Environmental risks and power plant suspensions

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Abstract

Power sector investment is crucial to accelerate a sustainable energy transition, but not all investments are successful. To shed light on investment trends, we examine 1393 Chinese overseas electric power projects spanned around 78 countries over the past two decades. We identify 5% have been cancelled or delayed, with coal and hydro projects having much higher failure rates than solar and wind projects. We find the suspension is associated with technology-specific, georeferenced environmental risks. 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 environmental protests, are more likely to be suspended. Additionally, hydro projects closer to protected areas have a higher suspension rate. Our results suggest that restraining from investing in environmentally risky projects helps mitigate environmental damages and prevent financial losses due to cancellation and postponement.

Keywords:
Project cancellation and postponement; Environmental risk; Chinese overseas investment; Environmental protest; Investment failure.
Introduction

Greater investment in the energy sector is crucial for building a global energy system capable of delivering several UN Sustainable Development Goals (McCollum et al., 2018). As of 2019, 770 million people (10% of the global population) still do not have access to electricity, and the COVID-19 pandemic may significantly slow progress to achieving global electricity access (IEA, 2020). Meanwhile, decarbonising the global energy sector is crucial to achieve net zero by 2050 (IEA, 2021). In recent years, China-funded power projects have received considerable attention both for their contribution to energy accessibility in less developed countries (Falchetta et al., 2021) and their impacts on climate change (Shearer and Buckley, 2019; Springer et al., 2021). China has emerged as one of the world’s largest financiers in the global electric power sector, with two Chinese policy banks—the China Development Bank and Export-Import Bank of China—providing a total of 245.8 billion USD in energy finance to more than 80 countries since 2000 (Gallagher, 2021). In September 2021, China pledged to stop building new coal-fired power plants abroad (Sullivan, 2021), a major step forward in aligning finance with the Paris Agreement.

The fate of China’s overseas energy investments, however, is not always assured (Malik et al., 2021). In total, about 65 billion USD of Chinese-backed coal-fired power plants have been shelved or cancelled, and many more projects have been significantly delayed (Center for Research on Energy and Clean Air, 2020; Nedopil Wang, 2021). For example, in February 2020, the China-funded 6.6 gigawatt Hamrawein coal power proposal in Egypt was postponed indefinitely, which would have been the world’s second-largest coal-fired plant (Nicholas, 2020). Despite a large number of studies applying ex-ante evaluation methods such as interviews (Egli, 2020; Gorbacheva and Sovacool, 2015), scenario analysis (Iyer et al., 2015; Khan et al., 2021; McCollum et al., 2018), and assumption-based modelling (Duan et al., 2018; Islam et al., 2019; Tietjen et al., 2016; Yuan et al., 2019) to explore potential risks that energy investments could face, there is a lack of evidence-based ex-post research quantifying the impact of risk factors on investment failures.

Environmental issues have been at the heart of the discussion on energy investments, driven by concerns about increased carbon emissions, environmental quality degradation, and biodiversity loss (Ascensão et al., 2018; Narain et al., 2020; Yang et al., 2021). The overseas coal power plants with partial or full financing from Chinese development finance institutions, if successfully in operation, will emit 11.8 Gt CO₂ over their lifetime, as much as the annual emissions from global operational coal-fired power plants in 2018 (Chen et al., 2020). Furthermore, Chinese companies have become the largest dam builders in the world, and some of their projects have been located in remote areas that have important ecological values (International Rivers, 2012). Although there has been a significant amount of attention on planned projects’ potential impacts on the natural environment, there is limited knowledge on whether these projects could be successfully commissioned.

Recent studies have revealed that environmental issues could trigger public resistance against energy projects (Coppens et al., 2018; Inter-American Development Bank, 2017; Temper et al., 2020). There have been cases of electric power projects facing opposition from local communities and environmental groups, and some campaigns have gained success (Renaldi, 2021; Yi, 2021). For example, after a long-lasting demonstration from local groups and non-government organisations (NGO) against Lamu coal power project in Kenya over its environmental impacts, a court ruling suspended the project’s permit in 2019, and the project was officially cancelled by the government in 2020 (Yi, 2021). While scholars continue to
enrich our understanding of the characteristics of environmental social movements related to energy projects (Fuller and McCauley, 2016; McAdam and Boudet, 2012; Temper et al., 2020; Upreti and van der Horst, 2004), the potential role of these public concerns in altering the trajectory of power projects remains unclear.

