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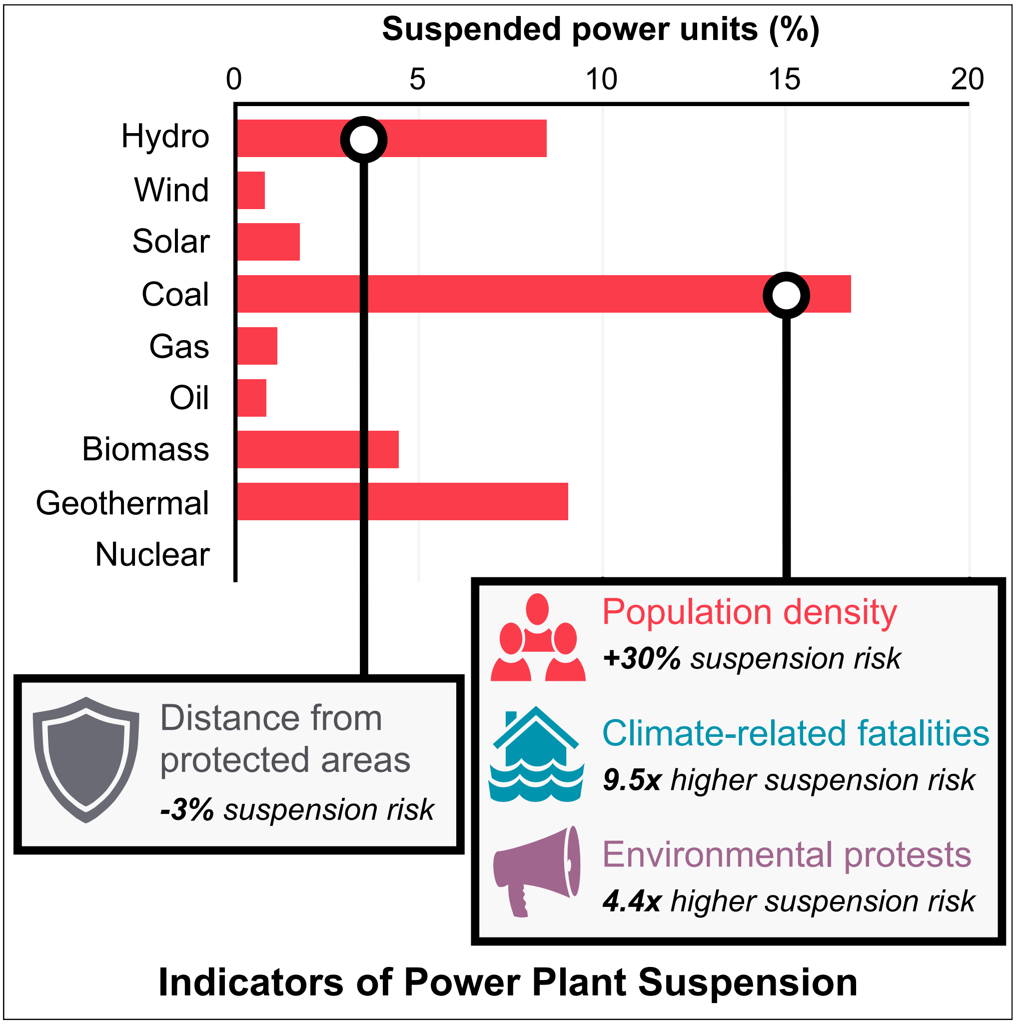
Empirical analysis of Chinese overseas power plant investments: Likelihood of suspensions and associated environmental risks



Yangsiyu Lu, Xiao Yan Zhou, B. Alexander Simmons

xiao.zhou@smithschool.ox.ac.uk

Highlights

5% of power projects examined, mostly coal and hydro, have been canceled or delayed

Power projects with higher environmental risks are more likely to be suspended

Coal projects near dense populations, high climate fatalities face greater suspension

Hydro projects situated closer to protected areas experience a higher suspension rate

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Empirical analysis of Chinese overseas power plant investments: Likelihood of suspensions and associated environmental risks

Yangsiyu Lu,[1,2,3] Xiao Yan Zhou,[4,7,*] and B. Alexander Simmons[5,6]

SUMMARY

Power sector investment is crucial to accelerate a sustainable energy transition, but not all investments are successful. We examine 1,393 Chinese overseas electric power projects across 78 countries over the past two decades. We identify 5% that have been canceled or delayed, with coal and hydro projects having much higher suspension rates than solar and wind projects. We find electric projects with higher environmental risks are more likely to be suspended. Specifically, coal projects located in more densely populated areas where more people are exposed to air pollutants, in countries with more fatalities from extreme weather events, and in places with a record of environmental protests, are more likely to be suspended. Additionally, hydro projects closer to protected areas have a higher suspension rate. Our results suggest that refraining from investing in environmentally risky projects helps mitigate environmental damages and prevents financial losses due to cancellation and postponement.

INTRODUCTION

Greater investment in the energy sector is crucial for building a global energy system capable of delivering the UN Sustainable Development Goal of affordable and clean energy.[1] As of 2019, 10% of the global population still does not have access to electricity, and the COVID-19 pandemic may significantly slow progress to achieving global electricity access.[2] In recent years, China has emerged as one of the world's largest financiers in the global energy sector, and China-funded overseas power projects have received considerable attention both for their large scale and influence on contribution to energy accessibility, particularly in less developed countries. Two Chinese policy banks—the China Development Bank and Export-Import Bank of China—have provided a total of 245.8 billion USD in energy finance to more than 80 countries since 2000.[3]

The fate of energy investments, however, is not always assured.[4] Between 2014 and 2020, about 65 billion USD of Chinese-backed coal-fired power plants have been shelved or canceled, and many more projects have been significantly delayed.[5,6] Therefore, understanding the factors that contribute to project setbacks and ensuring the efficient allocation of investments is essential to accelerate the sustainable transition.[7]

Among the risk factors that could lead to the project suspension, environmental concerns regarding Chinese overseas energy investment have been mostly discussed, ranging from carbon emissions to pollution and even biodiversity loss.[8–11] For example, the overseas coal power plants with full or partial financing from Chinese development finance institutions, if successfully in operation, will emit 11.8 Gt CO_2 over their lifetime, as much as the annual emissions from global operational coal-fired power plants in 2018.[12] In addition, as China has become the largest overseas financier of hydropower in low-income countries, many experts question the sustainability of projects situated within highly sensitive ecological regions, such as protected areas and critical habitats.[13]

How do environmental risks affect the implementation of energy investments across energy sources? Anecdotal evidence suggests that environmental risk is a significant factor contributing to delays and cancellations of electricity projects.[14,15] For instance, environmental issues were identified by Kumar (2021) as one of the five key reasons for the delay of hydro projects in India. A detailed case study of the Lamu coal project in Kenya also shows that the project cancellation was partially attributed to environmental risks. A court

[1]Paris School of Economics, 75014 Paris, France

[2]Institute for New Economic Thinking, University of Oxford, OX1 3UQ Oxford, UK

[3]Thrust of Carbon Neutrality and Climate Change, The Hong Kong University of Science and Technology (Guangzhou), Guangzhou 511400, China

[4]Smith School of Enterprise and the Environment, University of Oxford, OX1 3QY Oxford, UK

[5]Global Development Policy Center, Boston University, Boston, MA, USA

[6]Tampa Bay Estuary Program, St. Petersburg, FL, USA

[7]Lead contact

*Correspondence: xiao.zhou@smithschool.ox.ac.uk

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ruling suspended the Lamu project's permit in 2019 after a long-lasting demonstration from local groups and non-governmental organizations over its environmental impacts, and the government officially canceled the project in 2020.[16]

Previous academic research on energy investment risks is dominated by *ex ante* studies, using scenario analyses and assumption-based modeling to categorize potential risk factors associated with energy investments.[17–27] In these modeling studies, environmental risks are frequently listed as a critical dimension of investment risks, and their impacts vary with changes in assumptions and scenarios, making the implications less convincing for investors and practitioners. Despite abundant theoretical modeling and scattered case studies, there is a lack of quantitative evidence from large samples on whether and how environmental risks can affect energy project outcomes.

