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An empirical analysis of the environmental performance of China's overseas coal plants

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Abstract

China's ongoing commitment to overseas infrastructure investment through the Belt and Road Initiative (BRI) has ignited concern over environmental impacts. The BRI's environmental impacts will be determined by China's decisions not only on what kinds of projects to fund, but also how those projects end up operating relative to projects without Chinese involvement. It is critical to understand current performance and establish a baseline understanding of the environmental impacts of China's overseas projects thus far. We examine the environmental performance of coal-fired power plants in Asia in terms of carbon dioxide emissions intensity. Using generating unit-level data and a regression-based analysis, we estimate the comparative emissions intensity of overseas coal plants owned, designed, or constructed, by Chinese and non-Chinese companies. We find that Chinese coal plants tend to have significantly lower emissions intensity than similar non-Chinese coal plants. Given that total emissions rather than relative emissions intensity primarily drive the global warming impact of a plant, we also estimate total annual emissions and committed lifetime emissions of the plants in our dataset. We find that while Chinese plants may have relatively lower emissions intensity, their total emissions will grow as a proportion of the coal plant emissions in Asia over time.

1. Introduction

China's Belt and Road Initiative (BRI) is often introduced in terms of its scale: trillions of dollars; the largest infrastructure program since the Marshall Plan (Nature Editorial 2019); two-thirds of the global population and one-third of the global economy involved (Ascensão *et al* 2018). The BRI could contribute greatly to economic growth, and in the electricity generation sector, it can improve energy access and reliability in areas with rapidly growing energy demand (Powanga and Giner-Reichl 2019). However, the BRI's economic benefits and expansion of electricity systems may come at the expense of the environment. The sheer scale of the BRI has ignited increasing international concern about environmental damage (Horvat and Gong 2019). These environmental concerns include concern about infrastructure development in ecologically sensitive areas, concern about the large amounts of raw materials needed, and concern about lock-in of environmentally harmful types of infrastructure, such as fossil fuel-related infrastructure (Ascensão *et al* 2018).

However, these concerns are not only about the scale of BRI, but also the nature of Chinese investment, which has been flowing to foreign countries for several decades pre-dating the BRI. China's leaders describe the BRI as a massive effort to guide and expand China's existing overseas investment, facilitate South–South cooperation, and promote the Chinese model of development around the world (Ferdinand 2016, Yeh and Wharton 2016). At the same time, China is criticized for promoting extractive investment projects that have negative social and environmental impacts in host countries (Hofman and Peter 2012). These contrasting viewpoints in fact both reinforce the notion that Chinese overseas projects are qualitatively unique (Lee 2014).

To understand the potential environmental impacts of BRI, we seek to assess the current environmental performance of China's overseas projects in terms of CO_2 emissions intensity. We assemble a dataset of coal-fired power plants in Asia owned, designed, or built by companies of different national origin. The project type to be assessed, coal-fired power plants, was selected due to ongoing policy dialogue about the role of international finance for coal-fired power plants. In addition, as of 2016, almost half of Chinese investment in overseas power generation was for coal plants (Li *et al* 2020). The regional focus for this study is Asia: Asia is the first frontier for Belt and Road projects, and it is a locus of coal plant development. While 41% of operating coal plants (by MW) are located in Asia (excluding China), 64% of planned coal plants and 81% of coal plants under construction are in Asia (Global Energy Monitor 2020a).

This study provides aggregated, comparable quantitative evidence on the claim of the uniqueness of Chinese involvement and environmental performance. Many case studies have documented social and environmental impacts for individual BRI projects, however, they cannot shed light on relative or aggregated impacts. The BRI will play a large role in the future course of the global energy system based on China's decisions on what kinds of energy projects to fund and how those projects end up operating. Therefore, it is critical to understand how these coal-fired power plants perform and to establish a baseline understanding of the environmental impacts of China's overseas projects thus far.

1.1. Literature review

Prior studies have focused on the calculation of CO_2 emissions from coal-fired power plants. Oberschelp *et al* (2019) constructed a comprehensive inventory of coal-fired power plants around the world and calculated CO_2 emissions as well as emissions of several air pollutants associated with coal mining, transport, and coal-fired power generation (Oberschelp *et al* 2019). For airborne CO_2 emissions from coal-fired power generation, the authors calculate CO_2 emissions based on modeled generating unit-level fuel demand and the carbon content of the coal fuel. Tong *et al* (2018) similarly construct a global database of emissions associated with fuel combustion from biomass and fossil-fuel plants, including coal plants. Unit-based CO_2 and air pollutant emissions were estimated using unit-level fuel consumption as well as emissions factors based on country-level fuel heating values (Tong *et al* 2018). Another approach to constructing a global dataset of CO_2 emissions from coal power plants is to use a regression-based framework to estimate emissions from existing but incomplete data and a set of predictor variables, as in Steinmann *et al* (2014). As the focus of our research is not constructing a comprehensive emissions dataset, we draw from existing datasets that catalogue unit-level technology characteristics, fuel types, and heat rates to calculate emissions intensity for coal-fired power generating units in Asia.

