From the holdings of the Department of Special Collections , Princeton University Library, Princeton, NJ

These documents are either in the public domain, or can only be used for educational and research purposes (Fair use) as per U.S. Copyright law (text below). By accessing this file, all users agree that their use falls in the public domain or within fair use as defined by the copyrightlaw. We do not charge any permission or usage fees for the publication of images of material inour collections, including those provided by Princeton University Library, via our website, catalog, or directly from staff.For more information regarding copyright, credit, and citation please review the information onthe Copyright, Credit and Citation Guidelines page of our website.
https://library.princeton.edu/special-collections/policies/copyright-credit-and-citation-guidelines. If you have any questions, including how to order higher-quality images from the collection, contact Special Collections Public Services via our Ask Us! Form. https://library.princeton.edu/special-collections/ask-us

---

Doctoral Dissertations, 2011-2026 Public and International Affairs

2021

UNDERSTANDING THE ROLE OF CHINA IN THE POWER SECTOR OF OTHER DEVELOPING COUNTRIES

Li, Zhongshu

Princeton, NJ : Princeton University

---

http://arks.princeton.edu/ark:/88435/dsp01wh246w20n

U.S. Copyright law: The copyright law of the United States (Title 17, §108, United States Code) governs the making of photocopies or other reproductions of copyrighted material. Under certain conditions specified in the law, libraries and archives are authorized to furnish a photocopy or other reproduction. One of these specified conditions is that the photocopy or reproduction is not to be used for any purpose other than private study, scholarship, or research. If a user makes a request for, or later uses, a photocopy or reproduction for purposes in excess of fair use that user may be liable for copyright infringement. This institution reserves the right to refuse to accept a copying order if, in its judgment, fulfillment of the order would involve a violation of copyright law. https://www.copyright.gov/title17/title17.pdf

UNDERSTANDING THE ROLE OF CHINA IN THE POWER SECTOR OF OTHER DEVELOPING COUNTRIES

Zhongshu Li

A DISSERTATION

PRESENTED TO THE FACULTY

OF PRINCETON UNIVERSITY

IN CANDIDACY FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

RECOMMENDED FOR ACCEPTANCE BY

THE PRINCETON SCHOOL OF PUBLIC AND INTERNATIONAL AFFAIRS

Adviser: Denise L. Mauzerall

January 2021

Abstract

Facilitating renewable energy transition in developing countries' power sectors is critical to meet our climate targets. Since the early 2000s, China has been actively engaged with the power sector development in many developing countries through multiple forms of cross-border activities. As the Belt and Road Initiative further expands China's overseas impacts, Chinese climate policies can have significant impacts on global carbon emissions through governing Chinese domestic activities and through governing Chinese overseas activities. My dissertation focuses on improving the understanding on the scale and mechanisms of Chinese overseas activities in the global power sector.

Chapter 2 provides quantitative estimation of Chinese foreign direct investment in the global power sector. I find that Chinese firms hold $115 billion USD in power assets globally in a total capacity of 81 GW. The vast majority of Chinese investment goes to coal, gas and hydropower, while the share of wind and solar is relatively small but rising. The analysis also indicates that Chinese investors have utilized more efficient coal technologies with more end-of-pipe controls than non-Chinese firms.

Chapter 3 expands the quantitative analysis to all major forms of cross-border activities. I find that China was involved in 246 GW of new overseas power projects in other non-OECD countries from 2005 to 2018 with a diverse technology portfolio that includes coal, solar, and hydropower. The analysis also finds that the existing and expected future coal plants built before

2040 in other developing countries involving China would emit 9-77 Gton CO_2 over their lifetime, which adds 11-40% to China's power sector carbon emissions.

Chapter 4 analyzes the determinants of Chinese overseas financing in the global power sector using econometric models. On the push side, I find that exporting domestic overcapacity to overseas market could be an important driver for Chinese development finance in the power sector. On the pull side, I find that Chinese outward investment in overseas power projects could be driven by local demand pull from recipient countries. For other factors, I find that Chinese existing activities in the local power sector could facilitate future DF and FDI in recipient countries.

Acknowledgement

I would love to thank my advisor, committee members, professors, colleagues, friends and family. My dissertation would not be accomplished without their guidance and support over the past five and a half years.

I would love to firstly thank Professor Denise Mauzerall as my PhD advisor with my deepest gratitude. She has been an amazing advisor in guiding me through academic challenges and in helping me overcome non-academic barriers. Over the last five years, I have always enjoyed weekly meetings and conversations with her. Her visionary insights, rigorous thinking, and dedication to solving environmental challenges have set a great example for me to learn from. She also spent hundreds of hours to help me with my writings and communication skills. Without these meetings, I would never fully understand the importance of communication in science and in life. She also genuinely cares about me as her student and are supportive in helping me through challenges in life in general. Looking back to all the steps towards accomplishing this dissertation, her guidance and support were behind every single one.

I would also like to thank all my other committee members. Professor Kevin Gallagher introduced to me the field of development finance. This dissertation would be a complete different one if he did not offer me a pre-doc fellow at Boston University three years ago. I am extremely grateful that he provided his expertise in the field as well as warm encouragement for every bit of my work. Professor Jiahai Yuan is a respected Chinese scholar in the field of Chinese power sector. I enjoyed all the interesting conversations with him and appreciated his

guidance on my research. I would also like to thank Professor Wei Peng for her sincere support ever since I started my PhD at Princeton. Her passion for research and for life in general has inspired me a lot.

My academic study at Princeton also benefitted a lot from many other professors. Professor Joanna Lewis, Professor David Victor and Dr. Fabian Wagner were extremely helpful and supportive during my Ph.D. General Exams. Professor Lewis and Professor Victor introduced to me the field of political economy in Chinese power sector. It broadens my horizon and adds another dimension of my thinking on renewable energy transition. Dr. Wagner guided me through many important models and technologies needed in a decarbonized world. I also like to thank Professor Tobias Schmidt, Professor Robert Socolow and Professor Shiqiu Zhang who provided useful comments and guidance for my researches. The courses I took at Princeton also laid a solid foundation for this dissertation and I thank Professor Mitchell Small, Professor Tom Vogl, Professor Christopher Neilson, Professor Amy Craft, Professor Barry Rand, Professor Michael Oppenheimer, Professor Venkatachalam Ramaswamy, Professor Yi Ming, Professor Larry Horowitz, Professor John Ikenberry, Professor Andrew Moravcsik, Professor Gene Grossman, Dr. Anne Hoskins and Dr. Jeanne fox for their wonderful teaching.

I am also very grateful for the intellectual interactions and genuine support from my friends and colleagues in Denise's research group and the former STEP and now C-PREE community. I would love to say thank you to Professor Michael Oppenheimer and Professor David Wilcove for always being supporting and kind to me. I enjoyed all the hallway conversations with Professor Wilcove and they helped me a lot. I would also love to thank: Dr. Wei Peng, Dr. Yue Qin and Dr. Xiaoyuan Li, Dr. Phil Hannam, Dr. Yixin Guo, Xu Chen, Liqun Peng, Dr. Stuart

Riddick, DJ Rasmussen, Mayank Misra, Yixuan Zheng, and Dr. Da Pan, Xiangwen Fu, and Shangwei Liu, Mi Zhou, Feiqi Liu, Dr. Disha Sharma, Rohit Gupta, Mingwei Li, Hongxun Liu, Yiheng Tao, Yujie Wu, Malini Nambiar, Dr. Yang Guo, Chris Crawford, Helene Benveniste, and Nic Choquette-Levy. It has been my pleasure to meet all of you and I am grateful for your company in the last five year. I would also love to thank Charles Crosby and Keely Swan for always giving me warm greetings and preparing delicious food. My friends in the Chinese student community have also been important company over the years and I would love to thank: Yaofeng Zhong, Zhaorong Jin, Weitao Shuai, Lunyang Huang, Jianing Ying, Zidong Zhang, Yue Cao, Xuyuan Ai. I am also grateful to many other Princeton staff who have also helped me tremendously throughout these years: Ann Lengyal, Karen McGuiness, Barbara Hampton, Emily Sharples, Jimmy Wang. Although I decided to go back to Beijing after graduation, Princeton is no wonder my second home and I sincerely wish to meet every one of you again in the future.

In my third year, I spent four months at the Global Development Policy center at Boston University and I am very grateful that I met many interesting friends there. I would love to thank Dr. Youyi Zhang, Dr. Muyang Chen, Dr. Junda Jin, Xinyue Ma, Dr. William Kring, Dr. Rebecca Ray, and Rebecca Dunn and Professor Suchi Gopal for all the interesting conversations and happy hours.

Lastly, I would love to thank my family for always being supportive and caring.

Table of Contents

Abstract *2*

Acknowledgement *4*

Chapter 1: Introduction *8*

References **13**

Chapter 2: China's Global Power -Estimating Chinese Foreign Direct Investment in the Electric Power Sector *15*

1. Introduction **15**

2. Data and Methodology **18**

3. Results and Discussion **24**

4. Conclusions and Policy Implications **35**

References: **39**

Chapter 3: China's impact on non-OECD countries' power sector development *48*

1. Introduction **48**

2. Methodology **52**

3. Results **58**

4. Policy discussion **69**

References **72**

Chapter 4: Determinants of Chinese Outbound Energy Finance to Developing Countries *74*

1. Introduction **74**

2. Materials and method **77**

3. Results and discussion **84**

4. Concluding Discussion **97**

References **101**

Chapter 5: Conclusion *104*

Appendix for Chapter 2 ..... *108*

Appendix for Chapter 3 ..... *124*

Appendix for Chapter 4 ..... *127*

Chapter 1: Introduction

Decarbonizing the power sector is critical to avoid catastrophic changes in the climate system. In 2019, power sector was responsible for 42% of global carbon emission, or 28% of total greenhouse gas (GHG) emissions (IEA 2019), which makes power sector the single largest carbon emitting sector. More than 65% of the world electricity was generated from fossil fuel sources, including coal, gas and oil (BP 2019). The existing and proposed electricity infrastructures are also found to pose a severe and urgent threat to our commitment to limit global warming within 2° C by the end of the century (Tong et al., 2019). Driven by electrification of other end-use sectors, such as electric vehicles in the transportation sector, replacing combustion fuels for space and water heating in the building sector, the share of electricity supply in total energy production is expected to grow in the future, making power sector emissions to be even more important.

There have been positive signs showing an ongoing transition away from fossil fuel to renewable sources in the global power sector. Starting from the early 2010s, solar and wind power technologies have been able to increase their shares in the newly added power generation capacity. The transition is largely initiated by favorable energy policies to subsidize new solar or wind power projects, mostly in developed countries (Ouyang and Lin 2014; Nicolini and Tavoni 2017). As the scale of deployment increases, the high technology learning rate leads to a quick fall of levelized cost of electricity (LCOE) for solar and wind power projects (Mauleón 2016; Williams et al., 2017). In the case of China, the share of electricity generated from fossil fuel in China decreased from 81% in 2011 to 70% in 2019 and the share of renewable sources in annual added capacity grew from 18% in 2011 to 52% in 2019 (CEC 2020). Although the subsidies are

diminishing globally, renewable technologies are now able to outcompete fossil fuels economically without government subsidies in many cases.

Looking into the future, the current speed of renewable energy transition appears to be not fast enough to avoid catastrophic level of global warming. After two decades of efforts to reduce carbon emissions, the share of coal in global electricity generation remains relatively unchanged since the early 2000s at 40% level (IEA, 2019; BP 2019). Although the last five years witnessed a 5% growth in electricity supply from renewable generation sources, the established fossil-based power sector locks in substantial future carbon emission for decades, leaving little room for future coal plants without carbon capture and storage technologies (Socolow and Davis, 2014; Tong et al., 2019). Even worse, there are still 499 GW of new coal plants in pipeline, which is approximate 24% of the world existing coal power capacity (Shearer et al., 2020).

Decarbonizing the power sectors in developing countries is particularly important. While carbon emissions show signs of stabilizing and decreasing in some developed countries, there is a three-time growth in power sector carbon emission from developing countries. In 2018, the power sector emissions in non-OECD countries are twice as much as the power sector emissions in OECD countries (IEA, 2019). While developed countries have developed a mature power sector which locks in their future carbon emissions, most developing countries are still in the process of choosing development pathways, making it possible for a potential technology leapfrog from traditional fuels to renewable energy (Batinge et al., 2019; Arndt et al., 2019). Looking into the future, since we expect the electricity demand in developing countries to keep growing fast, clean energy transition in developing countries' power sector are critical for the global effort to mitigate greenhouse gas emissions.

