with CO_2 emissions (direct as well as indirect) of European firms suggests that larger and profitable firms produce more CO_2 emissions. This empirical observation is quite contrary to the theoretical expectation that as larger and profitable firms are more visible in the public eye, they attract higher public scrutiny and social demand; therefore, these firms are expected to invest resources to reduce their direct CO_2 emissions. A plausible explanation could be greenwashing by the bigger (Roulet and Touboul, 2015) and more profitable European firms. This conclusion seeks the attention of European policymakers to find the means to motivate and discipline the ESG reporting of European firms, especially larger and more profitable firms, that would help reduce their direct and indirect CO_2 emissions. These results and conclusions are contrary to the expectations and lead us to suggest that future research may investigate deeper to identify the causes of higher CO_2 emissions by the bigger and more profitable European firms. An in-depth industry-level analysis may provide us with some evidence to solve this puzzle. Future research can also be carried out by categorizing the firms into high and low environmental performers as the low-performing firms may potentially be involved in greenwashing activities (Wedari et al., 2021).

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Muhammad Azeem Qureshi: Conceptualization, Writing – original draft, preparation, Supervision. **Tanveer Ahsan:** Methodology, Software, Data collection, Formal analysis, Correspondence. **Ammar Ali Gull:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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