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Investment in renewable energy and emissions: Firm-level empirical evidence from the People's Republic of China

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ADBI Working Paper Series

**INVESTMENT IN RENEWABLE ENERGY
AND EMISSIONS: FIRM-LEVEL
EMPIRICAL EVIDENCE FROM THE
PEOPLE'S REPUBLIC OF CHINA**

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Abstract

This study investigates the impact of firms' emissions on their investments in renewable energy. Stricter environmental regulations are aimed at incentivizing firms to invest in low-emission/pollution technologies such as renewable energy. Recently, the People's Republic of China (PRC) announced a large number of environmental regulations in order to address emission and air pollution issues. Using the unique data set of annual firm-level data of 147 firms from the PRC that invested in renewable energy projects domestically during the period 2015–2020, our results demonstrate that firms with greater air pollution or greenhouse gas emissions (measured as a share of revenue) invest more in renewable energy (measured as a share of equity). The results have survived several robustness checks.

Keywords: renewable energy, air pollution, People's Republic of China, GHG emissions, green investment, COVID-19

JEL Classification: Q53, Q58, Q42, G32, G38

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1. INTRODUCTION

In the forthcoming decades, it will be imperative to reduce emissions of carbon dioxide (CO₂) and other greenhouse gases (GHGs) in order to prevent a potential environmental catastrophe arising from the escalation of global temperatures. To accomplish the objective of keeping global warming within the 1.5°C threshold, there is a pressing need for swift, profound, and unparalleled transformations across all sectors. This is particularly crucial for Asia and the Pacific, where GHG emissions currently account for over 50% of the world's total. Other related issues include air pollution and energy security (due to the fast-growing energy demand).

Renewable energy technologies have emerged as a compelling and effective approach to address climate change mitigation, combat air pollution, and alleviate global warming. Their growing prominence can be attributed to substantial cost reductions observed in recent times. The International Energy Agency's (IEA) global energy review for 2021 revealed a noteworthy 3% increase in renewable energy consumption during 2020, driven by reduced demand for conventional fuels. A pivotal factor behind this trend was the remarkable 7% growth in renewable electricity production. Furthermore, the IEA projected a remarkable surge of over 8% in electricity generation from renewable sources in 2021, leading to a total output of 8,300 TWh. This expansion represents the fastest annual growth since the 1970s. Solar photovoltaic and wind account for two thirds of investments in renewables. In the same vein, the Energy Transition Investment Trends 2022 report by Bloomberg New Energy Finance (BloombergNEF) indicated a remarkable advancement in global energy transition investment, with an unprecedented \$755 billion dedicated to decarbonizing the energy system in 2021, demonstrating a significant 27% of annual growth. Remarkably, the renewable energy and electrified transport sectors, recognized as the two primary categories, attained new milestones in 2021, driven by substantial growth in solar and wind installations, alongside a surge in electric vehicle sales.

In developing Asian countries, the energy industry is heavily reliant on fossil fuels, with energy prices frequently being subsidized or under government control. As a result, there is a pressing need for policies that stimulate investments in renewable energy throughout developing Asia. Nonetheless, the region faces limitations in public spending, which have been further exacerbated by the substantial costs associated with the coronavirus disease (COVID-19) pandemic. The projection from the IEA indicates that energy demand is expected to experience a continuous acceleration, fueled by the upswing in economic growth, population expansion, and improved access to energy. Developing Asia and the Pacific countries are anticipated to be responsible for approximately two thirds of the global surge in energy demand by 2040.

The PRC, renowned as one of the leading global energy consumers, has exhibited swift progress in its investments in renewable energy. In 2021, the PRC experienced a substantial upswing of nearly 50% in renewable energy investments, culminating in a remarkable \$168 billion. In the same vein, the PRC represented nearly 50% of the global expansion in renewable electricity in 2021, followed by the United States, the European Union, and India, according to the Global Energy Review 2021 of the IEA.

In addition, the public is soliciting the authorities to enforce stricter environmental regulations to cushion and enhance environmental sustainability in light of the growing knowledge about the environmental effects of CO₂ and other GHG emissions (Liao and Shi 2018). Environmental regulation rules for different sectors, particularly in the evolving sphere of energy transition, have been recently established by the Government of the PRC. Such environmental regulation policies include the Law on the Prevention and Control of Air Pollution, the Renewable Energy Law, the Carbon Trading Scheme, the Regulation on the Administration of Pollutant Discharge Permits, the Measures for the Administration of Legal Disclosure of Enterprise Environmental Information, and the Comprehensive Work Plan for Energy Saving and Emission Reduction. The recent regulatory developments indicate that, for enterprises operating in the PRC, adherence to green regulations will grow more crucial as releasing emissions becomes more expensive. Therefore, companies will enjoy a comparative advantage if they are well prepared for these changes. Given the need for further growth of renewable energy installations and the diversification of sectors financing renewable energy, as well as the important role of environmental regulations, it is of great interest to analyze the effects of enterprises' emissions on their investment in renewable energy. The existing literature often focuses on renewable energy firms when studying investments in renewable energy. However, other sectors (financial, industrial, information technology, communication services, consumer staples, consumer discretionary, materials, and utilities) also invest in renewable energy. Therefore, in this study, we fill the gap by including firms across different sectors that invest in renewable energy projects in the PRC. To the best of our knowledge, this is the first paper to do so. In addition, most of the studies investigating the impacts of environmental regulation rules are contingent upon data from industries or provinces. Telle and Larsson (2007) show that province- and industry-level data disregard heterogeneity among enterprises, which serve as the main decision-making entities for environmental and efficiency management and are subject to environmental regulation rules. Similarly, Plank and Doblinger (2018), using German data, addressed the need for a more granular firm-level analysis when conducting research in the renewable energy field. Accordingly, this study examines the effects of the external cost of emissions on companies' decisions to invest in renewable energy projects in the PRC.

This study utilizes a distinctive dataset consisting of yearly firm-level information from 147 companies operating in the PRC that undertook investments in renewable energy projects within the country between 2015 and 2020. This paper presents findings on how firms' emissions influence their investments in renewable energy. We find that firms' emissions (both air pollutants and GHG emissions) have a positive impact on their investments in renewable energy. Our results are robust to various model specifications.

The structure of the rest of the paper is as follows. Section II discusses related literature on the impacts of environmental regulations on firm performance, as well as on environmental regulations in the PRC. Section III describes the data. Section IV explains the methodology. Section V discusses the results. Section VI presents robustness checks. Section VII provides conclusions and policy recommendations.