Several prior studies have compared the technological characteristics of overseas Chinese and non-Chinese coal plants, focusing on the proportion of subcritical vs. supercritical coal plants as an indicator of potential environmental performance. Results vary depending on the year of the study, indicating the shifting composition of China's overseas coal plants. Using the Platts World Electric Power Plants (WEPP) database, Ueno *et al* (2014) found that between 2007 and 2012, subcritical coal plants represented 65% of overseas generating capacity using boilers from Chinese manufacturers, compared to 38% of Japan's overseas portfolio over that time period. Gallagher (2016) asserted that the majority (58%) of coal plants constructed between 2001 and 2016 with support from Chinese financial institutions were subcritical. Li *et al* (2020) compiled a list of Chinese companies that were potential investors in the global power industry and matched them to the companies named in the Platts WEPP database in order to identify which currently operating coal plants globally had Chinese involvement, and then compiled plant-level investment data. The authors found that among the total generating capacity with Chinese greenfield investment, subcritical plants represented 42% of the total capacity while supercritical plants represented the remaining 58%. In comparison, among the total generating capacity of non-Chinese greenfield investment, subcritical plants represented 66% of total capacity and supercritical plants represented the remaining 34%, indicating that Chinese coal plants might have relatively lower CO_2 emissions per unit of energy produced (Li *et al* 2020). These studies indicated that China's overseas coal plants have an increasing share of supercritical coal plants over time.

Our research extends this prior analysis by estimating emissions intensity, which incorporates more plant characteristics than just the subcritical vs supercritical distinction, and controlling for key factors such as the size of the generating unit with a regression approach. We identified one previous approach that used a difference-in-differences analysis to estimate the comparative sulfur dioxide emissions of Chinese and non-Chinese coal plants in Southeast Asia (Li and Gallagher 2019). The study used satellite data to track plant-level sulfur dioxide emissions, and defined Chinese plants as those that received finance from Chinese policy banks and government. The study found that overall, there was no statistically significant difference between sulfur dioxide emissions of Chinese and non-Chinese coal plants in Southeast Asia, however, that there were indications that larger subcritical Chinese plants might have relatively higher sulfur dioxide emissions, while larger supercritical Chinese plants might have relatively