In this study, we examine overseas power plant investments by Chinese firms that have been cancelled or delayed over the last two decades. We trace the status of Chinese firms’ overseas investments in power plants across power generation technologies, ranging from coal, hydro, wind, and solar, compare the differences between the suspended and progressed projects, and examine the association between suspension and factors of environmental risk. Of the 1393 overseas power investments by Chinese firms from 1997 to 2020, we identify 75 (5%) that have been cancelled or postponed. Using survival analysis, we find that coal and hydro power plants are more likely to be deferred or shelved than other types of plants. 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. Additionally, the presence of environmental protests near the power project increases the likelihood of suspension for coal projects, but not for hydro projects.

**Mapping suspended Chinese overseas power projects**

By combining several data sources, we construct 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 failures in high-income countries like Australia and Norway (Figure 1b).

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 cancelled at the time of suspension and a quarter of the 53 projects initially classified as ‘delayed’ were eventually cancelled 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.
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.

Figure 2 Status of suspended power units. Evolution in the status of the 75 power units that have been suspended at some point. Suspension includes project cancellation and delay (in red).
Central state-owned enterprises (SOEs) are the main investors in these energy projects, with 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 failure 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 Road and Initiative (BRI) in 2013 (Figure 3b). While some early project suspensions occurred in 2009, most suspensions occurred after 2015. Coal projects, in particular, encountered a significant number of suspensions for five continuous years up to 2020. Similarly, there has been a steep decline in the number of new hydro power projects since 2017, and the number of suspensions surpassed investments in 2020.

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. Grey bars in (b) represent the number of power units invested in a particular year and red bars refer to the number of power units suspended in a particular year.

If we compare 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, and peaked 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 (Global Energy Monitor, 2021; Shi et al., 2018), the number of suspended Chinese overseas investments also reached a peak.

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 have been increasing since 2010, peaking in 2020 with 432 suspensions. A similar trend is reflected in non-Chinese entities’ investments host countries, with a peak of 372 suspensions in 2020.

Figure 4 The changes in the number of newly invested and suspended coal (a) and hydro (b) projects by investment entity and region. Grey bars represent the number of power units invested 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.
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 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 cancelled or delayed) occurs at a particular time interval. We report hazard ratios of independent variables in the results tables. A hazard ratio greater than one suggests an increased risk of failure, while lower than one implies a decreased risk. We use a Weibull parametric proportional hazards model to compare the influence of power technology choice on the hazard rate, and for robustness purposes, we also estimate the semi parametric Cox hazards model (see Methods).

We include several controls for project-, firm- and country-level variables that have been shown to impact power generation projects from inception to implementation. 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 (Alova et al., 2021; Eybpoosh et al., 2011). We also control for firms’ foreign direct investment (FDI) experience, as firms could learn from their prior international experiences to better manage overseas projects (Collins et al., 2009; Halebian et al., 2006; Shaver et al., 1997). At the country level, we take into consideration the gross domestic product (GDP) per capita and the population’s electricity access rate. We also control for countries’ score on the voice and accountability index, as public opinion could impact the implementation of energy projects (Temper et al., 2020; Upreti and van der Horst, 2004). Definitions and sources of all variables are listed in Supplementary Table 1.

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. We obtain nearly identical, statistically significant estimates using the semi-parametric Cox proportional hazards model (Supplementary Table 4).
Table 1 The effect of technology choice on power project failures

| 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

Notes: 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. 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. *P < 0.10, **P<0.05, ***P<0.01.