2. LITERATURE REVIEW

2.1 Environmental Regulations and Firm Performance

In light of the linkage between environmental regulations and firm performance, there exist two profoundly opposing viewpoints in the literature. According to the traditional perspective put forth by Breyer (1982) and Walley and Whitehead (1994), environmental and economic targets frequently collide, and environmental regulations have a detrimental effect on corporate efficiency. This is because of increased production costs brought by environmental regulation policies that are still in the early stages of implementation. The revolutionary paradigm, particularly the “Porter hypothesis,” contends, however, that environmental regulations positively impact technological innovation and, subsequently, firm performance (e.g., Porter and Linde 1995; Blind 2012).

Studies have examined how various environmental regulations and enterprise types affect the relationship between environmental regulations and firm performance. A number of studies investigate this problem from a theoretical framework. According to Zerbe (1970), a production tax appears to have the least favorable effects on corporate innovation, while a pollution tax appears to have the strongest. Milliman and Prince (1989) demonstrate that market-based policy instruments (MBIs), such as pollution levies and permit auctions, may provide the strongest motivations to stimulate technological innovation, whereas direct regulations typically give the weakest. Environmental MBIs are popular as they allow governments to set incentives to reduce pollution, while giving flexibility to firms in choosing the most cost-effective solution that will allow this reduction to be achieved (BPK 2016) (e.g., in which environmental technologies to invest or reduced production). MBIs usually specify the outcome (e.g., environmental pollution) without prescribing the delivery mechanisms and the measures to be employed (IEA 2017). By implementing MBIs, governments aim to achieve national environmental targets by incentivizing investments in environmental technologies while minimizing the negative impact on production. That is why it is important to study the impact of environmental MBIs not only on meeting countries’ national environmental targets (as this could be achieved through reduced production) but also on firm performance and particularly on firms’ investments in environmental technologies. Findings from Williams (2012) emphasize that, compared to command-and-control regulations (CCRs), MBIs offer greater incentives to increase corporate efficiency. In the same vein, Downing and White (1986) discover that MBIs significantly foster corporate innovation and, therefore, corporate efficiency, as opposed to CCRs. The topic was also investigated in some empirical studies. For instance, Testa, Iraldo, and Frey (2011) show that MBIs have detrimental impacts on corporate performance, whereas direct regulations have the greatest effects on enhancing firm performance. In contrast, Zhao, Yin, and Zhao (2015) demonstrate that both MBIs and government subsidies positively impact efficiency improvement and CO₂ mitigation, while no significant effect is found for CCRs.

A number of empirical studies have examined how environmental regulations affect corporate performance in the PRC (e.g., Zhang et al. 2008; Bi et al. 2014; Zhao, Yin, and Zhao 2015; Zhang and Chen 2022). Nevertheless, most of these studies are rooted in data from industries or provinces. These data disregard heterogeneity among enterprises, which serve as the main decision-making entities for environmental and efficiency management and are subject to environmental regulation rules (Telle and Larsson 2007). In addition, these studies do not investigate how environmental regulations affect firms’ investments in renewable energy technologies, which are

widely recognized as one of the most efficient approaches in dealing with climate change and global warming. Zhao et al. (2022) explore the effects of environmental regulations on renewable energy development in the PRC, but they employ province-level data. Therefore, our paper fills the gap in the literature by examining the impact of environmental regulations, proxied by firms' emissions, on renewable energy investments using firm-level data from the PRC.

2.2 Recent Developments in Environmental Regulations in the PRC

Given the adverse effects on public health of air pollution and GHG emissions, various environmental regulations have been put into effect by the government. This section provides a brief overview of some of the environmental policies that were implemented in the PRC; it does not cover all policies.

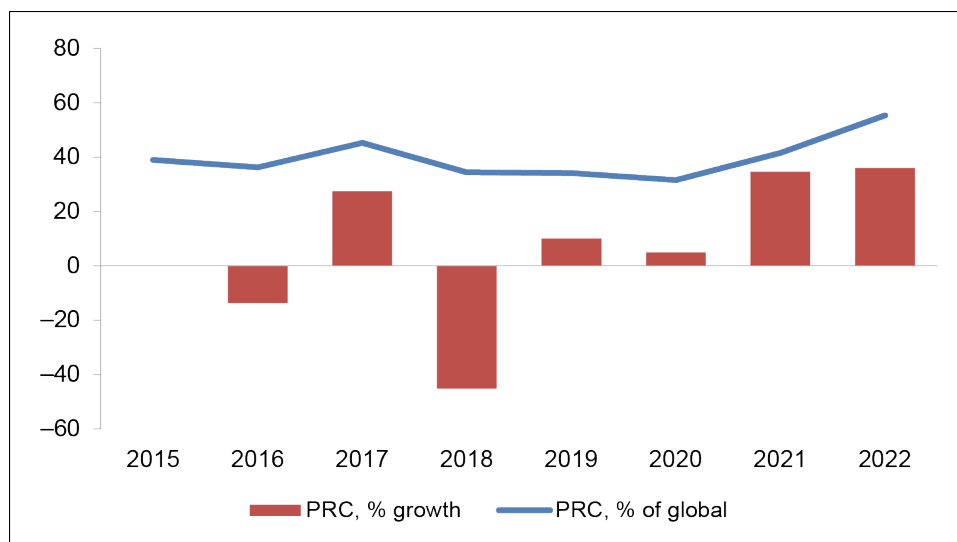
1. Environmental Protection

In 1983, the government launched the Managerial Guidelines for Standards of Environmental Protection, establishing requirements for environmental monitoring and pollutant discharge standards as well as defining standards for air, water, and soil quality. Because of growing concerns regarding environmental protection, the government gave special attention to pollutant control and put into effect the Law on the Prevention and Control of Air Pollution on 1 September 2000. This law requires organizations that release air pollutants into the atmosphere to register with their local environment protection department and notify them of their current emission and pollution treatment facilities, along with the quantities and concentrations of pollutants emitted during their regular operating conditions. The Air Pollution Action Plan released in September 2013 became one of the most influential environmental policies in the PRC. Recently, the government announced a large number of environmental regulations. The Three-year Action Plan for Winning the Blue Sky War was introduced in 2018. On 1 March 2021, a nationwide pollutant discharge permit system was established in the PRC with the enactment of the Regulation on the Administration of Pollutant Discharge Permits (the regulation). The goals of the regulation are to enhance discharge management, strengthen monitoring, simplify the permit application processes, and specify the duties of pertinent discharging units. To improve the ecological and environmental damage compensation system, the 14 authorities of the PRC jointly launched the Rules on Compensation for Ecological and Environmental Damage on 26 April 2022. Under this law, the responsibilities of the polluter for repairable and unrepairable damages were clarified. As a further step to protect the environment and ecology in the PRC, the Ministry of Ecology and Environment enforced the Measures for the Administration of Legal Disclosure of Enterprise Environmental Information on 8 February 2022. According to this regulation, major polluters and enterprises that finance them are required to submit an annual report called the Legal Disclosure Report for Environmental Information.

