

China's global power: Estimating Chinese foreign direct investment in the electric power sector

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ABSTRACT

We analyze the spatial and technological distribution of China's overseas electric power investments around the world, and the pollution intensity of Chinese coal fired power plants relative to those held by non-Chinese entities. We find that Chinese firms hold approximately \$115 billion USD in electric power assets globally, with an average of 73% ownership stake in a total capacity of 81 GW. Chinese power investments span the globe but are largely found in developing countries, particularly in Asia and Latin America. The vast majority of Chinese investment goes to coal (24.5 GW), gas (20.5 GW) and hydropower (18.1 GW), while the share of wind (7.2 GW) and solar (3.1 GW) is relatively small but may be rising. The energy mix of Chinese overseas investment is similar to the existing world portfolio. Within the coal sector, between 2011 and 2017, the majority of Chinese greenfield investment in coal used supercritical technologies (58 percent) while only 34 percent of non-Chinese coal plants built during this period were supercritical.

1. Introduction

For many developing countries, inward foreign direct investment (FDI) fills the local financial gap in the power sector and helps fuel the economy. In the 1980s, China suffered from severe power shortages as state investment alone could not meet soaring demand for electricity. The government later removed its regulatory barriers and restructured feed-in-tariff schemes to allow and attract private and foreign direct investment (Victor and Heller, 2007). China is now both the major destination of FDI inflows globally and the second largest country of origin after the United States for FDI outflows (UNCTAD, 2017). Through outward direct investment, Chinese corporate investors own a diverse portfolio of power projects in both developing and developed countries. A burgeoning literature covers Chinese outward direct investment in the world's electric power sector, including both greenfield investment (investors building new power plants from the ground up) and merger & acquisition investment (M&A, shares of existing power plants or power generating companies acquired by investors). In southeast Asia, Chinese firms are actively engaged in developing hydro power resources in the Greater Mekong Sub-region (UNCTAD, 2017). In the European market, China has also acquired power generating assets and participated in greenfield projects, especially in the renewable

energy sector (Alcaraz, 2017; Conrad and Kostka, 2017; Gippner and Torney, 2017). In the Latin-American market, electricity generation assets have also attracted billions of US dollars of Chinese investment, particularly in the Brazilian hydro electric sector (Ray and Gallagher, 2017). In Africa, Chinese energy investment focuses more on resource extraction, and Chinese firms invest in few power generation projects directly (Jiang, 2009; Kolstad and Wiig, 2011; Chen et al., 2016).

In addition to foreign direct investment, other forms of cross-border activities have fueled power sector development beyond China, including development finance from Chinese national development banks, import of power equipment from China, and foreign utilization of engineering, procurement, and construction (EPC) services from China. A more detailed description of the roles these stake-holders have in the global power generating market is in Table S1 in the Supplementary Information. Existing literature focuses largely on these three kinds of Chinese involvement while there have been few quantitative studies of Chinese foreign direct investment in the overseas power sector. For equipment export and EPC services, Hannam et al. (2015) estimated that 241 GW of global power plant capacity utilize Chinese equipment or EPC services and 125 GW of these plants are coal plants. For development bank finance, Kong and Gallagher (2017) estimated that, for the period 2000–2014, the Chinese Development Bank and Chinese Export-Import

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Bank financed approximately \$246 billion USD in the global energy sector, of which \$110 billion USD flowed into electricity generation. Within electricity generation, coal plant projects received \$48 billion USD or 43% of the total Chinese development finance for the power sector, followed by hydro power projects at \$36 Billion USD. The Natural Resource Defense Council (NRDC) also estimated that China's overseas policy banks have provided \$15 Billion USD to overseas coal projects between 2013 and 2016, the most of any country. China was followed by Japan (\$10 Billion USD), Germany (\$4 Billion USD), Russia (\$3 Billion USD), and South Korea (\$2 Billion USD) (Chen and Schmidt, 2017). Hervé-Mignucci and Wang, 2015 include both FDI and development bank loans as Chinese overseas finance. They estimate that overseas coal plants receive a total of \$21–38 billion USD from China's power companies and banks. In a more recent study, Shearer et al. (2019) found that China has committed \$21 Billion USD to coal plants under construction and another \$15 Billion USD to coal plants in the pre-construction phase. These three studies provide no estimate of Chinese finance for non-fossil power projects, which represents 54% of Chinese development finance according to Gallagher et al. (2018). For solar and wind power, the World Resources Institute has estimated that China, from 2000 to 2012, invested \$40 Billion USD overseas across the entire value chain with no specific estimation for electricity generation or equipment manufacture (Tan et al., 2013). So far, only two studies have looked specifically at Chinese foreign direct investment in the global power sector. Wei (2018) estimated the 'announced' value of Chinese overseas power investment (those plants in operation or announced as under contract) to be upwards of \$150 billion USD using data from the Heritage Foundation and other sources (Heritage Foundation, 2017; Wei, 2018). Gopal et al. (2018) examined Chinese overseas energy investment and found \$96 billion USD of Chinese investment in the global electricity generation sector but do not specify the share of each generation technology due to the limitation of the data sources.

This paper attempts, for the first time, to comprehensively trace Chinese outward direct investment to Chinese ownership of power plants around the world. We build our database using an integrative methodology, taking advantage of existing commercial and public databases, information disclosed by publicly listed companies, government and non-government entities, and the trade and business press. In the database we compile, we identify Chinese overseas electric power investment in global power projects at the plant level. We further analyze the spatiotemporal pattern, technology portfolio (ie. coal, hydro, wind, and solar power) and coal technology (sub- and super-critical) installed in coal power plants.