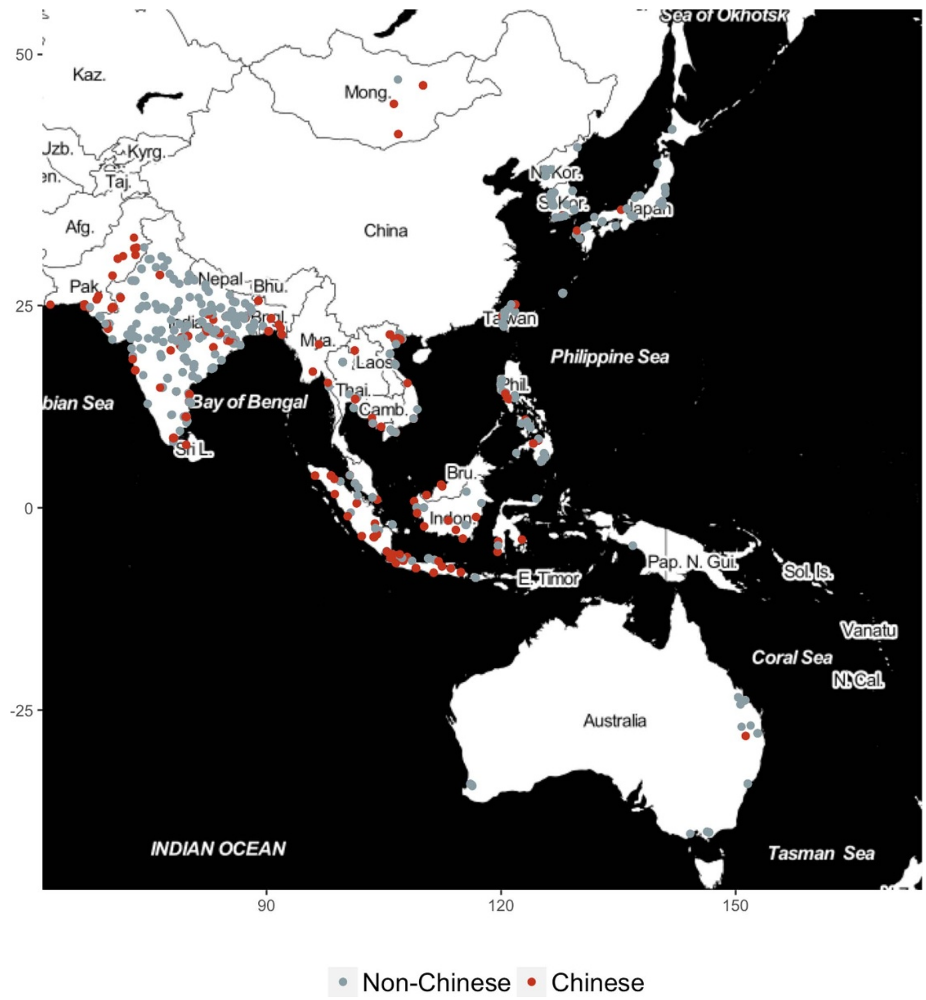

Figure 1. Map of Coal Plants in Asia (excluding China).

lower sulfur dioxide emissions compared to their non-Chinese counterparts.

2. Methods

2.1. Data

We collected generating unit-level data from the March 2018 version of the Platts WEPP database. The WEPP is a regularly published global inventory of units generating electric power. While the database maintains a high percentage of coverage for power generating facilities, there are some gaps in the types of data observed for each unit, which may systematically vary (i.e. better coverage of newer and larger plants). In our results section, we note the sample size for which there was complete data on the variables in our model. For this analysis, we used a subset of the WEPP data for units with coal as their primary fuel. Because a single coal plant may consist of several generating units of different age, size, fuel, and technology characteristics, we perform our analysis at the generating unit level, although our discussion of the results and possible mechanisms focuses on the plant level.

We selected data on generating units that were located in Asia. According to the WEPP classifications, Asia includes the countries of Afghanistan, Australia, Bangladesh, Cambodia, India, Indonesia, Japan, Laos, Malaysia, Mongolia, Myanmar, New Caledonia, New Zealand, North Korea, Pakistan, the Philippines, Singapore, South Korea, Sri Lanka, Taiwan, Thailand, and Vietnam. Because this analysis concerns the performance of China's overseas projects, we also excluded coal generating units within China. The final sample includes 4260 generating units. Figure 1 shows a map of the coal plants in this dataset that have latitude and longitude information.

Our dataset enables us to investigate Chinese involvement in overseas projects through engineering, procurement, and construction (EPC) arrangements with Chinese engineering and construction companies, the most common vehicle for Chinese investment prior to 2018 (Wang and Danqing 2019), as well as direct investments carried out by Chinese parent companies. We used the WEPP data on parent

