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Climate change exposure, environmental performance, and the cost of capital in the energy sector: Fossil fuel versus renewable energy firms

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Abstract

As the largest emitter of greenhouse gases, the energy sector is expected to make significant investments in green transformation to help combat climate change. However, the effect of climate risk on sector firms' cost of capital has been neglected in the literature. This study fills this gap by investigating the impact of climate change and environmental performance on the cost of capital in the energy sector using a large sample of energy firms from 34 countries. Specifically, we comparatively examine the impact of climate risk on weighted average cost of capital, cost of debt, and cost of equity for fossil fuel and renewable energy firms. Moreover, we examine the moderating role of corporate environmental performance on the relationship between climate risk and the cost of capital. Our results suggest that energy firms domiciled in countries with higher exposure to climate change have a significantly higher weighted average cost of capital, cost of equity, and cost of debt than the firms domiciled in countries with lower exposure to climate change. However, this effect is significantly stronger for fossil fuel firms than for renewable energy firms. Importantly, energy firms, both fossil fuel and renewable energy, can mitigate the adverse effect of climate change on their cost of capital by engaging in pro-environmental policies. These findings suggest that climate risk exposure and the environmental performance of energy firms are important factors to consider when designing policies to accelerate the green transformation of the energy sector.

1 | INTRODUCTION

The energy sector and its role in the global value chain have garnered significant attention from diverse stakeholders, including governments, non-governmental organizations, and civil societies, amidst growing concerns about climate change. The planning, analysis, and policy-making processes about energy generation have become critical components in combating climate change, given that the energy sector is responsible for three-quarters of total greenhouse gas emissions (IEA, 2023a). Extant literature emphasizes the importance of "green transformation" in energy firms to mitigate the contribution of energy firms to climate change (see, e.g., Donovan & Corbishley, 2016). The importance of such transformation is highlighted in a report published by the International Renewable Energy Agency (IRENA), which stresses that carbon emissions related to energy must decline 70% by 2050 compared to their current level, to achieve the goals of the Paris Agreement (IRENA, 2019). In line with these goals, most major energy firms pledge to become net zero-emission firms by 2050 and declare their investment plans related to transition to renewable energy technologies

(Murray, 2020). In addition to these rapid developments in the sector, the declining customer demand for fossil fuels and increasing investor pressure on firms to shift from fossil fuels to renewable are salient factors underpinning the significance of investing in renewable energy technologies (Nauman & Temple-West, 2020). Importantly, for the green transformation to take place in the energy sector, energy firms, especially fossil fuel firms, need to have significant financial resources to be utilized for greener investments.

The pressure on energy firms to accelerate their investments to achieve a more sustainable infrastructure poses additional financial challenges for them, as these investments require a substantial amount of capital.[1] However, there is a significant financial gap that needs to be closed, and energy sector firms, particularly fossil fuel firms, aiming to invest in green energy technologies face significant financial difficulties in sourcing capital (Geddes et al., 2018). In addition, many studies in the literature highlight that higher levels of cost of capital deter investments in greener technologies (Steckel & Jakob, 2018). These financial constraints present a significant challenge for fossil fuel firms as they strive to meet the growing demand for renewable energy and contribute to the transition toward a low-carbon economy.

Although the impact of growing concerns about global warming and recent environmental regulations on energy firms has drawn significant attention from scholars (Cao et al., 2022; Yildiz & Karan, 2020), the impact of climate risk on the cost of capital of energy firms is often neglected in the literature. Given the significant amount of investment required for the green transformation of the energy sector, it is important to reveal the link between climate risk and the cost of capital of energy firms in order to design tailored policies. Furthermore, there is no consensus in the literature on how energy firms can mitigate the adverse effects of climate risks on their cost of capital. In a recent study, van Benthem et al. (2022) suggest that increased public awareness of climate change has a considerable impact on the long-term strategies and financial decisions of energy firms. Importantly, it is suggested that further research is required to understand the direct and indirect effects of climate risk on the cost of capital of energy firms. In this paper, we aim to investigate (i) the extent to which energy firms domiciled in countries exposed to greater country-level climate risk have a higher weighted average cost of capital, cost of debt, and cost of equity; (ii) how the impact of climate risk on the cost of capital differs across fossil fuel and renewable energy firms; and (iii) whether and how energy firms can alleviate the adverse impact of country-level climate risks on their cost of capital.

While prior literature provides evidence on the relationship between climate risk and the cost of capital (Javadi & Masum, 2021; Kling et al., 2018, 2021), this study differs from its antecedents by focusing on energy firms which are at the center of the discussion and have business dynamics significantly different from other industries. Furthermore, this study aims to reveal the role of corporate environmental policies on the relationship between climate risk and cost of capital of energy firms, which is not fully addressed in the literature. Importantly, we provide new evidence on the impact of climate risk and environmental performance on the cost of capital of fossil fuel and renewable energy firms in a comparative way. As fossil fuel firms are more exposed to climate-related risks (particularly transition and liability risks) than renewable energy firms by the nature of their business, it is important to assess how the impact of climate risk and corporate environmental performance on the cost of capital varies across subsectors such as fossil fuel and renewable energy.

Given that climate change poses significant risks to energy firms, it is reasonable to expect that energy firms, particularly fossil fuel firms, will struggle to find easy access to capital or obtain external capital at a higher cost. Specifically, climate change may cause a demand shock due to rising temperatures (Chen et al., 2021; Zheng et al., 2020) and may increase energy investments and supply to meet rising demand (Chen et al., 2021), both of which are additional uncertainties for the sector firms as these shocks are unlikely to be precisely forecasted. Similarly, climate change causes a negative impact on the operational efficiency of energy firms by causing extreme weather events (Pryor & Barthelmie, 2010). This makes capital providers perceive energy firms as riskier and in turn require higher returns in their investments in these firms.

While climate change poses significant threats to the economy and businesses, firms can mitigate the adverse effects of climate change on their operations and turn climate risk into opportunity by investing in environmentally responsible projects.[2] Stakeholder theory suggests that firms should focus beyond the bottom line and consider the impact of their activities on the benefits of all stakeholders (Freeman, 1984). Embracing environmentally friendly policies increases firms' long-term value by meeting the stakeholders' expectations, fulfilling environmental obligations, and improving their reputation in the eyes of stakeholders (Benlemlih et al., 2022; King & Shaver, 2001). In the same vein, investing in environmentally friendly policies can reduce the likelihood of the firm facing extraordinary challenges including clean-up and reputation loss risks (Dhaliwal et al., 2011). Relatedly, lenders consider the environmental sensitivity of firms in their financing decisions which results in limited access to finance and a higher cost of capital for firms having poor environmental performance as they will be partially excluded from the financial system (Chava, 2014). Similarly, market participants perceive less risk for firms with good environmental performance since incorporating green policies into business strategy alleviates the adverse effects of environment-related risks (El Ghoul et al., 2018). Given that enhancing environmental performance boosts firms' financial performance by lowering their risk (Jo et al., 2015; Klassen & McLaughlin, 1996; Lundgren & Zhou, 2017), then the market is expected to demand a lower rate of return from these firms due to improved environmental risk management. Thus, we predict that energy firms, particularly fossil fuel firms, will be able to mitigate the adverse impact of climate-related risks on their cost of capital as better environmental performance provides insurance-like protection.

Utilizing an international sample of energy firms from 34 countries, we find that climate risks significantly increase energy firms' weighted cost of capital, cost of debt, and cost of capital. However, this effect is stronger for fossil fuel firms than for renewable energy firms. In addition, environmental performance has both direct and indirect effects on energy firms' cost of capital. More precisely, having higher environmental performance significantly reduces the cost of capital (direct effect) of energy firms and mitigates the adverse effect of climate risk on their cost of capital (indirect effect). These results are qualitatively similar after controlling for endogeneity and utilizing alternative measures of climate risk. Overall, our results suggest that climate change is an important risk factor for fossil fuel firms and investing more in environmentally friendly policies helps them to alleviate the adverse effects of climate risk on their financial outcomes.

This study extends the growing literature on the cost of capital, climate risk, and environmental performance in the context of energy firms in at least three important ways. First, despite the efforts devoted by scholars to reveal the determinants of the cost of capital (Bassen et al., 2006; Dhaliwal et al., 2014; Huynh et al., 2020; Kling et al., 2021), the effects of climate risk and environmental performance on energy firms' cost of capital have been often neglected by the literature. This study contributes to the climate change literature by showing that climate risk is a significant factor that increases energy firms' cost of capital. Second, our study focuses on the direct and indirect benefits of pro-environmental policies in reducing the cost of capital. In doing so, we show that corporate environmental performance can be used as a tool by energy firms to mitigate the adverse effects of climate risk on the cost of capital. Finally, the findings of this study suggest that determinants of the cost of capital of fossil fuel and renewable energy firms are significantly different from each other. Although climate change can be considered a significant risk factor for both sectors, the adverse effect of climate risk on the cost of capital is more prominent for fossil fuel firms due to their exposure to greater transition and liability risks.

This paper consists of the following sections. In the next section, we discuss the literature on climate risk, environmental performance, and the cost of capital and present our hypotheses. Section 3 discusses the data and empirical approaches used in the study. We present the main results and robustness checks in Section 4. Section 5 concludes the paper with a summary of the findings and practical implications for corporations, investors, and policymakers.

2 | LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

2.1 | Climate risk and cost of capital of energy firms

Climate risks pose significant industry-specific challenges to energy firms, deteriorate their financial performance, and pressure them to shift their investments into green energy. The risk stemming from climate change can be classified under three categories, namely, physical, transitional, and liability-related risks (FSB, 2022). In this section, we discuss extant literature and formulate our hypotheses based on these risks specific to energy sector firms.