2. Data and methodology

Our objective is to create a comprehensive plant-level dataset of all the power plants in which Chinese firms have invested around the world. For each power plant, we provide basic information regarding its name, location, fuel type, capacity, year it came online, primary Chinese investor, investment amount and percentage of shares owned by Chinese firms. The core approach we use to compile our database is to adapt the Platts World Electric Power Database to account for the foreign ownership of China's overseas power plants. Platts is an electric power unit-level database and its first global version was published in the early 1990s. We use the 2017 version. Platts includes a comprehensive list of all power plants in the world derived from a variety of sources including direct surveys, power company financial and statistical reports, vendor reference lists, and trade and business press. For every power generating unit, Platts provides information regarding its name, operational status, capacity (MW), year-on-line, primary fuels, pollution control equipment, owner company, location data and additional attributes (Platts, 2015). While Platts does include the name of the company that has the majority ownership in a particular plant, it does not indicate the country of origin of the firm. In addition, there is a variety of subsidiaries or

affiliates of the same holding companies, especially for China, and Platts makes limited effort to record them in a clear and consistent manner. Therefore, in order to better understand the reach of Chinese influence in the global power sector, we expand the ownership attributes of the Platts database and identify all power plants outside of China which involve Chinese foreign direct investment. Our approach is a five-step process which we describe below. The endpoint of our data collection is December 31st, 2017.

2.1. Generation of Chinese company list

We first generate a list of Chinese power companies that may invest globally by surveying a wide variety of online databases and public reports. Four online databases are intensively utilized, including FDI-Market (Times, 2017), Dealogic (2017), Coal Plant Tracker (2017), and Global Coal Exit List (2017). Combining these sources, we create an initial list of more than 100 Chinese companies that we consider to be potential Chinese investors in foreign power markets. We supplemented this effort with internet searches, and found several additional companies that were lacking from these formal sources. We acknowledge that there could be additional missing Chinese companies, especially small to medium-sized private companies. Our complete list of Chinese energy companies operating abroad is provided in the supplementary information.

2.2. Direct matching of Chinese companies within Platts

After compiling a list of Chinese firms that invest globally in the power sector, we then match the names in our company list with the companies listed in the Platts database. We use a simple matching algorithm that searches the Platts database for names of firms in our company list and variations thereof. For every Chinese company, we generate one to three keywords that are representative of all possible names that Platts uses for the company. We tag power plants with the name of a holding company when at least one of the keywords found in the Platts database indicates it is the original owner. We then put all of the power plants obtained via this matching process together into a new list. Examples of keywords are included in the supplementary information. After the direct match, we also check the list of Chinese overseas power plants and remove the false-positive matches: plants that are not Chinese-owned but were wrongly captured by matching keywords. Coverage of renewable power plants in Platts is much less comprehensive than coverage of non-renewable power plants. Therefore, the top down approach based on Platts that we use may under-estimate Chinese investment in the global renewable power sector.

2.3. Indirect matching for Chinese companies within Platts

In terms of capacity, approximately two thirds of Chinese overseas power plants in our database are found to directly match power plants in the Platts database. For another one third of power plants, Platts fails to record their Chinese ownership. For instance, after merger and acquisition deals when Chinese companies acquired overseas assets, Platts does not update the original corporate owner with the new Chinese owner in a timely manner. There are also cases where Platts incorrectly recorded a local partner as the owner when the primary investor in the power plant is in fact a Chinese company. To generate a more inclusive list of power plants that includes not only those plants indicated by Platts to be Chinese owned, but also those Chinese plants that Platts missed, we conducted an internet search for all Chinese companies in our original list. We looked for those company's overseas power generating assets and then identified and tagged the corresponding records in Platts. We call this indirect matching. The internet resources we accessed included annual reports of publicly listed firms, official websites of companies and governments, and trade and business press. For instance, Huanneng's website and business press show that Huaneng

acquired a 50% share of Ozgen from InterGen in 2003 via competitive bidding and now holds a majority stake in an 1800 MW power generating asset in Australia in which they invested \$227 million USD. In Platts, as we expect, there are also records of power plants with a total capacity of 1800 MW under Ozgen but they are still recorded as solely owned by InterGen. Therefore, we label these missing matches where Platts fails to update as Chinese plants. In a similar fashion, we complete the list of Chinese owned power plants overseas. There are two types of activities that we do not include: (1) Equity investment, defined here as a financial investment made by entities with limited technology capacity in power project development, and (2) projects with EPC companies as a minor shareholders. While we have not included any projects involving equity investment or EPC contractors that are minor shareholders, future research in this area could be illuminating. All links for websites we used for indirect matching are available in the SI.

2.4. Expand project level detail

In addition to identifying and validating all Chinese plants outside of China that are included in Platts, we also expand the record of power plant attributes with additional details, including the type of investment (greenfield vs. merger & acquisition), percentage of Chinese ownership, and amount of Chinese investment in USD. Using the same Huaneng example as in section 2.3, we record Chinese ownership as 50% and the deal completion year as 2003 in separate columns. A total investment of \$227 million USD is also recorded. However, for many other deals, the investment amount is unavailable. There is general consistency among sources. If there are contradictions or inconsistencies, we give more weight, in order, to government websites, company websites and annual reports, trade and business press.

2.5. Project status verification

A power plant project could take as long as a decade from its announcement to the day it starts operating. Many announced projects end up canceled or delayed and an incorrect recording of Chinese outward investment could wrongly include these “zombie deals”. The most famous example is the Myitsone hydroelectric power project in Myanmar. In 2009, \$3.6 billion USD of investment was announced but it was never realized as the project was suspended in 2011. Inclusion of such zombie projects would lead to an overestimation of Chinese investment. For merger and acquisition investment, we only include deals that are registered as completed by Dealogic or by multiple trade and business presses. Deals that were announced but have not been confirmed as completed are not included. For greenfield projects, we use the project status information provided by Platts, which records power plants as in operation, under construction, under planning, deferred, canceled or retired. In our analysis, we only include greenfield projects that are either in operation or under construction as valid investments. Investments at other project stages are excluded to avoid zombie deals. Since every investment is traced down to the power plant level, double counting is avoided. Similarly, the investment itself could also take years to finish. For greenfield projects, it is difficult to track the exact date of initial investment. Platts, however provides comprehensive data on the year in which projects start operating (commission date). Therefore, although investments precede commission dates by years, due to lack of a viable alternative we use the year in which projects commence operation as the year of the investment.