2. Renewable Energy

The PRC is one of the major investors in renewable energy in the world. It accounts for around 40% of global investments in renewable energy (Figure 1). In particular, investments increased by a third for two years in a row (in 2021 and 2022) (Figure 1). In order to boost the utilization of renewable energies, enhance the energy structure, conserve the ecology and the environment, and attain Sustainable Development Goals, the Standing Committee of the Tenth National People's Congress enacted the Renewable Energy Law on 28 February 2005 at the 14th gathering. This law is recognized as a framework policy that establishes broad guidelines for renewable energy to gain prominence as a source of energy in the PRC. Under the Renewable Energy Law, the overall development and utilization of renewable energy are administered and implemented at the national level by the State Council. In addition, the State Council regards research and development and the industrial development of renewable energy as the preferred field for hi-tech industrial development in the national program under this law. Apart from that, many other policies have been implemented in the PRC to promote renewable energy, such as subsidies, grants, tax incentives, public investments, and feed-in tariffs.

Figure 1: Investments in Renewable Energy in the PRC (%)



RC = People's Republic of China.

Source: Authors' elaboration using BloombergNEF.

3. Emission Trading Scheme

Following the implementation of seven pilot emission trading schemes (ETSs) at the provincial and city levels in 2013, a countrywide carbon market was officially announced at the end of 2017 (Wu et al. 2022). As part of a major initiative to restrict climate change through controlling carbon emissions, the PRC unveiled the largest carbon trading scheme in the world on 16 July 2021. Nearly 2,500 power generation enterprises participated in this carbon trading market at its commencement, most of which are state-owned companies. These firms account for about half of the PRC's energy-associated emissions, which is equivalent to 10%–14% of global emissions. Under this scheme, each enterprise is granted by the government a specific quantity of CO₂ to emit annually. If the enterprise does not reach its designated quota by the

end of the year, it can sell the shortfall as a credit on the carbon trading market. On the other hand, the enterprise must purchase additional credits to compensate if it surpasses its allocated amount. Although the fine for noncompliance is currently only CNY20,000–30,000 (\$3,000–4,300) per violation, our paper cannot capture the impact of the national ETS as we are using sample data from before 2021, when the national ETS was implemented.

3. DATA

The present study employs firm-level data derived from companies that invested in renewable energy within the PRC between 2015 and 2020. The data sources include BloombergNEF, Bloomberg terminal, S&P Capital IQ Pro, and Hale et al. (2021). The dataset incorporates information from 147 distinct firms, generating a total of 349 observations. Note that our sample only includes observations in years when firms invested in renewable energy, excluding when no investment in renewable energy was made, because firms (especially from nonenergy sectors) do not usually invest every year.

Given the large initial investments required for renewable energy projects, the financial status of firms plays an undeniable role for firms' owners in making decisions to invest in renewable energy technologies. Furthermore, firms care increasingly about their reputation in terms of environmental impact, and also more environmental regulations are implemented on releasing air pollutants and/or GHGs into the environment during firms' operational activities.

3.1 Dependent Variable: Renewable Energy Investment

The outcome variable in our study, denoted as (REI/K) , is calculated as the proportion of renewable energy investment relative to the total equity of the respective firm. We calculate renewable energy investments as annual investments in renewable energy projects that firm i makes during year t . For the selection of the denominator, we chose between total equity and working capital. Total equity, also regarded as shareholders' equity or net worth, denotes the difference between a firm's total assets and its total liabilities. Thus, shareholders' equity demonstrates the long-term financial health of a company. We use shareholders' equity instead of working capital because the latter, defined as the difference between a company's current asset and its current liability, captures the short-term financial health and is more volatile. In addition, since investing in renewable energy requires high upfront cost (relative to marginal cost), firms evaluate the long-term financial status of their company, and not only the short-term, before deciding whether to invest or not. For the above reasons, using the total equity as the denominator is more appropriate than the working capital.

Figure 2 displays renewable investments across sectors and types of renewable energy from our sample data. Renewable energy investments were mainly contributed by utilities, followed by industry and finance sectors. Wind and solar projects share the two leading positions of the new additional installed capacity, which is a sample representative for the PRC.

3.2 Explanatory Variable: Firms' Emissions

Stricter environmental policies in the country aimed at reducing GHG emissions and/or improving air quality could incentivize investments in low-emission solutions such as renewable energy. Such policies could achieve a reduction in emissions through loss of competitiveness and as a result reduced production. Thus, effective environmental policies are those that achieve emission reductions via increased investments in low-emission solutions such as renewable energy. We expect that firms with greater emissions will invest more in renewable energy due to stricter environmental policies in order to reduce emission levels. In this paper we test whether firms with greater emissions are incentivized to invest more in renewable energy.

Firms' emissions are measured using two variables: (i) the external cost of air pollutants (aircost) and (ii) the external cost of GHG emissions (ghgcost). They are measured as the total annual cost (in United States dollars) estimated by S&P. Note also that these are social (including externalities) costs rather than actual costs that the company is paying. Sometimes called "externalities" or "damage costs," they are the financial quantification of the damage to the environment caused by a given pollutant being released or a given resource being used. They encompass a diverse array of external impacts, such as harm to property, buildings, and infrastructure, as well as the reduced productivity of individuals and crops. The external cost of GHG emissions is used as an alternative variable to check the sensitivity of our findings. Both costs are measured as a percentage of the firm's revenue, also known as the "impact ratio." These data are obtained from the S&P Capital IQ pro database.