Climate change has a direct impact on energy firms' operations through significant changes in the demand and supply dynamics of the sector (Auffhammer & Mansur, 2014). On the demand side, it is argued that climate change has a growing impact on energy demand stemming from increasing electricity consumption associated with rising temperatures (Chen et al., 2021; Zheng et al., 2020). In a similar vein, Van Ruijven et al. (2019) document that energy demand will increase by 25%–58% by 2050[3] due to the effects of climate change. As for the energy supply, Chen et al. (2021) report that climate change shocks increase clean energy investments, which in turn boost the energy supply. Similarly, climate change may impact the energy supply in several other ways such as increasing the frequency of rainfalls, which may lead to floods resulting in changes in coal handling and its quality, and shifting the geographical distribution and the variability of wind speed (Pryor & Barthelmie, 2010). These possible channels put additional risk for energy companies, which in turn increases the uncertainty in their future operations. Furthermore, increases in temperature levels and the number of extreme weather events adversely affect the production processes of energy firms, which in turn are negatively reflected in their performance. In line with this, Luo (2021) estimates that a portfolio that includes thermal and hydro power assets, with only moderate climate change scenarios, will lose 3.3% of its annual generation by 2030 due to increasing water temperature, which may change the risk perceptions of capital providers about these firms. Similarly, energy firms are exposed to significant uncertainty due to changes in demand patterns resulting from rising temperatures and new regulations that might be implemented in the future to achieve long-term targets of net zero carbon emissions. Therefore, increased uncertainties stemming from climate change are expected to be reflected in the cost of capital of energy firms.

In addition to the effects of climate change on energy demand and supply, Semieniuk et al. (2022) draw attention to climate-related risks arising from stranded assets[4] for energy firms. As the value of energy firms' assets declines due to climate-related transition risks, this will be reflected in investors' expectations of the firm, which in turn will increase their cost of equity. Chen et al. (2022) point out that climate risks (both physical and transition risks) present additional uncertainties for energy firms by reducing foreign investments in this sector, which may result in difficulty in accessing external capital to finance their operations. In line with this, a recent report published by the Bank of England suggests that banks are planning to reduce lending to companies whose revenue is largely dependent on fossil fuels due to climate-related transition risks, which indicates that the cost of borrowing for these companies will be higher as the amount of lending is reduced (BOE, 2022). Similarly, van Benthem et al. (2022) argue that firms in the energy sector are uniquely affected by the growing awareness of climate risks in financial markets as they are major contributors to carbon emissions, making them directly exposed to transition risks as policymakers move the economy toward net-zero targets.

Another factor that may have an impact on the cost of capital for energy firms is related to liability risk, which has been on the rise in recent years. Parties who have suffered from climate change-related incidents can file a lawsuit and claim compensation for the damage. For example, as a result of a lawsuit brought by 15,000 villagers affected by Australia's worst oil spill in 2009, PTT Exploration and

Production agreed to pay $129 million to those who suffered from the oil spill at the end of 2022.[5] The uncertainty of the outcomes of the lawsuits (from cessation of operations to payment of compensation or dismissal of the lawsuit) may also increase energy firms' cost of capital by increasing the uncertainty in their future performance.

In summary, climate change can have a significant impact on the cost of capital for energy firms through several channels, including demand and supply dynamics. Rising temperatures and increased electricity consumption increase demand, while climate change shocks stimulate investment in clean energy and increase supply. In addition, climate-related risks, including stranded assets, increase the cost of equity for energy firms. Similarly, banks are planning to reduce their lending to fossil fuel-dependent companies, increasing their cost of borrowing. Liability risks, including claims for damages, are also increasing. These factors contribute to increased uncertainty in the operations of energy companies and the cost of capital. Based on this discussion, we predict that climate risk will adversely affect the cost of capital of energy firms due to significant sector-level uncertainties. We formulate our hypothesis as follows:

Hypothesis 1a. Climate risk increases the cost of capital of energy firms.

Fossil and renewable energy sectors differ from each other in terms of their climate risk exposure, which affects their cost of capital in different ways. Prior studies show that green firms have lower climate risk exposure than non-green firms (Engle et al., 2020). This can occur in the form of new regulations aiming to penalize non-green firms (e.g., fossil energy firms) due to their environmentally harmful activities (Pástor et al., 2021). As fossil energy firms are riskier due to their transition risk exposure, the expected return they offer to their capital providers must be higher. On the other hand, renewable energy firms may benefit from the same situation, such as carbon regulations, as these regulations can increase their competitive advantages while bringing additional costs to non-green firms (Pástor et al., 2021). In line with this, renewable energy producers are considered as key players who could reduce carbon emissions of the sector by 90% in 2050 suggesting that their transition risk is significantly lower than fossil energy firms. These differences between fossil and renewable energy firms require additional efforts for fossil energy firms to manage and mitigate the impact of climate risk exposure on their operations. Supporting this view, Pinto-Gutiérrez (2023) finds that mining companies that are exposed to greater climate risks face significantly higher loan spreads, which indicates that banks take into account climate-related risks in sensitive industries such as mining and fossil fuel. Based on this, we argue that the impact of climate risk on the cost of capital is stronger for fossil fuel firms than renewable energy firms as they are less exposed to transition and liability risks.

Hypothesis 1b. The impact of climate risk on the cost of capital is stronger for fossil fuel firms than renewable energy firms.

2.2 | The role of environmental performance

While it is acknowledged that climate risks present significant threats to energy firms, it is important to explore how these firms can alleviate the adverse effects of climate risks on their operations, performance, and cost of capital. Extant literature documents that better environmental performance increases the legitimacy of firms in the eyes of society (Bansal & Clelland, 2004), provides moral capital and goodwill (Trumpp & Guenther, 2017), and strengthens the corporate image (Cheng et al., 2014). Therefore, firms with better environmental performance are perceived as "less risky" by investors (Ahmed et al., 2019), which in turn reduces the cost of equity. Furthermore, in addition to the direct effect of environmental performance on firms' cost of capital, energy sector firms can mitigate the effect of climate risk on the cost of capital by improving their environmental performance, which can be considered as an indirect effect of environmental performance on the cost of capital of firms. For example, Ozkan et al. (2023) show that better environmental performance significantly reduces the negative impact of climate risk on firms' financial performance. Similarly, Sun et al. (2020) suggest that firms in the mining industry should respond to climate change risks by disclosing more information about their carbon emissions and improving their brand value.

Specifically, managing climate risk by embracing better environmental performance may be beneficial for firms to reduce their cost of capital as financial market participants (such as investors, banks, and asset managers) are increasingly taking into account climate risk exposure of their portfolios and environmental risk management practices followed by the firms (van Benthem et al., 2022). As the cost of capital is closely related to the uncertainty about the ability of firms to fulfill their future financial obligations and the riskiness of the future cash flows relative to other investment opportunities available (Orlitzky & Benjamin, 2001; Sharfman & Fernando, 2008), higher environmental performance can reduce the cost of capital by alleviating the climate-related risks and uncertainty that the firm may face in the future. Incorporating environmentally friendly policies into business strategies can also reduce the likelihood of events requiring a substantial amount of cash that firms may face due to extreme environmental events such as BP oil spills (Sharfman & Fernando, 2008). Similarly, Schneider (2011) argues that firms with poor environmental performance are more likely to have environmental obligations in the future, which exacerbates the firms' environmental risk and increases the likelihood that they may not be able to fulfill their financial obligations. Extant literature also suggests that poor environmental performance is reflected in bond prices. Today several external agencies publish reports on the relevance of environmental and social issues in credit ratings. For example, Fitch started to publish credit-focused ESG Relevance scores, which shows the sensitivity of ESG issues on credit rating decisions. These developments in the industry clearly show that capital providers are significantly concerned about environmental issues and punish firms with higher exposure to environmental risks. On the other hand, energy firms can turn the risks into opportunities and attract more external capital by diverting their investments into environmentally friendly projects.

Therefore, we argue that better environmental performance can mitigate the adverse effects of climate risk on the cost of capital of energy firms. We formulate our hypothesis as follows:

> **Hypothesis 2a.** Higher environmental performance mitigates the adverse impact of climate risk on the cost of capital of energy firms.

While climate risk poses significant challenges to the energy sector, energy firms can take pro-environmental actions to mitigate the adverse effects of climate risk on their businesses. Specifically, fossil energy firms can manage climate risk by investing in environmentally friendly operations, which in turn reduce their negative externalities and the cost of capital. The underlying reason is that fossil energy firms are more exposed to transition and liability risks than renewable energy firms, which can be managed by incorporating environmentally friendly strategies into their business model to achieve higher returns. As for renewable energy firms, since they are already considered "green" and do not have transition risk, there is no such gain for them to obtain by following the same strategy. In other words, increasing environmental performance can be used as a differentiation strategy by only fossil fuel firms as the exposure of fossil fuel firms to climate risks is significantly higher than that of renewable energy firms. Based on the above discussion, we formulate our hypotheses as follows:

> **Hypothesis 2b.** The moderating impact of environmental performance on the relationship between climate risk and cost of capital is stronger for fossil fuel firms than renewable energy firms.

3 | DATA AND METHODOLOGY

3.1 | Sample distribution and measures for climate risk and cost of capital

Our sample comprises 623 firms and 3146 firm-year observations of energy companies from 34 countries over the period 2015–2020.[6] We collect our data from different sources. We obtain financial information including the weighted average cost of capital (*WACC*), the cost of debt (*COD*), and the cost of equity (*COE*) and control variables from the Refinitiv database. WACC is a weighted measure of the cost of capital including debt and equity financing. COD is measured as the marginal cost of the firm in issuing new debt. Specifically, it is the ratio of the pre-tax interest expense of the firm in year *t* to the average total debt level in the same year. COE is calculated by multiplying the equity risk premium of the market with the beta of the stock plus an inflation-adjusted risk-free rate. We also collect the environmental performance score of each energy firm (*ENV*) from the same database. The environmental score is measured by considering three main categories namely "Resource Use," "Emissions," and "Innovation" scores of the firms and using more than 60 data indicators. Environmental scores range from 0 to 100 and a higher score indicates better environmental performance of the firm compared to their peers.