2.6. Coal power plant technologies

Platts provides important information on the technologies adopted by every coal plant, including types of steam turbine (subcritical/supercritical/ultra-supercritical) and types of end-of-pipe control technologies (SO₂, NO_x, and particulate matter). In section 3.4, we use this information to analyze the penetration rate of various pollution control

equipment in coal plants owned by Chinese firms versus other developers. According to Platts, the primary source for such information is direct survey, and “plant-specific inquiries are sent (by Platts) on a continuing basis to utilities, autoproducers, power companies, and suppliers around the world” (Platts, 2015). In most developing countries, there is no public information on such technology details and Platts is the only available dataset for such information. While we acknowledge that potential bias could result from Platts’ dependence on voluntary reporting, we use the case of China’s domestic market to quantify the data coverage in Platts for pollution control variables. As in Table S2, the results show that for all Chinese coal-fired power plants in operation, Platts accurately reports only 79% of installed particulate controls, 77% of sulfate controls, and 41% of NO_x controls. If the missing reporting issue persists in other countries in which China has invested, we may have underestimated the penetration rate of pollution control equipment in these overseas coal plants owned by both Chinese and non-Chinese investors, especially in the case of NO_x control. However, we are unable to determine whether non-Chinese investors have greater or lesser reporting to Platts of installation of pollution controls. Potential reporting bias could exist in which Chinese investors may be more likely to report the installation of control devices than other investors, but we are unable to examine such reporting bias due to a lack to data. We acknowledge this to be a limitation of our analysis and believe a more robust international collection of data on deployment of end-of-pipe control technologies is needed.

2.7. Partial ownership

In most cases, Chinese investors are one among many other shareholders in power projects. Therefore, it is important to track not only the total capacity of power projects receiving Chinese investment but also the capacity directly owned by Chinese firms. In our analysis, we use “total capacity” to describe the total capacity of power plants in which China has made an investment of any size and “net capacity” to describe the power capacity China directly owns.

For example, for a 600MW coal power plant in which China has 50% share, Chinese net capacity in this project is 300MW and its total capacity is 600MW. If the capacity number is not specified as net capacity, it represents the total capacity involved with Chinese FDI, rather than the capacity directly owned by China.

3. Results and discussion

We estimate that between 2000 and 2017 Chinese firms invested approximately \$115 billion USD in 462 overseas power plants, with a total generation capacity of 81 GW. Among the 81 GW of capacity, the net capacity owned by Chinese companies is 59 GW. In other words, the average weighted ownership of Chinese companies in overseas power plants is approximately 73%. \$115 billion USD is an approximate estimate of the capital cost of all projects based on the average capital cost per kW of new power projects. A table of capital costs for various energy technologies (coal, gas, oil, hydro power, wind, solar and biomass power) is in Table S3 in the supplementary information. Section 3.1 discusses China’s overseas power plant technology mix. Of the 81GW of plant capacity, 39 GW are greenfield projects while 42 GW of Chinese ownership has been obtained through merger and acquisition (M&A) deals. Fig. 1a and b shows these trends over time, and reveal that the bulk of these investments have occurred after 2008.

Although outward investment via the “Going Out” policy—China’s policy of encouraging flagship national firms to invest abroad—started in China in the 1990s, there were very few cases of Chinese overseas investments in the power sector completed before 2012. Huaneng Group is the Chinese pioneer in acquiring overseas power generating assets. In 2003, Huaneng acquired a 50% share of Ozgen from InterGen via competitive bidding and took control of 1800 MW of coal-fired power plants in Australia. Later in 2008, Huaneng acquired 100% ownership of

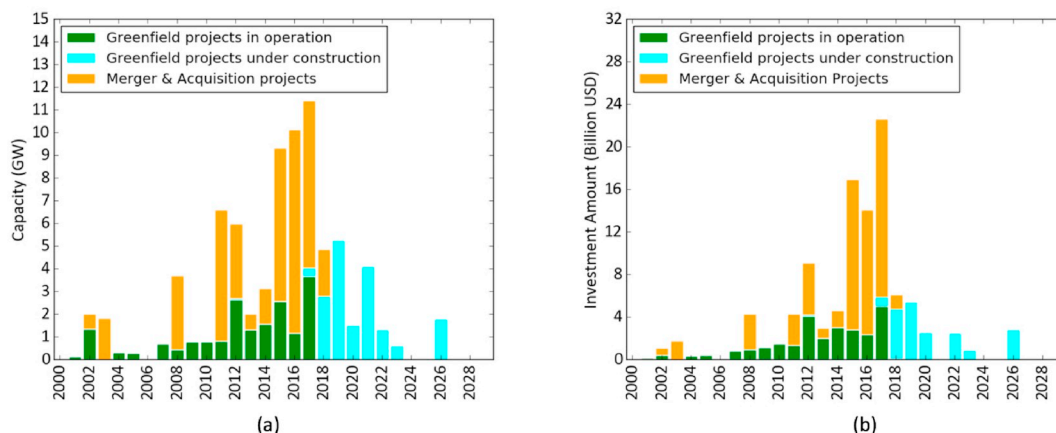


Fig. 1. (a) Time-series trend of Chinese outward investment in the electric power sector by capacity (left) and (b) by investment amount (right) based on data collected through 2017. For greenfield projects, the project date is defined as the first year or expected year of operation. For acquired projects, the date is defined as the year when the deal was completed. Planned projects are not included.

Tuas Power, a Singapore power company which owns 3 GW of gas and oil power plants. Around the same time, the Shweli Hydro Power station came online in Myanmar, which marks the beginning of more than 4 GW of Chinese greenfield investment in Southeast Asian hydro projects. Greenfield coal projects came relatively late and the first coal power plants, totalling 400 MW, were built in Indonesia by Shenhua Group in 2011.

One three year period (2015–2017) saw a surge, dominated by M&A investment projects, in Chinese overseas investment in the power sector. For greenfield investment, the Hinkley Point nuclear station in the United Kingdom is the most famous example of Chinese power companies entering the European market. In addition, China has also acquired several offshore wind farms in the United Kingdom and Germany, and a 28% share of Energias de Portugal (EDP). Brazil also rose to be the largest target for Chinese investment. Chinese companies, the State Grid

Corporation of China and China Three Gorges Corporation, collectively acquired 12 GW of hydro power projects in Brazil through divestment from the Brazilian government and Duke Energy, a US firm.