In this paper, we aim to address this empirical gap by providing novel evidence of the interaction between environmental risks and energy project outcomes from China's overseas power plant investments. We trace the status of 1,393 overseas power investments by Chinese firms in 78 countries over the past two decades and identify 5% of projects as having been canceled or postponed. Among the different power generation technologies, coal and hydro power plants are more likely to be deferred or shelved than other types of plants. We therefore explore whether environmental risks have contributed to the setback of these two types of power projects.

We focus on the most pronounced environmental risks by selecting risk factors from documented case studies of environmental conflicts over electricity projects. This approach ensures that the selected risk factors are not only present in theoretical frameworks but also have real-world consequences. For coal projects, we document that the most salient environmental risks are pollution exposure and climate change risks, while for hydro projects, biodiversity impact is the predominant environmental risk factor.[28] We construct project-level risk variables based on the geolocation of each project and use survival analysis to test the likelihood of specific environmental risks leading to project cancellations and delays. Overall, we find electric power projects with higher environmental risks are more likely to be canceled or delayed. Coal power projects have a higher chance of being suspended if they are in densely populated areas, where more people are exposed to pollution, or in countries that are more vulnerable to climate change. Meanwhile, the closer hydro power projects are to protected areas, the more likely they are to be suspended. We also find coal projects located in areas with a greater presence of environmental protests have a higher chance of being abandoned, but we do not find such an effect on hydro projects.

Our findings provide novel global evidence for why environmental risks should be considered seriously in investment decisions. To the best of our knowledge, this is the first empirical study to statistically investigate the link between environmental risks and energy project suspensions based on tracked project status of Chinese overseas investments. Investors usually view environmental risks as long-term risks, where the financial impacts will not be felt for decades to come. Our analysis shows that even on financial grounds, energy investors should seriously consider environmental issues in their decision-making process; otherwise, risks would likely transform investments into financial losses in a much shorter timescale by delaying or canceling the project.

RESULTS

Mapping suspended Chinese overseas power projects

By combining several data sources, including the World Electric Power Plants Database,[29] China's Global Power Database,[30] Bloomberg's Merger & Acquisition deal database,[31] and China Global Investment Tracker,[32] we constructed a dataset of 1393 power units with investments by Chinese firms in 78 host countries from 1997 to 2020 (Figure 1A). Chinese firms invest in all types of power units across the globe. Hydro power has received the most investment, followed by wind and solar. One-third of Chinese firms' investments are in fossil fuels. Chinese firms also invest in a small number of newer and less frequently applied technologies overseas, such as biomass (including waste incinerators), geothermal, and nuclear power.

Tracing back project status to the investment year, we identify 75 units, roughly 5% of the sample, that have been suspended at some point. The majority of these suspended units are located in emerging economies, such as Argentina and India, though Chinese firms also experience project cancellation and delays in high-income countries like Australia and Norway (Figure 1B).

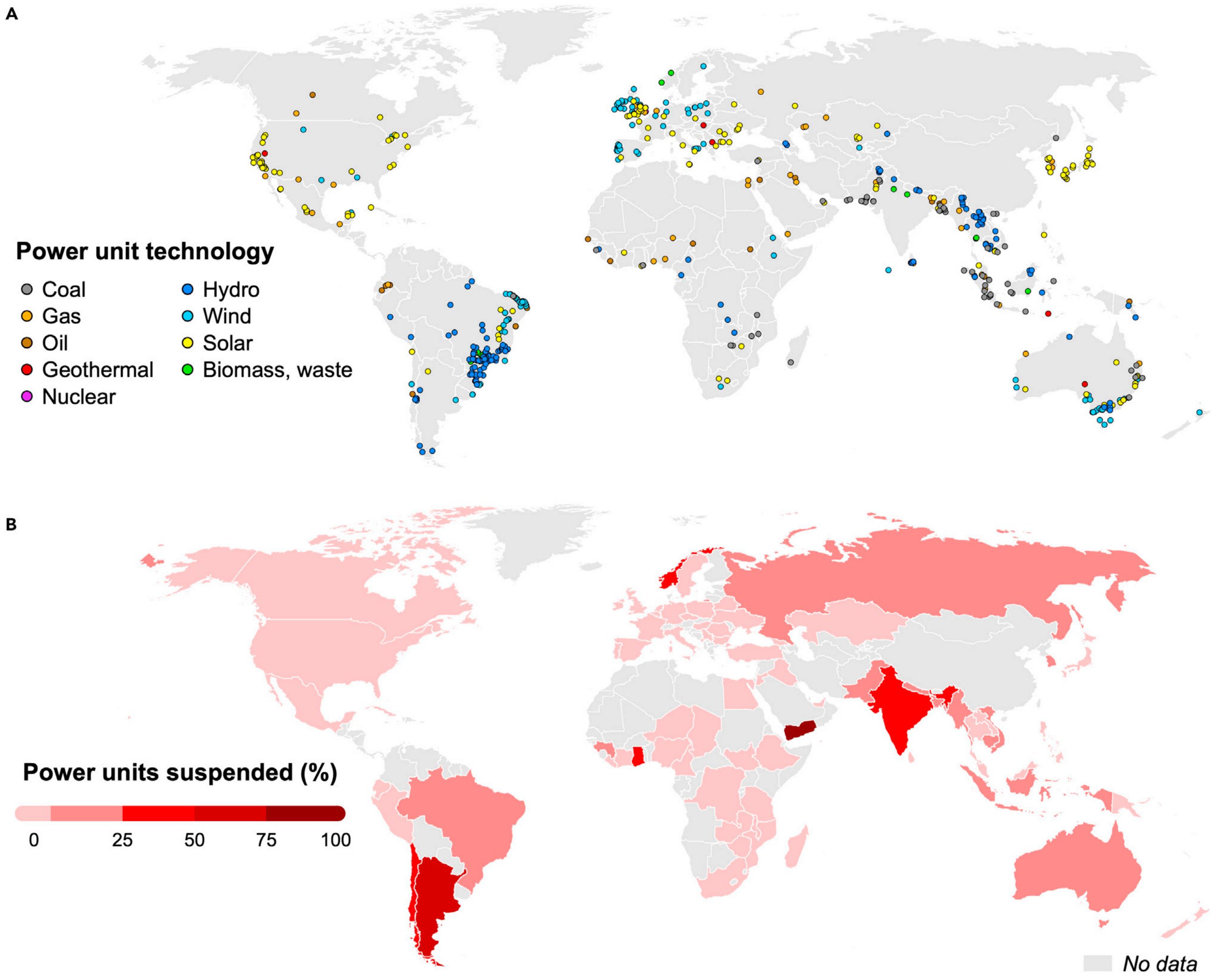

Figure 1. Location of Chinese firms' overseas investments in power units

(A) and suspension rate by country (B). Distribution of all 1393 Chinese firms' overseas investments in power units from 1997 to 2020 included in this study.