Following prior literature, we use ND-GAIN as our measure of climate risk (Cevik & Jalles, 2022; Lo & Chow, 2015; Ozkan et al., 2021; Ozkan et al., 2023). ND-GAIN index measures the vulnerability and readiness of the countries to adopt environmental policies to tackle climate change, and it captures both physical and transitional risks. Specifically, the ND-GAIN index considers both the propensity of society to be negatively affected by climate change (vulnerability dimension) and also the readiness to take adaptation actions to tackle the negative impact of climate change on society (readiness dimension). The vulnerability dimension of ND-GAIN includes three subcategories, namely, exposure, sensitivity, and adaptive capacity. The exposure dimension of the ND-GAIN index measures the climate change exposure of a country from a biophysical perspective that captures the physical climate change exposure of a country. This is a time-invariant component of the ND-GAIN index as the physical climate change exposure of a country does not change rapidly over the years. The sensitivity and adaptive capacity components of ND-GAIN are time-variant measures that measure the proportion of the population vulnerable to climate risks and the availability of resources to adapt to climate change. These two dimensions of ND-GAIN capture transition risks.[7] On the other hand, the readiness dimension considers the economic, social, and governance readiness components of the country. Higher ND-GAIN scores indicate lower exposure to climate change. We should also note that due to the high correlation of the raw ND-GAIN index with GDP levels, we use GDP-adjusted ND-GAIN scores, which are also provided by the Notre Dame Global Adaptation Initiative. Specifically, adjusted ND-GAIN scores are the residuals from the regression of raw ND-GAIN scores with GDP per capita on an annual basis. Using GDP-adjusted ND-GAIN scores allows us to isolate the net impact of climate change risk of the countries, which is not related to their economic development. We multiply the ND-GAIN score by -1 to make the interpretation easier. After this transformation, a higher ND-GAIN score shows higher exposure to climate risk (*Climate risk*) in our empirical framework.

Figure 1 depicts the relationship between the average *Climate risk* of the countries and the weighted average cost of capital and its components such as the cost of equity and cost of debt. Energy firms listed in countries with lower levels of climate adaptability and higher levels of climate risk have a higher cost of capital, cost of debt, and cost of equity, which supports our predictions. To strengthen our understanding of the relationship between climate risk and cost of capital over the years, we divide our sample countries into two as high and low *Climate risk* based on the median value of ND-GAIN across countries and present their relationship with the cost of capital in Figure 2. Confirming the results in Figure 1, energy firms listed in higher climate risk countries exhibit significantly higher weighted average cost of capital, cost of equity, and cost of debt.

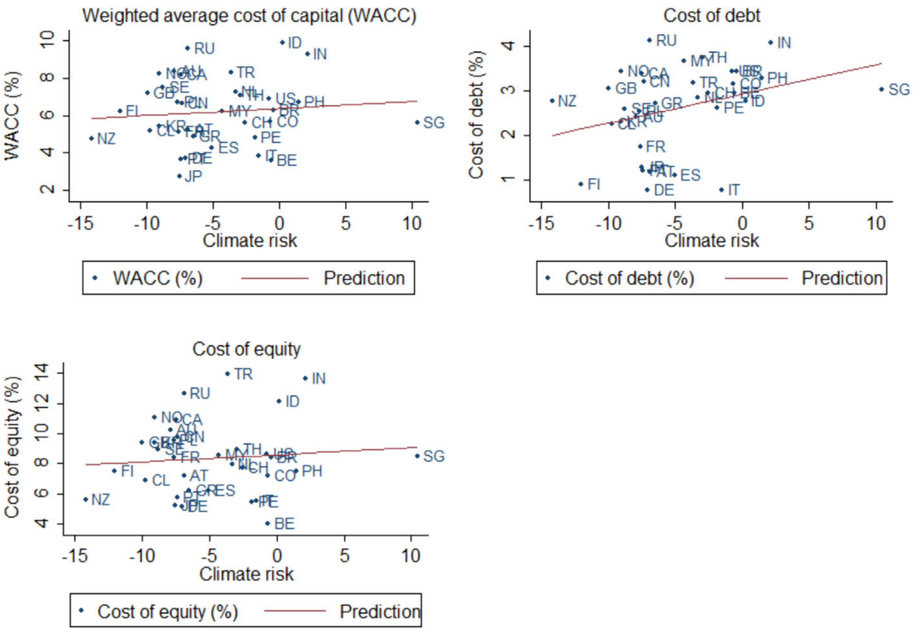

FIGURE 1 Climate risk and cost of capital across countries. This graph shows the relationship between country-average climate risk and cost of capital measures, namely weighted average cost of capital (WACC), cost of debt, and cost of equity. Definitions of the variables are given in Table 2.

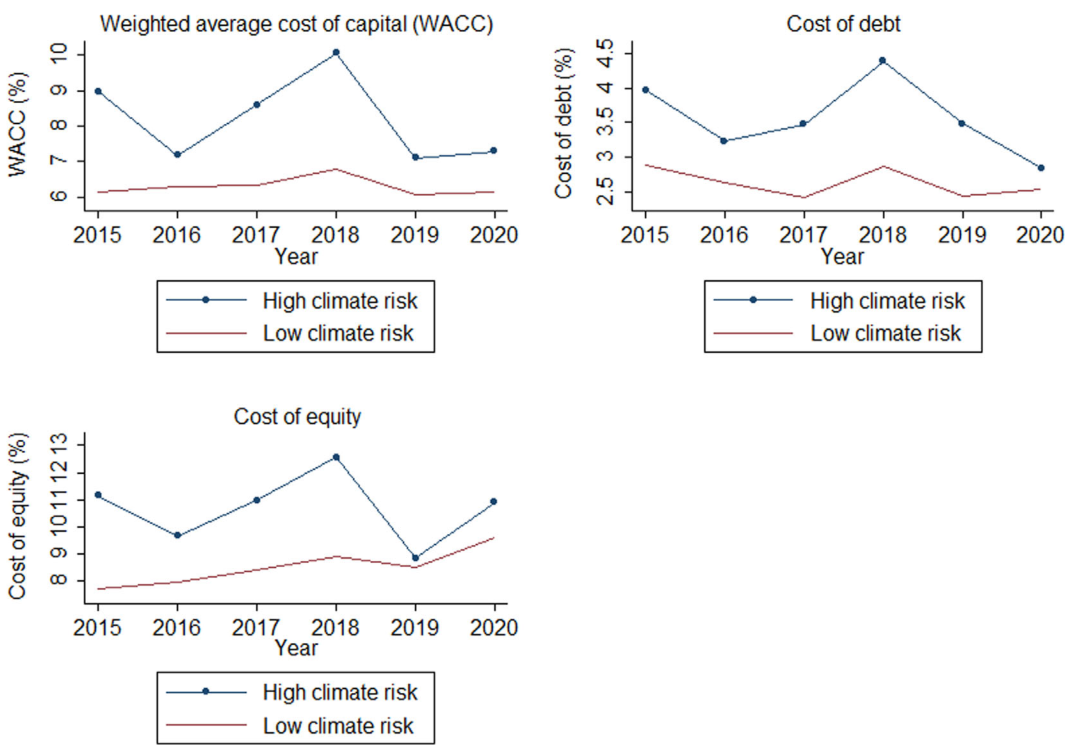

FIGURE 2 Climate risk and cost of capital across years. This figure shows the time evolution of the cost of capital measures, namely weighted average cost of capital (WACC), cost of debt, and cost of equity for high and low climate risk countries over the years. High (low) climate risk indicates the countries having a climate risk value greater (lower) than the sample median. Definitions of the variables are given in Table 2.

Importantly, the cost of capital of firms in higher climate risk countries tends to be more volatile than those of firms listed in low climate risk countries.

Table 1 presents the sample distribution and summary statistics of the variables of interest by country. Not surprisingly, the United States enters into analysis with the highest number of firm-year observations (1022), which is followed by Canada (369). Regarding our climate risk measure, Singapore and India have the highest *Climate risk* at 10.459 and 2.157, respectively. As for environmental performance, energy firms located in Spain (81.138), Finland (77.002), and Austria (73.893) have the highest environmental performance scores (*Environment*) on average.

TABLE 1 Sample distribution.