Environmental issues associated with coal and hydro power projects

Coal and hydro power projects have the greatest risk of suspension, particularly when they are located in countries where the people have a greater degree of voice and accountability. Given the potential environmental impacts of coal and hydro power projects (Carlson and Adriano, 1993; Rosenberg et al., 1997), it is possible that power plants with higher risk exposures may raise the salience of environmental concerns, ultimately influencing the likelihood of suspension. While the environmental risks posed by different types of coal and hydro power projects are often highly variable based on operational or mechanical characteristics (Cui et al., 2012; Kuriqi et al., 2021), we incorporate three variables to reflect the primary environmental claims expressed by mobilizing communities in global resistance movements to hydro and coal power projects, as systematically mapped in the Global Atlas of Environmental Justice (EJAtlas). The selected risk exposure variables also relate to the environmental issues that have been reported with suspended Chinese firms’ overseas coal and hydro projects (see Table 2 for a selection of exemplar case studies).
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 waterways¹                                                                 | 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 area²                                                                 | Cancelled              |
| Hydro      | Impacts on the ecosystems far larger than expected or stated in official documents | Batang Toru, Indonesia                              | Biodiversity loss                                                                      | International organisations warned the project’s potential threat to critically endangered species, i.e. Tapanuli orangutan³                                                                                                                                 | 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 species⁴                                                                 | Under construction     |

¹ Global Energy Monitor Wiki page, available at https://www.gem.wiki/; Global Atlas of Environmental Justice (EJAltas), available at: https://ejatlas.org/.
² Global Energy Monitor Wiki page.
³ IUCN Section on Great Apes (2020), Batang Toru Hydro power Project Factcheck and References on Key Issues.
⁴ China Dialogue (2021), New Argentina Government Reactivates Controversial Patagonia Dams; Global Atlas of Environmental Justice.
Firstly, we use local population density surrounding coal power projects as a proxy for the number of people exposed to pollution—the most prominent local environmental risk associated with coal-fired projects. Burning coal emits pollutants that are detrimental to the health of nearby populations (Barrows et al., 2019; Radford et al., 2021; Yang and Chou, 2018), 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 (Barrows et al., 2019), we use the mean population density for all areas within a radius of 25 km surrounding each coal power project.

Secondly, 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 awareness and spurring climate actions, particularly in areas that have suffered from the effects of climate change (Boudet et al., 2020; McAdam, 2017; Zanocco et al., 2018) (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 (Bakkensen and Mendelsohn, 2019; Boudet et al., 2020). Following the method of the Climate Risk Index (Eckstein et al., 2021), 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.

Thirdly, 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 (Kuriqi et al., 2021). 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 (UNEP-WCMC and IUCN, 2021) 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 (Ng et al., 2020; Yang et al., 2021), ultimately increasing the likelihood of suspension.

In addition to the above technology-specific risk exposure measures, we include the presence of place-based environmental protests as a proxy of the intensity of environmental movements in the local area. Anecdotal evidence suggests that protest is the main movement form used by affected communities and environmental organisations to express public opposition to power projects (Table 2). Protests could amplify public opinion and raise the salience of environmental issues to regulators and investors (Agnone, 2007; Gadgil and Guha, 1994). We hypothesize that the presence of environmental protests near the power project is positively related to the suspension risk of a project. We use protest data from Google’s Global Database for Events, Language and Tone (GDELT) project—currently the most powerful research tool to analyse 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 (Brancati and Lucardi, 2019; Iacoella et al., 2021; Manacorda and Tessei, 2020). To measure the recent environmental movement intensity around each power project, we follow
Iacoella et al. (2021) 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 zones. See Supplementary Table 1 for a description of all variables included in the analysis.

**Could environmental risks be contributing to the failure 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 (Supplementary Table 3), suspended coal power projects tend to be located in more densely populated communities, and in areas with more climate-related fatalities and higher 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 ten-fold. We also find that the hazard rate of coal projects in areas that have experienced recent environmental protests are 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 areas, 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 (Supplementary Table 3). 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 one-kilometre 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 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 apply an alternative semi-parametric Cox hazards model (Supplementary Table 5).
Table 3 The effect of environmental risks on coal and hydro power project failures