Out of 75 suspended projects, 60% were paused during the planning phase and 40% during the construction phase (Figure 2). Twenty-two projects were directly canceled at the time of suspension and a quarter of the 53 projects initially classified as 'delayed' were eventually canceled as of 2020. Once suspended, the chance of resuming a project is low. Only 16 suspended power units (21%) have resumed planning or construction as of 2020, and just 7 power units (9%) have since become operational following suspension.

Central state-owned enterprises (SOEs) are the main investors in these energy projects, holding the majority of investments in hydro and fossil fuel projects (Figure 3A). Provincial SOEs have a similar investing pattern, though the number of investments is much smaller relative to central SOEs. Private firms invest heavily in renewable power projects, particularly solar and geothermal. Across all types of technologies, coal and hydro projects have the highest suspension rates, 17% and 9%, respectively. Geothermal power units also have a high suspension rate of 9%, though the sample size is relatively small.

The fate of suspended projects is variable, but some trends are apparent. Chinese firms' investments in power units increased substantially after the launch of the Belt and Road Initiative (BRI) in 2013 (Figure 3B). While some early project suspensions occurred in 2009, most occurred after 2015. Coal projects, in particular, encountered a significant number of suspensions for five continuous years up to 2020. Similarly, there

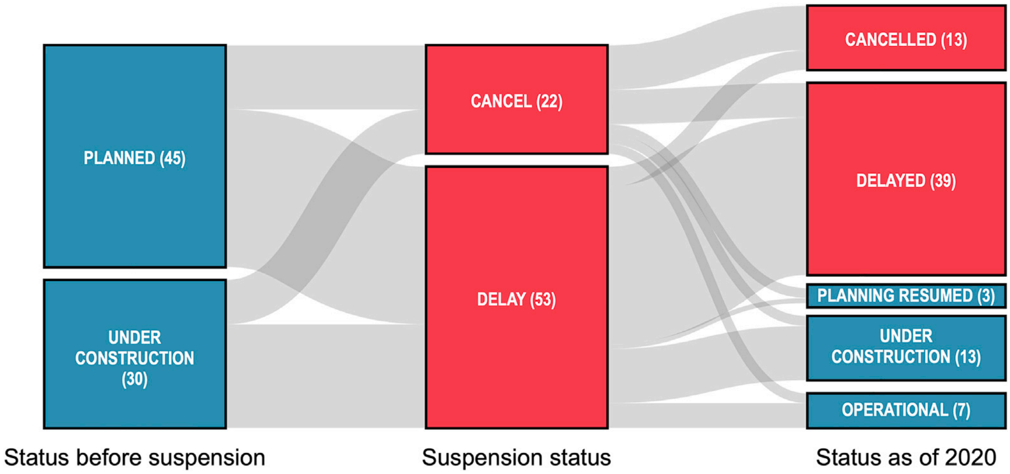

Figure 2. Status of suspended power units

Evolution in the status of the 75 power units that have been suspended at some point. The suspension includes project cancellation and delay (in red).

has been a steep decline in the number of new hydro power projects since 2017, and the number of suspensions surpassed investments in 2020.

If we compare the coal and hydro power project suspension trends of Chinese firms with other investment entities and regions, we find some comparable patterns and unique differences (Figure 4). The number of global suspended coal power projects surpassed the number of new coal investments in 2015 when the Paris Agreement was announced, peaking in 2017 with more than 600 suspensions (Figure 4A). Over the next three years, global newly invested coal power projects dropped to double digits. Taking a closer look at the 78 countries that host Chinese firms' investments in the electric power sector, Chinese firms began to push overseas coal projects in 2013, and their investments plateaued between 2013 and 2016, while non-Chinese entities' investments in host countries' coal power have gradually decreased since 2014. When the Chinese domestic market saw a surge in suspensions, presumably due to coal capacity cut policies imposed in 2016,[33,34] the number of suspended Chinese overseas investments also peaked.

In terms of hydro power (Figure 4B), while Chinese overseas investments have increased from 2015 to 2017, their domestic investments have decreased compared to earlier years. On a global scale, the number of hydro power project suspensions has been increasing since 2010, peaking in 2020 with 432 suspensions. A similar trend is reflected in non-Chinese entities' investments, with a peak of 372 suspensions in 2020.

While power projects face a range of risks, including technical, financial, and environmental risks,[18,23] our observations from Figures 1, 2, 3, and 4 suggest environmental risks are likely to be a major cause of project suspensions in our empirical setting. First, our data show that out of the 75 suspended projects, 45 of them (60%) were halted during the planning stage, suggesting that technical factors are unlikely to be responsible for the suspensions. Additionally, a significant percentage of investors for these suspended projects are Chinese state-owned firms with extensive experience in foreign direct investment in the power sector and are fully funded by the Chinese state or local governments. Therefore, financial factors are less likely to be at play. Notably, we observe that most power project suspensions occurred after the launch of the Paris Agreement in 2015 (as seen in Figure 2B), underscoring the increasing significance of environmental risks in shaping project outcomes. Based on these observations, as well as anecdotal evidence discussed in the Introduction, environmental risks are likely to be a major cause of project suspensions. This will be further explored in the next sections.

Power generation technology and suspension risk

To test whether suspension risks differ among power generation technologies, we perform a survival analysis, which considers not only whether the power unit was suspended but also the length of time it