Country	N	WACC (%)	COD (%)	COE (%)	Climate risk	ENV
Australia	167	8.362	2.418	10.193	−7.919	25.430
Austria	18	5.216	1.176	7.212	−6.896	73.893
Belgium	15	3.576	2.948	4.014	−0.621	40.366
Brazil	111	6.296	3.420	8.391	−0.430	46.944
Canada	369	8.157	3.376	10.887	−7.463	31.032
Chile	57	5.206	2.243	6.883	−9.752	53.094
China	181	6.617	3.201	9.766	−7.357	37.678
Colombia	25	5.648	3.158	7.215	−0.657	56.876
Finland	12	6.195	0.890	7.516	−12.032	77.002
France	58	5.137	1.738	8.371	−7.605	71.462
Germany	28	3.717	0.761	5.125	−7.072	57.647
Greece	36	4.874	2.706	6.209	−6.496	43.754
India	89	9.252	4.060	13.655	2.157	49.652
Indonesia	42	9.860	2.757	12.157	0.225	56.283
Italy	78	3.871	0.763	5.480	−1.525	73.945
Japan	109	2.722	1.268	5.192	−7.520	62.083
South Korea	31	5.436	2.315	9.384	−9.053	64.193
Malaysia	54	6.192	3.662	8.585	−4.310	40.886
Netherlands	30	7.247	2.843	7.974	−3.319	40.869
New Zealand	46	4.772	2.770	5.585	−14.192	25.380
Norway	48	8.238	3.438	11.031	−9.041	51.276
Peru	17	4.804	2.624	5.434	−1.850	18.070
Philippines	18	6.723	3.266	7.490	1.450	49.016
Poland	45	6.728	2.541	9.527	−7.656	44.092
Portugal	15	3.684	1.200	5.773	−7.405	70.284
Russia	90	9.575	4.127	12.665	−6.867	46.423
Singapore	15	5.627	3.025	8.454	10.459	38.879
Spain	55	4.256	1.097	6.185	−5.064	81.138
Sweden	11	7.480	2.592	8.964	−8.788	25.496
Switzerland	13	5.630	2.940	7.748	−2.555	33.285
Thailand	76	7.066	3.728	8.942	−2.949	52.474
Turkey	19	8.272	3.176	13.934	−3.635	52.182
United Kingdom	153	7.181	3.047	9.416	−9.970	40.833
United States	1,022	6.902	3.437	8.648	−0.740	32.569

Note: This table presents the distribution of the sample used in the study. N refers to the number of observations per country. WACC, COD, and COE denote the weighted average cost of capital, cost of debt, and cost of equity, respectively. Climate risk is measured by the ND-GAIN index which is an inverse measure of climate risk and captures both the vulnerability and readiness of the countries to climate change. It should be noted that we multiply the original ND-GAIN index with −1 to make the interpretation easier. Therefore, higher values of *Climate risk* indicate higher exposure to climate change. *Environment* is the environmental pillar score of the firms, which is obtained from the Refinitiv database.

3.2 | Methodology

We utilize panel data regression analysis to test our baseline model as our sample includes both time and cross-section dimensions. In other words, the same cross-sectional unit (each energy sector firm in this study) is observed over time in panel data regression analysis. The advantages of using this analysis are having "more informative data, more variability, less collinearity among variables, more degrees of freedom and more efficiency" (Gujarati, 2004:637). We test the impact of climate risk and environmental performance of the energy companies on their weighted average cost of capital (*WACC*), cost of debt (*COD*) and cost of equity (*COE*) using the following regression model.

$$Cost\ of\ capital_{i,t,c} = Climate\ risk_{t-1,c} + ENV_{i,t-1,c} + Controls_{i,t-1,c} + \varepsilon_{i,t} \quad (1)$$

In Equation (1), *i*, *t*, and *c* denote firm, year, and country, respectively. *Cost of capital* refers to the weighted average cost of capital (*WACC*), the cost of debt (*COD*), and the cost of equity (*COE*). *Climate risk* is our country-level climate risk proxy, which is obtained by the Notre Dame Global Adaptation Initiative (ND-GAIN index multiplied by −1), and *ENV* is the firm-specific environmental performance score of the energy firms, which is obtained from Refinitiv. *Controls* refer to the firm and country-specific control variables that are predicted to have an impact on the cost of capital of the energy firms. Independent variables are lagged by 1 year to avoid simultaneity issues.

Following prior studies (e.g., El Ghoul et al., 2011; Kling et al., 2021), we control for firm size (*Size*), financial leverage (*Leverage*), return on assets (*ROA*), firm age (*Age*), and market-to-book ratio (*MB*) as firm-specific variables. We also control for GDP per capita in US dollars (*GDP*) and GDP growth rate (*GDPgr*) to account for the economic development of the countries. We also include country and year-fixed effects into our model to control for unobservable country and year-fixed effects. We use heteroskedasticity-robust standard errors clustered at the firm level in all models. Definitions of the variables are provided in Table 2.

In the second stage of the analysis, we test the moderating impact of corporate environmental performance *(ENV)* on the relationship between *Climate risk* and our three cost of capital measures (*WACC*, *COD*, and *COE*) using the following regression model (Equation 2).

$$Cost\ of\ capital_{i,t,c} = Climate\ risk_{t-1,c} + ENV_{i,t-1,c} + Climate\ risk_{t-1,c} x ENV_{i,t-1,c} + Controls_{i,t-1,c} + \varepsilon_{i,t} \quad (2)$$

A negative coefficient of the interaction term (*Climate risk* × *ENV*) indicates that energy firms with greater environmental performance can mitigate the adverse effects of climate risk on their cost of capital. *Cost of capital*, *Climate risk*, and *ENV* are the same as in Equation (1). In all our regressions, we control for firm and country-specific factors as in Equation (1) (*Controls*) and year and country-fixed effects to account for any unobservable year and country-specific factors.[8] Similar to Equation (1), we use heteroskedasticity-robust standard errors clustered at the firm level in all models.

4 | RESULTS

4.1 | Climate risk, environmental performance, and the cost of capital

We present the summary statistics of the variables used in the study in Table 3. The average values of *Climate risk* and *Environment* are −4.285 and 41.064, respectively. Our sample firms have a mean value of *WACC*, *COD*, and *COE* of 6.804%, 3.025%, and 9.005%, respectively.

We present the correlation matrix in Table 4. Supporting our predictions, there is a positive relationship between *Climate risk* and

TABLE 2 Definitions of the variables and data sources.

Variable	Description	Source
WACC	Weighted average cost of capital. A firm-specific weighted measure of cost of capital including equity stock, preferred stock, and debt.	Refinitiv
COD	Weighted average cost of debt. Marginal cost to the firm of issuing new debt. It is the ratio of the total pre-tax interest expense reported by the firm in year t to the average total debt in year *t*.	Refinitiv
COE	Weighted average cost of equity. It is calculated by multiplying by equity risk premium of the market with the beta of the stock plus an inflation-adjusted risk-free rate. Equity risk premium is the expected market return minus the inflation-adjusted risk-free rate.	Refinitiv
ENV	Corporate environmental performance score ranging between 0 and 100.	Refinitiv
Climate risk	We use the ND-GAIN index, which is published by Notre Dame Global Adaptation Initiative as our measure of climate risk. ND-GAIN is an inverse measure of country-level climate risk which takes into account climate vulnerability and readiness of the countries to take adaptation policies by increasing climate awareness and facilitating public and private investments to manage climate risks. To make the interpretation easier, we multiply ND-GAIN with −1. Therefore, our ultimate measure of climate risk indicates higher climate risk for higher values of the ND-GAIN index.	Notre Dame Global Adaptation Initiative
Size	Natural logarithm of total assets in US dollars	Refinitiv
Leverage	The ratio of total debt to total asset	Refinitiv
ROA	The ratio of earnings before extraordinary items to total asset	Refinitiv
Age	Number of years since the establishment of the firm	Refinitiv
MTB	Market capitalization plus total debt scaled by the total assets	Refinitiv
GDP capita	Natural logarithm of gross domestic product per capita in US dollars	World Bank
GDP growth	Growth rate of GDP calculated as $([GDP_t - GDP_{t-1}]/GDP_{t-1})$	World Bank

Note: This table presents the definitions and data sources of the variables used in the study.

TABLE 3 Descriptive statistics.

	N	Mean	*SD*	Median	Minimum	Maximum
WACC (%)	3146	6.804	3.467	6.297	1.187	18.543
COD (%)	3146	3.025	1.703	2.893	0.000	6.197
COE (%)	3146	9.005	4.592	8.295	1.016	21.697
Climate risk	3146	−4.285	4.185	−3.932	−18.096	12.028
ENV	3146	41.064	27.441	41.179	0.000	97.045
Size	3146	23.391	2.856	23.055	14.473	32.917
Leverage (%)	3146	31.825	17.313	31.932	0.000	60.766
MTB	3146	1.694	1.613	1.310	0.000	10.29
ROA (%)	3146	0.148	9.764	2.331	−33.415	18.681
Age	3146	33.087	32.633	21.000	0.000	130.000
GDP capita	3146	28.866	1.504	28.606	25.905	30.696
GDP growth (%)	3146	0.008	0.073	0.028	−0.338	0.233

Note: This table presents the descriptive statistics of the variables used in the study. N represents the number of observations. Mean, *SD*, Median, Minimum, and Maximum represent the mean, standard deviation, median, minimum, and maximum values of the variables. Definitions of the variables are presented in Table 2.

TABLE 4 Correlation matrix.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) WACC	1.000											
(2) COD	0.393*	1.000										
(3) COE	0.793*	0.390*	1.000									
(4) Climate risk	0.039*	0.153*	0.019	1.000								
(5) ENV	−0.269*	−0.242*	−0.186*	−0.031	1.000							
(6) Size	−0.201*	−0.065*	−0.078*	−0.027	0.517*	1.000						
(7) Leverage	−0.310*	0.242*	−0.037*	0.052*	0.132*	0.200*	1.000					
(8) MTB	−0.065*	−0.139*	−0.201*	0.085*	−0.058*	−0.145*	0.009	1.000				
(9) ROA	−0.186*	−0.142*	−0.266*	0.052*	0.192*	0.347*	−0.089*	0.142*	1.000			
(10) Age	−0.225*	−0.285*	−0.204*	0.070*	0.296*	0.155*	0.006	0.001	0.102*	1.000		
(11) GDP capita	0.021	0.130*	0.002	0.455*	−0.175*	−0.135*	0.029	0.049*	−0.111*	−0.042*	1.000	
(12) GDP growth	0.083*	0.104*	0.039*	0.164*	−0.043*	0.032	−0.021	0.035*	0.120*	−0.003	0.234*	1.000

Note: This table presents the correlation coefficients of the variables. Definitions of the variables are presented in Table 2.
*Significance level at 5%.