| Variables                      | Coal power project | Hydro power project |
|-------------------------------|--------------------|---------------------|
|                               | (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**            | (4.571)           | (2.881)           |
| Distance to protected area    | 0.967***           | 0.968***           | (0.006)           | (0.006)           |
| Capacity (log)                | 1.345              | 1.380              | 1.492*            | 1.469             |
| FIRM FDI experiences          | 1.001              | 1.002              | 1.002             | 1.002             |
| GDP per capita (log)          | 0.778              | 0.494*             | 0.671             | 0.792             |
| Access to electricity         | 1.010              | 1.024              | 1.016             | 1.011             |
| Voice and accountability      | 2.439**            | 3.908**            | 2.019             | 2.865**           |
| Observations                  | 1044               | 1044               | 1044              | 1044              | 3278              | 3278              | 3278              |

Notes: 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. *P < 0.10, **P<0.05, ***P<0.01.

Discussions and Policy Implications

This study explores Chinese firms’ overseas power projects that have been suspended and whether environmental issues may be contributing to investment failures. Among all technologies of power plants, we find coal and hydro power projects have a higher chance of being suspended at some point in their development. We also identify technology-specific, georeferenced environmental risks associated with hydro and coal project suspensions. Coal projects located in more densely populated areas and in countries with more fatalities from extreme weather events are more likely to be suspended, and hydro power projects located closer to protected areas tend to have a higher probability of being halted. Additionally, coal projects located in areas with the presence of environmental protests have a higher chance of being abandoned, but we do not find such an effect on hydro projects.

Our results suggest that investing in environmentally risky projects is not only potentially detrimental on environmental grounds, but also 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 have on the environment (Chen et al., 2020; International Rivers, 2012). Previous studies have highlighted the stranding risk of investing in fossil fuels (McGlade and Ekins, 2015; Mercure et al., 2018; Tong et al., 2019), 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 time scale.

China’s pledge to stop building coal plants overseas in September 2021 is a significant step for the global effort against climate change. Meanwhile, there are still a significant number of China-funded overseas coal projects under construction and in the planning stage (Gallagher et al., 2019). These on-going projects are under high suspension risk, and how stakeholders deal with these projects is crucial for minimizing financial losses. Besides, Chinese financing is involved in only 13% of the global coal power capacity outside of China that is operational or being developed between 2013 and mid-2019 (Ma and Gallagher, 2021). Lessons learnt from Chinese overseas investments and the global trend of increasing coal project suspensions in the last five years should send a key message to the remaining international coal financiers that investing in coal is risky. As of November 2021, most international development finance institutions have committed to reducing or ending coal investment (Ray et al., 2021). The private sector, such as institutional investors and commercial banks (Urgewald, 2021), should 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 failure 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.

The surge in the number of cancelled 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 (Tritto, 2021; Voituriez et al., 2019) and these countries are often less developed and lack sufficient environmental policies and incentives to steer investment towards clean energy (Gallagher et al., 2021). Many environmentally risky projects were proposed by host countries, who then approached the Chinese side for funding (Kong and Gallagher, 2021). 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 (Yang et al., 2021). Seeking foreign investments in developing green energy, such as solar and wind power, as well as auxiliary grid connection to integrate the renewables is promising for host countries (Huang et al., 2019). For example, the Bangladesh government cancelled 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 (Nicholas, 2020).

Recognizably, our results come with several limitations. This study only focuses on technology-specific environmental risks based on where the power projects are located. Other risks, such as operational, political and financial risks may also affect the implementation of power projects (Yuan et al., 2019). 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 technical, economic, social, and political context that ultimately influences the fate of the investment. One needs to be cautious to interpret our findings, as strict causality may not be established from our analysis. While our results suggest a link between coal projects’ suspension and the presence of environmental protests in the area, more detailed analyses are necessary to determine whether public resistance to a power project has directly contributed to the failure of that specific project.
Data and Method

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 (S&P Global Market Intelligence, 2020). 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: cancelled, 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 “cancelled”, “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, maintained by Global Development Policy Center at Boston University (https://www.bu.edu/cgp/); 2) Bloomberg’s Merger & Acquisition (M&A) deal database; and 3) China Global Investment Tracker, 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 (2019), 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 (Eckstein et al., 2021). 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 (Bakkensen and Mendelsohn, 2019; Boudet et al., 2020; Eckstein et al., 2021). The relative form of fatalities (number of deaths per 100,000 inhabitants) is used.