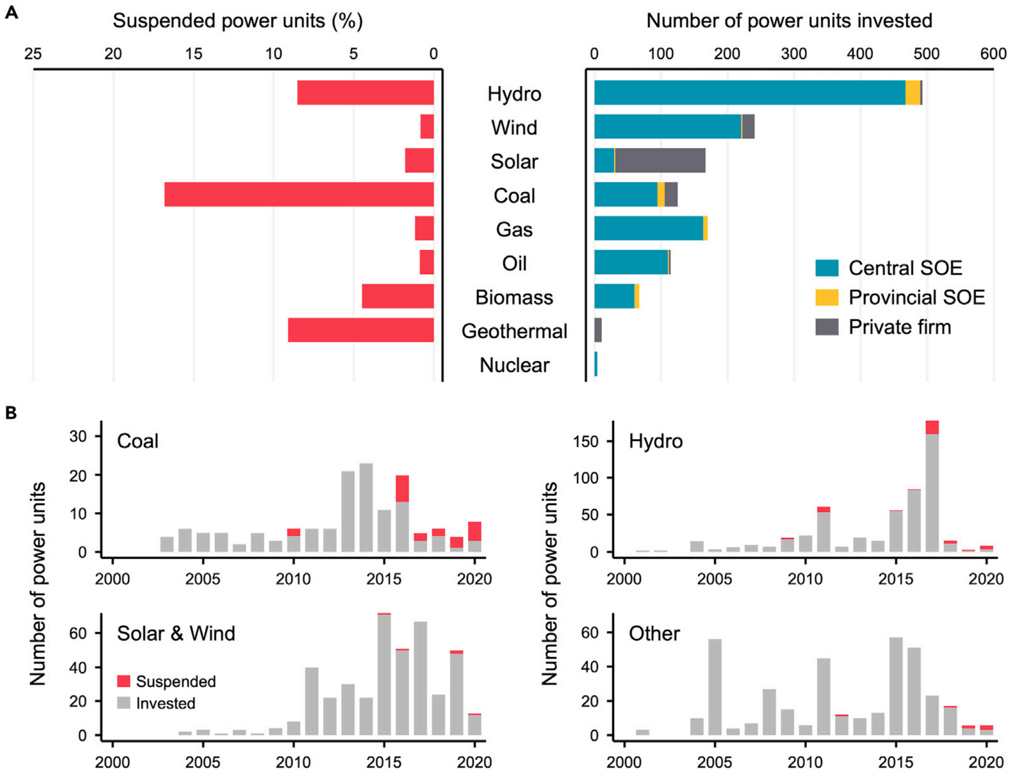

Figure 3. Chinese firms' overseas investments in power units by firm ownership
(A) and year (B), categorized by technology. The suspension percentage in (A) measures the number of suspended power units relative to the number of total power units with investments by Chinese firms. Gray bars in (B) represent the number of newly invested power units in a particular year and red bars refer to the number of power units suspended in a particular year. SOE, state-owned enterprise.

took for the suspension to occur. We collect annual observations for each power project from the year it was invested until the year it was suspended (for suspended projects) or 2020 (the end of sample period, for non-suspended projects), and each observation is recorded as sample year *t* for project *i*. The dependent variable is the hazard rate, which is the conditional probability that a failure event (i.e., an energy project is canceled or delayed) occurs at a particular time interval. We use a Weibull parametric proportional hazards model to compare the influence of power technology choice on the hazard rate. Hazard ratios are reported in the results tables. A hazard ratio greater than one suggests an increased risk of failure, while lower than one implies a decreased risk. More details on the calculation and description of the hazard ratios are presented in Method details section. For robustness purposes, we also estimate the semi-parametric Cox hazards model.

We include several controls for the project-, firm- and country-level variables that have been shown to impact power generation projects from inception to implementation to account for confounding factors. At the project level, we control for project size (capacity), as larger projects would have longer lead times and may encounter more uncertainties due to greater economic and technical complexity.[35,36] Internalization theory[37] suggests that the success of foreign direct investment (FDI) in the power plant sector could depend on the ability of the foreign investor to internalize certain activities, such as power plant construction and equipment maintenance. We incorporate firms' FDI experience to capture investing firms' overall technological and financing ability in FDI, as firms could learn from their prior international experiences to better manage overseas projects.[38–40] According to institutional theory,[41,42] the success of FDI in the power plant sector depends on the institutional framework of the host country, including the governance system, economic development, and political stability. We take into consideration the gross domestic product (GDP) per capita to account for economic and market influence. We include the population's electricity access rate to control for resource scarcity. We also control for countries' scores on the voice and

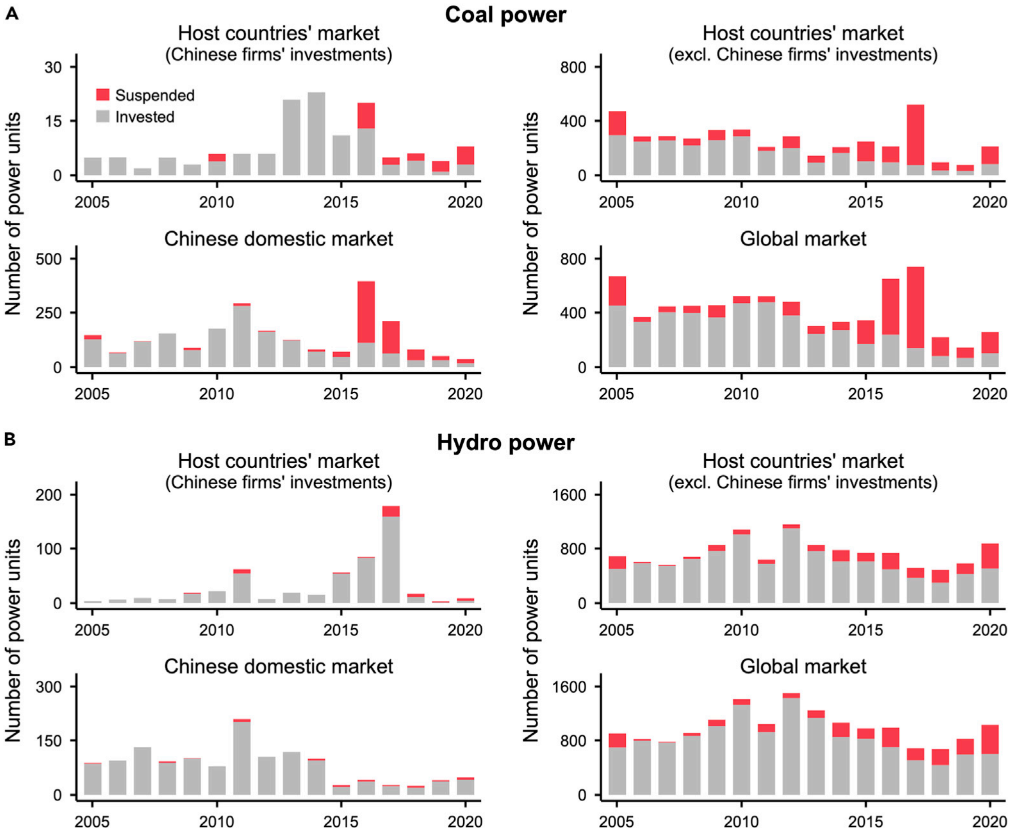

Figure 4. The changes in the number of newly invested and suspended coal

(A) and hydro (B) projects by investment entity and region. Gray bars represent the number of newly invested power units in a particular year and red bars refer to the number of power units suspended in a particular year. Host countries refer to the 78 countries where Chinese firms have invested in the electric power sector.

accountability index to catch variations in the host countries' governance systems, as public objections may have an impact on the implementation of energy projects.[28,43,44] Definitions and sources of all variables are listed in Table S1. The correlation among all variables is presented in Table S2.