WACC, *COD*, and *COE*, which implies that firms domiciled in countries with higher climate risk have a higher weighted average cost of capital, cost of debt, and cost of equity. However, the correlation between *Climate risk* and *COE* is not significant at conventional levels.

Table 5 presents the results of the relationship between climate risk and cost of capital measures in a multivariate setting. We find a significant positive impact of *Climate risk* on the weighted average cost of capital (Column 1), cost of debt (Column 3), and cost of equity (Column 5), hence supporting Hypothesis 1a. Specifically, one standard deviation increase in climate risk increases the weighted average cost of capital, cost of debt, and cost of equity by approximately 1.08, 0.30, and 2.35 percentage points, respectively. On the other hand, our results suggest that energy firms with higher environmental performance have lower cost of capital, which is evident by a negative coefficient of *ENV* in Columns 1, 3, and 5 of Table 5. One standard deviation increase in environmental performance reduces the weighted average cost of capital, cost of debt, and cost of equity by approximately 0.36, 0.19, and 0.58 percentage points, respectively. This result confirms earlier findings regarding the financial benefits of engaging more in corporate social responsibility and environmental performance (El Ghoul et al., 2018).

Columns 2, 4, and 6 of Table 5 present the results of our interaction analysis. Specifically, we multiply *Climate risk* with firms' environmental performance (*ENV*) to test the role of environmental performance in mitigating the adverse effects of climate risk on the cost of capital. The negative coefficient of the interaction term in all

TABLE 5 Climate risk, environmental performance, and cost of capital.

	(1) WACC	(2) WACC	(3) COD	(4) COD	(5) COE	(6) COE
Climate risk	0.259***	0.327***	0.072***	0.117***	0.561***	0.664***
	(0.052)	(0.066)	(0.027)	(0.030)	(0.072)	(0.090)
ENV	−0.013***	−0.021***	−0.007***	−0.012***	−0.021***	−0.033***
	(0.004)	(0.006)	(0.002)	(0.003)	(0.007)	(0.009)
Climate risk × ENV		−0.002**		−0.001***		−0.003**
		(0.001)		(0.000)		(0.001)
Size	−0.183***	−0.180***	−0.053	−0.051	−0.140	−0.135
	(0.063)	(0.063)	(0.033)	(0.032)	(0.095)	(0.095)
Leverage	−0.052***	−0.052***	0.026***	0.027***	−0.001	−0.001
	(0.006)	(0.006)	(0.003)	(0.003)	(0.009)	(0.009)
MTB	−0.184**	−0.183**	−0.175***	−0.174***	−0.606***	−0.604***
	(0.085)	(0.085)	(0.034)	(0.033)	(0.122)	(0.122)
ROA	−0.040***	−0.041***	−0.009*	−0.010*	−0.071***	−0.073***
	(0.014)	(0.014)	(0.005)	(0.005)	(0.018)	(0.018)
Age	−0.009**	−0.009**	−0.005***	−0.005***	−0.010*	−0.010*
	(0.004)	(0.004)	(0.001)	(0.001)	(0.005)	(0.005)
GDP capita	−2.045	−2.180*	−1.311*	−1.401**	−0.068	−0.273
	(1.254)	(1.252)	(0.695)	(0.704)	(1.754)	(1.744)
GDP growth	3.710***	3.813***	0.967**	1.035***	4.717***	4.873***
	(0.756)	(0.756)	(0.393)	(0.393)	(0.946)	(0.940)
Year fixed	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2480	2480	2480	2480	2480	2480
R-squared	0.355	0.357	0.409	0.415	0.291	0.295

Note: This table presents the regression results of the relationship between climate risk (Climate risk), environmental performance (ENV), and cost of capital measures. The dependent variable is the weighted average cost of capital (WACC) in Columns 1 and 2, cost of debt (COD) in Columns 3 and 4, and cost of equity (COE) in Columns 5 and 6. Definitions of the variables are given in Table 2. Firm-level clustered standard errors are reported in parentheses. ***Significance level at 1%, **Significance level at 5%, and *Significance level at 10%.

models suggests that engaging more in pro-environmental actions significantly alleviates the adverse effects of climate risk on the cost of capital, hence supporting Hypothesis 2a. This result is in line with the argument that environmental engagement has significant risk reduction benefits to corporations (Albarrak et al., 2019). The results for the control variables are generally in line with the findings of prior literature. We find that larger and older firms with higher leverage, market-to-book ratio, and profitability (*ROA*) have a lower weighted average cost of capital. Regarding the macroeconomic factors, the GDP growth rate exerts a positive influence on the cost of capital.

4.2 | Fossil fuel vs. renewable energy firms

We argue that the impact of climate risk on the cost of capital is stronger for fossil fuel firms than renewable energy firms as fossil fuel firms are more exposed to transition and liability risks related to climate change (Hypothesis 1b). To test this prediction, we divide our sample into two, that is, fossil fuel firms and renewable energy firms, and rerun our regressions for these two subsamples. We present the results for our subsample analysis in Table 6. Climate risk significantly increases the weighted average cost of capital, cost of debt, and cost of equity of fossil-fuel firms. Furthermore, fossil-fuel firms that have better environmental performance exhibit significantly lower costs of capital compared to firms with lower environmental performance. The environmental performance also mitigates the adverse effect of climate risk on the cost of capital which is evident by a negative coefficient of the interaction terms in columns 2, 4, and 6 of Panel A.

The results for the renewable energy firms are presented in Panel B of Table 6. Supporting our expectations and Hypothesis 2b, climate risk does not have a direct impact on the cost of capital, which is evident by an insignificant coefficient of *Climate risk* in columns 1, 3, and 5. While physical climate risk is still a factor for renewable energy firms, which may have an impact on their performance and business operations, they are less likely to be affected by transition and liability risks. Furthermore, similar to fossil fuel firms, environmental performance significantly mitigates the adverse effect of climate risk on the

TABLE 6 Fossil fuel versus renewable energy firms.

Panel A: Fossil fuel firms						
	(1) WACC	**(2) WACC**	**(3) COD**	**(4) COD**	**(5) COE**	**(6) COE**
Climate risk	0.244***	0.307***	0.069**	0.114***	0.547***	0.639***
	(0.060)	(0.074)	(0.031)	(0.035)	(0.081)	(0.101)
ENV	−0.012**	−0.019***	−0.007***	−0.012***	−0.022***	−0.031***
	(0.005)	(0.007)	(0.002)	(0.003)	(0.007)	(0.009)
Climate risk × ENV		−0.002*		−0.001***		−0.003*
		(0.001)		(0.000)		(0.001)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2233	2233	2233	2233	2233	2233
R-squared	0.361	0.363	0.419	0.424	0.300	0.303
Panel B: Renewable energy firms						
	(1) WACC	**(2) WACC**	**(3) COD**	**(4) COD**	**(5) COE**	**(6) COE**
Climate risk	0.170	0.276***	0.098	0.106	0.185	0.331**
	(0.107)	(0.101)	(0.081)	(0.082)	(0.138)	(0.137)
ENV	−0.013*	−0.033***	−0.017***	−0.019***	−0.008	−0.034**
	(0.007)	(0.010)	(0.004)	(0.006)	(0.009)	(0.017)
Climate risk × ENV		−0.004**		−0.000		−0.006**
		(0.002)		(0.001)		(0.003)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed	Yes	Yes	Yes	Yes	Yes	Yes
Observations	247	247	247	247	247	247
R-squared	0.635	0.654	0.631	0.631	0.614	0.629

Note: This table presents the regression results of the relationship between climate risk (Climate risk), environmental performance (ENV), and cost of capital measures for fossil fuel and renewable energy firms separately. We present the results for fossil fuel firms in Panel A and renewable energy firms in Panel B. The dependent variable is the weighted average cost of capital (WACC) in Columns 1 and 2, cost of debt (COD) in Columns 3 and 4, and cost of equity (COE) in Columns 5 and 6. Definitions of the variables are given in Table 2. Firm-level clustered standard errors are reported in parentheses.
***Significance level at 1%, **Significance level at 5%, and *Significance level at 10%.

weighted average cost of capital and cost of equity. While environmental performance does not have a direct significant effect on the cost of equity of renewable energy firms, it helps firms obtain cheaper equity capital in countries with higher exposure to climate risk (Column 6 of panel B). However, we do not observe the same interaction effect for the cost of debt, which is evident by an insignificant coefficient of the interaction term in Column 4 of panel B. Overall, we have partial support for Hypothesis 2b.

4.3 | Addressing endogeneity

Although our results suggest a significant relationship between climate risk and the cost of capital of energy firms, they may be biased due to endogeneity issues, which mainly result from omitted variables, measurement error, and reverse causality issues. For example, environmental performance and cost of capital of the firms may be simultaneously determined by other factors that are not included in the regression model. In addition, it might be argued that firms with higher costs of capital invest less in environmental projects due to the unavailability of external funds which may result in a reverse causality problem.

To address these concerns, particularly about the endogenous nature of environmental performance, we employ instrumental variable regressions in two stages as a robustness check. In the first stage, we predict the environmental performance of the firms by using the average subsector environmental performance score excluding the focal firm in our sample firms as an external instrument and other control variables included in our baseline specification. It is reasonable to expect a positive relationship between the industry average environment score (*Industry ENV*) and firm-level environment score due to the peer firm effect which is documented in the literature (Ozkan et al., 2023). On the other hand, we do not expect any impact of sector average environmental performance on firm-level cost of capital, which satisfies the relevance and exclusion conditions for instrumental variable regressions. In the second stage of the analysis, we use predicted environmental performance scores from the first stage (*ENV_pred*) as our main variable of interest.