In addition to Hinkley Point, there are another 17 GW of power projects under construction which will come online in the next several years. The majority of these projects, 11 GW, are coal-fired power plants in Asia and the Middle East. A large utility scale solar project, 600 MW, will come online very soon in Pakistan in addition to the existing 300 MW utility scale solar PV unit. In 2019, a 588 MW offshore wind farm in Scotland is expected to come online with 25% of Chinese ownership.

3.1. Technology mix

Although China's domestic power mix, measured by capacity, is

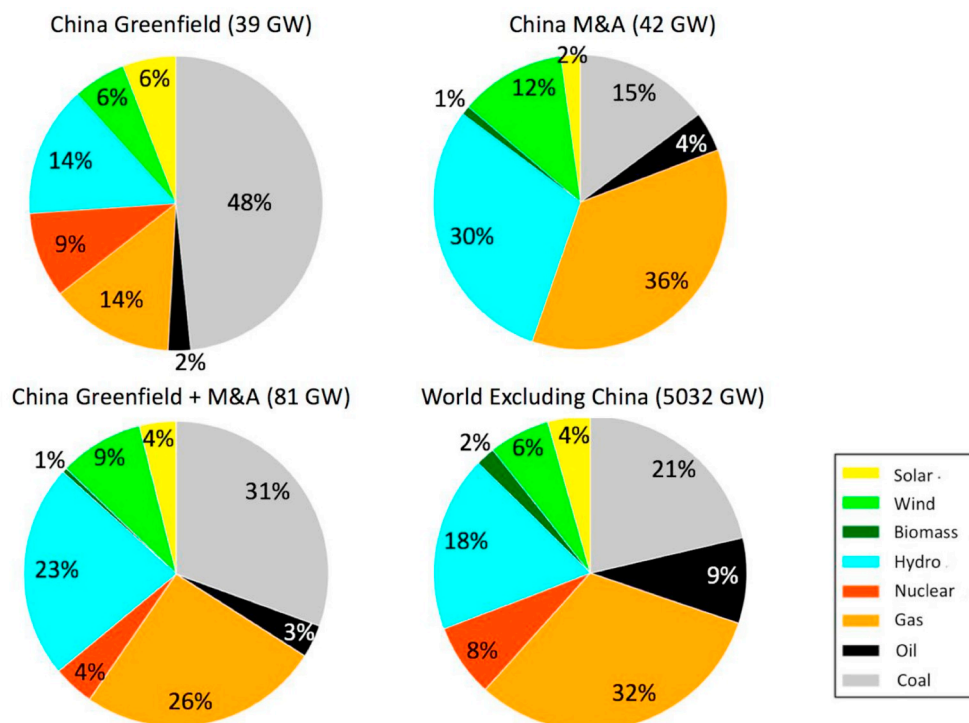


Fig. 2. Electricity generation technology mix of Chinese outward greenfield investment, M&A investment, greenfield and M&A combined and the electricity generation technology mix of the entire world excluding China's domestic market for the year 2016. The percentage is calculated by capacity (MW).

currently dominated by coal (58%), China's overseas portfolio is much more diverse and similar to the world average. According to World Energy Outlook (2016), outside of China there is a total of 5032 GW installed power capacity including gas, coal, hydropower, oil, nuclear, wind, solar and biomass (IEA, 2016). Thus, 81 GW of Chinese investment represents only 1.6% of the global market with the rest owned by local and other international investors. In Fig. 2, we compare the technology mix of China's overseas power plants with other plants owned by non-Chinese entities throughout the rest of the world (ROW). In both cases, three major fossil fuel technologies (coal, gas and oil) represent approximately 60% of total capacity with hydro power the largest source of non-fossil generation. The carbon intensity of Chinese investment is still relatively high because coal dominates the deployed Chinese fossil technologies. China also invests more in hydro power plants and wind farms, and less in nuclear and biomass plants than the rest of the world (ROW). By comparing Chinese global FDI with other forms of Chinese involvement in the global power sector, we find that 30% of China's overseas FDI flows into coal power plants, while 43% of bank loans and 52% of equipment exports and engineering services flow into coal power plants (Hannam et al., 2015; Hervé-Mignucci and Wang, 2015; Chen and Schmidt, 2017; Gallagher et al., 2018). This suggests Chinese FDI is less coal intensive than other forms of Chinese financial, equipment export and engineering services involvement overseas. For many coal projects, especially those in south and southeast Asia, Chinese firms only provide the equipment or are the engineering construction contractors while the local government or company operates the power plant and takes ownership.

The technology mix of Chinese investment also varies by investment type (eg. greenfield versus merger and acquisition). As shown in Fig. 2, the majority (48%) of greenfield investment is in coal plants, followed by gas (14%), hydro (13%) and nuclear (9%) plants, a pattern which is very similar to the Chinese domestic market. Merger & acquisition investment, on the other hand, is more equally shared by gas (36%), hydro (30%), coal (15%) and wind (12%) power plants.

Fig. 3 shows the mix of different power generating technologies funded by Chinese foreign direct investment since 2000. For greenfield projects, the year is defined as the year in which the power plants came online or are expected to come online. For M&A deals, the year is

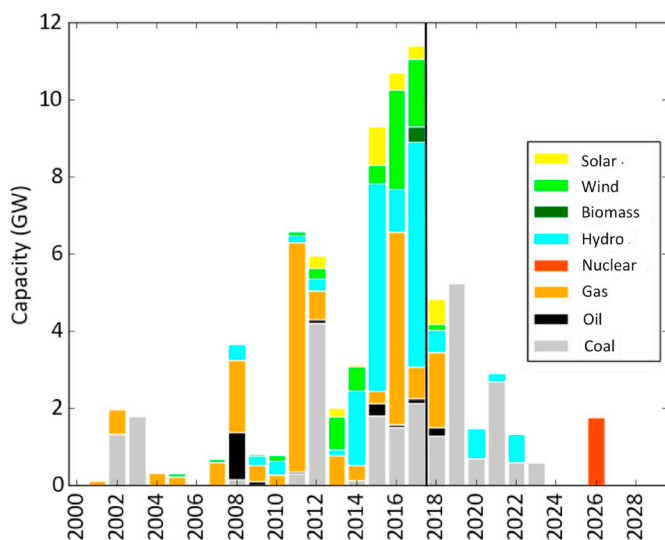


Fig. 3. Time-series of Chinese outward greenfield and M&A investment (measured by capacity) in the electric power sector by technology type from 2000 to 2029 based on data collected through 2017 (vertical line). For greenfield projects, the project date is defined as the first or expected year of operation. For M&A projects, the date is defined as the year when the deal was completed. Planned projects are not included. Beyond 2017, only greenfield investment projects under construction are included and shown.