Figure 3 shows the external cost of air pollutants by sector and year in our sample. It can clearly be seen that utilities account for the largest proportion of the cost. This is reasonable since utilities are usually heavy polluters because of the combustion of coal. Note also that the external cost of air pollutants increased over the years in our sample. However, in 2020, firms experienced a decrease in the external cost of air pollutants. This could have been due to the impact of COVID-19 stringency policies when many companies could not fully operate or even closed their activities. It is worth noting that we obtain similar trends when we employ the direct and indirect external costs of air pollutants. Note that direct costs quantify the potential financial impact on the environment and society based on pollutant releases from a company's own operations. Indirect costs quantify the potential damage costs associated with the upstream supply chain.

3.3 Control Variables

For other control variables, we use province-level COVID-19 government restrictions, firms' characteristics (financial leverage, return on asset, age, and size), and renewable energy cost. Firms' financial data (revenue, return on asset, firm age, and total assets) are obtained from the S&P Capital IQ pro database.

Government restrictions because of COVID-19 are measured using the COVID-19 stringency index, which measures the strictness of "lockdown style" policies that primarily restrict people's behavior, provided by the Oxford Coronavirus Government Response Tracker (OxCGRT). This is calculated using policy indicators, plus an indicator recording public information campaigns (Hale et al. 2021). It takes values from 0 to 100 (most stringent) for each province in the PRC, representing the restrictions applied by the government in each province. The index is available daily; to convert it to annual, we used the daily average index per year. The restrictions applied by the government to address the COVID-19 pandemic might exert adverse impacts on

the implementation of renewable energy projects. This is because when uncertainty increases, directors seek to procrastinate investment, resulting in the loss of lucrative initiatives (e.g., Ming et al. 2016; Shen et al. 2020). Increased external risks imposed by COVID-19 prompt directors to raise the cash holdings of their enterprises in the event of emergencies. The investment funds, in turn, are drained by increased financial reserves, which leads to a reduction in investing in renewable energy.

Firm leverage (*lev*) is calculated as a liability–asset ratio and serves as a proxy measurement of the firm's financial leverage. Firm leverage plays an essential role in firm investment. A moderate liability–asset ratio can offer enterprises more financial resources to invest (Cao, Guo, and Zhang 2020). In addition, when the return on investment is higher than the interest rate, financial leverage allows companies to enhance shareholders' returns by employing the debt leverage. However, a relatively high firm leverage might have adverse effects on corporate investment. This is because enterprises with greater financial leverage have to pay more interest in the upcoming years, thereby restricting investment capacity (Aivazian, Ge, and Qiu 2005). It can be clearly seen that the degree of dispersion for the liability–asset ratio among firms in our sample data is relatively large, with the lowest value being 0.085 and the highest standing at 2.014. This could be because firms that invest in renewable energy projects borrow more because of the high upfront cost of renewable energy projects (with relatively small marginal cost), resulting in a high financial leverage.

Firm return on asset (ROA), calculated as the proportion of net income relative to the total assets, is utilized as a proxy to gauge firm profitability. Since firms with greater profitability can borrow more, we expect a positive impact of firm ROA on firm investments in renewable energy. However, the ROA is averaged at only 2.1%. The degree of dispersion for this variable, despite being a smaller degree compared to the financial leverage, is still large.

Firm age (*age*) is measured as the number of years the firm has existed. We use it as a measure for enterprise experience. The utilization of establishing time as a metric to gauge firm experience has been a common practice in scholarly research (e.g., Lee 2010; Bai, Lin, and Liu 2021; Azhgaliyeva and Le 2023). Firm size (*size*) is measured as a logarithm of firm assets and used as a proxy for the firm size. Chang et al. (2019) predicted a negative impact of firm size on investment of renewable energy firm. Firm revenue (*rev*) is measured as a ratio of revenue to the total assets.

Energy cost (*energycost*) is the weighted average of the levelized cost of energy (LCOE) in the PRC. We weighted the LCOE across energy from several renewable energy sources: solar photovoltaic, wind offshore, wind onshore, geothermal, bio, and hydropower. Weights are calculated based on the shares of renewable energy in the PRC. We use it as a proxy for energy cost. The unit is United States dollars per megawatt-hour.

The definition of variables as well as the sources are displayed in Table 1. Using these variable descriptions, we report the descriptive statistics in Table 1.

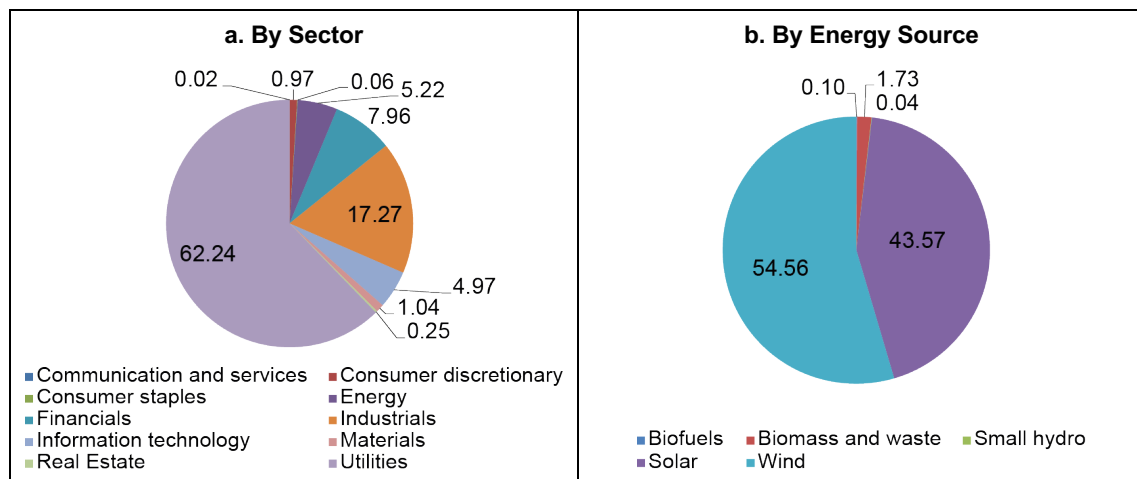
Table 1: Variable Description and Summary Statistics