We present the first-stage regression results in Column 1 of Table 7. There is a positive relationship between the industry average environmental performance (*Industry ENV*) and firm-level environmental performance score, which confirms the relevance condition of instrumental variable regression analysis. Columns 2–7 in Table 7 present the results of the second stage analysis. Similar to our prior results, environmental performance has a significant moderating effect on the relationship between *Climate risk* and all cost of capital measures, namely *WACC*, *COD*, and *COE*. These results suggest that our main conclusion regarding the direct and indirect effect of environmental performance on the cost of capital is robust after controlling for the endogeneity of environmental performance.

In Table 8, we present the instrumental variable regression results for subsamples of fossil fuel (Panel A) and renewable energy firms (Panel B). The results in Panel A of Table 8 confirm our earlier results. Climate risk significantly increases the weighted average cost of capital, cost of debt, and cost of equity of the fossil fuel firms. Environmental performance exerts a negative impact on all cost of capital measures in the fossil fuel subsample. Furthermore, environmental performance also mitigates the adverse effects of climate risk on the

TABLE 7 Instrumental variable regressions.

	(1) First Stage	(2) WACC	(3) WACC	(4) COD	(5) COD	(6) COE	(7) COE
Climate risk	0.812**	0.389***	0.554***	0.072**	0.126***	0.775***	0.971***
	(0.337)	(0.068)	(0.103)	(0.034)	(0.044)	(0.095)	(0.147)
ENV_pred		−0.234***	−0.251***	−0.061***	−0.067***	−0.355***	−0.376***
		(0.029)	(0.031)	(0.011)	(0.011)	(0.043)	(0.046)
Climate risk × ENV_pred			−0.005**		−0.001*		−0.005*
			(0.002)		(0.001)		(0.003)
Size	6.419***	1.390***	1.398***	0.322***	0.324***	2.238***	2.247***
	(0.685)	(0.218)	(0.220)	(0.088)	(0.089)	(0.320)	(0.324)
Leverage	0.013	−0.055***	−0.056***	0.027***	0.026***	−0.001	−0.001
	(0.047)	(0.007)	(0.007)	(0.003)	(0.003)	(0.010)	(0.010)
MTB	−0.188	−0.194**	−0.181**	−0.207***	−0.202***	−0.694***	−0.678***
	(0.488)	(0.089)	(0.090)	(0.038)	(0.038)	(0.135)	(0.136)
ROA	−0.007	−0.035**	−0.039**	−0.009	−0.011*	−0.080***	−0.084***
	(0.068)	(0.016)	(0.016)	(0.006)	(0.006)	(0.021)	(0.021)
Age	0.061**	0.009*	0.009**	−0.000	−0.000	0.016**	0.016**
	(0.031)	(0.004)	(0.004)	(0.001)	(0.001)	(0.006)	(0.006)
GDP capita	−7.316	−5.247***	−5.087***	−3.222***	−3.170***	−1.796	−1.605
	(8.660)	(1.934)	(1.903)	(1.060)	(1.066)	(2.580)	(2.506)
GDP growth	5.417	7.335***	6.970***	3.018***	2.899***	8.420***	7.985***
	(4.787)	(1.546)	(1.518)	(0.780)	(0.791)	(2.050)	(2.004)
Industry ENV	0.336***						
	(0.081)						
Year Fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country Fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,480	1855	1855	1855	1855	1855	1855
R-squared	0.496	0.408	0.412	0.430	0.432	0.360	0.364

Note: This table presents the two stages instrumental variable (2SLS IV) regression results of the effects of climate risk and firms' environmental performance on firms' cost of capital. In the first stage, we regress environmental performance (ENV) on sub-industry (by GICS Sub-Industry Name) average environmental performance (Industry ENV) and other control variables. We use predicted environmental performance scores (ENV_pred) in the second stage of the analysis. The dependent variable is the weighted average cost of capital (WACC) in Columns 2 and 3, cost of debt (COD) in Columns 4 and 5, and cost of equity (COE) in Columns 6 and 7. Definitions of the variables are given in Table 2. Firm-level clustered standard errors are reported in parentheses.

***Significance level at 1%, **Significance level at 5%, and *Significance level at 10%.

TABLE 8 Instrumental variable regressions for subsamples.

Panel A: Fossil fuel firms						
	(1) WACC	(2) WACC	(3) COD	(4) COD	(5) COE	(6) COE
Climate risk	0.377***	0.517***	0.068*	0.120**	0.767***	0.914***
	(0.076)	(0.111)	(0.039)	(0.048)	(0.106)	(0.160)
ENV_pred	−0.251***	−0.267***	−0.070***	−0.076***	−0.387***	−0.403***
	(0.032)	(0.033)	(0.011)	(0.011)	(0.047)	(0.050)
Climate risk × ENV_pred		−0.004**		−0.001*		−0.004
		(0.002)		(0.001)		(0.003)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,681	1,681	1,681	1,681	1,681	1,681
R-squared	0.424	0.427	0.445	0.448	0.383	0.385
Panel B: Renewable energy firms						
	(1) WACC	(2) WACC	(3) COD	(4) COD	(5) COE	(6) COE
Climate risk	0.078	0.568**	0.091	0.214	0.005	1.095**
	(0.151)	(0.238)	(0.104)	(0.184)	(0.232)	(0.462)
ENV_pred	0.054	−0.029	0.019	−0.002	0.118	−0.066
	(0.065)	(0.070)	(0.047)	(0.056)	(0.089)	(0.097)
Climate risk × ENV_pred		−0.011***		−0.003		−0.025**
		(0.004)		(0.003)		(0.010)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed	Yes	Yes	Yes	Yes	Yes	Yes
Observations	174	174	174	174	174	174
R-squared	0.659	0.681	0.615	0.618	0.600	0.647

Note: This table presents the two-stage least squares instrumental variable (2SLS IV) regression results of the effects of climate risk and firms' environmental performance on firms' cost of capital for subsamples of fossil fuel and renewable energy firms. In the first stage, we regress environmental performance (ENV) on the sub-industry (by GICS Sub-Industry Name) average environmental performance (Industry environment) and other control variables and predict the environmental performance score. We use predicted environmental performance scores (ENV_pred) in the second stage of the analysis. The dependent variable is the weighted average cost of capital (WACC) in Columns 1 and 2, cost of debt (COD) in Columns 3 and 4, and cost of equity (COE) in Columns 5 and 6. Definitions of the variables are given in Table 2. Firm-level clustered standard errors are reported in parentheses.
***Significance level at 1%, **Significance level at 5%, and *Significance level at 10%.

cost of capital in our instrumental variable setting. The results in Panel B of Table 8 are also qualitatively similar to earlier results (Table 6). As reported in the panel, climate risk, and environmental performance do not have a direct impact on the cost of capital of energy firms. However, environmental performance significantly interacts with climate risk in determining the weighted average cost of capital (*WACC*) and cost of equity (*COE*) of renewable energy firms. Although environmental performance does not have a direct impact on the cost of capital, renewable energy firms can benefit from engaging more in pro-environmental activities which reduce their weighted average cost of capital and cost of equity when climate risk is higher.

Another potential reason for endogeneity is sample heterogeneity. Energy firms located in high- and low-climate-risk countries can have different characteristics that result in sample selection bias. To address this, we employ propensity score matching (PSM) analysis which allows us to compare the cost of capital of two groups (high vs. low climate risk) with similar characteristics. Specifically, we create two groups, Treatment (high climate risk) and Control (low climate risk) groups, and compare the cost of capital of energy firms in these groups in a multivariate setting. The treatment (control) group includes firms located in high(low)-climate-risk countries. We define high- and low-climate-risk countries based on the median value of ND-GAIN. We employ PSM in two stages. In the first stage, we match each firm in the Treatment group with a similar firm in the Control group considering firm-specific factors, utilizing a nearest-neighborhood algorithm with one-to-one matching without replacement. We find matches of 781 firms in our Treatment group. We present the mean values of the covariates in the Treatment and Control groups after the matching process in Table 9. As is evident in Panel A of Table 9, energy firms in the Treatment and Control groups share very similar characteristics after the matching process. We have very similar results for fossil fuel (Panel B of Table 9) and renewable energy (Panel C of Table 9) subsamples, which is evident by the insignificant mean difference test, and variance ratio, which is close to 1, which confirms the validity of the first stage of PSM analysis.

In the second stage of PSM analysis, we rerun our regressions with matched samples. The results presented in Panel A of Table 10 are qualitatively similar to our prior results, suggesting that climate risk significantly increases the cost of capital. Furthermore, environmental performance has both direct and indirect effects on the cost of capital by reducing the adverse effects of climate risk on the cost of capital. The results for fossil fuel energy firms are also qualitatively similar to the results of the main analysis (Panel B of Table 10). Regarding renewable energy firms, the results of the PSM analysis suggest that climate risk significantly increases the weighted average cost of capital and cost of debt of renewable energy firms (Panel C of Table 10). On the other hand, environmental performance exerts a negative influence on only the cost of debt, which is evident by a negative coefficient of *ENV* in Column 3 of Panel C. In addition, different from the results for fossil fuel firms, environmental performance does not help renewable energy firms mitigate the adverse effects of climate risk on any cost of capital measure. Overall, our

TABLE 9 Covariate balance test for propensity score matching (PSM).