China plays an important role both in its domestic power sector and in other developing countries. Being the largest developing economy and the largest carbon emitting country, renewable energy transition in China's domestic power sector is important. While China has established a fossil fuel based electricity supply infrastructure starting from the early 2000s and operates the largest coal fleet (1006 GW in 2018) in the world, China is also the largest market for renewable technologies. In the September of 2020, China's President Xi made an ambitious statement to reach carbon neutrality domestically in China by 2060, which signals an extremely positive sign for a renewable energy transition in China's domestic power sector. Beyond its border, China has also been deeply involved in the power sector development in other countries through providing finance and exporting power equipment and services. Like many other industries, development of a power sector is a globalized business. From the perspective of international trade, the sheer size of China's domestic market has helped China to develop a competitive domestic power industry to manufacture power equipment and deliver power engineering contracts for both traditional coal and hydropower projects and renewable projects (Gosens and Lu 2014; Hannam et al., 2015; Huang et al., 2016; Ren et al., 2017; Gao and Rai et al., 2019; Lacal-Arántegui 2019). From the perspective of finance, Chinese National Development Banks (NDBs) and state-owned power companies are also important sources of finance for new power projects in developing countries (Gallagher et al., 2018; Li et al., 2020; Chen et al., forthcoming). Moving forward, the Belt and Road Initiative (BRI) will help expand Chinese involvement in energy infrastructure development in other developing countries, leaving huge impacts on the local power sector development pathways. However, there has been very little policy attention addressed to decarbonize Chinese overseas activities and recent estimates

found that Chinese BRI projects in 15 selected countries to be extremely carbon intensive with only 9% of investments in green technologies (Ma and Zadek 2019; Tao et al., 2020).

The policy goal of this thesis is to help direct China's overseas activities to facilitate renewable energy transition in other developing countries and the thesis identifies three knowledge gaps to achieve this policy goal. First, there is an information gap on the scale of Chinese activities in the global power sector. Since neither China or the recipient countries have the obligations to report China's cross-border activities in the power sector, there is no official data to record where, when, and how China has been involved in the power sector development in other developing countries. Second, the potential impacts of China's overseas activities in the power sector on carbon emissions remains unclear. As the current annual emissions from these Chinese overseas activities remain low compared with Chinese domestic carbon emissions, this fact likely contributes to the lack of climate policy attention paid to Chinese overseas activities. However, it is important to assess in advance the life-cycle climate impacts of these Chinese overseas activities to inform timely policy decision. Both the growing trend of Chinese overseas activities and the lifetime emission of these long-standing infrastructure projects should be considered. Third, the determinants for Chinese overseas activities in the power sector are poorly understood. There have only been a handful of papers on the broad determinants of Chinese overseas activities across all sectors but very few with a focus in the power sector (Dreher et al., 2018; Kong and Gallagher 2019; Morris et al., 2020; Gallagher et al. forthcoming). Understanding the determinants of Chinese overseas activities is important to drive the change.

The thesis is structured as follows. **Chapter 2** develops a novel approach to track Chinese foreign direct investment in the global power sector, combining commercial databases and public

resources. It provides the first overall landscape of Chinese foreign direct investment in the global power sector, which fills the existing knowledge gap of China's role in the global power sector in addition to China's development finance. **Chapter 2** further analyzes the installed coal technology and penetration rate of end-of-pipe control technologies in coal plants in which Chinese companies invested and compares them with coal plants receiving non-Chinese financing. **Chapter 3** builds up upon **Chapter 2** and provides an overview of China's existing involvement in the power sector in other developing countries across all forms of involvement, including development finance, foreign direct investment, export of power equipment, and export of engineering services. **Chapter 3** further estimates the future carbon emissions from Chinese overseas activities in other non-OECD countries' coal power sector. **Chapter 4** develops a "push and pull" analytical framework to examine the potential determinants of Chinese foreign direct investment and development finance in overseas power projects. **Chapter 4** applies fixed effect econometric models to quantitatively examine each of the push, pull and control factors to understand how they determine Chinese overseas financing in power projects.

References

Adom, P.K., 2011. Electricity consumption-economic growth nexus: the Ghanaian case. *International Journal of Energy Economics and Policy*, *1*(1), p.18.

Arndt, C., Arent, D., Hartley, F., Merven, B. and Mondal, A.H., 2019. Faster Than You Think: Renewable Energy and Developing Countries. *Annual Review of Resource Economics*, *11*, pp.149-168.

Audoly, R., Vogt-Schilb, A., Guivarch, C. and Pfeiffer, A., 2018. Pathways toward zero-carbon electricity required for climate stabilization. *Applied energy*, *225*, pp.884-901.

Batinge, B., Musango, J.K. and Brent, A.C., 2019. Sustainable energy transition framework for unmet electricity markets. *Energy Policy*, *129*, pp.1090-1099.

China Electricity Council, 2020. Zhongguodianlihangyeniandufazhanbaogao. https://www.cec.org.cn/upload/zt/ngfzbg2020/index.html

Christine Shearer, Lauri Myllyvirta, Aiqun Yu, Greig Aitken, Neha Mathew-Shah, Gyorgy Dallos, and Ted Nace, 2020. Boom and Bust 2020: Tracking The Global Coal Plant Pipeline.

Clarke, L., Jiang, K., Akimoto, K., Babiker, M., Blanford, G., Fisher-Vanden, K., Hourcade, J.C., Krey, V., Kriegler, E., Löschel, A. and McCollum, D., 2014. Assessing transformation pathways.

Davis, S.J. and Socolow, R.H., 2014. Commitment accounting of CO2 emissions. *Environmental Research Letters*, *9*(8), p.084018.

Dreher, A., Fuchs, A., Parks, B., Strange, A.M. and Tierney, M.J., 2018. Apples and dragon fruits: The determinants of aid and other forms of state financing from China to Africa. *International Studies Quarterly*, *62*(1), pp.182-194.

Gallagher KS, Rishikesh Ram Bhandary, Easwaran Narassimhan, and Nguyen Quy Tam. Drivers of Chinese Overseas Investments in Coal-Fired Power. Energy Research and Social Science. Forthcoming.

Gallagher, K.P., Kamal, R., Jin, J., Chen, Y. and Ma, X., 2018. Energizing development finance? The benefits and risks of China's development finance in the global energy sector. *Energy policy*, *122*, pp.313-321.

Gao, X. and Rai, V., 2019. Local demand-pull policy and energy innovation: Evidence from the solar photovoltaic market in China. *Energy Policy*, *128*, pp.364-376.

Gosens, J. and Lu, Y., 2014. Prospects for global market expansion of China's wind turbine manufacturing industry. *Energy Policy*, *67*, pp.301-318.

Hannam, P.M., Liao, Z., Davis, S.J. and Oppenheimer, M., 2015. Developing country finance in a post-2020 global climate agreement. *Nature Climate Change*, *5*(11), pp.983-987.

Huang, P., Negro, S.O., Hekkert, M.P. and Bi, K., 2016. How China became a leader in solar PV: An innovation system analysis. *Renewable and Sustainable Energy Reviews*, *64*, pp.777-789.

International Energy Agency, 2019. *World energy outlook*. IEA/OECD.

Kong, B. and Gallagher, K.P., 2019. *Globalization as Domestic Adjustment: Chinese Development Finance and the Globalization of China's Coal Industry*. GCI Working Paper 04/2019, Global

Development Policy Center, Boston University: http://www. bu. edu/gdp/files/2019/04/GCI-GDP. WP6-Globalization-as-Domestic-Adjustment-Kong-Gallagher. pdf.

Lacal-Arántegui, R., 2019. Globalization in the wind energy industry: contribution and economic impact of European companies. *Renewable energy*, *134*, pp.612-628.

Li, Z., Gallagher, K.P. and Mauzerall, D.L., 2020. China's global power: Estimating Chinese foreign direct investment in the electric power sector. *Energy Policy*, *136*, p.111056.

Ma, J. and Zadek, S., 2019. Decarbonizing the Belt and Road: A Green Finance Roadmap. *Tsinghua University Center for Finance and Development, Vivid Economics and the Climateworks Foundation*.

Mauleón, I., 2016. Photovoltaic learning rate estimation: Issues and implications. *Renewable and Sustainable Energy Reviews*, *65*, pp.507-524.

Nicolini, M. and Tavoni, M., 2017. Are renewable energy subsidies effective? Evidence from Europe. *Renewable and Sustainable Energy Reviews*, *74*, pp.412-423.

Ouyang, X. and Lin, B., 2014. Impacts of increasing renewable energy subsidies and phasing out fossil fuel subsidies in China. *Renewable and sustainable energy reviews*, *37*, pp.933-942.

Peng, R., Chang, L. and Liwen, Z., 2017. China's involvement in coal-fired power projects along the Belt and Road. *Global Environmental Institute.*

Petroleum, B., 2019. BP Energy Outlook 2019 edition. *Outlook to*, *2035*.

Rogelj, J., Shindell, D., Jiang, K., Fifita, S., Forster, P., Ginzburg, V., Handa, C., Kheshgi, H., Kobayashi, S., Kriegler, E. and Mundaca, L., 2018. Mitigation pathways compatible with 1.5 C in the context of sustainable development.

Tang, C.F. and Tan, E.C., 2013. Exploring the nexus of electricity consumption, economic growth, energy prices and technology innovation in Malaysia. *Applied Energy*, *104*, pp.297-305.

Tao, Y., Liang, H. and Celia, M.A., 2020. Electric power development associated with the Belt and Road Initiative and its carbon emissions implications. *Applied Energy*, *267*, p.114784.

Tong, D., Zhang, Q., Zheng, Y., Caldeira, K., Shearer, C., Hong, C., Qin, Y. and Davis, S.J., 2019. Committed emissions from existing energy infrastructure jeopardize 1.5 C climate target. *Nature*, *572*(7769), pp.373-377.

Williams, E., Hittinger, E., Carvalho, R. and Williams, R., 2017. Wind power costs expected to decrease due to technological progress. *Energy Policy*, *106*, pp.427-435.

Yuksel, T., Tamayao, M.A.M., Hendrickson, C., Azevedo, I.M. and Michalek, J.J., 2016. Effect of regional grid mix, driving patterns and climate on the comparative carbon footprint of gasoline and plug-in electric vehicles in the United States. *Environmental Research Letters*, *11*(4), p.044007.

Chapter 2: China's Global Power -Estimating Chinese Foreign Direct Investment in the Electric Power Sector

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 (Urban et al., 2013). 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; Wiig and Kolstad, 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, Gallagher et al., (2018) estimated that, for the period 2000-2014, the Chinese Development Bank and Chinese Export-Import 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 billon USD or 43% of the total Chinese development finance for the power sector, followed by hydro power projects at $36 Billon 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 FDiMarket (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 investment 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 (SO_2, 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 inqueries 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. Figure 1a and 1b show 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 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, 25otaling 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 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 Figure 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 Figure 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.

Figure 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 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, Figure 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 Figure 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 (MOFCOM, 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 Figure 4b. In Cambodia, as the most extreme example, almost 80% of the generating capacity is owned by Chinese companies. For the countries in Figure 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 feature of Chinese investment compared to its western counterparts. Figure 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). Nontheless, 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 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 et al., 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 supercriticial 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 supercritical 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 (SO_2) 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 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 SO_2 (93%), NO_x (30%), and particulate matter air pollution control (82%) technology than ROW plants, which have lower penetration rates of SO_2 (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 2003-2014, 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 degrees Celsius 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 (Birol 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 nations 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; Meng et al., 2018). 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 (Meng et al., 2018). 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.

Acknowledgements

This chapter is published as **Li, Z.**, Gallagher, K.P. and Mauzerall, D.L., 2020. China's global power: Estimating Chinese foreign direct investment in the electric power sector. *Energy Policy*, *136*, p.111056. An earlier version of Chapter 2 was presented at the China Global Research Colloquium hosted by the Global Development Policy Center at Boston University on April. 25, 2018. Zhongshu Li thanks the co-authors of this paper.

References:

Birol, F., 2018. World energy outlook 2018. *International Energy Agency*.

Chen, H. and Schmidt, J., 2017. Power shift: shifting G20 international public finance from coal to renewables. *Natural Resources Defense Council (NRDC), December*.

Chen, W., Dollar, D. and Tang, H., 2016. Why is China investing in Africa? Evidence from the firm level. *The World Bank Economic Review*, *32*(3), pp.610-632.

Heritage Foundation., 2017. China Global Investment Tracker. https://www.heritage.org/asia/report/china-global-investment-tracker.

Conrad, B. and Kostka, G., 2017. Chinese investments in Europe's energy sector: Risks and opportunities?

Dealogic., 2017. Online database*, accessed October*, *2017*.

Davis, S.J. and Socolow, R.H., 2014. Commitment accounting of CO2 emissions. *Environmental Research Letters*, *9*(8), p.084018.

Du, H., Guo, J., Mao, G., Smith, A.M., Wang, X. and Wang, Y., 2011. CO2 emissions embodied in China–US trade: Input–output analysis based on the emergy/dollar ratio. *Energy Policy*, *39*(10), pp.5980-5987.

Gallagher K. and Qi Q., 2018. Policies Governing China's Overseas Development Finance Implications for Climate Change, The Center for International Environmental & Resource Policy.

Franco, A. and Diaz, A.R., 2009. The future challenges for "clean coal technologies": joining efficiency increase and pollutant emission control. *Energy*, *34*(3), pp.348-354.

Gallagher K. Rohini K., Junda J., Yanning C., and Xinyue M., 2018. Energizing Development Finance? The benefits and risks of China's development finance in the global energy sector. *Energy Policy*, 122, pp.313-321.

Gallagher, K., 2007. Toward a Theory of Innovation and Industrial Pollution: Evidence from Mexican Manufacturing, *Industrial Innovation and Environmental Regulation*, Saeed Parto and Brent Herbert-Copley (eds), New York, United Nations University Press.

Gippner, O. and Torney, D., 2017. Shifting policy priorities in EU-China energy relations: Implications for Chinese energy investments in Europe. *Energy Policy*, *101*, pp.649-658.