defined as the year in which the deal was completed. From 2000 to 2011, fossil fuel technologies dominate Chinese foreign investments while hydro and wind power have minor shares. From 2012 to 2017, solar and wind as well as large hydro power investment grew rapidly to become as important as carbon-intensive investments. Moving forward, Fig. 3 shows that the majority of planned investments are in coal and hydropower. The average construction time needed for renewable projects, six to twelve months, is substantially shorter than traditional fossil power plants or large hydro power plants, which take two to five years or even longer to complete. Therefore, our database includes no Chinese investment in renewables after 2018 because all projects under construction in 2017, the last year of our data search, are expected to come online by the end of 2018. Similarly, future M&A deals completed after 2018 are also missing from the database. The apparent dominance of carbon-intensive coal investment after 2018 could be misleading as recent completed projects indicate substantial investment in hydro, wind and solar power.

3.2. Spatial distribution

Chinese power investment spans the entire globe and involves a wide spectrum of countries, from the most to least developed and from the most to least politically stable. In addition to the diversified portfolio, there are two clear features of Chinese investment, a strong interest in emerging economies particularly in Asia, and a technology preference strongly linked to local resource availability. Table 1 shows Chinese investment portfolios in various regions and in Belt and Road Initiative (BRI) countries. South Asia and Southeast Asia receive 41% of Chinese investment, followed by Latin American countries (LAC). As shown in Fig. 4a, the vast majority of top recipient countries are emerging economies with the only exceptions being the United Kingdom and Australia. This is also consistent with the general pattern of overall Chinese foreign direct investment (Ministry of Commerce People's Republic of China, 2017). Although Africa has received much Chinese government aid and development loans, it is a much less important destination for Chinese outward investment than emerging economies with more mature markets.

China has invested overseas in all major types of electricity generating assets and local resource availability strongly impacts Chinese technology preference, particularly for hydro and coal power. In Brazil, Laos and Cambodia, the majority of Chinese investment goes to hydro power plants where the local hydro power potential is large and fossil fuel resources are relatively poor. In the year 2015, hydro power generated 62%, 79%, and 46% of electricity in these three countries respectively. Australia, Pakistan, and Indonesia have large coal reserves and are the largest destinations of Chinese coal investment, with more than 4 GW in each country. According to IEA, Australia, Pakistan and Indonesia rank 4th, 13th and 18th in the world by coal reserve (IEA, 2017).

Chinese investment is an important source of funding for the development of generating capacity in the developing countries shown in Fig. 4b. In Cambodia, as the most extreme example, almost 80% of the generating capacity is owned by Chinese companies. For the countries in Fig. 4b, the penetration of Chinese ownership is large enough to have considerable impact on the local power market and on local energy policies. In turn, the performance and profitability of Chinese companies are also very sensitive to local policy and regulation.

3.3. Investing companies

Chinese state-owned enterprises (SOEs) are the dominant investor in the overseas power sector market. Central SOEs (those that are directly controlled by the Chinese State-owned Asset Supervision and Administration Committee (SASAC)) have collectively invested in 64 GW of generating capacity overseas, which is 80% of Chinese total power sector investment. Such a high level of state involvement is a unique

Table 1
Chinese Electric Power Investment Portfolio Around the World (unit: capacity in MW).

Region	Coal	Gas/LNG	Hydro	Nuclear	Oil	Solar	Wind	Bio	Percent
Africa	0	2446	285	0	145	42	449	0	4%
East Asia	1320	1476	0	0	507	231	0	0	4%
Europe/Central Asia	0	4689	24	3540	350	578	2541	0	15%
North America	0	2505	0	0	0	962	331	0	5%
Latin America	0	21	12806	0	168	1	1535	420	19%
Middle East	2400	0	0	0	0	0	0	0	3%
South Asia	7260	3757	800	0	320	1120	1211	0	18%
Southeast Asia	8820	4280	4372	0	1226	168	0	0	23%
Oceania	4685	1368	45	0	91	60	1301	0	9%
BRI Countries	18480	10409	5196	0	1562	1676	1731	0	48%
Non BRI Countries	6005	10133	12926	3540	1245	1487	5433	420	52%

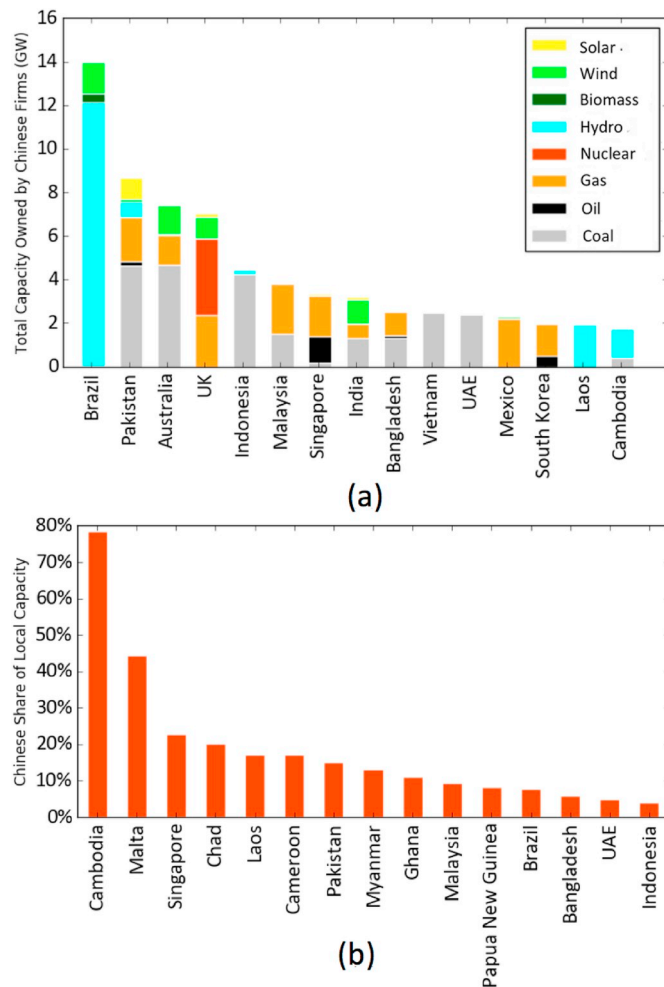


Fig. 4. (a) Top destination countries of Chinese outward investment by total capacity (top) and (b) by share of local capacity (bottom). The share of local capacity is calculated by dividing Chinese total investment in the country by total generating capacity in the same country.