	High climate risk	Low climate risk	Diff. (*p* value)	Variance ratio
Panel A. Full sample				
ENV	42.130	41.859	0.843	1.08
Size	23.698	23.697	0.994	0.70
Leverage	30.758	31.312	0.527	0.82
MTB	1.508	1.511	0.967	0.86
ROA	0.077	0.455	0.412	1.07
Age	30.046	31.433	0.341	0.89
Panel B. Fossil fuel firms				
	High climate risk	**Low climate risk**	**Diff. (*p* value)**	**Variance ratio**
ENV	42.938	43.009	0.963	1.12
Size	23.780	23.637	0.396	0.70
Leverage	30.114	30.264	0.870	0.81
MTB	1.525	1.502	0.750	0.86
ROA	−0.001	0.166	0.743	1.01
Age	31.317	32.593	0.437	0.96
Panel C. Renewable energy firms				
	High climate risk	**Low climate risk**	**Diff. (*p* value)**	**Variance ratio**
ENV	39.253	37.018	0.553	1.19
Size	24.191	24.305	0.751	0.63
Leverage	39.552	43.267	0.221	1.07
MTB	1.542	1.679	0.489	0.65
ROA	3.411	2.714	0.250	1.48
Age	25.944	26.611	0.884	1.60

Note: This table presents the covariate balance test for Propensity Score Matching (PSM) analysis for full sample (Panel A), fossil fuel firms (Panel B), and renewable energy firms (Panel C). The treatment group (High climate risk) includes the firms listed in countries with above median climate risk. The control group (Low climate risk) includes the firms listed in countries with below median climate risk. The covariate balance test assesses whether the average values of covariates (firm-specific variables) are similar across treatment (high climate risk) and control (low climate risk) groups. Diff. (*p* value) indicates the *p* value of the *t* test for the difference in means between high climate risk and low climate risk firms. Variance ratio is the ratio of the variance of the covariate in high climate risk group to that of low climate risk firms. A variance ratio close to 1 indicates a good balance between the treatment and control groups. The propensity score is estimated as a logit function of ENV, Size, Leverage, MTB, ROA, Age, and year dummies. We match each firm in the high climate risk group to a firm in the low climate risk group using the nearest neighbor without replacement subject to a caliper of 0.01. Definitions of the variables are given in Table 2.

TABLE 10 Propensity matched sample.

Panel A. Full sample						
	(1) WACC	**(2) WACC**	**(3) COD**	**(4) COD**	**(5) COE**	**(6) COE**
Climate risk	0.197***	0.270***	0.081***	0.117***	0.501***	0.617***
	(0.060)	(0.072)	(0.031)	(0.035)	(0.089)	(0.105)
ENV	−0.012**	−0.023***	−0.005*	−0.010***	−0.019***	−0.037***
	(0.005)	(0.007)	(0.002)	(0.003)	(0.007)	(0.010)
Climate risk × ENV		−0.002**		−0.001**		−0.004**
		(0.001)		(0.000)		(0.001)
Observations	1,562	1,562	1,562	1,562	1,562	1,562
R-squared	0.398	0.402	0.405	0.409	0.330	0.335
Panel B. Fossil fuel firms						
	(1) WACC	**(2) WACC**	**(3) COD**	**(4) COD**	**(5) COE**	**(6) COE**
Climate risk	0.309***	0.376***	0.077**	0.110***	0.659***	0.776***
	(0.072)	(0.088)	(0.036)	(0.039)	(0.104)	(0.124)
ENV	−0.013***	−0.022***	−0.005**	−0.010***	−0.025***	−0.041***
	(0.005)	(0.007)	(0.003)	(0.003)	(0.007)	(0.010)
Climate risk × ENV		−0.002*		−0.001*		−0.003**
		(0.001)		(0.000)		(0.002)
Observations	1,350	1,350	1,350	1,350	1,350	1,350
R-squared	0.403	0.406	0.428	0.431	0.358	0.362
Panel C. Renewable energy firms						
	(1) WACC	**(2) WACC**	**(3) COD**	**(4) COD**	**(5) COE**	**(6) COE**
Climate risk	0.243**	0.291**	0.170**	0.162*	0.243	0.248
	(0.114)	(0.121)	(0.083)	(0.083)	(0.168)	(0.170)
ENV	−0.010	−0.023**	−0.020***	−0.018	0.016	0.014
	(0.008)	(0.010)	(0.007)	(0.012)	(0.012)	(0.016)
Climate risk × ENV		−0.003		0.000		−0.000
		(0.002)		(0.001)		(0.003)
Observations	144	144	144	144	144	144
R-squared	0.714	0.720	0.683	0.683	0.734	0.734
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed	Yes	Yes	Yes	Yes	Yes	Yes

Note: This table presents the regression results using matched firms for full sample (Panel A), fossil fuel firms (Panel B), and renewable energy firms (Panel C). We match each firm in the high climate risk group to a firm in the low climate risk group using the nearest neighbor without replacement subject to a caliper of 0.01. Definitions of the variables are given in Table 2. Firm-level clustered standard errors are reported in parentheses.
***Significance level at 1%, **Significance level at 5%, and *Significance level at 10%.

additional analysis confirms the results of the main analysis in terms of the significant adverse effect of climate risk on the cost of capital. However, we acknowledge that the sample size for renewable energy firms is lower than fossil fuel firms, which can make the results sensitive to the methodological approach. Further studies can utilize a larger sample particularly for renewable energy firms to further validate our main findings.

4.4 | Alternative measure of climate risk

As explained earlier, our main measure of climate risk is the ND-GAIN index published by the Notre Dame Global Adaptation Initiative, which takes into account both the vulnerability and readiness of the countries to climate-related risks. As an alternative measure, we also employ only the vulnerability dimension of the ND-GAIN index, which allows us to test the impact of climate vulnerability on the countries on the cost of capital of energy firms in isolation.

The results presented in Table 11 are quite similar to that of the main analysis, which employ the ND-GAIN measure. Specifically, Climate risk, which is measured by the *Vulnerability* index, has a significant positive impact on the cost of capital of energy firms including the cost of debt and cost of equity (Panel A of Table 11). However, this adverse effect is only observed for the fossil fuel firms (Panel B of Table 11). We do not find any significant impact of climate-related vulnerability on the cost of capital of renewable energy firms. On the other hand, the results for both the direct and indirect impacts of environmental performance on the cost of capital are qualitatively similar to the results of the main analysis reported in Tables 5 and 6.

TABLE 11 Alternative measure of climate risk—Vulnerability.

	(1) WACC	(2) WACC	(3) COD	(4) COD	(5) COE	(6) COE
Panel A. Full sample						
Climate risk	0.496***	0.606***	0.132**	0.189***	0.990***	1.162***
	(0.118)	(0.128)	(0.065)	(0.070)	(0.170)	(0.187)
ENV	−0.013***	−0.017***	−0.007***	−0.009***	−0.020***	−0.027***
	(0.004)	(0.005)	(0.002)	(0.002)	(0.007)	(0.007)
Climate risk × ENV		−0.003***		−0.001***		−0.004***
		(0.001)		(0.000)		(0.001)
Observations	2,480	2,480	2,480	2,480	2,480	2,480
R-squared	0.353	0.359	0.409	0.415	0.286	0.294
Panel B. Fossil fuel firms						
	(1) WACC	(2) WACC	(3) COD	(4) COD	(5) COE	(6) COE
Climate risk	0.474***	0.579***	0.120*	0.178**	0.987***	1.144***
	(0.128)	(0.139)	(0.070)	(0.075)	(0.183)	(0.201)
ENV	−0.012**	−0.015***	−0.007***	−0.009***	−0.021***	−0.026***
	(0.005)	(0.005)	(0.002)	(0.002)	(0.007)	(0.008)
Climate risk × ENV		−0.003***		−0.001***		−0.004***
		(0.001)		(0.000)		(0.001)
Observations	2,233	2,233	2,233	2,233	2,233	2,233
R-squared	0.360	0.365	0.419	0.425	0.297	0.303
Panel C. Renewable energy firms						
	(1) WACC	(2) WACC	(3) COD	(4) COD	(5) COE	(6) COE
Climate risk	0.141	0.370	0.173	0.094	0.051	0.517
	(0.299)	(0.311)	(0.219)	(0.221)	(0.357)	(0.399)
ENV	−0.013*	−0.034***	−0.017***	−0.010*	−0.007	−0.049**
	(0.007)	(0.011)	(0.004)	(0.006)	(0.008)	(0.019)
Climate risk × ENV		−0.005**		0.002		−0.009***
		(0.002)		(0.001)		(0.003)
Observations	247	247	247	247	247	247
R-squared	0.631	0.642	0.629	0.632	0.611	0.631
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed	Yes	Yes	Yes	Yes	Yes	Yes

Note: This table presents the regression results using an alternative measure of climate risk (Vulnerability) for full sample (Panel A), fossil fuel firms (Panel B), and renewable energy firms (Panel C). Definitions of the variables are given in Table 2. Firm-level clustered standard errors are reported in parentheses. ***Significance level at 1%, **Significance level at 5%, and *Significance level at 10%.

4.5 | Controlling corporate governance

Prior literature suggests that corporate governance has a significant impact on the cost of capital (Chen et al., 2009; Ghouma et al., 2018; Zhu, 2014). In this section, we investigate the impact of climate risk and environmental performance on the cost of capital of energy firms after controlling for several governance attributes of the firms. Specifically, we control for *Board size*, *Board independence*, *Board gender*

TABLE 12 Controlling corporate governance.