Variable	Indicator	Unit	Definition	Source	Mean	Std. Dev.	Min	Max
REI	REI/K	Ratio	Firm annual investments in renewable projects divided by firm's total equity	Authors' own calculation using data from BloombergNEF and S&P Capital IQ pro	0.127	0.260	−0.357	2.762
Firm leverage	lev	Ratio	The liability–asset ratio	S&P Capital IQ pro	0.664	0.197	0.085	2.014
Firm sales	rev	Ratio	The total revenue for each firm divided by the total asset	S&P Capital IQ pro	0.334	0.290	0.009	3.586
ROA or profitability	ROA	Ratio	The ratio of net income to total assets	S&P Capital IQ pro	0.021	0.047	−0.346	0.171
Firm age	age	Years	The number of years since foundation of firm	S&P Capital IQ pro	26.433	16.851	4.000	112
Firm scale	size	United States dollars	Logarithm of the total asset of firm	S&P Capital IQ pro	16.666	2.244	11.919	22.354
Energy cost	energycost	United States dollars/MWh	The levelized cost of energy in the PRC, weighted by energy type	Authors' own calculation using data from Bloomberg terminal	72.600	15.530	56.432	105.709
External cost of air pollutants	aircost	Ratio (%)	The external cost of air pollutants as a percentage of the company's revenue	S&P Capital IQ pro	3.928	9.433	0	77.612
External cost of GHG emissions	ghgcost	Ratio (%)	The external cost of GHG emissions as a percentage of the company's revenue	S&P Capital IQ pro	11.331	22.489	0	166.962
COVID-19 stringency index	stringency	Index	COVID-19 stringency index for each province in the PRC representing the restrictions applied by the Government of the PRC	Hale et al. (2021)	9.846	20.714	0	63.479

GHG, greenhouse gas, Max = maximum, Min = minimum, MWh = megawatt-hour, PRC = People's Republic of China, REI = renewable energy investment, ROA = return on asset, Std. Dev. = standard deviation.

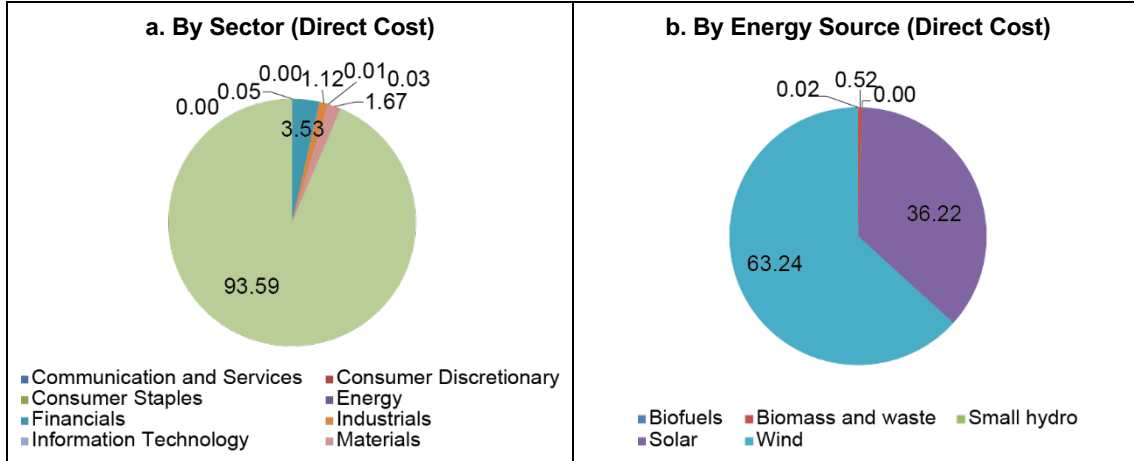
Note: N = 349.

Source: Authors' calculation.

Figure 2: Sample Distribution: Renewable Energy Investment

Note: Distribution of data used in this paper, not data for the whole country.

Source: Authors' elaboration using BloombergNEF

Figure 3: Sample Distribution: The External Cost of Air Pollutants (Direct Cost)

Note: Distribution of data used in this paper, not data for the whole country.

Source: Authors' own elaboration using S&P Capital IQ Pro.

4. RESEARCH METHODOLOGY

We use fixed-effect and instrumental variable models to estimate the impact of firms' emissions, financial status, and restrictions due to COVID-19 on firms' investments in renewable energy.

4.1 Fixed-Effect Models

To estimate the impacts of the external cost of emissions we present the following fixed-effect econometric model:

$$\frac{REI_{i,t}}{K_{i,t}} = \alpha + \beta_1 aircost_{i,t} + \beta_2 stringency_{p,t} + \gamma' \mathbf{X} + \mu_i + \varepsilon_{i,t}, \quad (1)$$

where $REI_{i,t}$ represents the total values of renewable projects invested by firm i in year t ; α is a constant; $aircost_{i,t}$ indicates the external cost of air pollutants as a percentage of a firm's revenue.¹ $stringency_{p,t}$ denotes the COVID-19 stringency index (from 0 to 100) in province p . \mathbf{X} indicates a vector of control variables (including financial leverage $lev_{i,t}$, the ratio of revenue to total asset $rev_{i,t}$, profitability $ROA_{i,t}$, firm age $age_{i,t}$, firm scale $size_{i,t}$, and energy cost ($energycost_t$) and γ is a vector of associated parameters. μ_i denotes the individual effect of firm i and $\varepsilon_{i,t}$ captures the error term. Lang, Ofek, and Stulz (1996) employ a pooling regression to estimate the investment equation based on the assumption that the unobserved individual effect is zero. This is, however, a strong assumption because of the fact that there is high heterogeneity across firms. Therefore, in this study, we use both fixed-effect and random-effect models to control for firm heterogeneity, following Aivazian, Ge, and Qiu (2005). Further, we employ suitable statistical tests to determine which empirical model is preferred to estimate the investment equation.

¹ We employ two different approaches to quantify this cost: (i) the external cost of direct air pollutants and (ii) the external cost of both direct and indirect air pollutants.

There might be a lag in response to the changes in the external cost of air pollutants. Therefore, this study also investigates the delayed effects of the external cost of air pollutants on firms' investments in renewable energy.

$$\frac{REI_{i,t}}{K_{i,t}} = \alpha + \beta_1 aircost_{i,t-1} + \beta_2 stringency_{p,t} + \gamma'X + \mu_i + \varepsilon_{i,t}, \quad (2)$$

where $aircost_{i,t-1}$ demonstrates the external cost of air pollutants as a percentage of the firm's revenue in year $t-1$.