Following Germanwatch’s Climate Risk Index methodological framework (Eckstein et al., 2021), 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 minimize 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 (UNEP-WCMC and IUCN, 2021). Protected areas without mapped boundaries 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. (2021) 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 $t-1$. 

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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 (Cleves et al., 2008; Melnyk et al., 1995). 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 (Alandejani et al., 2017; Espenlaub et al., 2016a, 2016b, 2012; Hoang and Rothaermel, 2010; Pappas et al., 2017). Survival analysis has also been used in energy literature. For example, Wang, Akimoto and Nemet (2021) 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 (Hosmer and Lemeshow, 2008). 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:

$$h(t|x) = h_0(t)r(x, \beta)$$

(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 characterizes 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:

$$h_0(t) = p\lambda t^{p-1}$$

(2)

where the value of $p$ determines the shape of the distribution and the value of $\lambda$ 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:

$$r(x, \beta) = \exp(\beta_1 x_1 + \cdots + \beta_p x_p)$$

$$= \exp(\beta_1 \text{Risk} + \beta_2 \text{Controls}_i)$$

(3)

where, the covariates, $x_1 + \cdots + x_p$, include variables of interest (i.e. power generation technology types or environmental risks) and control variables, and $\beta_1 + \cdots + \beta_p$ 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:

$$h(t|x) = p\lambda t^{p-1} \exp(\beta_1 \text{Risk} + \beta_2 \text{Controls}_i)$$

(4)

where $h(t|x)$ is the hazard at time $t$ for a given set of covariates $x_1 + \cdots + x_p$. 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 (Hosmer and Lemeshow, 2008). Unlike Weibull model that
assumes a parametric form on the baseline hazard $h_0(t)$ (Cleves et al., 2008), 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.
## Supplementary Table 1 Definition of variables

| Variables              | Definition                                                                 | Sources                                                                 |
|------------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------|
| **Technology types**   |                                                                           |                                                                        |
| Coal                   | An indicator that equals one if it is a coal power project and zero otherwise | S&P Global Platt’s World Electric Power Plants (WEPP)                   |
| Hydro                  | An indicator that equals one if it is a hydro power project and zero otherwise |                                                                        |
| Solar & Wind           | An indicator that equals one if it is a solar or wind power project and zero otherwise |                                                                        |
| **Coal related**       |                                                                           |                                                                        |
| Population density     | The average number of persons per square kilometre in buffer zones with a radius of 25km around each power unit. Log form is used. | NASA’s Socioeconomic Data and Applications Center’s world gridded population |
| **Environmental risks**|                                                                           |                                                                        |
| Climate-related fatalities | The country’s annual average number of deaths per 100,000 inhabitants in extreme weather events over the years \(t-19\) and \(t\). | Climate RiskIndex reports, published by Germanwatch (Eckstein et al. 2020). |
| **Hydro related**      |                                                                           |                                                                        |
| Distance to protected area | The shortest Euclidean distance in kilometres from each power unit to the nearest protected area. | UNEP-WCMC and IUCN (2021)                                             |
| **Environmental Protest** | An indicator that equals one if there was at least one environmental protest recorded in 50km buffer zones of power projects in either year \(t\) or year \(t-1\) and zero otherwise. | Google’s Global Database for Events, Language and Tone project          |
| **Control variables**  |                                                                           |                                                                        |
| Capacity               | The amount of electricity a power generator can produce when it’s running at full blast. It is measured in megawatts (mw). Log form is used. | WEPP                                                                   |
| Firm FDI experiences   | Firm’s foreign direct investment experience, i.e. the accumulative number of power units invested overseas until year \(t\) by firm \(i\). | WEPP                                                                   |
| GDP per capita         | Gross Domestic Product (GDP) per capita (in constant 2010 USD). Log form is used. | World Bank Development Indicators                                      |
| Access to electricity  | The percentage of the country’s population with access to electricity.     | World Bank Development Indicators                                      |
| Voice and accountability | A country index that captures perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media. | World Bank Worldwide Governance Indicators                             |
## Supplementary Table 2 Matrix of correlations