Global Coal Exit List., 2018. Online database, accessed March, 2018.

Gopal, S., Pitts, J., Li, Z., Gallagher, K. and Kring, W., 2018. Fueling Global Energy Finance: The Emergence of China in Global Energy Investment. *Energies*, *11*(10), 2804.

Hannam, P.M., Liao, Z., Davis, S.J. and Oppenheimer, M., 2015. Developing country finance in a post-2020 global climate agreement. *Nature Climate Change*, *5*(11), p.983.

Hervé-Mignucci, M. and Wang, X., 2015. Slowing the Growth of Coal Power Outside China: The Role of Chinese Finance. *Climate Policy Initiative*.

IEA., 2016. World Energy Outlook 2016. Organisation for Economic Co-operation and Development, OECD.

IPCC., 2018. Global Warming of 1.5 °C. Intergovernmental Panel on Climate Change.

IRENA., 2018, Renewable Power Generation Costs in 2017, International Renewable Energy Agency, Abu Dhabi.

Jiang, W., 2009. Fuelling the dragon: China's rise and its energy and resources extraction in Africa. *The China Quarterly*, *199*, pp.585-609.

Kolstad, I. and Wiig, A., 2011. Better the devil you know? Chinese foreign direct investment in Africa. *Journal of African Business*, *12*(1), pp.31-50.

Kong, B. and Gallagher, K.P., 2017. Globalizing Chinese Energy Finance: The Role of Policy Banks. *Journal of Contemporary China*, *26*(108), pp.834-851.

Lin, L.W. and Milhaupt, C.J., 2013. We are the (national) champions: Understanding the mechanisms of state capitalism in China. *Revista Chilena de Derecho*, *40*, p.801.

McGlade, C. and Ekins, P., 2015. The geographical distribution of fossil fuels unused when limiting global warming to 2 C. *Nature*, *517*(7533), p.187.

Meng, B., Peters, G.P., Wang, Z. and Li, M., 2018. Tracing CO2 emissions in global value chains. *Energy Economics*, *73*, pp.24-42.

Meng, J., Mi, Z., Guan, D., Li, J., Tao, S., Li, Y., Feng, K., Liu, J., Liu, Z., Wang, X. and Zhang, Q., 2018. The rise of South–South trade and its effect on global CO 2 emissions. *Nature communications*, *9*(1), p.1871.

Ministry of Commerce People's Republic of China., 2017. Zhongguo Zhijie Duiwai Touzi Tongji Gongbao 2016.

Pareja-Alcaraz, P., 2017. Chinese investments in Southern Europe's energy sectors: Similarities and divergences in China's strategies in Greece, Italy, Portugal and Spain. *Energy Policy*, *101*, pp.700-710.

Peng, R., Chang, L. and Liwen, Z., 2017. China's involvement in coal-fired power projects along the belt and road. *Global Environmental Institute*.

Peters, G.P., Minx, J.C., Weber, C.L. and Edenhofer, O., 2011. Growth in emission transfers via international trade from 1990 to 2008. *Proceedings of the national academy of sciences*, p.201006388.

Pfeiffer, A., Hepburn, C., Vogt-Schilb, A. and Caldecott, B., 2018. Committed emissions from existing and planned power plants and asset stranding required to meet the Paris Agreement. *Environmental Research Letters*, *13*(5), p.054019.

Platts 2015. "Data Base Description and Research Methodology UDI World Electric Power Plants Data Base". McGraw Hill Financial, Washington DC.

Ray, R., Gallagher, K., 2017. China-Latin America economic bulletin 2017 edition. *Global Economic Governance Initiative, Boston University: Boston*.

Shearer, C., Brown, M., Buckley, T., 2019. China at a Crossroads: Continued Support for Coal Power Erodes Country's Clean Energy Leadership. *Institute for Energy Economics and Financial Analysis.*

Schreifels, J.J., Fu, Y. and Wilson, E.J., 2012. Sulfur dioxide control in China: policy evolution during the 10th and 11th Five-year Plans and lessons for the future. *Energy Policy*, *48*, pp.779-789.

Tan, X., Zhao, Y., Polycarp, C. and Bai, J., 2013. China's overseas investments in the wind and solar industries: trends and drivers. *World Resources Institute Working Paper*.

Times, F., 2017. fDiMarkets. *Online database, accessed October*, *2017*.

Tracker, G.C.P., 2017. Global coal plant tracker.

UNCTAD, U., 2017. World Investment Report 2017: Investment and the Digital Economy.

Victor, D.G. and Heller, T.C. eds., 2007. *The political economy of power sector reform: the experiences of five major developing countries*. Cambridge University Press.

Wei, Hanyang., 2018. Chinese Power Companies' Global Investment Strategies: Seeking returns and managing risks. *Bloomberg New Energy Finance*.

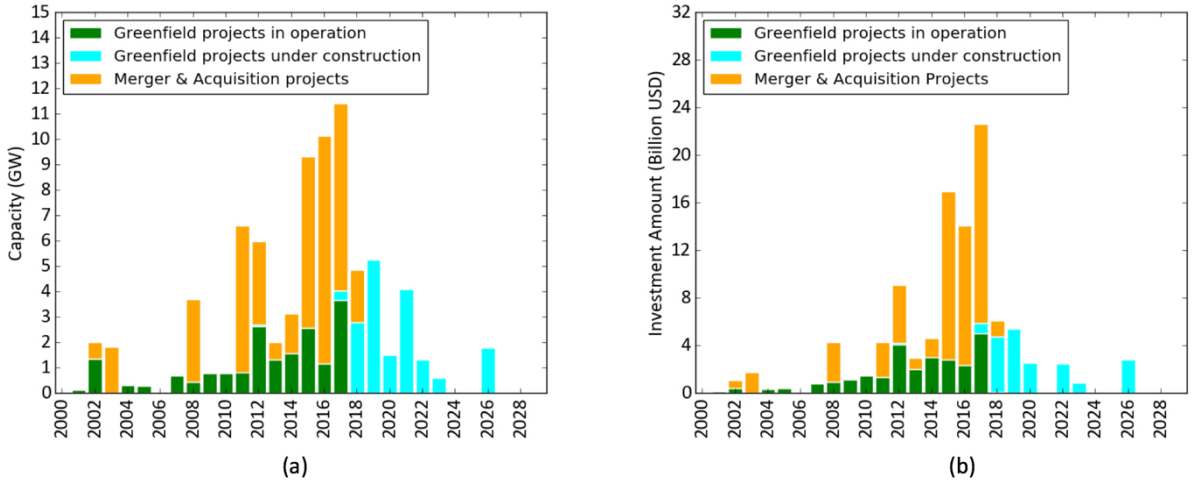


Figure 1. (a) Time-series trend of Chinese outward investment in the electric power sector by capacity (left) and (b) by investment amount (right) based on data collected through 2017. For greenfield projects, the project date is defined as the first year or expected year of operation. For acquired projects,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

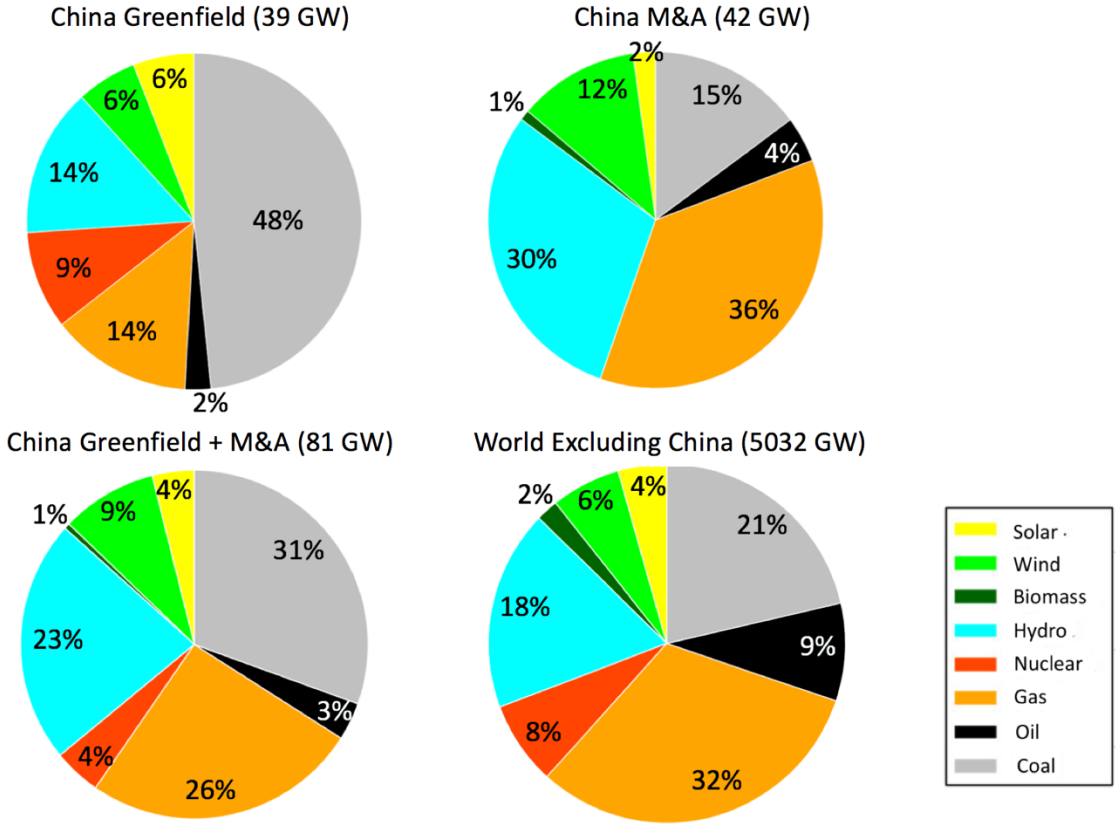


Figure 2. Electricity generation technology mix of Chinese outward greenfield investment, M&A investment, greenfield and M&A combined and the electricity generation technology mix

of the entire world excluding China's domestic market for the year 2016. The percentage is calculated by capacity (MW).