4.2 Instrumental Variable Regressions

There might be omitted variables that are correlated with both the external cost of air pollutants and renewable energy investment, and the external cost of air pollutants is possibly measured with errors. As a result, the external cost of air pollutants can be correlated with error terms, and the model suffers from endogeneity. In addition, the cost of air pollutants can be affected by renewable energy investment, and thus reverse causality arises. To overcome these challenges, we employ two-stage least squares regression by using the sector-level external cost of air pollutants as an instrumental variable (IV) for the external cost of air pollutants. The former is computed by taking the average of the external costs of air pollutants from all firms in the same sector. The usage of the sector-level external cost of air pollutants as an IV can be explained by the following arguments. First, the firm's external cost of air pollutants tends to follow the trends of the sector-level external cost of air pollutants. Therefore, the sector-level and firm-level external costs of air pollutants should be highly correlated with each other. Second, the sector-level cost of air pollutants is not highly correlated with the firm's renewable energy investment. These two arguments are indeed true in our dataset, which means that our selected variable is suitable for use as an IV. The correlation between sector-level and firm-level external costs of air pollutants is 0.532, while the correlation between the firm's renewable investment and sector-level external cost of air pollutants is 0.085, demonstrating that the sector-level external cost of air pollutants is an appropriate IV. The IV regression can be written as follows:

In the first stage, we isolate the part of $aircost_{i,t}$ that is uncorrelated with $\varepsilon_{i,t}$ by regressing $aircost_{i,t}$ on the sector-level external cost of air pollutants $aircost_sector_{i,t}$, stringency index $stringency_{p,t}$, and other control variables X :

$$aircost_{i,t} = \varpi + \pi_1 aircost_sector_{i,t} + \pi_2 stringency_{p,t} + \phi'X + u_{i,t}, \quad (3a)$$

where ϖ , π_1 , π_2 , and ϕ are unknown parameters. Using the estimated results, we obtain the predicted value of the external cost of air pollutants $\widehat{aircost}_{i,t}$, which captures the exogenous portion of $aircost_{i,t}$. In the second stage, we regress renewable energy investment on the predicted value of the external cost of air pollutants, the stringency index, and other control variables:

$$\frac{REI_{i,t}}{K_{i,t}} = \alpha + \beta_1 \widehat{aircost}_{i,t} + \beta_2 stringency_{p,t} + \gamma'X + \varepsilon_{i,t}, \quad (3b)$$

4.3 Robustness Regressions

To check the robustness of our results, we use alternative measures of two variables: (i) the external cost of GHG emissions as an alternative proxy for the external cost of emissions; (ii) a binary variable of COVID-19, $covid_{p,t}$ (which equals 1 in 2020 and 0 otherwise), instead of the COVID-19 stringency index in the following econometric models:²

$$\frac{REI_{i,t}}{K_{i,t}} = \alpha + \beta_1 ghgcost_{i,t} + \beta_2 covid_{p,t} + \gamma'X + \mu_i + \varepsilon_{i,t}, \quad (4)$$

where $ghgcost_{i,t}$ represents the external cost of GHG emissions as a percentage of the enterprise's revenue, and $covid_{p,t}$ is a binary variable that is assigned a value of 1 in 2020 and 0 otherwise.

As in previous sections, we also report the estimated results for the lag of the external cost of GHG emissions and the IV regressions. To be more specific, we use the sector-level external cost of GHG emissions as an IV for the firm-level external cost of GHG emissions.³

5. EMPIRICAL RESULTS

This section describes and discusses findings on the impact of emissions on investments in renewable energy. Since there might be a lag in response in investments to emissions and financial leverage, we include both nonlagged and one-year-lagged impact.

5.1 Without Lag

The estimated results are reported in Table 2 with results from the fixed-effect models⁴ in columns 2–4 and from IV regressions⁵ (to further address the potential endogeneity issues) in columns 5–7. The main findings can be summarized as follows.

² It is worth noting that we also apply the instrumental variable approach when the COVID-19 dummy $covid_{p,t}$ is used as an alternative proxy for COVID-19 restrictions.

³ This is an appropriate instrumental variable since the sector-level external cost of GHG emissions and firm-level external cost of GHG emissions are highly correlated with each other (0.635), whereas the sector-level external cost of GHG emissions is not highly correlated with the firm's renewable energy investment (0.082).

⁴ Further, we conduct two widely utilized statistical tests, namely the Breusch and Pagan Lagrangian Multipliers (LM) test and the Hausman specification test, with the purpose of determining the most appropriate research framework among pooling, random-effect, and fixed-effect regression. Initially, we examine the LM test and observe that the chi-square statistics reject the null hypothesis, indicating the existence of individual effects at a significance level of 1%. Thus, accounting for the individual effect is crucial in our analysis. Subsequently, the Hausman specification test is conducted to compare the random-effect model with the fixed-effect model. Findings indicate that the fixed-effect model is better suited for analyzing the effects of a company's emissions on the company's investments in renewable energy.

⁵ It is also worth noting that all the exogeneity tests (Durbin, Wu–Hausman, Wooldridge's score, and the regression-based) reject the null hypothesis that the external cost of air pollutants is exogenous. Therefore, we should treat this variable as endogenous and employ the IV regressions. More importantly, the Stock and Yogo tests indicate that our instrumental variable is not weak for all three IV models considered.

We find that the external cost of air pollutants positively influences a company's investments in renewable energy once we control for the potential endogeneity issues (columns 5–7). The impact of the external cost of air pollutants across all three fixed-effect models is not significant (columns 2–4). The possible explanation is that the external cost of air pollutants can be correlated with error terms, and the model suffers from endogeneity. In addition, the cost of air pollutants can be affected by renewable energy investment, and thus reverse causality arises. Therefore, the IV regressions should be preferred. The estimated impacts of the external cost of air pollutants on renewable energy investment for all three IV models are positive and highly significant. If the external cost of air pollutants relative to the firm's revenue rises by 1%, the renewable investment in equity increases by nearly 0.8 p.p. This could be because of the effectiveness of environmental policies in the PRC. Also, our finding is consistent with the Porter hypothesis: The environmental pollution increases firms' production costs (if effective environmental policies are in place), and thus has a detrimental impact on corporate productivity and performance in the short run. Nevertheless, over the medium and long runs, firms will ultimately offset rises in production costs through technological advancement, increased investments in renewable energies, or adjustments to their manufacturing processes (e.g., Zhao, Yin, and Zhao 2015; Zhao et al. 2022).