Consistent with our observations in Figure 2, coal and hydro power units are more likely to be suspended than solar and wind projects, even after controlling for project-, firm-, and country-specific characteristics (Table 1). The hazard rate is 3.8 and 8.2 times as high for coal and hydro projects, respectively, in comparison to other power generation technologies. Among control variables, we also find that the likelihood of suspension is greater for projects with larger capacity, financed by firms with less FDI experience, and located in countries with a greater degree of voice and accountability. After performing several robustness checks to verify the stability of our results, we obtain nearly identical, statistically significant estimates using the semi-parametric Cox proportional hazards model (Table S4). Another concern with the results documented so far is that other risk factors, such as firm-level governance and ownership heterogeneities, and economic relations between China and the host countries, likely affect the success of the power plant investments. To rule out this alternative explanation, we added firm type and the economic relation between China and the host countries in the robustness tests. Firm type is a dummy variable which equals one if it is a state-owned firm and zero if it is a private firm. We use the trade ratio (export value to import value) to proxy the economic and political relations between China and the host countries. The regression estimates incorporating these additional explanatory variables (Tables S4 and S5) were consistent with those reported in Table 1.

Environmental risks associated with coal and hydro power projects

Because we find that coal and hydro power projects have the highest risk of cancellation and delay, and both technologies can impose significant impacts on the environment,[11,13] we focus on these two types

Table 1. The effect of technology choice on power project suspensions

	Hazard ratios			
Variables	(1)	(2)	(3)	(4)
Coal	9.499***	3.568***	3.104**	3.787***
	(4.146)	(1.591)	(1.397)	(1.791)
Hydro	4.678***	5.477***	6.128***	8.188***
	(1.910)	(2.254)	(2.527)	(3.672)
Solar & Wind	0.642	1.018	1.018	0.847
	(0.376)	(0.605)	(0.603)	(0.505)
Capacity (log)		2.037***	1.987***	1.975***
		(0.226)	(0.224)	(0.217)
Firm FDI experiences			0.996**	0.994***
			(0.002)	(0.002)
GDP per capita (log)				0.956
				(0.176)
Access to electricity				0.991
				(0.009)
Voice and accountability				1.807**
				(0.425)
Observations	10,195	10,195	10,195	10,195

Results of the Weibull parametric proportional hazards model are reported as hazard ratios. A hazard ratio greater than one suggests an increased risk of failure, while a lower than one implies a decreased risk. Column (1) reports the estimated hazard ratios and (standard errors) for the three interest variables: coal, hydro and solar & wind without controlling specific characteristics. Columns (2) to (4) report the estimated hazard ratios and (standard errors) for the three interest variables by gradually controlling for the project-, firm-, and country-specific characteristics. All variables are defined in Table S1. The parametric Weibull model description is described in Method details section. *,**,*** Denote statistical significance at the 10, 5, and 1% confidence levels, respectively.

of power projects and investigate whether environmental risks are associated with their cancellation and postponement. Environmental risks refer to the probability and consequence of unwanted changes in the natural environment caused by human and business activities. While a wide range of environment-related factors can impact project development, we focus on the most pronounced risks associated with coal and hydro projects.

We select environmental risks from the Global Atlas of Environmental Justice (EJAtlas), a database that collects and documents social conflicts around environmental issues worldwide. This strategy ensures that the risks identified are the most likely to impact project outcomes since they represent the main environmental concerns stated by communities campaigning against coal and hydropower projects (Table 2). These risks are also pertinent to Chinese firms' overseas coal and hydro projects (see a few exemplar case studies in Table 2).

We see from Table 2 that environmental issues about coal projects are primarily pollution exposure (a local risk) and climate change (a global risk). We first use local population density surrounding coal power projects as a proxy for the number of people exposed to pollution. Burning coal emits pollutants that are detrimental to the health of nearby populations,[45–47] and if there is a larger population exposed to these pollutants, the pollution issue may be more salient, ultimately increasing the risk of suspension (cf. Indonesia and Ghana case studies in Table 2). Because coal projects tend to be placed 10–20 km from densely populated areas,[45] we use the mean population density for all areas within a radius of 25 km surrounding each coal power project.

Second, regarding the global climate change concern, we hypothesize that people who have experienced catastrophic losses as a result of extreme weather events would be more concerned about the construction of coal power plants nearby, as extreme weather events have been found to play a role in raising public

Table 2. Examples of environmental issues in suspended coal and hydro projects

Technology	Main environmental claims recorded in EJAtlas	Project, Country	Environmental concerns	Conflicts documented	Project status in 2020
Coal	Pollution concerns (air, water, and waste), Climate justice concerns	Nagan Raya, Indonesia	Air pollution, water pollution, waste disposal	Local residents protested against the coal dust and other air pollutants generated from the plant; local media reported chemicals discharged from the plant were killing fish in nearby waterways[a]	Delayed
		Aboano, Ghana	Air pollution, climate change effects	Environmental activists protested as vulnerable population will be exposed to the air pollutants released by the plant; NGOs expressed opposition to the project in response to heavy flooding events in local area[b]	Canceled
Hydro	Impacts on the ecosystems far larger than expected or stated in official documents	Batang Toru, Indonesia	Biodiversity loss	International organizations warned the project's potential threat to critically endangered species, i.e., Tapanuli orangutan[c]	Delayed
		President Nestor Kirchner and Jorge Cepernic, Argentina	Biodiversity loss, impacts on glaciers	Suspended by Supreme Court order for environmental impact assessment; Environmental groups expressed concerns on UNESCO-declared glaciers and critically endangered species[d]	Under construction

[a] Global Energy Monitor Wiki page, available at https://www.gem.wiki/; Global Atlas of Environmental Justice (EJAltas), available at: https://ejatlas.org/.
[b] Global Energy Monitor Wiki page.
[c] IUCN Section on Great Apes (2020), Batang Toru Hydro power Project Factcheck and References on Key Issues.
[d] China Dialogue (2021), New Argentina Government Reactivates Controversial Patagonia Dams; Global Atlas of Environmental Justice.

awareness and spurring climate actions, particularly in areas that have suffered from the effects of climate change[48–50] (cf. Aboano example in Table 2). To account for climate concerns from local communities, we include climate-related fatalities as a proxy of the salience of perceived climate vulnerability, which is frequently used in climate risk analyses.[48,51] Following the method of the Climate Risk Index,[52] we take the country's annual average number of deaths from weather-related loss events (i.e., storms, floods, heatwaves) per 100,000 inhabitants over the past 20 years.

The environmental concern of hydro power projects to date has centered on their impacts on local ecosystems. Hydro power projects can have many negative ecological impacts upstream or downstream of the dam, such as wildlife injury, reductions in connectivity, changes in water temperature and pH values, or declines in species richness.[53] As documented in the EJAtlas, mobilizing communities are mostly concerned about the potential impacts of hydro power projects that far exceed the expected or stated impacts in official documents, particularly when there are threatened species or protected habitats nearby (cf. Indonesia and Argentina case studies in Table 2). Therefore, we include the distance from each hydro power project to the nearest international, national, or regional protected area[54] as a proxy for the project's risks to ecosystems of high ecological importance and biodiversity value. We hypothesize that hydro projects located closer to protected areas may be more likely to adversely impact these important ecosystems,[10,55] ultimately increasing the likelihood of suspension.