feature of Chinese investment compared to its western counterparts. Fig. 5 shows the top 20 Chinese investing companies. The top three Chinese central SOEs are responsible for almost half of the investment and the top 10 companies are responsible for more than 80%. There is some correlation between the companies' domestic expertise and its overseas investment but there are also many outliers. For instance, China Three Gorges Corporation is the owner of the Chinese Three Gorges dam and its overseas assets are also dominated by hydro power. Similar cases are Harbin Electric (top coal plant equipment manufacturer), Goldwind (wind manufacturer and developer), Canadian Solar

(solar manufacturer and developer), and China National Petroleum Corporation. These companies have a stronger technology preference with respect to their domestic focus, or less technology flexibility to a certain extent, when they are making overseas investments. The other companies have different investment portfolios overseas compared with their domestic portfolios. For example, 51% of Huaneng Group's domestic generating capacity in China is coal while the majority of Huaneng Group's overseas investments have been gas power plants.

3.4. Analyzing China's overseas coal plants

This section of the paper examines the efficiency and pollution intensity of the coal-fired power plants in our database—separately comparing Chinese greenfield and M&A investments in the database with those owned by non-Chinese entities, or the rest of world (ROW). Since 2002, our database shows that Chinese investors have invested in a total of 23.4 GW of coal plants in overseas markets, with a net capacity of 19.8 GW. Among the 23.4 GW, 12.3 GW of coal plants have already come online and 11.1 GW are under construction. This is comparable to coal plants supported by Chinese development finance (23.7 GW, Gallagher et al., 2018) and much smaller than coal plants involving Chinese power equipment or engineering services (125 GW, Hannam et al., 2015). According to Platts, there is a total of 455.1 GW of new coal plants outside China which came online after 2002 or are still under construction. Therefore, Chinese overseas direct investment in coal plants represents 5.1% of the total growth globally since 2002. Another 27.5% of the growth is supported by Chinese export of power equipment and engineering services, which has been the dominant form of Chinese involvement in the overseas coal power sector. According to the Platts database, another 17.3 GW of coal plants, supported by Chinese investment, are planned and are very likely to come online in the next few years. In addition, a total of 236.2 GW of new coal plants are planned around the world outside of China. While we acknowledge that the data coverage for pipeline coal plants is less reliable, it indicates that Chinese overseas investment represents 7.3% of planned coal plants outside of China. This is over 40% higher than the current Chinese contribution to coal plants in operation or under construction, suggesting a growing presence of Chinese investment in the future in the global coal sector. Due to data limitations in Platts, the observed trend is less reliable than the historical trend and would benefit from further validation when a more comprehensive pipeline dataset is available.

Coal power plants have negative impacts on climate, air quality, public health and water resources. The further development of coal power commits the world to additional carbon dioxide emissions at a time when climate science is indicating the world must rapidly phase out fossil fuel use to avoid catastrophic changes to the global climate (IPCC, 2018). Nonetheless, the development of cleaner coal technologies can reduce the impacts of pollutant emissions on air quality, public health and water. For example, utilization of end-of-pipe pollution controls (e. g. sulfur scrubbers; particle filters; and selective catalytic reduction to remove NO_x) can reduce reactive air pollutant emissions by more than

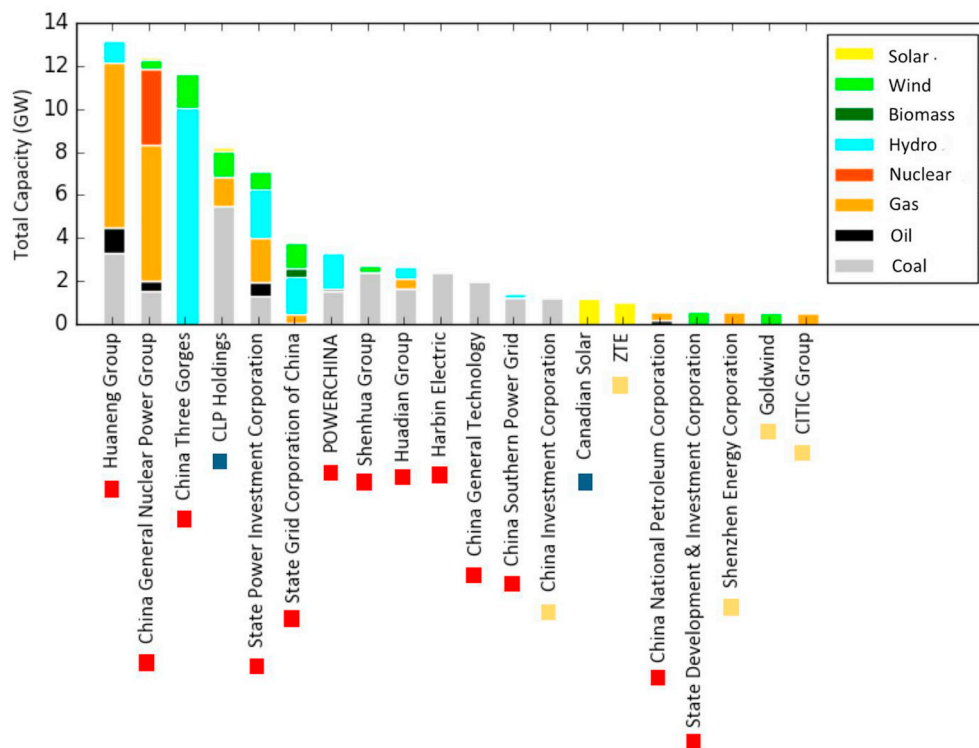


Fig. 5. Top Chinese companies investing in overseas electricity generation by total capacity of each type of generation overseas. Companies are categorized into central SOEs (red), local SOEs (yellow), and non-SOEs (blue). SOE: State-Owned-Enterprises. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