| Variables                      | VIF  | Coal   | Hydro  | Solar & Wind | Distance to protected area | Population density | Climate-related fatalities | Environmental protest | Capacity (log) | Firm FDI experiences | GDP per capita (log) | Access to electricity | Voice and accountability |
|--------------------------------|------|--------|--------|--------------|----------------------------|--------------------|--------------------------|------------------------|----------------|----------------------|----------------------|------------------------|-------------------------|
| Coal                           | 1.96 |        |        |              |                             |                    |                          |                        |                |                      |                      |                        |                         |
| Hydro                          | 2.64 | -0.4229| 1      |              |                             |                    |                          |                        |                |                      |                      |                        |                         |
| Solar & Wind                   | 1.79 | -0.2319| -0.3432|              |                             |                    |                          |                        |                |                      |                      |                        |                         |
| Distance to protected area     | 1.41 | -0.0544| 0.2685 | -0.0847      |                             |                    |                          |                        |                |                      |                      |                        |                         |
| Population density            | 2.04 | 0.1319 | -0.2292 | -0.2457      | 0.0125                     |                    |                          |                        |                |                      |                      |                        |                         |
| Climate-related fatalities     | 1.34 | 0.0028 | -0.0646 | -0.0807      | -0.0335                    | 0.1023             |                          |                        |                |                      |                      |                        |                         |
| Environmental protest         | 1.18 | -0.0157| -0.1012 | -0.0325      | -0.1174                    | 0.3041             | -0.0208                  |                        |                |                      |                      |                        |                         |
| Capacity (log)                | 1.45 | 0.4649 | -0.2566 | -0.0905      | -0.0169                    | 0.0404             | 0.1244                   | 0.0513                 |                |                      |                      |                        |                         |
| Firm FDI experiences          | 1.90 | -0.4243| 0.4034 | 0.1463       | 0.2769                     | -0.0639            | -0.2955                  | -0.1019                | -0.3659 |                      |                      |                        |                         |
| GDP per capita (log)          | 5.84 | -0.2449| -0.1168 | 0.2818       | -0.2646                    | -0.3647            | -0.3024                  | 0.0361                 | -0.1466 | 0.1995               |                      |                        |                         |
| Access to electricity         | 2.49 | -0.2202| -0.0285 | 0.188        | -0.1208                    | -0.1704            | -0.1989                  | 0.0297                 | -0.0878 | 0.309                | 0.7332               |                        |                         |
| Voice and accountability      | 4.33 | -0.1849| -0.0962 | 0.2964       | -0.0485                    | -0.4757            | -0.4112                  | -0.0321                | -0.2128 | 0.1984               | 0.8051               | 0.5122                 |                         |

Notes: The variance inflation factors (VIF) of all variables were calculated to test the effects of multicollinearity in the regression analysis. The VIF value for the GDP per capita is less than 6, suggesting that there is no multicollinearity among variables.
## Supplementary Table 3 Summary statistics of survival analysis sample