In addition to these technology-specific environmental risk measures, we include environmental protests as a proxy for local society's reactions to perceived negative environmental consequences. This captures the intensity of local resistance to environmental issues. Anecdotal evidence suggests that protest is the main tactic used by affected communities and environmental organizations to express opposition to power projects (Table 2). Studies of social movements argue that protests could amplify public opinion to regulators and investors and ultimately affect changes in environmental issues.[56–59] We use protest data from Google's Global Database for Events, Language, and Tone (GDELT) project—currently the most powerful research tool to analyze the occurrence of protests globally—that monitors the world's news media in print, broadcast, and web formats in over 100 languages from 1979 onwards.[60–62] We match environmental protest records with power projects based on the location of the protest and power project. Specifically, we follow Iacoella et al. (2021)[61] to construct a dummy variable for each project at sample year *t* that indicates if there was at least one environmental protest recorded nearby in either year *t* or year *t-1* within a 50-km buffer zone. See Table S1 for a description of all variables included in the analysis.

Could environmental risks be contributing to the suspension of power projects?

Our results provide evidence of the association between these environmental risks and the likelihood of power projects being suspended, but to varying degrees. As shown in the summary statistics (Table S3), suspended coal power projects tend to be located in more densely populated communities, and in areas with more climate-related fatalities and a greater presence of recent environmental protests, than non-suspended projects. Our analysis confirms these environmental risks are associated with coal project suspension (Table 3). A one-unit increase in the population density within a radius of 25 km increases the hazard rate by 29% for coal power units, accounting for all control variables. Coal projects are also more likely to be suspended where climate-related fatalities are greater—one death increase per 100,000 inhabitants in host countries increases the hazard rate nearly 10-fold. We also find that the hazard rate of coal projects in areas that have experienced recent environmental protests is more than four times higher than projects located in areas with no environmental protests.

On average, hydro power projects tend to be located more than 90 km from any protected area, with the closest distance for a single hydro project being 8 km from the nearest protected area. Suspended hydro power projects, however, tend to be closer to protected areas than non-suspended projects (Table S3). By applying a parametric Weibull survival analysis model, we find that the distance to protected areas is significantly associated with the fate of hydro power projects, with suspension risk decreasing the further a hydro power project is from protected areas (Table 3). A 1-km increase in the distance from a nearby protected area reduces the hydro power project's hazard rate by 3%. However, we find no significant effect of local environmental protests on hydro project suspension. One possible explanation may be that hydro projects tend to be located in remote areas and the place-based protest measure may not fully capture the environmental movement pressure linked to the project's location, as protests often take place in regions where regulators/investors are based rather than at the remote dam site. These results remain robust when we add more control variables, including the firm type and the trade relation between China and the host countries (Table S6). Furthermore, we produce similar results using the semi-parametric Cox hazards model (Table S7).

DISCUSSION

This study investigates Chinese firms' overseas power projects and how environmental risks likely lead to project suspension. We focus on coal and hydro projects, which are the two types of power generation technologies that have the highest cancellation and postponement risks. Our empirical evidence suggests that environmental risks are associated with suspensions of coal and hydropower plants, and the risks are technology-specific. While coal power suspensions are associated with pollution and climate change risks, hydropower suspensions are related to biodiversity risks.

Our results suggest that investing in environmentally risky projects is not only potentially detrimental on environmental grounds, but also on financial grounds. There is a long history of public scrutiny over the financial support for coal or hydro power plants because of the significant impacts their investments might

Table 3. The effect of environmental risks on coal and hydro power project suspensions

	Hazard ratios						
	Coal power project				Hydro power project		
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Population density	1.426**			1.291*			
	(0.205)			(0.195)			
Climate-related fatalities		10.968**		9.503**			
		(10.699)		(9.194)			
Environmental protest			7.852***	4.355**	0.00001		0.00001
			(4.571)	(2.881)	(0.001)		(0.002)
Distance to protected area						0.967***	0.968***
						(0.006)	(0.006)
Capacity (log)	1.345	1.380	1.492*	1.469	2.623***	3.420***	3.385***
	(0.323)	(0.337)	(0.358)	(0.356)	(0.415)	(0.603)	(0.596)
Firm FDI experiences	1.001	1.002	1.002	1.002	0.994***	0.997	0.997
	(0.005)	(0.005)	(0.005)	(0.006)	(0.002)	(0.003)	(0.003)
GDP per capita (log)	0.778	0.494*	0.671	0.792	2.390*	3.359**	3.067**
	(0.256)	(0.208)	(0.228)	(0.293)	(1.156)	(1.702)	(1.611)
Access to electricity	1.010	1.024	1.016	1.011	0.960**	0.947***	0.949***
	(0.017)	(0.018)	(0.017)	(0.020)	(0.015)	(0.015)	(0.015)
Voice and accountability	2.439**	3.908**	2.019	2.865**	1.092	0.815	0.873
	(1.086)	(2.425)	(0.888)	(1.455)	(0.515)	(0.460)	(0.503)
Observations	1044	1044	1044	1044	3278	3278	3278

We run a parametric Weibull model on two sets of environmental risks associated with coal and hydro power plants, namely (1) population density to a coal power plant, (2) climate-related fatalities around a coal power project, (3) environmental protests that occurred near the coal and hydro power plants, and (4) distance to the protected area. The control variables include project-specific (power plant capacity), firm-specific (firm foreign direct investment experiences) and country-specific (the host countries' GDP per capita, access to electricity, and voice and accountability) characteristics. All variables are defined in Table S1. Results of the Weibull parametric proportional hazards model are reported as hazard ratios. A hazard ratio greater than one suggests an increased risk of failure, while lower than one implies a decreased risk. Columns (1) to (4) report the estimated hazard ratios and (standard errors) for coal power projects. Columns (5) to (7) report the estimated hazard ratios and (standard errors) for hydro power projects. The parametric Weibull model description is described in Method details section. *,**,*** Denote statistical significance at the 10, 5, and 1% confidence levels, respectively.

have on the environment.[12,63] Previous studies have highlighted the stranding risk of fossil fuels as they can worsen climate change consequences,[24,64–66] yet the implications may not be salient enough to stop fossil fuel financing for investors who view such risks as long-term risks, where the financial impacts will not be felt for decades to come. As our study suggests, environmental risks embedded in coal and hydro projects are likely to translate into cancellation or postponement, resulting in financial losses in a much shorter timescale.

Lessons learnt from Chinese overseas investments can provide insights to all energy investors. Most public development finance institutions have committed to reducing or ending coal financing.[67] The private sector, such as commercial banks,[68] should also join public financiers to phase out financing coal and consider directing more capital toward less risky power generation technologies, such as solar and wind. Of equal importance, hydro power projects face a similar level of suspension risk as coal power projects due to their potential damage to the ecological systems nearby. This result sends a wake-up call for investors to proactively review plans for future hydroelectric projects and take further action to end the financing when the environmental costs outweigh the economic benefits. Another implication for investors is to avoid investing in coal and hydro power plants that are prone to environmental risks when applying a diversification strategy in order to minimize the risk of loss.