90% and have been key drivers for recent air pollution mitigation in China. While use of end-of-pipe technology is usually a function of host country regulations, carbon intensity is more a function of core technology (Gallagher, 2007). More efficient supercritical power plants can reduce carbon emissions by as much as 20% compared with older sub-critical plants per MWh of electricity produced (Franco and Diaz, 2009; Schreifels et al., 2012). In this section, we evaluate the technological parameters of Chinese overseas coal-fired power plants (including steam type and end-of-pipe controls) and compare them with local power plants to evaluate how emissions of carbon dioxide and air pollutants from power plants financed by China compare to their local counterparts.

In Table 2, we compare the technology parameters of coal plants owned by Chinese firms with coal plants built in the same countries and during the same period, but by local or other non-Chinese entities. Given that information on utilized technology is only comprehensive for plants that have already come online, we include only operational coal plants and exclude those under construction or in earlier phases of development. The earliest greenfield coal project China developed overseas came online in 2011. A total of 5.7 GW of new coal plants (fifteen power generating units in six coal plants) have come online through Chinese outward investment in Indonesia, Cambodia, Pakistan, Vietnam and India since then. Another 145.8 GW of new coal plants have also come online through investments by non-Chinese entities in these five countries, so Chinese investments represent roughly four percent of all coal investment from 2011 to 2017 in these five countries.

With respect to efficiency and carbon intensity of coal power in Indonesia, Cambodia, Pakistan, Vietnam and India, the majority (58 percent) of Chinese total overseas power capacity utilizes supercritical technologies while the remaining 42 percent are equipped with less efficient subcritical technologies. No ultra-supercritical coal plants had been built in these countries by the end of 2017. In comparison, the majority (66 percent) of the coal plant capacity from non-Chinese investment are subcritical plants. All Chinese supercritical coal plants are

in Pakistan and India. Although overall China invests in more super-critical coal plants than the rest of world, these more efficient investments have so far been exclusively in Pakistan and India. From another perspective, although Chinese entities have only invested in four percent of the global total coal capacity from 2011 to 2017, seven percent of the more efficient supercritical coal plants have been built with Chinese investment, making Chinese greenfield investment in coal less carbon intensive than the investments of its counterparts. Average unit size is an important explanatory factor contributing to the difference since supercritical technologies are more likely to be installed in larger power generating units. Table S4 shows differences in average and median sizes for the two technologies for all operational coal power plants in the world. The average unit size for Chinese greenfield investment is 378 MW, significantly larger than the 269 MW size for non-Chinese investment.

In terms of reactive air pollutant emissions, our analysis using the Platts database finds that Chinese overseas greenfield coal plants have more capacity with sulfur dioxide (SO₂) and nitrogen oxide (NO_x) emission controls than power plants owned by local or other foreign entities. We note that our data for pollution control comes solely from Platts and we found that there are missing reporting issue within Platts, especially in the case of NO_x. The data limitation influences the robustness of this analysis and we are unable to determine whether non-Chinese investors have greater or lesser reporting to Platts of installation of pollution controls; this analysis would benefit from a more robust collection of data on end-of-pipe control technologies. Our findings lend some support to anecdotal messages from Chinese government officials that they have been voluntarily bringing cleaner coal technologies than non-Chinese entities to developing countries (Gallagher and Qi, 2018). Table S5 provides further details on every coal unit over time. We note that the Indian coal market is so large that it inflates our comparison group. While China only invested in one 1.3 GW coal plant in India, 120.4 GW of the 145.8 GW non-Chinese coal investment actually occurred in India. To avoid the inherent bias of such a large

Table 2
Summary of Chinese Overseas Coal Plants and Recipient Countries' Coal Plants Developed by non-Chinese entities.

	Chinese Greenfield Investment ^a	Non-Chinese Greenfield Investment ^b	Chinese M&A Investment ^c
Recipient Countries	Indonesia, Pakistan, Vietnam, Cambodia, India	Indonesia, Pakistan, Vietnam, Cambodia, India	Australia, Singapore, Malaysia
Time Period ^d	2011–2017	2011–2017	2003–2016
Total Capacity of Coal Plants	5.7 GW (100%)	145.8 GW (100%)	6.3 GW (100%)
Average Unit Size	378 MW	269 MW	405 MW
Capacity of Subcritical Plants	2.4 GW (42%)	96.0 GW (66%)	4.5 GW (71%)
Capacity of Supercritical Plants	3.3 GW (58%)	49.8 GW (34%)	1.8 GW (29%)
Capacity of Plants with SO ₂ Controls	5.4 GW (95%)	123.6 GW (85%)	3.9 GW (62%)
Capacity of Plants with NO _x Controls	2.6 GW (45%)	12.0 GW (8%)	1.8 GW (29%)
Capacity of Plants with Particulate Controls	4.9 GW (86%)	130.8 GW (90%)	6.2 GW (98%)

^a Direct investment by China in new coal power plants which became operational between 2011 and 2017. 2011 is the first year when Chinese greenfield coal projects came online. Operational coal plants with Chinese investment only occurred in Indonesia, Pakistan, Vietnam, Cambodia and India. There are more coal plants with Chinese investment under construction in other countries but we exclude them in this table.

^b Direct investment by non-Chinese entities in new coal power plants which became operational between 2011 and 2017 in Indonesia, Pakistan, Vietnam, Cambodia and India.

^c Chinese M&A of power plants has only occurred in Australia, Singapore and Malaysia. The first M&A deal involving a coal plant was completed in 2003. The latest M&A deal involving a coal plant was completed in 2016.