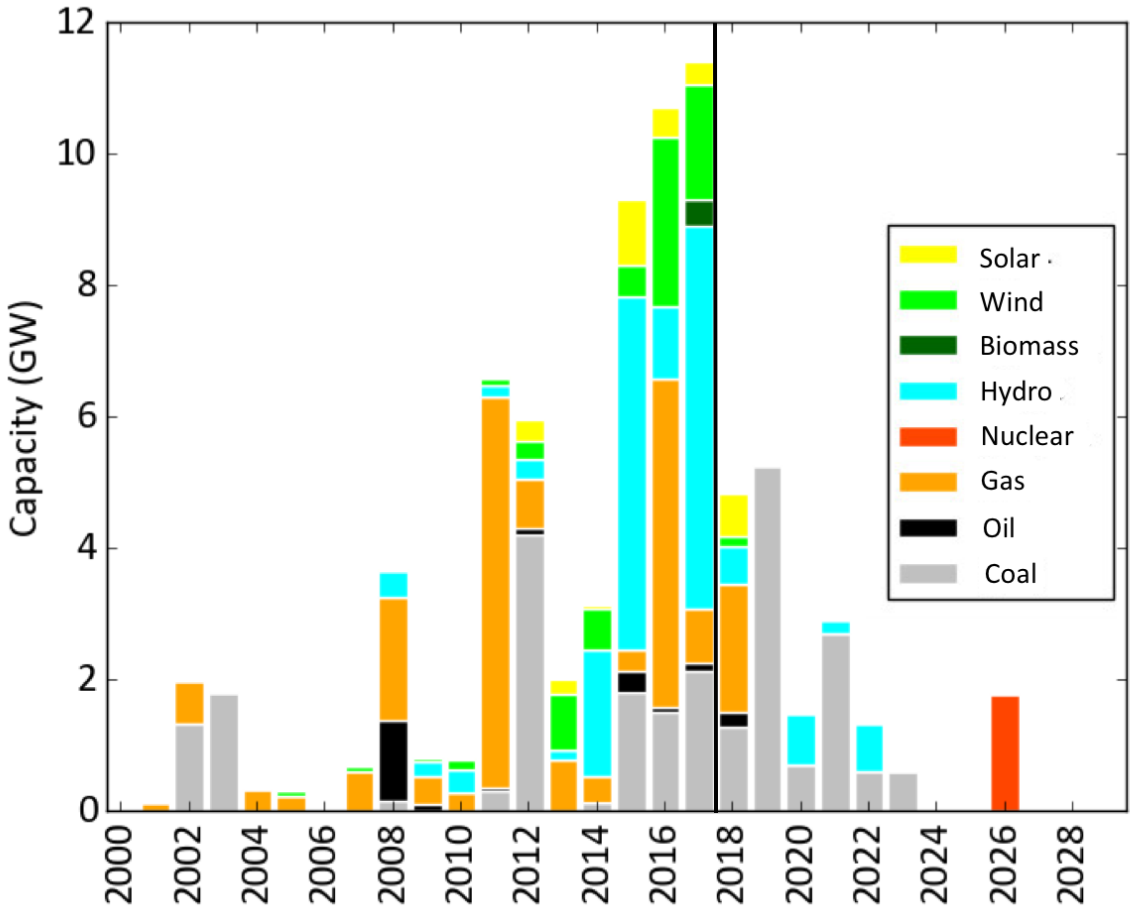
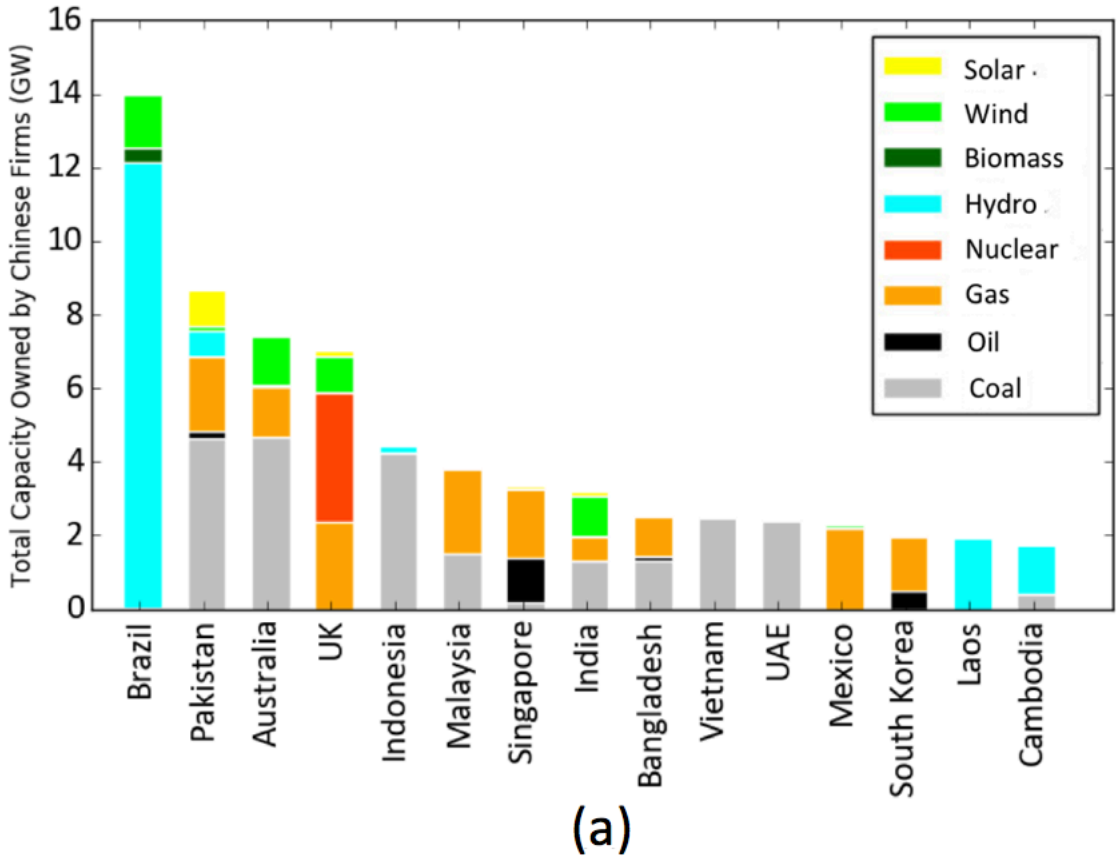
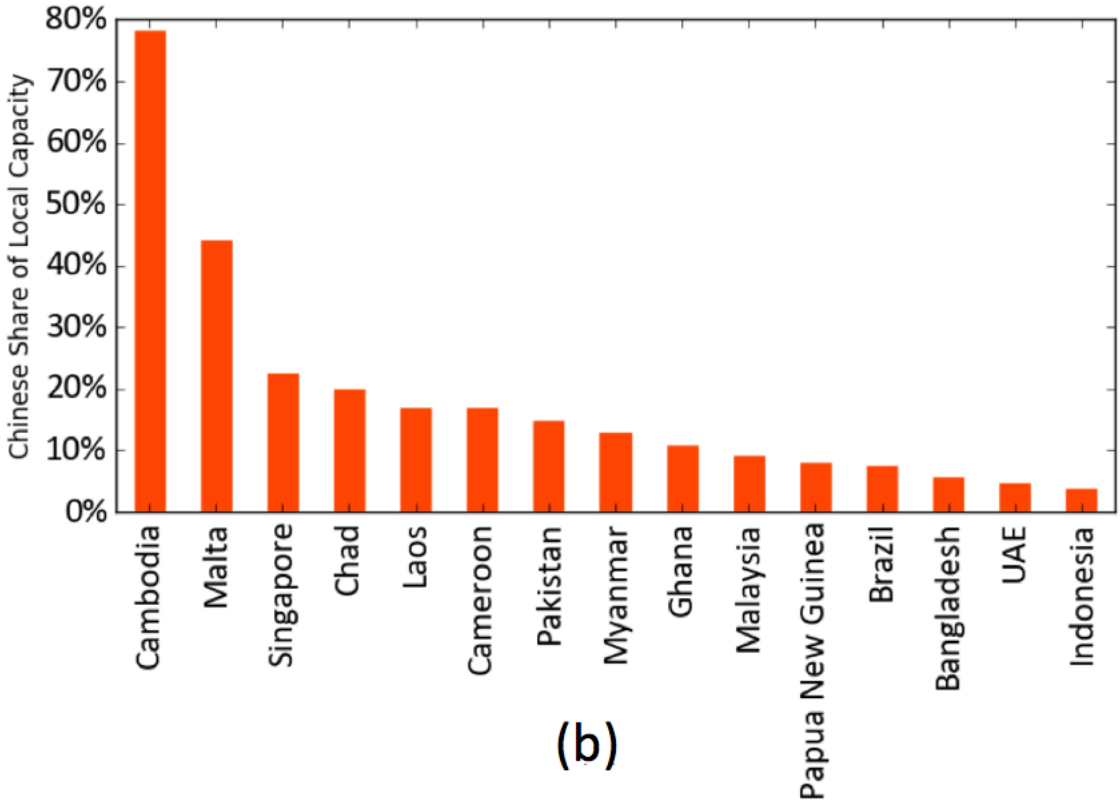


Figure 3. Time-series of Chinese outward greenfield and M&A investment (measured by capacity) in the electric power sector by technology type from 2000 to 2029 based on data collected through 2017 (vertical line). For greenfield projects, the project date is defined as the first or expected year of operation. 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.


Total Capacity Owned by Chinese Firms (GW)
16
14
12
10
8
6
4
2
0
Solar
Wind
Biomass
Hydro
Nuclear
Gas
Oil
Coal
Brazil
Pakistan
Australia
UK
Indonesia
Malaysia
Singapore
India
Bangladesh
Vietnam
UAE
Mexico
South Korea
Laos
Cambodia

(a)


Chinese Share of Local Capacity
80%
70%
60%
50%
40%
30%
20%
10%
0%
Cambodia
Malta
Singapore
Chad
Laos
Cameroon
Pakistan
Myanmar
Ghana
Malaysia
Papua New Guinea
Brazil
Bangladesh
UAE
Indonesia

(b)

Figure 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.

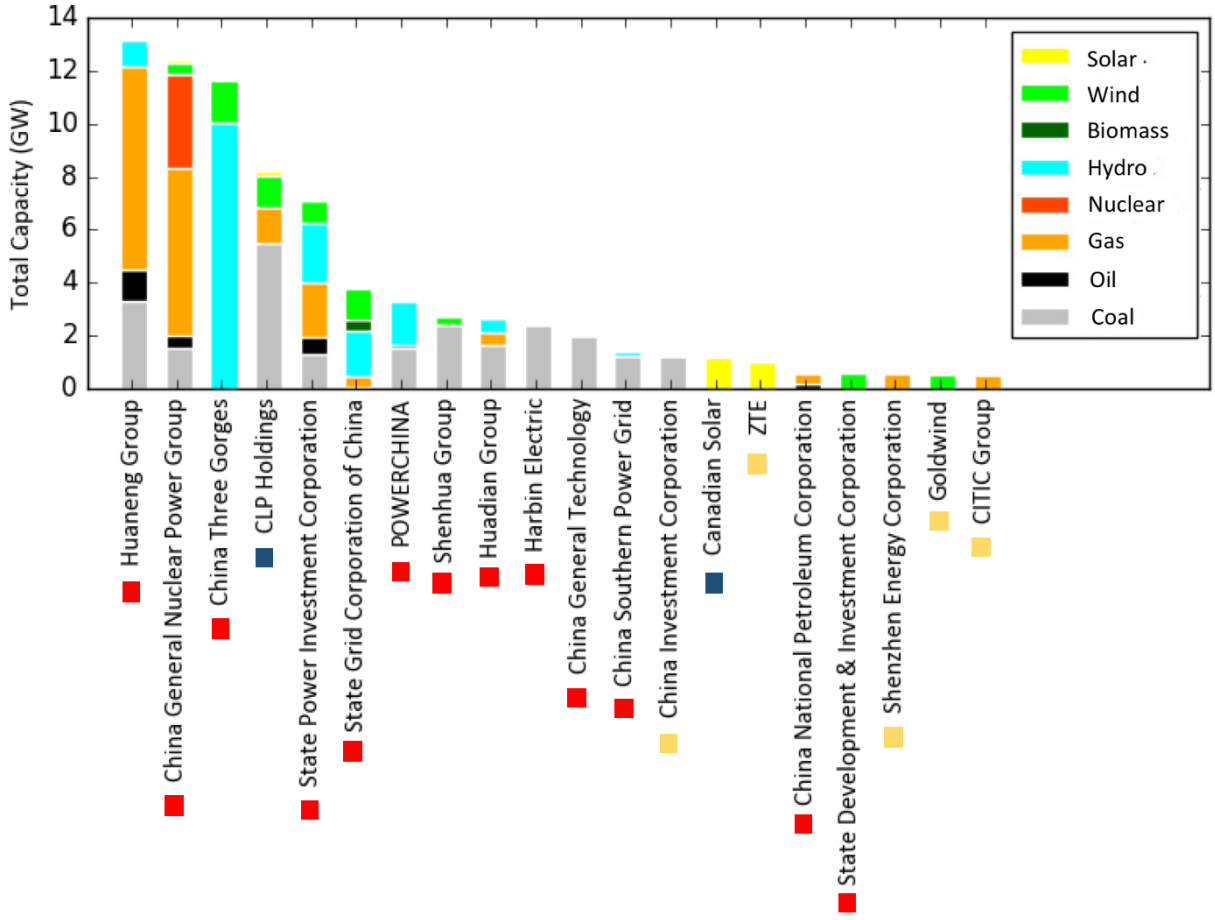


Figure 5. Top Chinese companies investing in overseas electricity generation by total capacity of each type of generation overseas. Companies are categorized into central SOEs (red), local SOEs (yellow), and non-SOEs (blue). SOE: State-Owned-Enterprises.

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%

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

	Chinese Greenfield Investment[1]	Non-Chinese Greenfield Investment[2]	Chinese M&A Investment[3]
Recipient Countries	Indonesia, Pakistan, Vietnam, Cambodia, India	Indonesia, Pakistan, Vietnam, Cambodia, India	Australia, Singapore, Malaysia
Time Period[4]	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%)

[1] Direct investment by China in new coal power plants which became operational between 2011-2017. 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.

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

[3] 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.

[4] 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.

Chapter 3: China's impact on non-OECD countries' power sector development

1. Introduction

Decarbonizing developing countries' power sectors faces enormous challenges but is a critical step in meeting the greenhouse gas mitigation targets in the Paris Agreement. While there are signs of slowdown and decrease of emission in the power sector of many developed economies, International Energy Agency (IEA) still expects carbon emissions in developing countries' power sector to grow in most of its future scenarios (IEA 2019). The established fossil-fuel based energy infrastructure, fast growing electricity consumption and slow penetration of low-carbon power generating technologies are important obstacles for a low-carbon transition in developing countries. While coal-fired power plant is the most carbon intensive power generating technology, it is the world's largest source of fuel for electricity. Even worse, there are also 499 GW of new coal plants in pipeline, which is approximate 24% of the world existing coal power capacity (Shearer et al., 2020). Adding the existing and proposed power projects, Tong et al., 2019 estimated that the existing and purposed electricity infrastructures have already committed to 52% of the remaining carbon budget under 2° C scenario.

Being the largest developing economy and the country with the largest carbon emissions, China's role in influencing global carbon emissions is enormous. Among all sectors, China's power sector attracts the most attention, given its lion share in China's carbon emissions (51% in 2018) and the growing trend of electrification in other end-use sectors (Yuksel et al., 2016; Audoly et al., 2018; IEA 2019). Since the early 2000s, China has established a fossil fuel based electricity supply infrastructure and operates the largest coal fleet (1006 GW in 2018) in the world. The share of electricity generated from fossil fuel in China peaked at 93% in 2006 and

decreased to 70% in 2018 (IEA 2007; IEA 2019). China is also the largest market for renewable technologies and the share of renewable sources in annual added capacity grew from a tiny amount in 2008 to 52% in 2019 (CEC 2020).