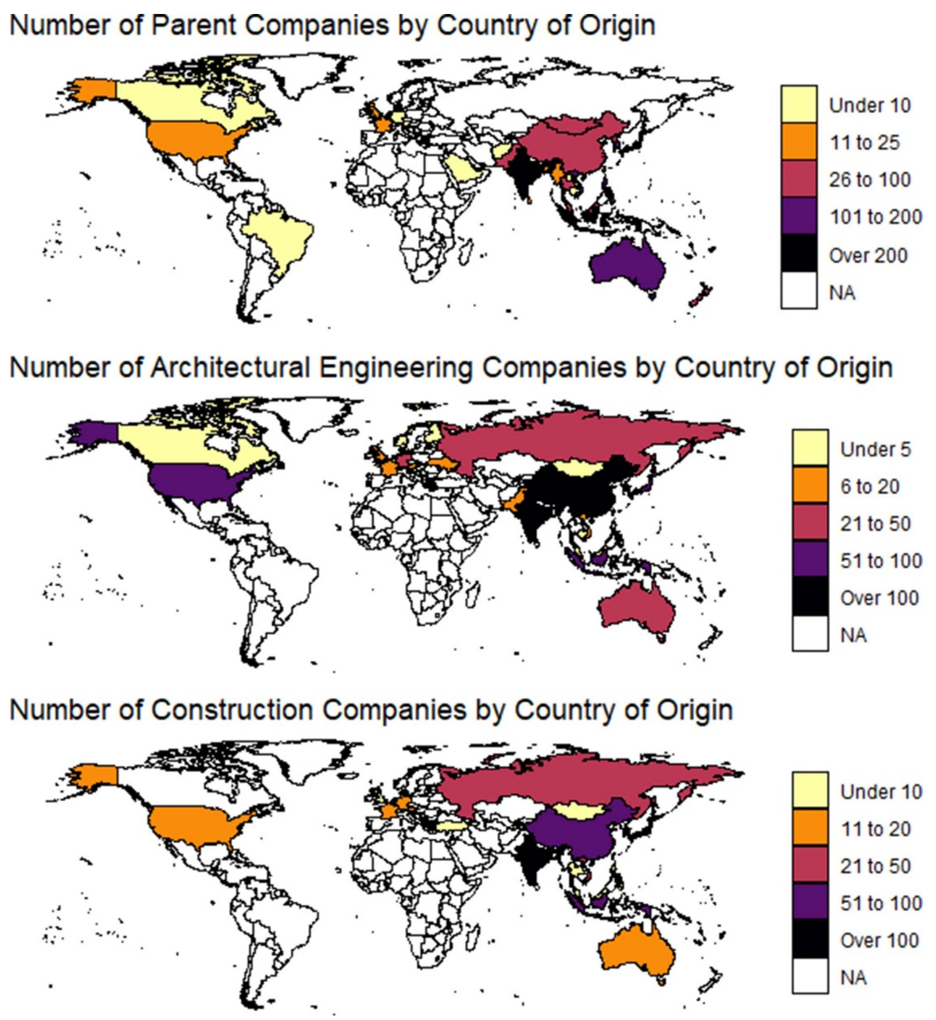

Figure 2. Countries of origin for Coal Plant Company types.

company, architect or engineering company[5], and construction company to identify the country of origin for each of these types of companies. This was determined by searching the name of the company and identifying the country in which it is registered and located. From the maps below (figure 2), which show the number of each type of company originating from different countries, we can see that various countries specialize in different services related to coal plant management and construction, to some extent. For example, Russia has no parent companies involved in coal plant development in Asia, but has many such engineering and construction companies. However, the maps do not reveal the relative sizes of the companies. India clearly has many companies of all types, while China, which tends to consolidate resources in large state-owned companies, may have fewer companies but not necessarily a lower market share.

Each type of company (parent, engineering, and construction) was then coded with an indicator 'treatment' variable for Chinese or non-Chinese ownership. Joint ventures with a Chinese company were coded as Chinese[6]. This indicator variable represents identifiable Chinese involvement in a project, which may include management practices, technology choices, or other mechanisms that are unique (Dean *et al* 2009). A full list of the 33 unique Chinese parent companies we identified is in the supplementary information (available online at stacks.iop.org/ERL/16/054062/mmedia), as we also provide a full list of parent companies and their countries of origin. 94% of observations had either both Chinese or both non-Chinese engineering and construction companies, and for observations with both Chinese engineering and construction companies, these companies were almost always the same, so we combined

[5] Platts describes these firms as the 'primary architect or engineering company', from here on simply referred to as engineering company.

[6] Hong Kong and Taiwanese companies were coded as non-Chinese, although there is some empirical evidence that Sinophone and ethnically Chinese areas may have similar FDI patterns (Dean *et al* 2009).

Table 1. Assumed base heat rate by steam type (Source: Reproduced with permission from Global Energy Monitor 2020b). "Estimating carbon dioxide emissions from coal plants," GEM.wiki, accessed 12/14/20.

Steam type	Heat rate (btu MWh^{-1})
Subcritical	8.98
Supercritical	8.12
Ultra-supercritical	7.76

Table 2. Adjustments to heat rate for capacity and age of plants (Source: Reproduced with permission fromGlobal Energy Monitor 2020b). "Estimating carbon dioxide emissions from coal plants," GEM.wiki, accessed 12/14/20.

	0–349 MW	350–449 MW	450+ MW
0–9 years	+20%	+10%	0%
10–19 years	+30%	+20%	+10%
20–29 years	+40	+30%	+20%
30+ years	+45%	+35%	+25%

these two company types into a single variable in our analysis.

As our outcome variable, we assessed CO_2 emissions intensity as a metric of global environmental impact. CO_2 emissions intensity, or the emissions rate, is the product of the emissions factor and the heat rate of a given generating unit—the amount of CO_2 a generating unit produces per unit of energy generated (equation (1)).

$$\text{Emissions Factor}\left(\frac{\text{tons CO}_2}{\text{btu}}\right){}^{*}\text{Heat Rate}\left(\frac{\text{btu}}{\text{MWh}}\right) = \text{CO}_2\ \text{Intensity}\left(\frac{\text{tons CO}_2}{\text{MWh}}\right). \quad (1)$$