Table 2: Results: External Cost of Air Pollutants (Direct Cost and No Lag)

Dependent Variable: REI/K (1)	FE1 (2)	FE2 (3)	FE3 (4)	IV1 (5)	IV2 (6)	IV3 (7)
Air pollutants cost, share in revenue	0.001 (0.001)	0.001 (0.001)	0.001 (0.001)	0.008*** (0.003)	0.008*** (0.003)	0.008*** (0.003)
Stringency index		–0.002* (0.001)			–0.000 (0.001)	
Coronavirus disease (COVID-19) dummy			–0.089* (0.050)			–0.006 (0.039)
Financial leverage	0.363** (0.141)	0.348** (0.150)	0.353** (0.149)	0.364*** (0.107)	0.363*** (0.107)	0.363*** (0.107)
Return on asset	–0.629 (0.527)	–0.699 (0.566)	–0.692 (0.563)	0.330 (0.384)	0.329 (0.384)	0.329 (0.384)
Revenue, share in total asset (ratio)	–0.705** (0.289)	–0.710** (0.289)	–0.707** (0.288)	–0.109** (0.050)	–0.108** (0.050)	–0.108** (0.050)
Total asset (logarithm)	–0.253*** (0.079)	–0.237*** (0.075)	–0.239*** (0.076)	–0.065*** (0.009)	–0.064*** (0.009)	–0.064*** (0.009)
Firm age	0.017 (0.023)	0.080* (0.047)	0.076 (0.047)	0.001 (0.001)	0.001 (0.001)	0.001 (0.001)
Energy cost	0.001 (0.002)	0.006 (0.004)	0.005 (0.004)	–0.002** (0.001)	–0.002** (0.001)	–0.002** (0.001)
Constant	3.869*** (1.201)	1.594 (1.215)	1.724 (1.219)	1.096*** (0.155)	1.100*** (0.157)	1.100*** (0.157)
R square	0.168	0.183	0.182	0.157	0.158	0.157

Notes: N = 349. This table provides the estimated results for our models using alternative regression techniques (fixed-effect model and IV regression). *** p < 0.01, ** p < 0.05, * p < 0.1. Robust standard errors are in parentheses.

Source: Authors' calculation.

5.2 With Lag

There might be a lag in response of investment to the changes in the external cost of emissions. Therefore, in this section, we explore the impacts of the lagged external cost of emissions on the firm's investments in renewable energy. The results are presented in Table 3 (with the results from fixed-effects models in columns 2–4 and the results from the IV models in columns 5–7).

Although there is a significant decrease in observations due to the use of lagged variables, we find that firms with greater emissions, proxied by the external cost of air pollutants, invest more in renewable energy in the following year (once we address the potential endogeneity issues in columns 5–7).⁶ In light of the economic significance, the renewable investment to shareholders' equity ratio increases by nearly 1 p.p. if the external cost of air pollutants relative to the firm's revenue rises by 1%. This could indicate the effectiveness of environmental policies.⁷ Financial leverage has no statistically significant impact on renewable energy investments in the following year. COVID-19 has no significant impact on renewable energy investments.

Table 3: Results: External Cost of Air Pollutants (Direct Cost and One-year Lag)

Dependent Variable: REI/K (1)	FE1 (2)	FE2 (3)	FE3 (4)	IV1 (5)	IV2 (6)	IV3 (7)
Air pollutants cost, share in revenue (lag)	0.001 (0.001)	0.001 (0.001)	0.001 (0.001)	0.010** (0.004)	0.010** (0.004)	0.010** (0.004)
Stringency index		–0.001 (0.001)			–0.000 (0.001)	
Coronavirus disease (COVID-19) dummy			–0.077 (0.056)			–0.006 (0.039)
Financial leverage (lag)	0.066 (0.166)	0.030 (0.167)	0.037 (0.167)	0.252 (0.177)	0.252 (0.177)	0.252 (0.177)
Return on asset	–0.530 (0.357)	–0.668* (0.376)	–0.657* (0.373)	–0.317 (0.598)	–0.318 (0.598)	–0.317 (0.598)
Revenue, share in total asset (ratio)	–0.785*** (0.270)	–0.800*** (0.267)	–0.798*** (0.267)	–0.318** (0.130)	–0.320** (0.131)	–0.319** (0.131)
Total asset (logarithm)	–0.312*** (0.085)	–0.291*** (0.075)	–0.291*** (0.075)	–0.049*** (0.013)	–0.049*** (0.013)	–0.049*** (0.013)
Firm age	0.042 (0.031)	0.101 (0.063)	0.100 (0.062)	–0.001 (0.001)	–0.001 (0.001)	–0.001 (0.001)
Energy cost	0.005 (0.003)	0.010* (0.006)	0.010* (0.006)	–0.001 (0.002)	–0.001 (0.002)	–0.001 (0.002)
Constant	4.129*** (1.597)	1.881 (1.788)	1.927 (1.770)	1.039*** (0.260)	1.046*** (0.272)	1.042*** (0.272)
R square	0.252	0.265	0.264	0.074	0.074	0.074

Notes: N = 173. This table provides the estimated results for our models using alternative regression techniques (fixed-effect model and IV regression). *** p < 0.01, ** p < 0.05, * p < 0.1. Robust standard errors are in parentheses.

Source: Authors' own calculation.

⁶ It is also worth mentioning that the null hypothesis that the external cost of air pollutants is exogenous is rejected by the exogeneity tests (Durbin, Wu–Hausman, Wooldridge's score, and the regression-based). As a result, we should treat this variable as endogenous and employ the IV regressions. In addition, the results of the Stock and Yogo tests demonstrate that our instrumental variable is not weak for all three IV models considered.

⁷ We also present the results for the lag of the external cost of air pollutants when both direct and indirect costs are included. The estimated results are reported in Table A2.2. We obtain similar results: environmental regulation, proxied by the external cost of air pollutants (both direct and indirect costs), positively affects renewable energy investment.

6. ROBUSTNESS CHECKS

In this section, we check our main findings for robustness using alternative measures of two explanatory variables: (i) the external cost of GHG emissions as an alternative measure for the external cost of emissions, and (ii) COVID-19 binary variable (equals 1 if $t = 2020$ and 0 otherwise) as an alternative proxy for COVID-19 stringency index. As in the previous section, we first investigate the impacts of firms' GHG emissions and COVID-19 restrictions on renewable energy investment without lag (Table 4) and then explore the effects of lagged GHG emissions and financial leverage (Table 5). We have demonstrated that our results are robust with regard to different measures of the external costs of air pollutants, financial leverage, and COVID-19 restrictions.