Beyond its border, China has also been deeply involved in the power sector development of other countries via both international trade and cross-border finance. Like many other industries, the development of the power sector is a globalized business. From the perspective of international trade, developed countries have been exporting key power equipment and engineering services to developing countries where there is a lack of industrial capacity (Hannam, 2016). The sheer size of China's domestic market has helped China to develop competitive domestic power industries to manufacture power equipment and deliver power engineering contracts. There have been several existing studies on Chinese export in the coal sector and they find that China has exported coal power equipment and engineering services to 128 GW of new coal plants in 58 countries since 2005 (Hannam et al., 2015; Ren et al., 2017). China has also developed a globally competitive renewable energy industry and is home to more than 80% of the world's solar manufacturing capacity (Huang et al., 2016; Gao and Rai et al., 2019). China's wind manufacturing industry is also gaining in global competitiveness (Gosens and Lu 2014; Lacal-Arántegui 2019). From the perspective of cross-border finance, foreign sources of finance are important in developing new power capacity in developing countries. Multilateral development banks (MDBs) and national development banks (NDBs) provide development finance to developing countries and Chinese NDBs have grew to become the largest NDB in financing power projects (Steffen and Schmidt 2019; Chen et al., forthcoming). Commercial banks also provide loans to power projects in developing countries, but these activities are much less transparent than loans provided by development banks. In addition to banks, international power

developers invest in overseas power projects using their retained earnings or loans from banks. Such foreign direct investment (FDI) is another important source of finance. For energy mix of these cross-border finance from China, Gallagher et al., 2018 found out that the majority (64%) of Chinese development finance goes to coal-fired power plants while Li et al., 2020 estimated that Chinese foreign direct investment is more diversified in gas (32%), coal (21%) and hydropower plants (18%).

Analyzing the role of China in non-OECD countries' power sector development and the impact this will have on future carbon dioxide emissions is the focus of this paper. There has not been a comprehensive analysis that takes into account the entire breadth of Chinese overseas involvement in other developing countries' power sectors. A complete analysis across key forms of Chinese involvement and key power generating technologies can establish an important baseline to understand the role of China in the global power sector without sectoral biases. To this end, the first goal of this paper is to provide a quantitative analysis on Chinese overseas involvement in power projects built in other developing countries from 2005 to 2018. We will include Chinese export of power equipment, export of engineering services, Chinese development finance and foreign direct investment. We will cover coal, gas, oil, hydro, solar, wind and nuclear power projects.

The second goal of this paper is to provide quantitative analysis to inform Chinese policy makers about the scale and importance of future carbon emissions from Chinese overseas involvement. While China has announced and implemented a series of climate policies to decarbonize its domestic economy, there has been relatively fewer and weaker climate policies governing China's overseas involvement. Recent estimates found that Chinese BRI projects in 15 selected

countries to be extremely carbon intensive with only 9% of investments in green technologies (Ma and Zadek 2019; Tao et al., 2020). As Chinese overseas involvement in the power sector today and its carbon emission is still small relative to Chinese domestic power sector, this fact likely contributes to the lack of climate policy attention paid to Chinese overseas activities. However, it is important to consider both the growing trend of the overseas power sector and the lifetime emission of the long-standing infrastructure projects. In this paper, we will focus exclusively on coal plants and they are the largest carbon emitting source in the power sector. Taking into account the growing size of power sector in other developing countries and the long-lifetime nature of coal power plants, we will compare the carbon emissions from overseas coal plants involving China with the carbon emissions from China's domestic emissions across different future scenarios. We will also put these carbon emissions amount in the context of the remaining global carbon budget. While President Xi has made an ambition statement at the United Nations to decarbonize China's economy domestically, we expect the results of this paper to improve our understanding on the relative importance of Chinese overseas carbon footprint and attract more policy attention towards it.

The paper is structured as followed. In methodology section, we will go through the sources of the data we use and the scenarios we develop for future emission analysis. In the results section, first, we will present an overview of how China has been involved in developing countries' power sector since 2005. Second, we will present results of the carbon emissions for both Chinese domestic coal plants and overseas coal plants under different scenarios. In the last section, we discuss the policy implications of our analysis.

2. Methodology

2.1 Data for Chinese existing involvement in developing countries

2.1.1 Foreign direct investment and Development Finance

We obtain information on projects receiving Chinese foreign direct investment or development finance from Chinese Global Energy Finance Database published by Boston University (Gallagher et al., 2020). It includes a comprehensive list of projects receiving Chinese development finance or foreign direct investment. The project information includes date of commission, type of power generating technology, location, capacity etc. coal, gas, oil, hydro, solar, wind and nuclear power are included.

2.1.2 Trade of equipment and engineering services

For power projects using power equipment or engineering services importing from China, we use a variety of sources, including World Electric Power Plant database (WEPP), UN Comtrade database and reports from Chinese Photovoltaic Industry Association (CPIA) and Chinese Renewable Energy Industries Association (CREIA). For traditional power generating technologies, including coal, hydropower, nuclear, gas and oil power, we use WEPP to obtain information on projects using Chinese equipment or Chinese engineering services (Platts 2019). WEPP provides nationality information of the manufacturers for key power equipment and engineering contractors for project construction or project design at the project level. While WEPP has a comprehensive coverage for traditional power generating technologies, it is considered to have a relatively poor coverage of solar and wind projects. We obtained the aggregate total capacity of Chinese export of solar and wind equipment to the world from reports published by CPIA and CREIA. However, these reports do not have detailed capacity information for developing countries at country level. We compared the aggregated capacity

reported by Chinese organization with the aggregate capacity we obtained from WEPP for solar and wind projects using Chinese equipment. The comparison results are shown in Figure S1, suggesting that WEPP has a good coverage for wind projects but underestimates Chinese solar export substantially. Therefore, we use WEPP as the source to track wind projects in developing countries importing equipment or engineering services from China. For solar projects, we use a combination of the aggregate number reported by CPIA and country level data published by UN Comtrade (UN Comtrade 2019). In UN Comtrade database, bilateral trade value between any two countries are recorded and all traded commodities fall into a six-digit classification code (Harmonized System Code). Solar cell, solar module and other photo-sensitive semiconductors are included in the same the code (HS.854140). The trade value within the code likely overestimates the total value of Chinese export of solar equipment since some photo-sensitive semiconductors are not used for solar projects. We compare the total value China exported to the world under 854140 reported by UN Comtrade with the aggregate value reported CPIA and the result is shown in Figure S1. There is an overestimation by UN Comtrade but the annual trend agrees pretty well. We then use the aggregate number reported by CPIA as a scale to calibrate the country level data reported by UN Comtrade, under the assumption that the extent of overestimation is the same across all countries.

2.1.3 The issue of double counting

There are projects receiving multiple forms of Chinese involvement. For instance, a coal power project could be financed by Chinese power developers and also uses coal equipment exported from China. For all power technologies excluding solar, we obtain all Chinese involvement information from WEPP, which is based on individual projects. Therefore, we have complete information on the extent of such overlap of involvement for all power generating technologies

excluding solar power and we count each plant only once. For solar projects, all projects receiving Chinese finance use Chinese equipment. We therefore use the total exported capacity for all forms of Chinese involvement for solar projects.

2.2 Future Emission Projections of Coal Plants

2.2.1 Future Emission Scenarios

We use the future power capacity projections in developing countries published by IEA in the World Energy Outlook 2019. We use their three future scenarios for development of the power sector in non-OECD (developing) countries. The current policy scenario (CPS) is the most carbon intensive scenario where only existing green policies are taken into account. The stated policy scenario (SPS) reflects not only the impact of existing policy frameworks but also announced policy intentions. The sustainable development scenario (SDS) is the least carbon intensive and includes a major transformation in the power sector to meet the 2DC target, which aims to stop the global surface temperature from increasing more than 2° C by 2100.

For each future scenario developed by IEA, we design three sub-scenarios of the way China may facilitate non-OECD countries development of their coal power projects. In the Business As Usual (BAU) scenario, China will continue to be involved with new coal projects in other developing countries. From 2010 to 2017, China was involved with 45% of all new coal power projects in developing countries and BAU expects China to continue to be involved with 45% of all new coal plants from 2019-2040, inclusive. In the No Coal Finance (NCF) scenario, China will not provide new finance to any new coal plants overseas but will complete already committed projects. From 2010 to 2017, China has been exporting coal equipment and engineering services to 26% of all the new coal power projects in developing countries and NCF

expects China to continue to export power equipment and engineering services to 26% of new coal plants from 2019-2040, inclusive. In the Green As Domestic (GAD) scenario, we expect the share of coal in Chinese overseas involvement for all power technologies to be the same as the share of new coal plants in the Chinese domestic power sector by capacity in any given year between 2019 and 2040, inclusive leading to reduced overseas carbon emissions. The new capacity of all power plants in developing countries excluding China varies across different IEA scenarios and are given by IEA. We assume total Chinese involvement in all new power capacity additions in developing countries to be the same as it is from 2010 to 2017, which is 24%. The amount of coal plant capacity China will be involved since 2019 is quantified using the equation below. The share of new coal plants in China's domestic power sector varies across different IEA scenarios and we quantify them accordingly. In these three sub-scenarios, we assume how China is involved with the power sector development in other non-OECD countries to have no effect on the future coal power sector development in other countries. The total carbon emissions in non-OECD countries still follow the three IEA scenarios. In other words, the three sub-scenarios present three different allocation schemes to account for Chinese future overseas carbon emissions. While we acknowledge that how China is involved in the new coal power plants in other countries would influence the local carbon emissions, the mechanisms behind remained poorly investigated. Our analysis presents a first-order estimation on the future outlook of Chinese overseas carbon emissions in coal power sector.

$$\text{New capacity of overseas coal plants involving China in GAD scenario}_t =$$
$$\text{New capacity of all power plants in developing countries excluding China}_t \times$$
$$\text{Chinese share of new capacity in other developing countries} \times$$
$$\text{Share of new coal plants in China's domestic new power capacity addition}_t$$

Combining the three WEO scenarios (describing how much new coal capacity developing countries are going to build) and three sub-scenarios (describing how will China be involved in other developing countries), we generate nine scenarios of how much coal plants China will be involved with domestically and internationally. Detailed description of all the scenarios is shown in Table 1. We take into account all existing coal plants and the new coal plants to be built from 2019 to 2040 and quantify the emission from these plants from 2019 to 2080.

2.2.2. Future Emission Quantification

We quantify the emissions from coal plants involving China from 2019 to 2080 using the following equation (t=year):

$$Emission_t = Emission\ from\ plants\ built\ before\ 2018_t + Emission\ from\ plants\ built\ after\ 2019_t$$
$$= (Existing\ coal\ capacity_{\ t-1} - Retired\ coal\ capacity_t) \times Average\ Capacity\ factor_t \times 8760h \times Average\ Emission\ factor_t + (New\ coal\ capacity_t) \times Average\ Capacity\ factor_t \times 8760h \times Average\ Emission\ factor_t$$

We obtain the existing and expected total coal capacity in 2018, 2025, 2030 and 2040 for non-OECD countries for all three future scenarios from WEO 2019 and interpolate the years in between assuming a linear growth. For retired coal capacity, we obtained the age structure of coal plants from WEPP and assume a 40-year lifetime for all existing coal plants to retire. We quantify the new coal power capacity added in year t by adding the retired coal capacity in year t to the difference between the total capacity in year t and t-1 expected by WEO. We only include new coal plants built before 2040 since WEO 2019 does not provide projections for power sector development after 2040. We quantify the emissions for all coal plants till 2080 when we expect the last batch of coal plants built in 2040 retire. For capacity factor, we obtain the capacity factor by dividing the total electricity generated from coal plants by the total coal capacity in 2018,

2025, 2030 and 2040 from WEO 2019. We assume the existing coal fleet and the future coal fleet have the same capacity in a given year. The capacity factor for the entire coal fleet decreases overtime from 2019 to 2040 as indicated by WEO 2019. For emission factors, we obtain the emission factors by dividing the total carbon emissions by the total amount of electricity generated from coal plants in 2018, 2025, 2030 and 2040 from WEO 2019. We assume the existing coal fleet and the future coal fleet have the same emission factor in a given year. The emission factor for the entire coal fleet decreases overtime from 2019 to 2040 as indicated by WEO 2019. We interpolate the years in between for both capacity factor and emission factor assuming a linear decrease. Figure S2-5 show the level of decrease in both capacity factor and emission factor across different future scenarios. As shown in the equation, we classify the emission into two categories: the emissions from coal plants built before and the emissions from coal plants built after 2019. In our analysis, we name the emissions from existing coal plants as unrealized committed emission and the emissions from new plants as anticipated emissions.