We followed the approach to calculating generating unit-level emissions factors used by the Global Coal Plant Tracker (GCPT), another database for coal plants around the world. GCPT data on emissions factors are assigned based on fuel type according to IPCC guidelines for national greenhouse gas inventories (Global Energy Monitor 2020b). However, the WEPP database has greater detail than GCPT on fuel types and combinations of fuel types used in each generating unit. Our method for assigning emissions factors for the additional fuel types and combinations of fuel types in WEPP can be found in the supplementary information. Heat rate was assigned based on the steam type of each generating unit (table 1), and then adjusted for the year the generating unit was built and the capacity of the generating unit. This reflects the fact that older and smaller generating units tend to be less efficient. This approach is based on the methodology proposed by Global Energy Monitor as well as heat rate data from Global Energy Monitor. Table 2 shows the assumed penalties for generating unit age and capacity (Global Energy Monitor 2020b).

Summary statistics for the final list of variables are provided in table 3 below. Other categorical variables included in the regression analysis are generating unit status (operational, retired, planned, etc) and electricity type (utility, private, autoproducer).

2.2. Empirical design

A simple comparison of the emissions factors and heat rates for Chinese and non-Chinese generating units by company type indicates that Chinese companies have a lower average emissions intensity (see table 3). To explore this intriguing difference further, we control for other variables using several different regression specifications.

We analyzed the effect of ownership for parent companies and engineering/construction companies separately. For assessing CO_2 emissions, we used ordinary least squares (OLS) regression to examine the effect of a Chinese parent, engineering, or construction company on CO_2 emissions intensity of generating units. In our OLS regressions, we control for the status of the generating unit (operational, retired, etc) and the type of the plant (i.e. producing utility scale electricity or electricity for industrial or commercial use on-site). Capacity and age of the generating unit are incorporated into the calculation of the heat rate (see section 2.1), and are thus not included as explanatory variables. We did a log transformation of the outcome variable, which produces a more normal distribution of values.

Our general model is laid out in equation (2) below, with the indicator variable for Chinese company being 0 if a company was not Chinese and 1 if a company was Chinese. The generating unit level index is represented by i. We ran various specifications, beginning with OLS with and without controls.

$$\begin{aligned}\text{Environmental Performance}_i &= \beta\,(\text{Chinese Company}_i) + \gamma\,(\text{Controls}_i) \\ &\quad + \alpha_i + \mu_t + \varepsilon_{i,t}. \quad (2)\end{aligned}$$

In addition to the basic OLS regressions, we run a model with year fixed effects (μ_t, where t represents the year the generating unit was built) and country fixed effects (α_i) in order to control for unobservable factors that may confound the relationship between company ownership and environmental performance. Of particular concern is the fact that Chinese generating units are generally built more recently than non-Chinese generating units and thus differences in environmental performance are due to age, not ownership. The year fixed effects specification controls for differences in the year the generating unit was built, and therefore differences that could be explained by Chinese investments simply being more recent. The country fixed effects specifications plausibly controls for variation explained by Chinese involvement in areas with stricter emissions controls or regulations. We abbreviate fixed effects as 'FE' in our results tables.

Table 3. Summary statistics by company type.

		Parent company			Engn./const. company		
	Full sample	Chinese	Non-Chinese	Difference	Chinese	Non-Chinese	Difference
Capacity (MW)	268.6	445.5	264.9	180.5	305.6	267.4	38.26
	(312.4)	(284.3)	(311.9)	(33.73)	(266.7)	(264.2)	(13.87)
Year built	1996	2016	1995	20.2	2012	2002	10.5
	(21.5)	(8.37)	(21.5)	(3.07)	(7.08)	(16.9)	(0.89)
Steam pressure (bar)	124.8	206.0	124.4	81.62	185.2	144.2	40.97
	(63.2)	(38.6)	(63.0)	(22.3)	(59.4)	(62.8)	(6.37)
Steam temperature (C)	520.3	554.7	520.1	34.69	559.8	532.1	27.62
	(54.8)	(12.1)	(54.9)	(19.4)	(78.8)	(37.3)	(4.82)
Heat rate (btu kWh^{-1})	11 961	10 226	11 988	−1762.3	11 113	11 653	−539.9
	(1644.8)	(1676.9)	(1630.1)	(239.71)	(1789.9)	(1770.4)	(102.47)
Emissions intensity (tCO_2 MWh^{-1})	1.22	1.01	1.22	−0.20	1.11	1.17	−0.06
	(0.18)	(0.14)	(0.18)	(0.04)	(0.19)	(0.21)	(0.02)
Observations	4260	87	4173		485	1468	

It is clear from table 3 that there are differences between Chinese and non-Chinese owned generating units other than the ownership structure. In order to address possible selection bias, we also run a regression on a matched data set where Chinese-owned generating units are matched to similar non-Chinese owned generating units. Generating units are matched on the propensity score, which is estimated using the same generating unit-level characteristics that are used on controls in the basic OLS model. The resulting matched dataset includes generating units with similar age and features.