	(1) WACC	(2) WACC	(3) COD	(4) COD	(5) COE	(6) COE
Panel A. Full sample						
Climate risk	0.260***	0.324***	0.070***	0.112***	0.563***	0.661***
	(0.053)	(0.066)	(0.026)	(0.029)	(0.075)	(0.091)
ENV	−0.007	−0.014**	−0.004*	−0.009***	−0.013*	−0.024***
	(0.004)	(0.006)	(0.002)	(0.003)	(0.007)	(0.009)
Climate risk × ENV		−0.002**		−0.001***		−0.003**
		(0.001)		(0.000)		(0.001)
Observations	2,480	2,480	2,480	2,480	2,480	2,480
R-squared	0.392	0.394	0.437	0.441	0.329	0.332
Panel B. Fossil fuel firms	(1) WACC	(2) WACC	(3) COD	(4) COD	(5) COE	(6) COE
Climate risk	0.248***	0.307***	0.068**	0.108***	0.553***	0.638***
	(0.061)	(0.075)	(0.030)	(0.034)	(0.084)	(0.102)
ENV	−0.005	−0.012*	−0.004*	−0.008***	−0.012*	−0.021**
	(0.005)	(0.006)	(0.002)	(0.003)	(0.007)	(0.009)
Climate risk × ENV		−0.002*		−0.001***		−0.002*
		(0.001)		(0.000)		(0.001)
Observations	2,233	2,233	2,233	2,233	2,233	2,233
R-squared	0.397	0.399	0.452	0.456	0.338	0.341
Panel C. Renewable energy firms	(1) WACC	(2) WACC	(3) COD	(4) COD	(5) COE	(6) COE
Climate risk	0.183*	0.290***	0.095	0.110	0.164	0.318**
	(0.106)	(0.105)	(0.084)	(0.086)	(0.139)	(0.131)
ENV	−0.014**	−0.033***	−0.017***	−0.020***	−0.001	−0.029
	(0.007)	(0.011)	(0.005)	(0.006)	(0.009)	(0.018)
Climate risk × ENV		−0.004**		−0.001		−0.006**
		(0.002)		(0.001)		(0.003)
Observations	247	247	247	247	247	247
R-squared	0.649	0.667	0.633	0.633	0.633	0.648
Financial controls	Yes	Yes	Yes	Yes	Yes	Yes
Governance controls	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed	Yes	Yes	Yes	Yes	Yes	Yes

Note: This table presents the regression results for full sample (Panel A), fossil fuel firms (Panel B), and renewable energy firms (Panel C) after controlling for corporate governance. Specifically, we control *Board size*, *Board independence*, *Board gender diversity*, *CEO-Chair duality*, and *CEO equity compensation* in all regressions. *Board size* is the number of board members, *Board independence* is the ratio of independent members to board size, *Board gender diversity* is the ratio of women board members to board size and *CEO-Chair duality* is a dummy variable that is equal to 1 if CEO serves as the chairman of board of directors. *CEO equity compensation* is a dummy variable that is equal to 1 if CEO compensation is linked to total shareholder return. Definitions of other variables are given in Table 2. Firm-level clustered standard errors are reported in parentheses.

***Significance level at 1%, **Significance level at 5%, and *Significance level at 10%.

diversity, *CEO-Chair duality*, and *CEO-equity compensation*. *Board size* is the number of board members, *Board independence* is the ratio of independent members to board size, *Board gender diversity* is the ratio of women board members to board size, and *CEO-Chair duality* is a dummy variable that is equal to 1 if CEO serves as the chairman of the board of directors. *CEO equity compensation* is a dummy variable that is equal to 1 if CEO compensation is linked to total shareholder return. The results presented in Table 12 suggest that our main conclusion regarding the impact of climate risk, environmental performance, and cost of capital is robust after controlling for corporate governance.

5 | CONCLUSION AND POLICY IMPLICATIONS

Green transformation is a key policy in the fight against climate change and, especially for the energy sector, which is in the spotlight because of the greenhouse gas emissions it produces, requires significant amounts of capital. Considering the importance of the sector in combating climate change, this paper examines the impact of climate risk on the cost of capital of energy firms utilizing an international dataset, comparing fossil and renewable energy firms. Furthermore, we also investigate the role of corporate environmental performance on the relationship between climate risk and cost of capital. By doing this, we aim to provide useful insights and implications for not only energy sector firms but also regulatory bodies to utilize in shaping their climate change action plans.

We find that fossil fuel firms located in countries with greater exposure to climate risk face a significantly higher weighted average cost of capital, cost of equity, and cost of debt. This implies that capital providers, both equity and debtholders, require a premium from their investments in fossil fuel firms domiciled in high climate-risk countries, which translates into a higher cost of capital. We do not find any significant impact of climate risk on the cost of capital of renewable energy firms. Our further analysis shows that energy firms that engage in pro-environmental policies can mitigate the adverse effect of climate risk on their cost of capital, which supports the argument that embracing environmentally friendly policies can be used as a risk reduction tool for energy firms. However, engaging more in pro-environmental action helps them to reduce their cost of equity if they are located in high-climate-risk countries.

Our findings have several implications for energy firms, managers, and policyholders. First, energy firms should be aware of the climate risk associated with their operations and need to follow pro-environmental policies to mitigate its impact. Given the increased public attention to climate risk, energy firms in high-climate-risk countries may not be able to obtain sufficient capital to finance their operations due to the higher returns required by capital providers. In other words, climate risk may result in increased regulatory scrutiny, higher insurance costs, and even more stranded assets, increasing the perceived risks of energy companies, and therefore, capital providers may demand higher returns. Second, our results should motivate managers in energy firms in terms of investing in socially responsible practices. Not only do these activities contribute to the overall well-being of society, but they can also benefit from them by lowering their financing costs. As documented in Goldstein et al. (2019), as the consequences of climate change become financially material, investors and lenders are increasingly taking into account firms' environmental performance in their financial decisions. Fossil energy firms that demonstrate a commitment to reducing their environmental impact and shifting their energy production from fossil to renewable sources are more likely to attract external capital at lower costs. This strategic shift also aligns them with evolving market trends and regulatory expectations. Finally, the findings of this study are important for policyholders. As underlined in the Paris Agreement, the fight against climate change needs an acceleration of the transformation of energy production toward cleaner, more sustainable, and lower carbon sources, requiring a significant amount of capital and investments from fossil fuel firms. However, the increased cost of capital of these firms in high-climate risk environments may slow down the transition process as fossil fuel firms face additional costs in shifting their investments into renewable energy sources. Therefore, policies that support the financing of green transformation and meet the financing need at lower costs should be implemented. In this regard, a recommendation, which is also in line with the Paris Agreement, could be the implementation of policies aiming to improve the environmental performance and climate-related disclosure of energy firms. The policies toward this end would promote transparency in the sector, reduce information asymmetry, and incentivize environmentally sound practices, ultimately aligning with global climate goals. In addition, these policies are more important for developing countries as they need a substantial amount of capital investment[9] to achieve ambitious goals. As documented in this study, policymakers should consider the effect of embracing environmentally friendly policies on the cost of capital, especially in countries with greater exposure to climate risk and for fossil energy firms, in their policy-making process that aims to achieve the transition to net-zero emissions by 2050.

This study has limitations leaving room for future studies to address. First, this study focuses on country-level climate risk measures (ND-GAIN and Vulnerability) considering several aspects and provides evidence demonstrating that climate risk increases the cost of capital (and its components) of energy firms. However, to provide insights specific to energy firms on the impact of climate risk on the cost of capital, studies focusing on specific types of climate risk (such as transition risk or liability risk) would be useful to reveal the relative importance of different aspects of climate risk. Second, this study focuses on the environmental performance of energy firms as a tool to mitigate the negative impacts of climate risk exposure on the cost of capital. However, the quality and the quantity of energy firms' environmental disclosure may also be important factors in mitigating the increasing impact of climate risk on energy firms' cost of capital by informing capital providers about the efforts that energy firms are making toward a “green transformation”. Studies addressing these issues would help to improve our understanding of the relationship between climate risk and the cost of capital of energy firms.

CONFLICT OF INTEREST STATEMENT

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 STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

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ENDNOTES

[1] McKinsey (2022) estimates that spending on the physical assets needed to reach net zero will amount to $275 trillion between 2021 and 2050 meaning $3.5 trillion of new spend per year to 2050 to keep global warming well below 2°C.

[2] In addition to expected positive effects of embracing environmentally friendly policies on firms' outcomes such as financial performance and cost of capital, International Energy Agency (IEA) points to a different area where energy sector firms can gain advantage. According to IEA (2022), the expansion of renewable energy capacity over the next 5 years will be much faster than expected. Between 2022 and 2027, it is estimated that renewables will grow by almost 2400 GW, which is equivalent to China's entire installed power capacity today. That is an 85% acceleration over the previous 5 years. Over the forecast period, renewables will account for more than 90% of global power capacity expansion which, offers substantial opportunities for energy firms if they invest more green investments.

[3] This estimation is based on 210 different climate scenarios and vigorous (moderate) warming increases global climate-exposed energy demand before adaptation around 2050 by 25%–58% (11%–27%).

[4] Asset stranding is defined as "is the process of collapsing expectations of future profits from invested capital (the asset) as a result of disruptive policy and/or technological change" (Semieniuk et al., 2022, p. 532).

[5] For further information, please see: https://www.pttep.com/en/Investorrelations/Regulatorfilings/Setnotification/download.aspx?Content=5328&File=1391.

[6] We start with all available firm-year observations for the energy sector and exclude observations with missing data. The data provider does not cover all firms in the sector and the number of observations significantly decreases in previous years (pre-2015), especially for the environmental performance scores of energy sector firms. That is why we start our sample period from 2015.

[7] For further information about the methodology of ND-GAIN: https://gain.nd.edu/our-work/country-index/methodology/.

[8] As the sample of the study consists of energy sector firms, industry fixed effects are not controlled in the models. However, we employ additional analysis by including sector level fixed effects (fossil fuel vs. renewable energy). Our results remain qualitatively similar.

[9] According to IEA (2023b), These countries will need about $2 trillion annually by 2030. This is a fivefold increase from the current $400 billion of climate investments planned over the next 7 years.

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