Table 3 Scenario description

		Scenarios for future power sector development pathways from IEA		
	Scenario description	**Current Policy Scenarios (CPS)**: The most carbon intensive scenario where only existing green policies are taken into account.	**Stated Policy Scenario (SPS)**: Impact of existing policy frameworks and announced policy intentions.	**Sustainable Development Scenario (SDS)**: Least carbon intensive and includes major transformation in the power sector to meet the 2DC target.
Scenarios for China's future engagement with new overseas power projects	**Business As Usual (BAU)**: China will continue to be involved with new coal projects in other developing countries. From 2010 to 2017, China was involved with 45% of all the new coal power projects in developing countries and BAU expects China to continue to be involved with 45% of all new coal plants for 2019-2040.	**CPS-BAU**: No new green policies are implemented in the developing world; China is involved with 45% of all new coal power projects (including financing, exporting equipment and engineering services) in developing countries from 2019 to 2040.	**SPS-BAU**: Announced green policies are put in place in the developing world; China is involved with 45% of all new coal power projects (including financing, exporting equipment and engineering services) in developing countries from 2019 to 2040.	**SDS-BAU**: The developing world is on track to meet the 2DC target; China is involved with 45% of all new coal power projects (including financing, exporting equipment and engineering services) in developing countries from 2019 to 2040.
	No Coal Finance (NCF): China will not provide new finance to any new coal plants overseas but will complete already committed projects. From 2010 to 2017, China has been exporting coal equipment and engineering services to 26% of all the new coal power projects in developing countries and NCF expects China to continue to be involved with 26% of new coal plants from 2019-2040.	**CPS-NCF**: No new green policies are implemented in the developing world; China does not provide financing for any new coal power plants in developing countries. However, it continues to provide equipment and engineering services to 26% of new coal power projects in developing countries from 2019 to 2040.	**SPS-NCF**: Announced green policies are put in place in the developing world; China does not provide financing for any new coal power plants in developing countries. However, it continues to provide equipment and engineering services to 26% of new coal power projects in developing countries from 2019 to 2040.	**SDS-NCF**: The developing world is on track to meet the 2DC target; China does not provide financing for any new coal power plants in developing countries. However, it continues to provide equipment and engineering services to 26% of new coal power projects in developing countries from 2019 to 2040.
	Green As Domestic (GAD): the share of coal, as a fraction of all energy technologies, in Chinese overseas involvement is the same as the share of new coal plants in Chinese domestic power sector development by capacity.	**CPS-GAD**: No new green policies are implemented in the developing world. The share of coal in Chinese overseas involvement for all power technologies will be the same as the share of new coal plants in Chinese domestic power sector development by capacity.	**SPS-GAD**: Announced green policies are put in place in the developing world. The share of coal in Chinese overseas involvement for all power technologies will be the same as the share of new coal plants in Chinese domestic power sector development by capacity.	**SDS-GAD**: The developing world is on track to meet the 2DC target. The share of coal in Chinese overseas involvement for all power technologies will be the same as the share of new coal plants in Chinese domestic power sector development by capacity.

3. Results

3.1 China's growing involvement in developing countries power sector

Across all power generating technologies we examine, China has been involved in 246 GW of new power projects in other non-OECD countries from 2005 through 2018 inclusive. As shown in Figure 1a, overseas power projects involving China grew from less than 1 GW per year in 2005 to about 35 GW per year in 2018. As the total capacity is estimated using a bottom-up methodology by summing up all individual projects, this is likely to be a lower-bound estimate.

There are two important implications from China's growing involvement in other developing countries' power sector. First, for the electric power market in other non-OECD countries, China is now an important, if not indispensable, source for key power equipment, engineering service, and finance. From 2005 to 2018, China was involved in 20% of all new power projects added in other non-OECD countries. This share grew from less than 5% in 2005 to around 30% in 2018. Second, for China's domestic power industries, overseas markets are now an important source of revenue growth. As early as the 1990s, China implemented the "Going Out" policy to incentivize Chinese companies to expand their business in overseas markets. While China gradually slowed down new power capacity additions domestically, most Chinese power companies list "overseas expansion" as one of their primary development goals. From 2005 to 2018, China added 1112 GW of new power capacity domestically. The 246 GW of overseas power projects involving China provided substantial additional revenue. Moving forward, the Belt and Road Initiative (BRI) will help expand Chinese involvement in energy infrastructure development in other non-OECD countries. Chinese overseas involvement in new power projects will be important for both recipient countries and China's domestic power industries in the future.

China is involved in diverse power generating technologies overseas with 41% (101 GW) of power project involvement in coal, 25% (61 GW) in solar, 19% (48 GW) in hydropower, 12%

(30 GW) in oil and gas, 2% (5 GW) in wind, and less than 1% (1 GW) in nuclear power measured by capacity. As shown in Figure 1b, coal plants dominated Chinese overseas involvement in the 2000s and early 2010s. Starting in 2017 solar power generation has surpassed coal power plants as the dominant technology for Chinese involvement. We also compare Chinese involvement with total new capacity added for every power generating technology in other non-OECD countries from 2005 to 2018. As shown in Figure 1c, China was involved in 60% of all new solar plants, 38% of all new coal plants, 14% of all new hydropower plants, 7% of all new gas plants, 6% of all new wind plants and 2% of all new nuclear plants.

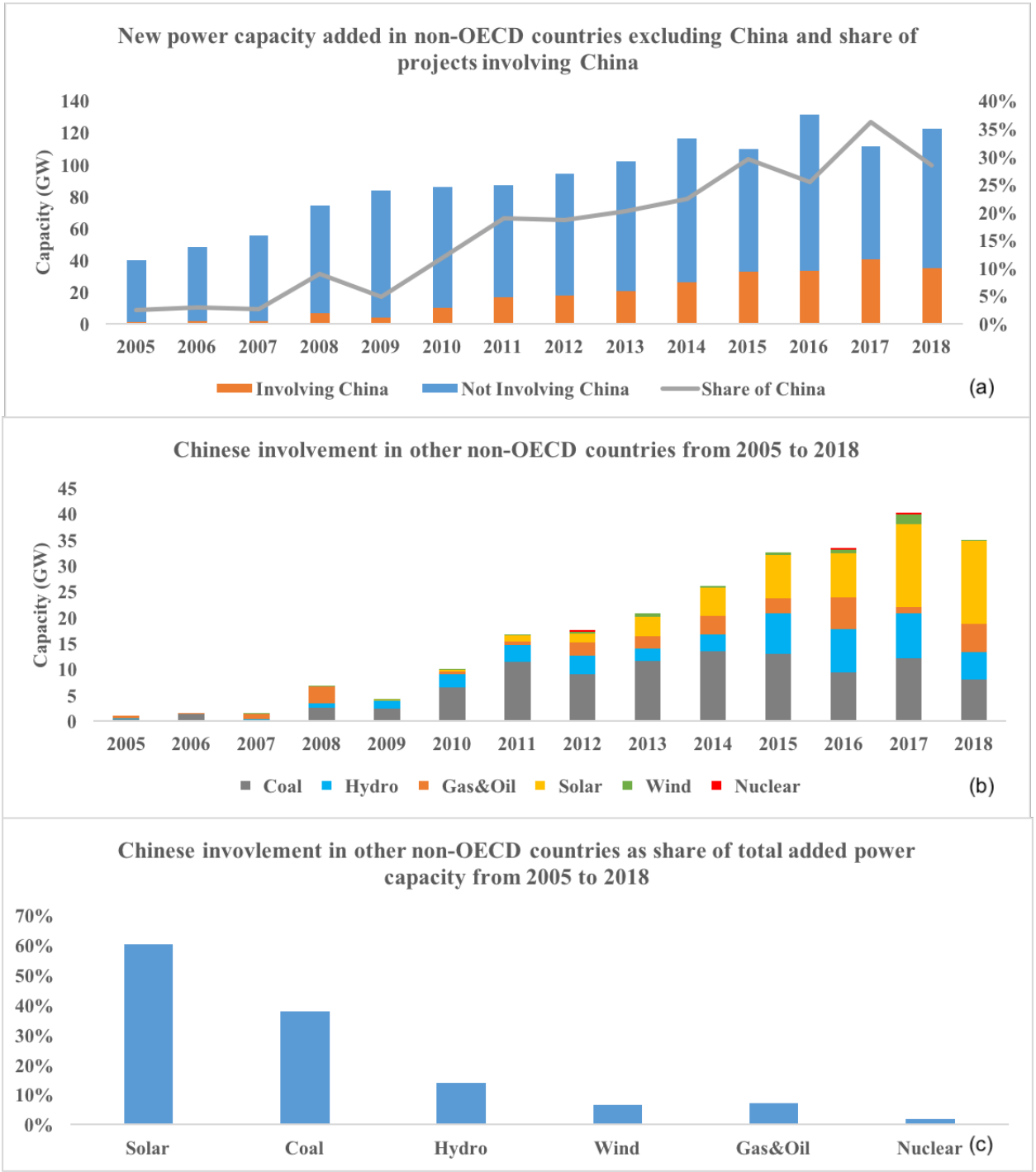
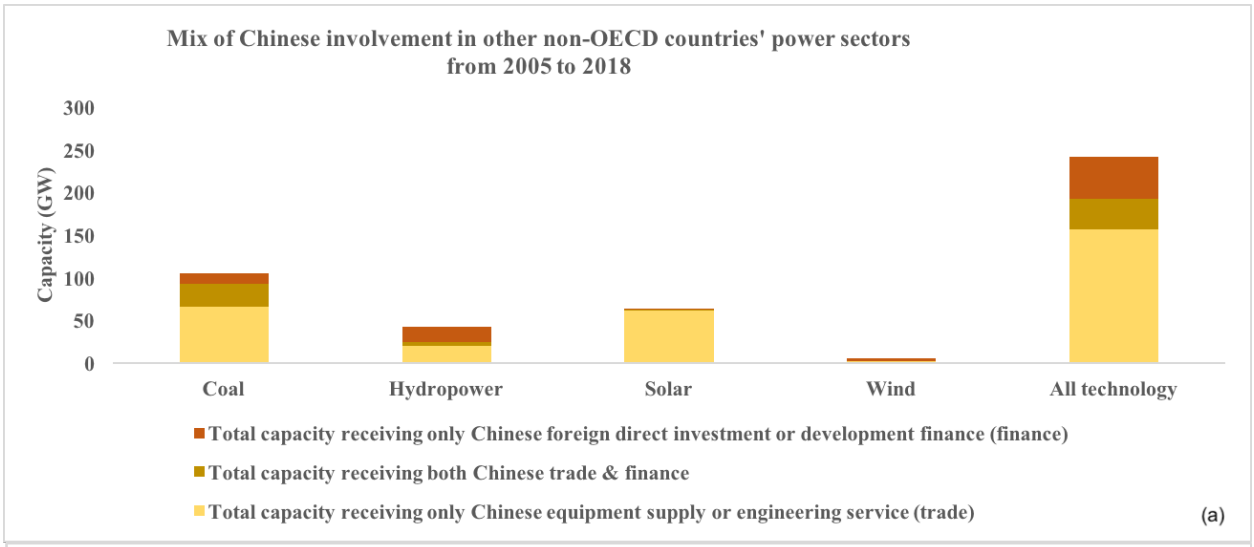


Figure 2 (a) New power capacity added in Non-OECD countries excluding China and the share of projects involving China; (b) Chinese involvement in other non-Non-OECD countries by technology from 2005 to 2018; (c) Chinese involvement in other non-OECD countries as share of total added power capacity by technology from 2005 to 2018

We find that export of power equipment is the major form of Chinese involvement in overseas power projects. However, from a project development perspective, equipment manufacturers or

engineering service contractors, in most cases, take a marginal role in the project development process. In contrast, Chinese development banks and foreign direct investors have larger responsibility for the final outcome of the project. To facilitate the discussion, we use "Chinese trade" to describe Chinese involvement in overseas power projects in the form of supplying power equipment or engineering services, and "Chinese finance" to describe Chinese involvement in overseas power projects in the form of foreign direct investment or development finance. As shown in Figure 2a, we find that 65% of all the power projects involving China use only power equipment or engineering services provided by Chinese companies. This suggests that export of power equipment and engineering services has been the major form of Chinese involvement in the global power sector instead of providing finance. Due to a potential underestimation for seller's credit from Chinese banks to support Chinese export of power equipment in the CGEP database, our analysis could underestimate the amount of development finance provided to overseas power projects, therefore overestimating the share of "Chinese trade" in all Chinese involvement. The share of exporting power equipment is especially true for solar projects. Only 2% of the overseas solar projects with Chinese involvement receive Chinese finance while the vast majority of the overseas solar projects are export of Chinese solar panels. Therefore, while China has successfully built a global distribution network and provided solar panels for 61 GW or 60% of new solar projects in other non-OECD countries, China's role in contributing to a renewable energy transition in the developing world is limited by the role of being a supplier without providing finance for renewable projects. We find the case to be different for Chinese overseas coal plants. As shown in Figure 2b, we identify approximately 30% of all overseas coal plants using Chinese power equipment or engineering services to be further supported and financed by Chinese investors or development banks. Although the total overseas capacity involving China is large for both coal (101 GW) and solar (61 GW)

technologies, a higher share of coal than solar projects receive finance from China indicating the more proactive role China has played in supporting overseas coal plants than solar projects.