The surge in the number of canceled coal and hydro projects and the associated environmental risks should also signal an alarm to host countries. Chinese overseas investments tend to follow the demand of host countries[69,70] and these countries are often less developed and lack sufficient environmental policies and incentives to steer investment toward clean energy.[71] Many environmentally risky projects were proposed by host countries, who then approached the Chinese side for funding.[72] With China committing to stop building new overseas coal projects, the scarce opportunities to get public coal finance may push host countries to appeal for hydro finance, which is, nonetheless, also highly risky as shown in our analysis and others.[10] Seeking foreign investments in developing green energy, such as solar and wind power, and auxiliary grid connections to integrate the renewables is promising for host countries.[73] For example, the Bangladesh government canceled the China-funded Gazaria 350 MW coal-fired plant in 2020 and replaced it with electricity grid updates to reduce system losses in the rural electricity system.[74]

Limitations of the study

Recognizably, our results come with limitations. This study only focuses on technology-specific environmental risks based on the power projects' locations. Other risks, such as operational, political, and financial risks may also affect the implementation of power projects.[18] We control for project-, firm-, and country-level characteristics to minimize confounding factors, though there could still be omitted variables as each project will be situated in its own unique context. In addition, there may be other environmental risks associated with coal and hydro technologies. We are not able to investigate the exhaustive list of environmental risks and therefore we focus on the most salient risks from documented case studies. While our results suggest electric power projects with higher environmental risks are more likely to be canceled or delayed, more detailed case-by-case analyses are required to unpack the reasons that have directly led to a specific project's suspension.

STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

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SUPPLEMENTAL INFORMATION

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AUTHOR CONTRIBUTIONS

Y.L.: Project conception and development, data collection, data archiving, data analysis, manuscript writing. X.Y.Z.: Project conception and development, data analysis, research design, manuscript writing. B.A.S.: Data collection, data analysis, graph presentation, manuscript editing.

DECLARATION OF INTERESTS

The authors declare no competing interests.

INCLUSION AND DIVERSITY

We support inclusive, diverse, and equitable conduct of research.

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STAR★METHODS

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Deposited data		
Chinese firms' investments	China's Global Power Database (Gallagher et al., 2019)[30]	https://www.bu.edu/gdp/files/2021/02/GCI_CGEF_PB_FIN.pdf
Firm ownership	Qichacha	https://www.qcc.com/
GDP per capita	World Bank Development Indicators	https://databank.worldbank.org/source/world-development-indicators
Access to electricity	World Bank Development Indicators	https://databank.worldbank.org/source/world-development-indicators
Annual voice and accountability	World Bank's Worldwide Governance Indicators	https://info.worldbank.org/governance/wgi/
Power unit's geolocation	WEPP data with Global Energy Monitors (GEM) Coal Plant Tracker; World Resource Institute (WRI) Global Power Plant Database	https://globalenergymonitor.org/projects/global-coal-plant-tracker/ https://datasets.wri.org/dataset/globalpowerplantdatabase
High resolution population density	NASA's Socioeconomic Data and Applications Center	https://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-density-rev11
Climate-related fatalities	Climate Risk Index reports published by Germanwatch (Eckstein et al., 2021)[52]	https://www.munichre.com/en/solutions/for-industry-clients/natcatservice.html
Distance to protected areas	UNEP-WCMC and IUCN, 2021	https://www.unep-wcmc.org/en
Environmental protest	Google's Global Database for Events, Language and Tone	https://www.gdeltproject.org/
Software and algorithms		
Stata software	Stata	https://www.stata.com/

RESOURCE AVAILABILITY

Lead contact

Further information and requests for resources and materials should be directed to and will be fulfilled by the lead contact, Dr. Xiaoyan Zhou (xiao.zhou@smithschool.ox.ac.uk).

Materials availability

Not applicable.

Data and code availability

- This paper analyses existing, publicly available data, which are listed in the key resources table. ALL data reported in this paper will be shared by the lead contact upon request.
- This paper does not report original code. The code for the analysis was written in Stata and is available from the lead contact upon request.
- Any additional information required to reanalyse the data reported in this paper is available from the lead contact upon request.

METHOD DETAILS

Data sources and key variables

Power unit data and suspension status: We obtain unit-level power plant data from the World Electric Power Plants (WEPP) database.[29] The WEPP database provides information such as power unit name, technology, capacity, status, commission year, location, investing company, etc. The power unit status is recorded in ten categories: canceled, under construction, planned, deferred (halted before construction started), delayed (halted after construction started), in operation, deactivated, retired, shutdown, and unknown. We treat the status recorded as ''canceled'', ''delayed'', and ''deferred'' to be suspension statuses. By tracing the historical release of the WEPP database from 2000 to 2020, we construct a panel dataset that records the evolution of power unit's status from the first year it appeared in the database to the most recent year.

Chinese firms' investments: To identify Chinese firms' overseas power investments, we compile investment data from the following sources: 1) Foreign direct investments from China's Global Power Database,[30] maintained by Global Development Policy Center at Boston University (https://www.bu.edu/cgp/); 2) Bloomberg's Merger & Acquisition deal database[31]; and 3) China Global Investment Tracker,[32] compiled by the American Enterprise Institute and the Heritage Foundation (https://www.aei.org/china-global-investment-tracker/). We matched these investment data with the WEPP power unit and identify 1393 overseas power units that have investments by Chinese firms, among which 75 units have suspension statuses recorded.

Investment year: The investment year of each power unit with investments from Chinese firms is defined in the following way: 1) For investments that we are able to identify the exact year when the investment was made (e.g. from news reports, archives, or investing company's website), we use it as the investment year; 2) For M&A deals, we use the year when the M&A deals were signed as the investment year; 3) For the rest of power units where accurate investment year information is not available, we use the first year when a power unit appeared in the WEPP database as the investment year. For the non-Chinese overseas investments and Chinese domestic investments (Figure 4), we use the first year when a power unit appeared in the WEPP database as the investment year. WEPP database started to have a wide coverage of global power plants from 2004. Therefore, we produce Figure 4 from 2005 onwards.

For the purpose of survival analysis, we convert the data into a panel format. The observations started from the investment year and ended either the first year when a power unit has a suspension status recorded (for power units that have been suspended) or in 2020 (for power units that do not have suspension statuses recorded). Each observation is recorded as a sample year *t* for project *i*. This allows us to construct a panel of 10,195 observations. Eight power units were invested by Chinese firms before 2000 (the earliest is in 1997), but these units were not suspended during 2000 to 2020. For years before 2000 that we are not able to trace power plants' status, we assume they were not suspended from their investment year to 2000.

Firm ownership: To define the ownership of Chinese firms, we collect firms' registered capital and shareholder information from Qichacha (https://www.qcc.com/). Qichacha is a corporate information query tool that provides information on firms recorded in the National Enterprise Credit Inquiry System. If the main shareholder of a Chinese firm is the State Council's State-owned Assets Supervision and Administration Commission or provincial governments, we classify the firm as a central state-owned enterprise (SOE) or provincial SOE. Other types of firms are all treated as private firms.

Country-level controls: We obtain annual GDP per capita (2010 constant USD) and access to electricity (percent of population) data from World Bank Development Indicators (https://databank.worldbank.org/source/world-development-indicators). The annual voice and accountability data are gained from World Bank's Worldwide Governance Indicators (https://info.worldbank.org/governance/wgi/).