6.1 Without Lag

The estimated results for the impacts of firms' GHG emissions are shown in Table 4 (with fixed-effect models in columns 2–4 and IV models in columns 5–7). The findings are in line with our main findings from Table 1. In summary, the main results on the impact of firms' emissions survive the robustness check.

Table 4: Robustness Check: External Cost of Greenhouse Gas Emissions (Direct Cost and No Lag)

Dependent Variable: REI/K (1)	FE1 (2)	FE2 (3)	FE3 (4)	IV1 (5)	IV2 (6)	IV3 (7)
GHG emissions cost, share in revenue	0.001 (0.001)	0.001 (0.001)	0.001 (0.001)	0.003*** (0.001)	0.003*** (0.001)	0.003*** (0.001)
Stringency index		−0.002 (0.001)			−0.000 (0.001)	
Coronavirus disease (COVID-19) dummy			−0.086 (0.067)			−0.012 (0.038)
Financial leverage	0.365* (0.189)	0.350* (0.201)	0.354* (0.199)	0.364*** (0.106)	0.362*** (0.106)	0.363*** (0.106)
Return on asset	−0.625 (0.697)	−0.694 (0.749)	−0.687 (0.745)	0.371 (0.380)	0.368 (0.380)	0.368 (0.380)
Revenue, share in total asset (ratio)	−0.705* (0.385)	−0.710* (0.384)	−0.707* (0.383)	−0.117** (0.050)	−0.117** (0.050)	−0.117** (0.050)
Total asset (logarithm)	−0.246** (0.109)	−0.231** (0.103)	−0.233** (0.104)	−0.065*** (0.009)	−0.064*** (0.009)	−0.064*** (0.009)
Firm age	0.016 (0.030)	0.078 (0.064)	0.075 (0.063)	0.001 (0.001)	0.001 (0.001)	0.001 (0.001)
Energy cost	0.001 (0.003)	0.006 (0.005)	0.005 (0.005)	−0.002* (0.001)	−0.002* (0.001)	−0.002* (0.001)
Constant	3.728*** (1.644)	1.531 (1.627)	1.660 (1.626)	1.077*** (0.153)	1.087*** (0.156)	1.086*** (0.156)
R square	0.171	0.185	0.183	0.174	0.174	0.174

Notes: N = 349. This table provides the estimated results for our models using alternative regression techniques (fixed-effect model and IV regression). *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors are in parentheses.

Source: Authors' calculation.

6.2 With Lag

In this section, we provide a robustness test for the results from Table 2. The results are displayed in Table 5 (fixed-effect models in columns 2–4 and IV models in columns 5–7). The impacts of GHG emissions (from Table 5) are consistent with the results from Table 2. In summary, the main results on the impact of firms' emissions survive the robustness check.

**Table 5: Robustness Check: External Cost of Greenhouse Gas Emissions
(Direct Cost and One-year Lag)**

Dependent Variable: REI/K (1)	FE1 (2)	FE2 (3)	FE3 (4)	IV1 (5)	IV2 (6)	IV3 (7)
GHG emissions cost, share in revenue (lag)	0.001 (0.001)	0.001 (0.001)	0.001 (0.001)	0.004*** (0.001)	0.004*** (0.001)	0.004*** (0.001)
Stringency index		−0.001 (0.001)			−0.000 (0.001)	
Coronavirus disease (COVID-19) dummy			−0.078 (0.074)			−0.017 (0.052)
Financial leverage (lag)	0.072 (0.222)	0.036 (0.224)	0.043 (0.225)	0.247 (0.172)	0.246 (0.172)	0.246 (0.172)
Return on asset	−0.545 (0.483)	−0.688 (0.511)	−0.676 (0.506)	−0.261 (0.583)	−0.264 (0.583)	−0.262 (0.583)
Revenue, share in total asset (ratio)	−0.792** (0.359)	−0.809** (0.355)	−0.806** (0.355)	−0.364*** (0.133)	−0.370*** (0.134)	−0.369*** (0.134)
Total asset (logarithm)	−0.307*** (0.114)	−0.285*** (0.102)	−0.286*** (0.101)	−0.050*** (0.013)	−0.049*** (0.013)	−0.049*** (0.013)
Firm age	0.040 (0.043)	0.100 (0.085)	0.098 (0.084)	−0.001 (0.001)	−0.001 (0.001)	−0.001 (0.001)
Energy cost	0.005 (0.005)	0.010 (0.008)	0.010 (0.007)	−0.000 (0.002)	−0.001 (0.002)	−0.001 (0.002)
Constant	4.098* (2.117)	1.798 (2.402)	1.856 (2.374)	1.045*** (0.254)	1.075*** (0.266)	1.071*** (0.266)
R square	0.255	0.269	0.268	0.121	0.121	0.121

Notes: N = 173. This table provides the estimated results for our models using alternative regression techniques (fixed-effect model and IV regression). *** p < 0.01, ** p < 0.05, * p < 0.1. Robust standard errors are in parentheses.

Source: Authors' calculation.

7. CONCLUSIONS AND POLICY RECOMMENDATIONS

This study investigates how firms' emissions affected their investments in renewable energy projects. We employ a unique dataset from 147 firms from the PRC that invested in renewable energy between 2015 and 2020. The key findings can be summarized as follows.

Firms with greater air pollutants or GHG emissions (measured as a share in revenue) invest more in renewable energy (measured as a share in total equity). This is probably due to the effectiveness of emission policies in the PRC, which incentivized firms to invest in renewable energy in order to reduce their emissions.

Although this study uses data from the PRC, based on the above-mentioned key findings, we provide the following evidence-based policy recommendations to promote firms' investments in renewable energy for other countries, particularly from developing Asia. Regulations on emissions might encourage firms to invest in renewable energy in order to reduce their emissions. However, policies supporting renewable energy are also needed.

This paper has limitations mainly because of the limited availability of firm-level data from developing countries (including the PRC). Our data sample includes only 147 firms operating within the PRC that invest in renewable energy projects in the same region, which does not allow us to estimate the impact of foreign firms. Therefore we focused only on domestic firms. We did not include emission and renewable energy policy data because of a lack of firm-level policy data. For this reason we could not identify which policy instruments specifically have a positive impact on investments in renewable energy. We have missing variables, such as ownership (foreign and government), gender, and electricity price, due to missing observations in many firms. When more firm-level data from developing countries become available such limitations can be resolved.

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