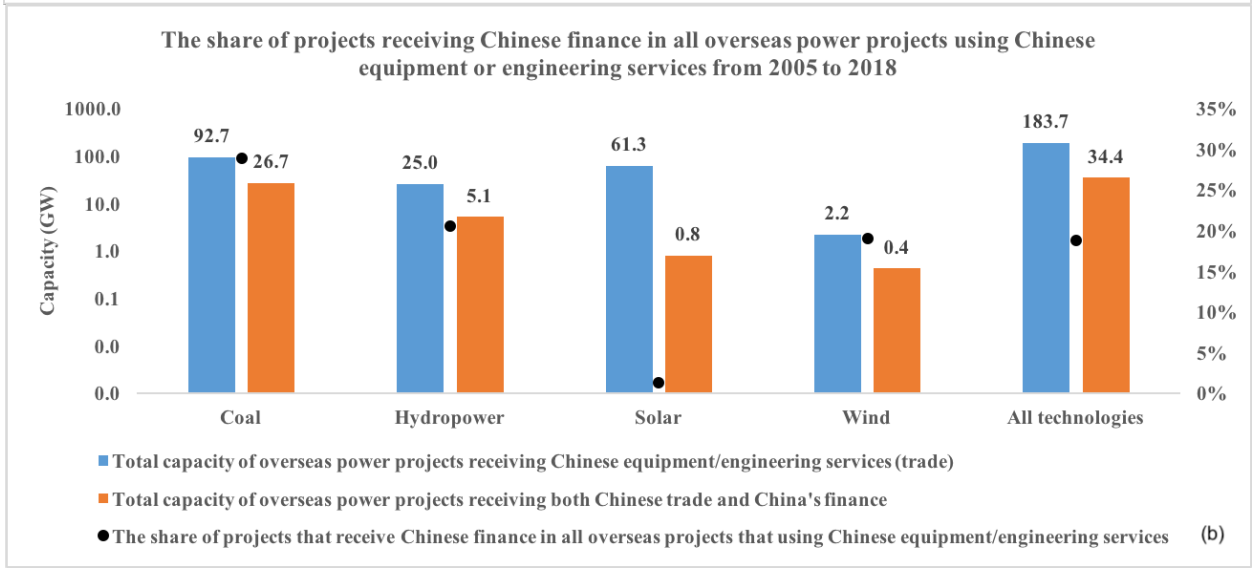


Figure 3 (a) Mix of Chinese involvement in other non-OECD countries' power sector from 2005 to 2019 and (b) The share of projects receiving Chinese finance in all overseas power projects using Chinese equipment or engineering services.

3.2 CO_2 Emissions from China's coal plants

In this section, we estimate the lifetime emissions for all existing coal plants and future coal plants built before 2040 in China as well as emissions from coal plants involving China in other developing countries over the same time periods. We include development finance, foreign direct

investment, export of power equipment and engineering services and we consider a coal plant to be “Chinese coal plant” if it is involved with China through at least one of the four forms. As there are various possibilities for future coal plant development in China and in other developing countries, we use the three future scenarios established by IEA as described in the methodology section to explore the implications of various development pathways. They are the Current Policy Scenario (CPS), Stated Policy Scenario (SPS), and Sustainable Development Scenario (SDS). There are also various ways in which China could be involved in overseas new coal plants and we develop three sub-scenarios as described in the methodology section. They are the Business As Usual (BAU) scenario, No Coal Finance (NCF) scenario, and Green As Domestic (GAD) scenarios. Combining these two sets of scenarios, we quantify the range of lifetime carbon emissions from coal plants in China and from overseas coal power plants involving China across these nine scenarios. As noted in the methodology section, our estimation only provides a first-order estimation on the future carbon emissions from Chinese domestic and overseas coal plant and do not include a second-order effect Chinese overseas involvement has on the local power sector development.

Figure 3a shows the emission trajectories for all nine scenarios combining China’s domestic coal plants with overseas coal plants involving China. The trajectories include emissions from both existing coal plants and all new coal plants built before 2040. We assume a 40-year lifetime for all coal power plants. The carbon emissions are much lower in the Sustainable Development Scenario (SDS) than the others, regardless of how China is involved in overseas coal plants. This is due to a faster decreasing capacity factor, emission factor and number of new coal plants added in the SDS scenario. Within each IEA future scenarios, Chinese total carbon emissions are lower in Green As Domestic (GAD) than No Coal Finance. Therefore, a green as domestic

pledge by China has the largest potential to reduce Chinese overseas carbon emissions in coal power plants. A pledge to stop financing new coal plants alone would not be as effective because power equipment export and engineering services would continue. Figure 3b also shows the committed carbon emissions of Chinese coal plants across nine scenarios, separating Chinese domestic plants and Chinese overseas plants. Across the various scenarios we find lifetime emissions can range from 88-194 Gton from Chinese domestic coal plants and 9-77 Gton from Chinese overseas coal plants. We find that Chinese oversea activities could add 11-40% to China's power sector carbon emissions. In the year of 2019, overseas coal plants involving China emitted about 10% of the emissions from Chinese domestic coal plants. While China has committed to reach carbon neutrality domestically by 2060, increasing emissions from Chinese overseas coal power plants suggests that to meet a 2DC target, additional effort to reduce China's overseas carbon footprint is equally important.

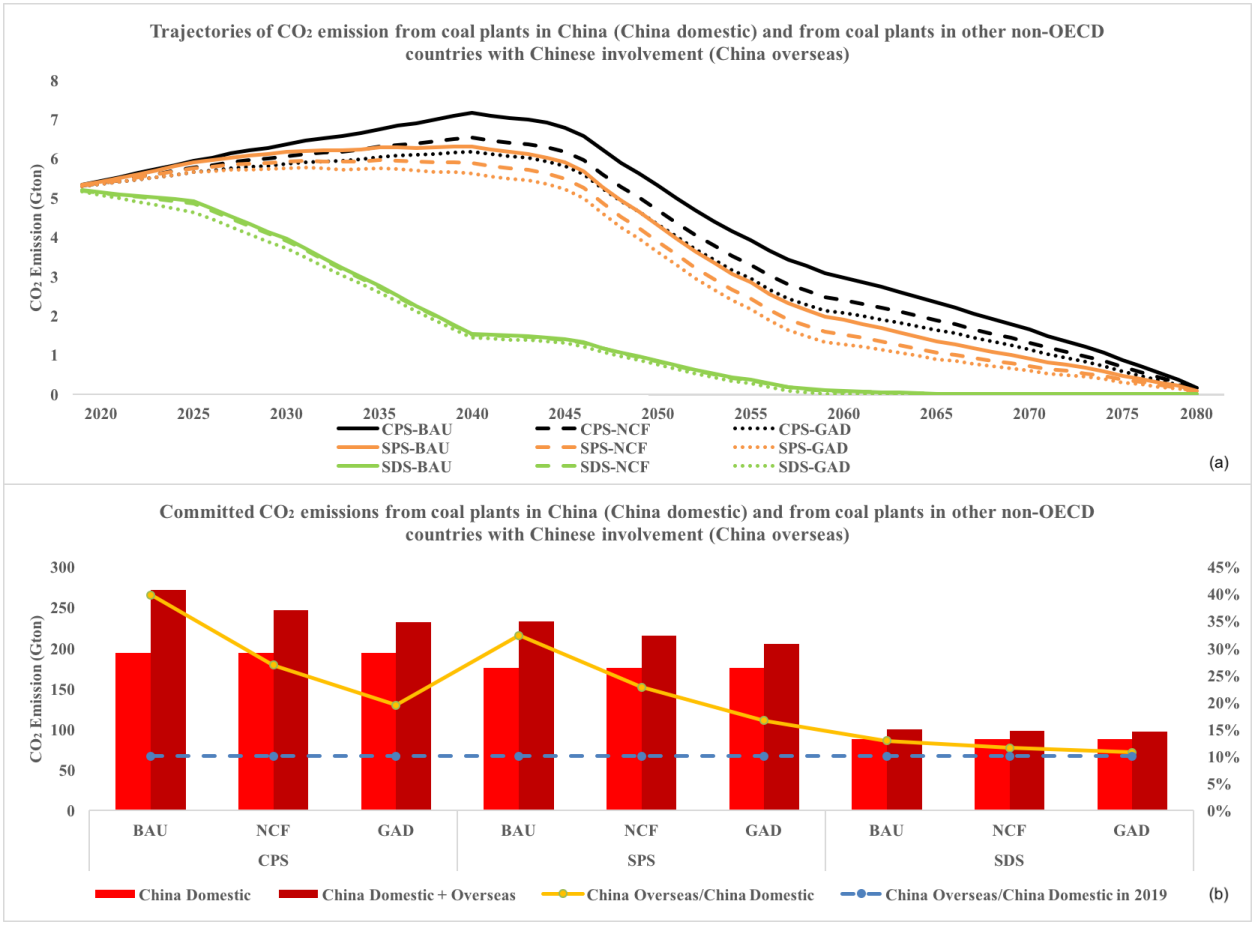


Figure 4 (a) Trajectories of CO2 emissions from coal-fired power plants in China (China domestic) and from other non-OECD countries with Chinese involvement (China overseas); (b) Total CO2 emission from Chinese coal plants from 2019 to 2080. Both graphs include existing coal plants and coal plants likely to be built (according to IEA scenarios) before 2040. CPS: Current Policy Scenario; SPS: Stated Policy Scenario; SDS: Sustainable Development Scenario; BAU: Business As Usual; NCF: No Coal Finance; GAD: Green As Domestic.

We show the committed carbon emissions from existing coal plants and the lifetime emissions from future new coal plants separately in Figure 4. For Chinese domestic coal plants, the majority of future emissions come from existing coal plants, regardless of the future development pathways. Early retirement, reduced capacity factors, and applying carbon capture and storage technologies on existing coal plants are important measures to reduce future emissions from Chinese domestic coal plants. For overseas coal plants involving China, the majority of future emissions will come from new coal plants in most scenarios. In both the Current Policy Scenario and Stated Policy Scenario, coal would continue to be the main fuel for

electricity generation in most non-OECD countries with more new coal plants being built in those countries to meet growing electricity demand. To reduce climate change, it is critical for China to direct its overseas activities away from coal plants towards renewable projects. This would facilitate carbon emission reductions from overseas coal plants with which China is involved. As most other coal financing countries, like German and Japan, have announced to stop financing new overseas coal plants and many coal equipment manufacturers are diversifying their manufacturing capacity, a lower level of Chinese involvement in future overseas coal plants would further decrease the global supply of coal power resources and discourage new coal plants additions in other non-OECD countries.

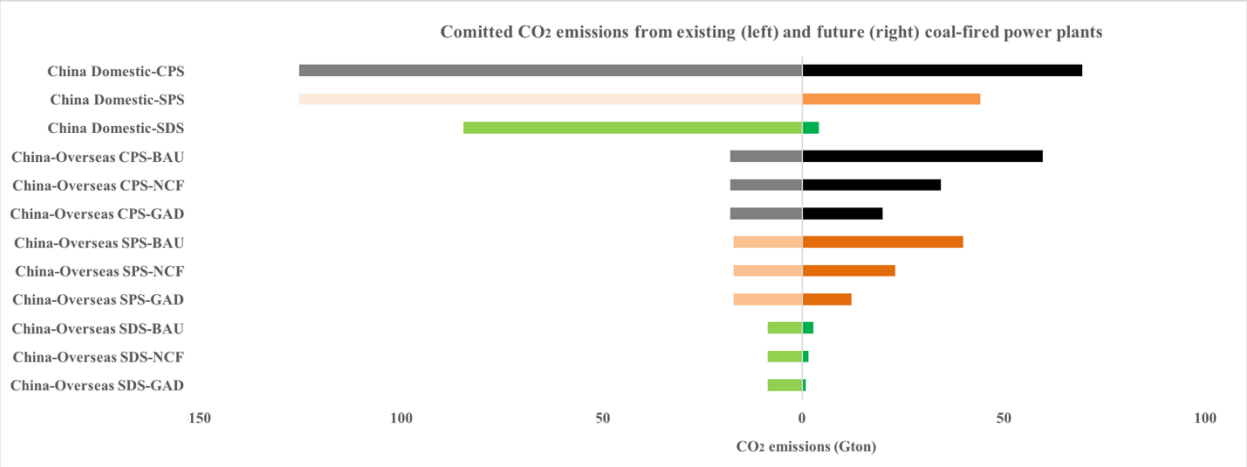


Figure 5 Committed CO_2 emissions from existing and future coal-fired power plants in China's domestic market and other developing countries involving China. Future coal plants include all new coal plants built before 2040. CPS: Current Policy Scenario; SPS: Stated Policy Scenario; SDS: Sustainable Development Scenario; BAU: Business As Usual; NCF: No Coal Finance; GAD: Green As Domestic.

We also compare Chinese domestic and overseas carbon emissions from coal power plants with the possible carbon budget remaining in 2100 when attempting to meet 1.5 °C and 2 °C global temperature targets. As shown in Figure 5a, the existing global energy infrastructure has already committed more carbon emissions than the global carbon budget remaining for a 1.5 °C target,

assuming no early retirement or applications of carbon capture technologies. While there is still 49% left in the global carbon budget for a 2°C target, the existing infrastructure presents a heavier burden for the power sector. If we allocate 35% of the global carbon budget to the power sector, the existing global electricity infrastructure already commits 76% of the total global carbon budget remaining for a 2 °C target, as shown in Figure 5b. Adding the new coal plants China may build domestically and overseas, the future emissions from these new Chinese coal plants, if built, would utilize another 1-27% of the remaining carbon budget depending on the future development scenario. This would further squeeze the remaining headroom we have to achieve the 2 °C target from the power sector perspective. In the worst-case scenario (CPS-BAU), Chinese new coal plants would take up all the remaining carbon budget targeting 2 °C in the global power sector, leaving no headroom at all for any other countries or any other fossil fuel generation technologies operating without carbon capture and storage. This further strengthens the point for China to expand the climate goals to include overseas activities as well.