Power unit's geolocation: We collect power unit's longitude and latitude by matching WEPP data with Global Energy Monitors (GEM) Coal Plant Tracker (https://globalenergymonitor.org/projects/global-coal-plant-tracker/) and World Resource Institute (WRI) Global Power Plant Database (https://datasets.wri.org/dataset/globalpowerplantdatabase). 80% of the coal power units covered in our dataset are included in the GEM database, therefore we use the geographical coordinates GEM provides for these units. For the rest of coal power units and other types of power units, we match them to the WRI database, which provides latitude and longitude information for a range of publicly available power plants. If the power unit is not included in the GEM or WRI databases, we geolocate the asset based on the best available location information, such as the city, state, and country information provided in the WEPP and available information from archives, news reports, and other sources.

High resolution population density: The high resolution population density data based on power units' geolocation are extracted from NASA's Socioeconomic Data and Applications Center's gridded population of the world (https://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-density-rev11). The data consist of estimates of population density at 30 arc-second grid cells based on counts consistent with national census and population register data, and are available for every 5 years from 2000 to 2020. Following Barrows, Garg and Jha[45], We use the average population density in buffer zones with a radius of 25 km around each point as the proxy of population exposure to pollution from coal-fired projects. The variable is measured in average number of persons per square kilometre. We use population density data in the year 2000 for observations before 2000, data in the year 2005 for observations between 2001 and 2005, and so forth.

Climate-related fatalities: We extract the number of deaths of climate-related events at the country level from Climate Risk Index reports published by Germanwatch.[52] The raw data are retrieved from Munich Re's NatCatSERVICE, one of the world's most comprehensive databases for analysing natural catastrophe losses. The number of deaths incorporate fatalities in weather-related events, i.e., storms, floods, extreme heat and cold waves, etc. Fatalities is a common indicator used in climate risk analysis to measure the loss from climate-related events.[48,51,52] The relative form of fatalities (number of deaths per 100,000 inhabitants) is used.

Following Germanwatch's Climate Risk Index methodological framework,[52] we use the country's annual average number of weather-related deaths over the past 20 years to capture the degree to which countries have been affected by extreme weather events. For example, the 2017 value represents the annual average of fatalities over the years 1998 and 2017. This could minimise the measurement error associated with the likelihood that a single extreme weather event is recorded. Most years take the average value over the past 20-year period, except for years before 2009, which take the average value dating back to 1990 due to data availability constraints.

Distance to protected areas: We estimate the shortest Euclidean distance in kilometres from each power unit to the nearest protected area. To reduce the large skew in distribution, distances greater than 100 km are assigned a value of 100. We include all international, national, and regional protected areas officially designated or inscribed as of April 2021.[54] Protected areas without mapped boundaries (i.e., point centroids) are excluded.

Environmental protest: We obtain environmental protest data from Google's Global Database for Events, Language and Tone (https://www.gdeltproject.org/). The protest data is gathered by Google Jigsaw from the world's print, broadcast and web news media in over 100 languages from 1979 till present. The big data project identifies action types, location, year and actors involved in protest events by encoding key terms in the news pieces and through lexical analysis. Environmental protest data are downloaded by selecting protestors' type being ''environment'', i.e. entities for whom environmental and ecological issues are their primary focus, such as wildlife preservation and climate change. We follow Iacoella et al.[61] to match the geocoded information of protest events with power projects' 50 km buffer zones and construct a dummy variable to indicate whether environmental protests were recorded over the past two years within the defined buffer zones. For example, the variable equals one in sample year *t* if there was at least one environmental protest recorded in 50km buffer zones surrounding the power project in either year *t* or year *t-1*.

Methods

The purpose of the study is to investigate factors associated with power plant suspension. Because the power plant project data involve right-censoring, which occurs when they have not yet been suspended and remain operation until the end of the study (December 2020), we use survival analysis for censored data as our research method.[75,76] Compared to (e.g.) logit regression, survival analysis does not only consider information on whether an event occurred, but also the length of time it took for the event to occur. Survival analysis originates from medical research to study the impact of certain treatments on the survival of patients and the model has been widely used in business and management literature, such as Initial Public Offerings (IPO) survival, research project termination, and the survival of religiously motivated financial institutions.[77–82] Survival analysis has also been used in energy literature. For example, Wang, Akimoto and Nemet[83] apply a survival analysis to examine factors that contribute to the failure of carbon capture and sequestration projects worldwide.

In our study, the event of interest occurs when a power generation unit is suspended. In survival analysis, the dependent variable is the hazard rate, which is the conditional probability that an event occurs at a particular time interval.[84] It is an unobservable variable and controls both the event occurrence and the timing of the event. We first use a parametric Weibull model to address our research question. In general, we specify the parametric hazard rate as a function of time and covariates, as follows:

$$h(t|x) = h_0(t)r(x,\beta) \quad \text{(Equation 1)}$$

The hazard rate, $h(t|x)$ is a product of two functions. The function, $h_0(t)$, is often referred as the baseline hazard function, which characterises how the hazard rate changes as a function of survival time. It can be casually described as the 'time function'. The other function, $r(x,\beta)$, describes how the hazard rate changes as a function of our subject covariates. It can be casually described as the 'characteristics function'. The Weibull parametric model assumes the baseline time function follows Weibull distribution, which is specified as:

$$h_0(t) = p\lambda t^{p-1} \quad \text{(Equation 2)}$$

where the value of p determines the shape of the distribution and the value of λ determines its scale. When $p = 1$, the entire time function collapses to 1, and the overall hazard function turns into an exponential regression that is suitable for modelling data where the hazard (i.e. risk) is constant over time. The hazard rate increases when $p>1$ and decreases when $p<1$.

Following Cox (1972), we define the characteristics function as:

$$r(x,\beta) = \exp\left(\beta_1 x_1 + \ldots + \beta_p x_p\right) = \exp(\beta_1 Risk + \beta_2 Controls_i) \quad \text{(Equation 3)}$$

where, the covariates, $x_1 + \ldots + x_p$, include variables of interest (i.e. power generation technology types or environmental risks) and control variables, and $\beta_1 + \ldots + \beta_p$ are the model parameters describing the effect of the covariates.

Integrating Equations 2 and 3 into Equation 1, the Weibull parametric regression model is specified as:

$$h(t|x) = p\lambda t^{p-1}\exp(\beta_1 Risk + \beta_2 Controls_i) \quad \text{(Equation 4)}$$

where $h(t|x)$ is the hazard at time t for a given set of covariates $x_1 + \ldots + x_p$. The quantities $\exp(\beta_i)$ are called hazard ratios. In our analysis, a hazard ratio greater than one would indicate that the power project is more likely to be suspended, and a hazard ratio less than one means it is less likely to be suspended.

The semi-parametric Cox hazard model takes the same form as the Weibull parametric model, but it does not specify the baseline hazard function.[84] Unlike Weibull model that assumes a parametric form on the baseline hazard $h_0(t)$[75], Cox model uses a non-parametric Aalen-Breslow estimator to estimate the hazard function. As a robustness test, we use the semi-parametric Cox hazards model to compare with the results of the Weibull parametric model.