In addition, given that the above analysis focuses on emissions intensities, we also calculate total CO_2 emissions per year as well as committed lifetime emissions in order to compare the absolute impact of Chinese and non-Chinese generating units. Committed emissions are defined as the future emissions expected from a given set of infrastructures, such as coal-fired power plants, calculated based on current characteristics and expectations (Davis and Socolow 2014). We extend our calculation of generating unit-level emissions intensity (equation (1)) to calculate committed emissions for non-retired generating units in our dataset, following the approach of Davis and Socolow (2014):

$$\text{Committed Emissions } (tCO_2) = \text{Capacity } (MW)^* \text{ Capacity Factor } (\%)^* \, 8{,}760 \left(\frac{\text{hours}}{\text{year}}\right)^* CO_2 \text{ Intensity } \left(\frac{tCO_2}{MWh}\right)^* \text{Remaining Lifetime (years)}. \quad (3)$$

We calculated the remaining lifetime for each operating generating unit by assuming Davis and Socolow (2014) average lifetime of 40 years for a coal-fired power plant, subtracting the date the generating unit came into operation from the current year, where the difference between that number of years and 40 years represents the generating unit's remaining lifetime. We also used the average capacity factor, weighted by generating capacity, in Davis and Socolow (2014) coal plant dataset, 44%. Our calculation of annual emissions follow the same approach, less the term for remaining lifetime.

3. Results

3.1. Regression analyses

Table 4 presents the results from our analysis of CO_2 emissions intensity. We show the coefficient for the effect of Chinese ownership, controlling for status and type of coal generating unit, for four specifications: OLS (models 1 and 5), OLS with controls (models 2 and 6), country-year fixed effects (models 3 and 7; the most restrictive specification), and propensity score matching (models 4 and 8). These specifications indicate a statistically significant effect similarly large in magnitude for generating units with Chinese parent companies—that is, generating units with Chinese parent companies have around 8%–18% lower emissions intensity. We find that the effect on CO_2 emissions intensity is in the same direction but lower in magnitude for a Chinese engineering or construction company.

Because the above analysis was performed on an unweighted dataset, we also performed an electricity-generation weighted analysis to reflect the fact that smaller power generating units in the dataset contribute little to overall environmental impact. Although our outcome metric is a measure of the rated emissions intensity of a generating unit, it is important to consider total effects (see calculation of total emissions below). We find that the weighted regression yields coefficients similar in magnitude and level of significance for the effect of Chinese company involvement on CO_2 emissions intensity (see supplementary information for full results).

Table 4. CO_2 emissions results, coefficient of Chinese ownership indicator.

	Log *(Emissions Factor * Heat Rate)*							
	Parent company				Engn./const. company			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Chinese parent company	-0.181^{***} (0.033)	-0.101^{***} (0.029)	-0.079^{***} (0.023)	-0.151^{***} (0.046)				
Chinese Engn./const. company					-0.063^{***} (0.013)	0.038^{***} (0.013)	0.007 (0.011)	-0.030^{*} (0.016)
Controls	No	Yes	Yes	No	No	Yes	Yes	No
Country FE?	No	No	Yes	No	No	No	Yes	No
Year FE?	No	No	Yes	No	No	No	Yes	No
Observations	1863	1863	1796	50	1054	1054	1025	488
Adjusted R^2	0.006	0.599	0.762	0.126	0.051	0.691	0.785	0.027

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

We also tested the hypothesis that any foreign company's involvement (not just a Chinese company) may be associated with cleaner plants. We found that foreign parent companies tend to be associated with lower emissions intensity compared to plants with parent companies from the same country they are located in. Foreign engineering or construction companies have the opposite effect. However, when looking only at non-Chinese foreign parent companies, there is almost no difference in emissions intensity between foreign-owned and domestic generating units. For non-Chinese engineering and construction companies, foreign generating units tend to have even higher emissions intensity than domestic generating units. This indicates that much of the former effect is driven by Chinese companies with relatively lower emissions-intensity generating units. Overall, the results from our analysis of the general effect of foreign ownership provide support for the findings in our main results, that generating units associated with Chinese companies have lower emissions intensity. A full discussion of this analysis is provided in the supplementary information.

In order to understand potential mechanisms driving these results, we also investigated the relative efficiency of the coal generating units in our dataset using primary steam temperature and pressure to proxy net electric efficiency. We found indications that Chinese generating units have higher efficiency, which could partially explain the lower CO_2 emissions intensity. A full discussion of this mechanism can be found in the supplementary information.