| Variables | Mean (1) | Std (2) | Min (3) | Max (4) | Obs (5) |
|-----------|----------|---------|---------|---------|---------|
| **Overall summary statistics for 1997–2020** | | | | | |
| **Technology types** | | | | | |
| Coal | 0.102 | 0.303 | 0 | 1 | 10195 |
| Hydro | 0.322 | 0.467 | 0 | 1 | 10195 |
| Solar & Wind | 0.235 | 0.424 | 0 | 1 | 10195 |
| **Population density (log)** | | | | | |
| All coal | 5.003 | 1.866 | 0.055 | 9.30 | 1044 |
| Suspended | 5.646 | 1.753 | 3.57 | 7.99 | 121 |
| Non-suspended | 4.894 | 1.864 | 0.05 | 9.30 | 911 |
| **Climate-related fatalities** | | | | | |
| All coal | 0.220 | 0.210 | 0 | 2.04 | 1044 |
| Suspended | 0.300 | 0.460 | 0 | 2.04 | 121 |
| Non-suspended | 0.210 | 0.150 | 0 | 0.64 | 911 |
| **Environmental risks** | | | | | |
| All coal | 0.045 | 0.207 | 0 | 1 | 1044 |
| Suspended | 0.116 | 0.321 | 0 | 1 | 121 |
| Non-suspended | 0.032 | 0.176 | 0 | 1 | 911 |
| **Distance to protected area (km)** | | | | | |
| All hydro | 91.001 | 22.864 | 8.28 | 100 | 3278 |
| Suspended | 77.598 | 28.306 | 32.12 | 100 | 247 |
| Non-suspended | 92.093 | 22.011 | 8.28 | 100 | 3031 |
| **Controls** | | | | | |
| Capacity (mw) | 109.752 | 185.324 | 0.003 | 1770 | 10195 |
| Firm FDI experiences | 77.234 | 65.702 | 1 | 206 | 10195 |
| GDP per capita (log) | 8.830 | 1.405 | 5.42 | 11.44 | 10195 |
| Access to electricity (percent of population) | 88.929 | 20.513 | 6 | 100 | 10195 |
| Voice and accountability | 0.023 | 0.932 | -2.23 | 1.73 | 10195 |
**Supplementary Table 4 The effect of technology choice on power project failures (Semi-parametric Cox model result)**

| Variables             | Hazard ratios   |   |   |   |
|-----------------------|----------------|---|---|---|
|                       | (1)            | (2) | (3) | (4) |
| Coal                  | 9.431***       | 3.572*** | 3.161** | 3.803*** |
|                       | (4.116)        | (1.593) | (1.421) | (1.798) |
| Hydro                 | 4.634***       | 5.347*** | 5.963*** | 7.852*** |
|                       | (1.892)        | (2.200) | (2.459) | (3.514) |
| Solar & Wind          | 0.643          | 1.012  | 1.017  | 0.851  |
|                       | (0.376)        | (0.601) | (0.603) | (0.508) |
| Capacity (log)        | 2.016***       | 1.965*** | 1.961*** |         |
|                       | (0.223)        | (0.220) | (0.216) |         |
| Firm FDI experiences  | 0.996**        | 0.994*** |         |         |
|                       | (0.002)        | (0.002) |         |         |
| GDP per capita (log)  | 0.969          |        |         |         |
|                       |                |        |         | (0.178) |
| Access to electricity | 0.992          |        |         |         |
|                       |                |        |         | (0.009) |
| Voice and accountability | 1.733**      |        |         |         |
|                       |                |        |         | (0.403) |

Observations: 10,195 10,195 10,195 10,195

Notes: Results of the semi-parametric Cox 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. 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. *P < 0.10, **P < 0.05, ***P < 0.01.
### Supplementary Table 5 The effect of environmental risks on coal and hydro power project failures (Semi-parametric Cox model result)

| Variables                    | Coal power project | Hydro power project |
|------------------------------|--------------------|---------------------|
|                              | (1) (2) (3) (4)    | (5) (6) (7)        |
| Population density           | 1.405** (0.200)    | 1.280* (0.192)     |
| Climate-related fatalities   | 7.364** (6.931)    | 7.235** (6.831)    |
| Environmental Protest        | 7.735*** (4.520)   | 4.534** (2.957)    |
| Distance to protected area   |                    |                    |
| Capacity (log)               | 1.331 (0.321)      | 1.383 (0.339)      |
| Firm FDI experiences         | 1.001 (0.005)      | 1.002 (0.005)      |
| GDP per capita (log)         | 0.795 (0.255)      | 0.527 (0.216)      |
| Access to electricity        | 1.011 (0.018)      | 1.023 (0.018)      |
| Voice and accountability     | 2.291* (1.004)     | 3.435** (2.061)    |
| Observations                 | 1044               | 1044               |

Notes: Results of the semi-parametric Cox 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. *P < 0.10, **P<0.05, ***P<0.01.
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