^d For greenfield projects, the project date is defined as the first year of operation. For M&A projects, the date is defined as the year when the deal was completed. Projects under construction or planning are not included.

contribution, we conduct a separate analysis in [Table S6](#) excluding India and using only Chinese investment in Indonesia, Pakistan, Vietnam and Cambodia. When we exclude India from both the China greenfield coal plants and the ROW, 45 percent of Chinese coal plants are supercritical, whereas only 16 percent of the operational coal plants from ROW are supercritical. Moreover, Chinese coal plants have higher penetration rates of SO₂ (93%), NO_x (30%), and particulate matter air pollution control (82%) technology than ROW plants, which have lower penetration rates of SO₂ (79%), NO_x (13%), and particulate matter air pollution control (74%).

In addition to greenfield investment, China has also invested in overseas coal through M&A deals. Since 2003, Chinese firms have purchased 6.3 GW of coal plant assets in Australia, Singapore and Malaysia. As we do not have data on M&A deals made by other major coal investing countries, we are unable to form a valid comparison group and can not elucidate the relative role of China compared to non-Chinese entities in these three countries. [Table S7](#) further shows Chinese M&A investment in coal at the unit level. There are four M&A deals with 14 coal power generating units involved. Since those acquired plants are relatively older, with the oldest one dating back to 1973, the share of supercritical technology (29%), is smaller than Chinese greenfield investment. The penetration rates of various end-of-pipe control technologies for those acquired projects, however, are at similar levels as greenfield investments. Chinese greenfield coal projects apply a higher rate of sulfur control but a lower rate of particulate matter control than Chinese M&A coal plants. This analysis is based on total capacity in which Chinese firms have invested, rather than the net capacity China

directly owns. We find similar results if we take into account the exact ownership fraction of China (net capacity) in each of the coal plants, as shown in [SI Table S8](#).

4. Conclusions and policy implications

Building on earlier work, this paper is the first to provide estimates of Chinese overseas investment in the global power market with technological and spatial information. China began investing in overseas power projects in 2003 and has been accelerating those investments ever since. After steady growth from 2003 to 2014, 2015–2017 has witnessed a substantial increase in Chinese investment. In terms of capacity, there is a total of 81 GW power plants outside China owned or partially owned by Chinese firms, of which 59 GW of net capacity is directly owned by Chinese firms. 81 GW is equivalent to the total generating capacity of Iran in 2015, which ranks 14th in the world. It also represents approximately 5% of Chinese domestic generating capacity, or 1.2% of global generating capacity. We find that China has been investing in a diverse portfolio of electricity generating assets, covering all major electricity generation technologies. Coal projects represent 31% of the total capacity, followed by gas (26%) and hydro power (23%) projects. Chinese energy investments span the entire globe but are largely found in emerging markets and developing countries, particularly in Asia and Latin America. A handful of Chinese state-owned enterprises dominate China's overseas markets.

In new greenfield investments, Platts data indicates Chinese investors have utilized more efficient super-critical technologies than are typically used in a given recipient country. In terms of mergers and acquisitions (M&As), the vast majority of coal fired M&As by both China and firms from the rest of the world are subcritical and tend to have less air pollution control technology than their Chinese counterparts.

Although Platts data indicate that China utilizes more efficient, less carbon-intensive power generation technology through greenfield coal investment than non-Chinese investors, any new investment in coal is problematic given the urgent need to reduce carbon emissions and the committed future emissions that result from any new coal investment ([Davis and Socolow, 2014](#); [Pfeiffer et al., 2018](#)). Scientists have shown that there is very little room for any new coal, even cleaner coal, if the world is to limit global warming to 1.5 or 2 °C above pre-industrial levels ([IPCC, 2018](#)). It is also estimated that 88% of known coal reserves are unburnable under the 2-degree target ([McGlade and Ekins, 2015](#)). Despite the need to phase-out coal to limit global warming, non-OECD countries are expected to almost double their coal capacity by 2040 according to the Current Policy Scenario developed by World Energy Outlook. Even in the New Policy Scenario, coal is still projected to be a major source of electric power generation to meet soaring electricity demand globally ([Biroi et al., 2018](#)).

In addition to compiling estimates of Chinese overseas investment, we propose a consideration of a new accounting system to track such investments. The proposal may lend itself to broader global and policy analyses. Linking foreign investments to emissions in power plants by nationality would allow analysts and policy makers to obtain a more complete picture of a nation's carbon footprint. While significant work has estimated a nation's carbon footprint with respect to a given nation's international trade, there is at present no analogous work with respect to foreign investment. Several recent high profile studies reveal that significant carbon emissions in China occur due to production of goods exported to the US and other countries ([Peters et al., 2011](#); [Du et al., 2011](#); [B. Meng et al., 2018a](#)). In addition, China has begun offshoring many of its carbon intensive industries to developing countries and thus exporting its domestic emissions through south-south trade ([J. Meng et al., 2018b](#)). In addition to consumption-based accounting, an ownership-based accounting system could provide a new viewpoint of carbon emissions in the context of globalization and should be the subject of further research. According to the Paris Agreement, responsibilities for greenhouse gas mitigation have been kept within

individual borders. Our analysis reveals that, in addition to export of power equipment and engineering services, foreign direct investment is an important form of cross-border activities in today's globalized power sector. Investors from developed countries as well as China, with technology and capital advantages, are actively engaged in the power market of many developing countries. Such an accounting system requires substantial further research to establish. For instance, how should the responsibilities of project investor/owner be attributed with respect to banks, engineering companies and equipment manufacturers? These entities play different and also indispensable roles in the process of project development. Co-ownership is also an issue where fractional responsibility may need to be attributed. Should we quantify greenhouse gas emission responsibility based on percentage ownership for each shareholders in each project? Or should all the emission responsibility be attributed to the largest shareholder? These questions are beyond the scope of our analysis but addressing them is needed before such a system could be established. Quantifying such ownership-based carbon emissions could expose potentially huge cross-border carbon leakage. In the coal sector, for instance, Japan and Germany, in addition to China, have long been recognized as major coal investors in developing countries although they have also developed substantial domestic renewable energy markets.

In this paper, we introduce a novel approach to combine publicly accessible information with a commercial database and identify, at the unit level, Chinese ownership of global power projects. In the future, the methodology could be used to track ownership by other nationalities and to estimate the global carbon footprint of major power investing countries.

Declare of interest competing interest

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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Appendix A. Supplementary data

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