For our calculation of total emissions, we find that out of the total annual emissions represented by the plants in our dataset (1402 Mt CO_2 yr^{-1}), Chinese plants represented 25%, while non-Chinese plants represented the remaining 75% of annual emissions. In contrast, the installed capacity of all coal plants with Chinese involvement is 166 GW (30% of total capacity), with the remaining plants in our dataset representing 386 GW (70% of total capacity), further confirming our results that emissions intensity is relatively lower for Chinese plants. However, looking at committed emissions, we found that the total committed emissions of plants in our dataset is 36 Gt CO_2. Chinese plants will emit 11 Gt CO_2 (30.5% of total) over their remaining lifetimes, while non-Chinese plants will emit 25 Gt (69.5% of total). Comparing annual and committed emissions, we can see that the fraction of total emissions from Chinese coal plants will increase over time, since Chinese plants tend to be newer and larger. Thus, while Chinese plants may have relatively lower emissions intensity, their total impacts will grow proportionally over time.

3.2. Discussion of company types and potential mechanisms

For the above analyses, we used parent and engineering/construction companies as proxies for Chinese involvement, suggesting a potential mechanism through which differential environmental impacts occur. The results suggest that the companies that manage, design, and build coal plants are what drive relative performance. Parent companies are hypothesized to mediate external pressures (i.e. from government, activists, and shareholders) and potentially translate these policies into a specific plant's adoption of environmental management practices (Delmas and Toffel 2004). From our dataset, the top five Chinese parent companies with the most coal plants elsewhere in Asia are CIIDG Erdos Hongjun Electric Power, China Hongqiao Group, Huadian, Datang, and Gezhouba. Huadian and Datang are among the largest state-owned power generation companies in China, while Gezhouba is one of the largest construction and engineering companies in China. China Hongqiao Group is a state-owned aluminum producer, and the largest aluminum producer in the world. CIIDG Erdos Hongjun Electric Power is a joint venture between a Cambodian investment development group and a Chinese electric power company. For their overseas endeavors, these parent companies receive financial support from Chinese state banks, like the China Development Bank, as well as commercial banks, like Bank of China. These companies are directly subject to various guidelines issued by China's state agencies. For example, in addition to complying with host country environmental regulations, firms are requested 'undertake environmental impact assessments for their overseas construction and business operation, to apply for environment related permits from the host country…to reduce the emission of pollutants through clean production, and also to actively engage in ecological restoration' (Gallagher and Qi 2018). While many of these guidelines are voluntary or unenforced, Chinese parent companies could direct plant-level technology choices and operational practices in order to meet China's and host country's suggestions for environmental performance. A full list of Chinese parent companies in this analysis is included in the supplementary information.

The top Chinese engineering companies from our analysis are large private companies that specialize in engineering services for the electric power sector. Many of these same companies are also the top construction companies, such as SEPCO3, the Shandong Electric Power Construction Corporation. Such companies are vertically integrated, providing logistics and shipping, equipment, design services, etc. Engineering and construction services are often bundled in the form of EPC contracts. Though not reflected in our dataset, these arrangements may even go further, with build–operate–transfer projects or design–build–operate projects that receive concessional finance through public-private partnerships (World Bank Group 2019). Chinese state or commercial banks could provide finance for such arrangements. The technology selection, operation, and maintenance of these plants by Chinese companies is a potential driver of relative environmental performance. In addition to different policy, technological, and managerial practices on the part of Chinese companies, the relative difference in environmental performance between Chinese companies and companies with other national origins could indicate consistent political factors in how Chinese plants operate overseas, particularly in how host countries may receive or regulate such plants. We are not able to directly test this mechanism, but advocate for future research in this area.

3.3. Limitations and future research

This study has several limitations. First, the study does not engage with the broader question of what kinds of electric power stations China is involved with in other Asian countries. That is, we do not investigate any sort of 'displacement effect' or fuel switching based on the broader portfolios of different countries involved in the electric power sector in Asia. Future research should investigate the factors that determine what type of energy projects Chinese companies choose to invest in. In addition, because we lack time series data on ownership, we are unable to characterize how long a given plant has had Chinese involvement, which could be an important consideration given that around half of Chinese ownership of overseas power plants has been through mergers and acquisitions rather than greenfield investment (Li and Gallagher 2019). Although our results are robust to controlling for the year the plant was built as well as within-year country fixed effects, data on the influx of Chinese involvement at different points in time could open up a new set of analyses.

We hope future research can improve upon key data limitations. First, our characterization of Chinese involvement is proxied by company ownership. However, there are many complex arrangements in which Chinese finance may reach an overseas power plant, including mergers and acquisitions and other financial instruments that are difficult to track at the firm level. Because we used a dichotomous indicator of Chinese involvement, we were not able to assess how different kinds and scales of involvement affect environmental performance. Second, there could be significant effort dedicated to filling gaps in WEPP for key variables such as fuel type, heat rate, steam pressure, steam temperature, engineering and construction company, etc. Prior studies have used satellite imagery and regression analysis to fill data gaps in WEPP (e.g. Raptis and Pfister 2016), while other global power plant databases like GCPT use internet searches to identify new plants or updates to plants that WEPP may not track. In addition to improving overall coverage, emissions data could be expanded and improved by drawing from prior research on global inventories for emissions from coal-fired power plants, (e.g. Tong *et al* 2018, Oberschelp *et al* 2019), or Steinmann *et al* (2014) (see section 1.1). Future research can also address issues with emissions calculations for co-generation plants, which would require a different treatment of heat rate estimates due to the higher range of heat-to-power ratios for co-generation steam turbines. We have included a regression specification that compares electricity-only power plants in the supplementary information. However, a more comprehensive treatment of emissions calculation, including the above recommendations as well as allocation techniques for co-generation plants, could significantly affect the results of this analysis.

We believe that future research can investigate other outcome variables besides CO_2 emissions and CO_2 emissions intensity. The proxies for net electric efficiency discussed in the supplementary information could be significantly expanded to include better data on a wider range of characteristics. In addition, air pollution impacts of coal-fired power plants are a key metric to consider given significant environmental and health impacts of pollutants such as $PM_{2.5}$, sulfur dioxide, and nitrous oxides. Given that WEPP data on air pollution control technology is self-reported by plants, we propose a metric that evaluates that quality of control technologies within the subset of plants that self-report air pollution controls, such as classifying these control technologies as best available technologies (BAT) or non-BAT according to BAT guidelines. However, our current study lacked sufficient data to rigorously carry out this analysis. Another approach would be to use plant-level satellite data to estimate air pollutant emissions for Chinese and non-Chinese plants (e.g. Li and Gallagher 2019). Future research can combine detailed emissions and technology inventories with our comparative framework to understand systematic differences in coal plants with varying company management structures and financial arrangements.

4. Conclusions

This paper provides a systematic comparison of Chinese and non-Chinese coal plants outside of China, collecting and analyzing data on CO_2 emissions intensity. We find compelling evidence that plants with a Chinese parent company, engineering company, or construction company often perform better on this metric than other plants, contrary to our stated hypothesis in the Introduction. These results are conditional upon data quality, issues with which are discussed above in our section 3.3. We find that our emissions intensity results are robust to year and country fixed effects specifications and a matching strategy, indicating that Chinese plants are distinct in their environmental performance for reasons other than Chinese generating units being built more recently or Chinese plants being concentrated in countries with more stringent environmental controls.

Since emissions intensity is less important that total emissions for understanding a plant's impact on climate change, we have also estimated total annual emissions and committed lifetime emissions for the plants in our dataset. In terms of committed lifetime emissions, we find that the share of CO_2 emissions from coal plants associated with Chinese companies will grow over time, since these plants tend to be larger and newer. For reducing emissions that cause climate change, therefore, there will need to be policy incentives and regulations for reducing new construction of coal plants both in China and in host countries.

We aim to provide aggregated, comparable quantitative information on the relative environmental performance of Chinese coal plants in order to better understand how the geopolitics of overseas investment map onto environmental impact. Our comparative framework also introduces a methodological approach to answering questions about relative environmental impact of the overseas investments of different countries. This analysis provides suggestive evidence that coal plants with Chinese parent, engineering, or construction companies perform better in terms of emissions intensity than those with companies from other countries. This indicates that Chinese coal plants may have technological or managerial characteristics that correlate with better environmental performance by these metrics. We are not advocating for increased Chinese investment in coal, nor should our empirical results be used to problematize efforts to stop investment in coal. In fact, our research further demonstrates the pressing need for BRI host countries to have competitive alternative sources of energy. China's overseas investments will play a large role in the future course of the global energy system based on China's decisions on what kinds of energy projects to fund as well as how those projects end up operating. Our research helps establish a baseline understanding for this dialogue, as well as a methodological framework for understanding the relative impact of countries' overseas projects.

Data availability

The Global Coal Plant Tracker database that supports the findings of this study is available by request at: https://endcoal.org/global-coal-plant-tracker/.

The data that support the findings of this study are available upon reasonable request from the authors.

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