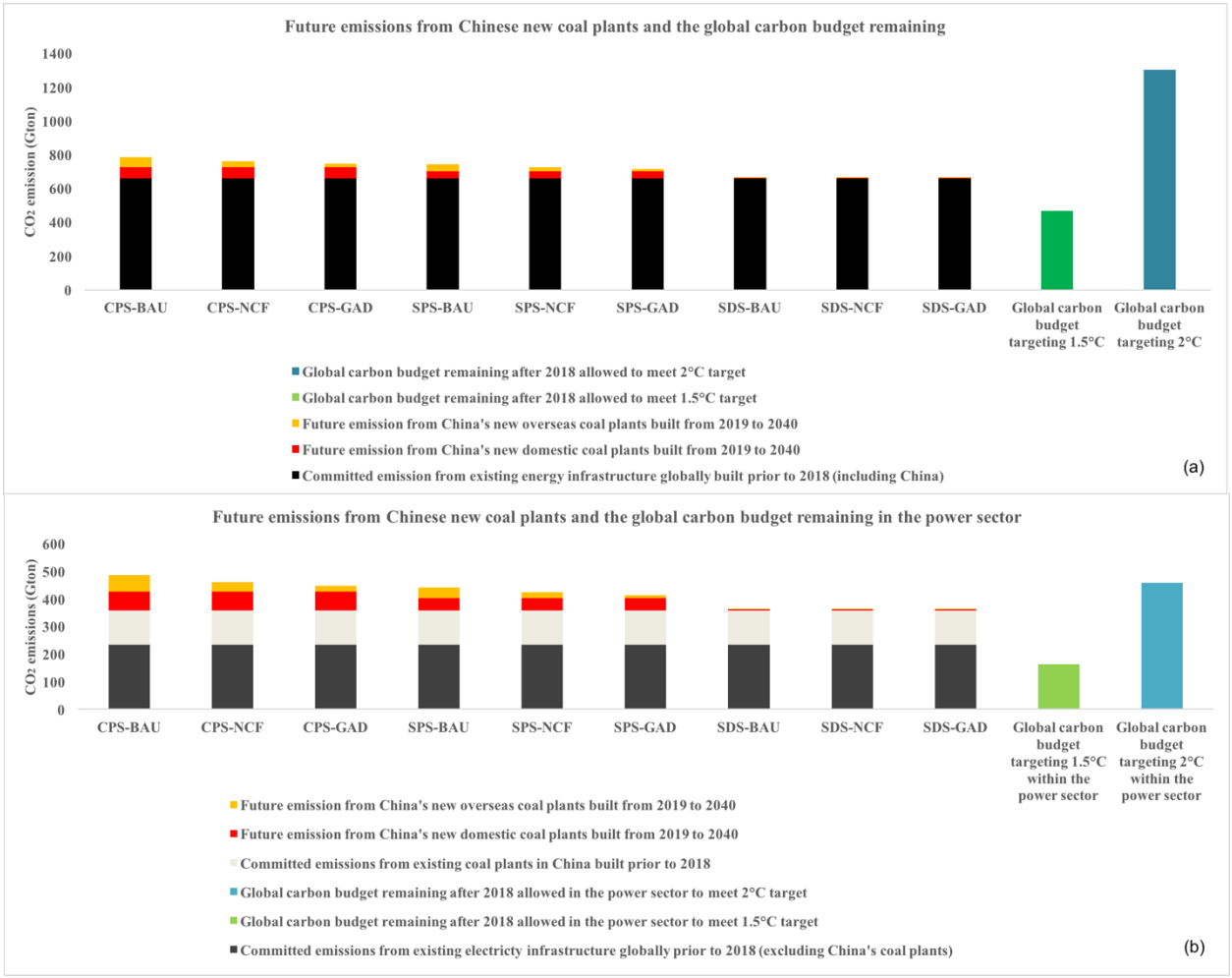


Figure 6 Future emissions from Chinese coal plants and committed emissions from existing infrastructure in the context of the remaining global carbon budget. The committed emissions from existing energy infrastructure are cited from Tong et al., 2020. The global carbon budget is cited from Rogelj et al., 2018. The global carbon budget in the power sector is 35% of the total global budget. 35% is the average share of global power sector emissions of all carbon emissions in IEA's Sustainable Development Scenarios from2019 to 2040. CPS: Current Policy Scenario; SPS: Stated Policy Scenario; SDS: Sustainable Development Scenario; BAU: Business As Usual; NCF: No Coal Finance; GAD: Green As Domestic.

4. Policy discussion

While previous studies of Chinese overseas activities in the power sector have focussed on coal and hydropower technologies and have focused mainly on finance, our results provide a more comprehensive overview across different technologies and across different forms of Chinese activities. Although coal power plants represent 41% by capacity of the power projects with which China has been involved in other non-OECD countries from 2005 to 2018, the share of

solar and wind projects have also been increasing and by capacity solar projects have dominated China's portfolio since 2017. However, the ways in which China is involved with solar and coal projects have differed. China has been exporting power equipment and engineering services globally for both coal and solar power plants while Chinese overseas coal power plants received more finance by percentage than Chinese overseas solar projects. We find 29% of the coal projects, using Chinese power equipment or engineering services, to be further supported and financed by Chinese investors or development banks. However, for solar projects using Chinese PV modules, we find little supporting financing occurring from Chinese state-owned banks or state-owned power investors, leaving China as an equipment supplier only. Understanding the reason for the lack of state-led financial support for the private- and Chinese owned solar industry in the overseas market is important and requires further research. As Chinese solar equipment manufacturers have developed globally competitive technical expertise and have successfully built a global distribution network, there is huge potential for China to better facilitate the renewable energy transition in other developing countries if further supported by Chinese state-led finance.

As China expands its impact in the global power sector fueled by the Belt and Road Initiative, the future carbon footprint of Chinese overseas activities is enormous and requires more policy attention. Although the current accounting system only holds a country responsible for emissions within its borders, cross-border activities such as trade and finance will have enormous global climate consequences. We find that China's overseas carbon footprint from 2019 to 2040 could add another 9-77 Gton of CO_2 emissions, above China's domestic emissions, depending on which future scenario is followed. This is equivalent to 1-6% of the remaining global power

sector carbon budget under the 2° C target by 2100, or 11-40% of China's future power sector carbon emissions from 2019 to 2040.

While China's President Xi declared China's ambition to reach domestic carbon neutrality by 2060 at the 2020 meeting of the General Assembly at the United Nations, the statement does not include any commitment regarding Chinese overseas activities. As China further discourages coal use and supports renewable energy domestically, the outlook for Chinese overseas activities is highly uncertain. On the one hand, as China builds fewer coal plants domestically, there will be an increasing excess capacity for coal both in terms of technical expertise and manufacturing capacity. Existing studies (Kong and Gallagher 2019; Li et al., in preparation) suggest that such overcapacity in coal could fuel more coal projects overseas. On the other hand, China's renewable industry will benefit from the commitment to carbon neutrality by 2060 and will gain more technical, economic and political support. This could attract more state-led finance to Chinese overseas renewable projects, which would help China's renewable power industry grow and take a more proactive role in a global renewable energy transition. Looking into the future, the role of China in the global effort to combat climate change is crucial. While we have seen optimistic signs of China taking the lead in decarbonizing China's domestic economy, it is equally important and imperative for future endeavors to expand China's climate responsibilities beyond its border.

Acknowledgements

Zhongshu Li thanks the following co-authors of this chapter: Wei Peng, Denise L. Mauzerall.

References

Audoly, R., Vogt-Schilb, A., Guivarch, C. and Pfeiffer, A., 2018. Pathways toward zero-carbon electricity required for climate stabilization. *Applied energy*, *225*, pp.884-901.

Birol, F., 2019. World energy outlook. *Paris: International Energy Agency*.

Clarke, L., Jiang, K., Akimoto, K., Babiker, M., Blanford, G., Fisher-Vanden, K., Hourcade, J.C., Krey, V., Kriegler, E., Löschel, A. and McCollum, D., 2014. Assessing transformation pathways.

Gao, X. and Rai, V., 2019. Local demand-pull policy and energy innovation: Evidence from the solar photovoltaic market in China. *Energy Policy*, *128*, pp.364-376.

Gosens, J. and Lu, Y., 2014. Prospects for global market expansion of China's wind turbine manufacturing industry. *Energy Policy*, *67*, pp.301-318.

Hannam, P.M., Liao, Z., Davis, S.J. and Oppenheimer, M., 2015. Developing country finance in a post-2020 global climate agreement. *Nature Climate Change*, *5*(11), pp.983-987.

Hannam, P.M., 2016. *Contesting authority: China and the new landscape of power sector governance in the developing world* (Doctoral dissertation, Princeton University).

Huang, P., Negro, S.O., Hekkert, M.P. and Bi, K., 2016. How China became a leader in solar PV: An innovation system analysis. *Renewable and Sustainable Energy Reviews*, *64*, pp.777-789.

Kong, B. and Gallagher, K.P., 2019. *Globalization as Domestic Adjustment: Chinese Development Finance and the Globalization of China's Coal Industry*. GCI Working Paper 04/2019, Global Development Policy Center, Boston University: http://www. bu. edu/gdp/files/2019/04/GCI-GDP. WP6-Globalization-as-Domestic-Adjustment-Kong-Gallagher. pdf.

Lacal-Arántegui, R., 2019. Globalization in the wind energy industry: contribution and economic impact of European companies. *Renewable energy*, *134*, pp.612-628.

Li, Z., Gallagher, K.P. and Mauzerall, D.L., 2020. China's global power: Estimating Chinese foreign direct investment in the electric power sector. *Energy Policy*, *136*, p.111056.

Ma, J. and Zadek, S., 2019. Decarbonizing the Belt and Road: A Green Finance Roadmap. *Tsinghua University Center for Finance and Development, Vivid Economics and the Climateworks Foundation*.

Peng, R., Chang, L. and Liwen, Z., 2017. China's involvement in coal-fired power projects along the Belt and Road. *Global Environmental Institute.*

Rogelj, J., Shindell, D., Jiang, K., Fifita, S., Forster, P., Ginzburg, V., Handa, C., Kheshgi, H., Kobayashi, S., Kriegler, E. and Mundaca, L., 2018. Mitigation pathways compatible with 1.5 C in the context of sustainable development.

Shearer, C., Myllyvirta, L., Yu, A., Aitken, G., Mathew-Shah, N., Dallos, G. and Nace, T., 2020. *Boom and bust 2020: Tracking the global coal plant pipeline*.

Steffen, B. and Schmidt, T.S., 2019. A quantitative analysis of 10 multilateral development banks' investment in conventional and renewable power-generation technologies from 2006 to 2015. *Nature Energy*, *4*(1), pp.75-82.

Tao, Y., Liang, H. and Celia, M.A., 2020. Electric power development associated with the Belt and Road Initiative and its carbon emissions implications. *Applied Energy*, *267*, p.114784.

Tong, D., Zhang, Q., Zheng, Y., Caldeira, K., Shearer, C., Hong, C., Qin, Y. and Davis, S.J., 2019. Committed emissions from existing energy infrastructure jeopardize 1.5 C climate target. *Nature*, *572*(7769), pp.373-377.

Yuksel, T., Tamayao, M.A.M., Hendrickson, C., Azevedo, I.M. and Michalek, J.J., 2016. Effect of regional grid mix, driving patterns and climate on the comparative carbon footprint of gasoline and plug-in electric vehicles in the United States. *Environmental Research Letters*, *11*(4), p.044007.

Chapter 4: Determinants of Chinese Outbound Energy Finance to Developing Countries

1. Introduction

Although carbon emissions show signs of stabilizing and decreasing in some developed countries, emissions from most developing countries are rising as they strive to raise their country's standard of living (IEA, 2019). The energy sector is pivotal from both a climate and development perspective. While energy is a key driver of economic development, the energy sector is also the source of two-thirds of global greenhouse gas emissions. Redirecting financial flows towards renewable energy technologies (RETs) in developing countries is crucial to minimize committed future emissions and to limit climate change to manageable levels (Davis and Socolow 2014; Gielen et al., 2017). Indeed, Article 2.1(c) of the Paris Agreement aims to "mak[e] finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development." Importantly, finance for the energy sector in developing countries, and power sector development in particular, comes from a combination of domestic and international sources. Multilateral development banks (MDBs), national development banks (NDBs), and international power developers are all important sources of finance for new power projects in developing countries (Strange et al., 2017; Kong and Gallagher 2017; Steffen and Schmidt 2019; Li et al., 2020). While most development banks have transparent lending practice guidelines and open data portals, relatively little is known about the lending practices and detailed project information of Chinese development banks, or overseas investments of Chinese power companies. While the Belt and Road Initiative (BRI) is expected to further increase the influence of Chinese finance in developing countries' power sector, recent estimates within 15 BRI countries found BRI's carbon footprint there to be extremely carbon intensive with only 9% of investments in green technologies (Ma and Zadek 2019; Tao et al., 2020). In order to steer

Chinese finance more towards RETs in the power sectors of developing countries, an understanding of the drivers of Chinese energy financing is critical.

While the Chinese government does not publish a project-by-project breakdown of its overseas finance activities, extensive data collection efforts have identified two major mechanisms of Chinese finance in the global power sector. The first mechanism is development finance (DF) provided by China's policy banks and Chinese export credit agencies (ECA) to host governments in developing countries in the form of trade credits, concessional loans, and non-concessional lending. In the DF mechanism, China's policy banks provide debt finance to sovereign governments and do not directly own the projects nor are they involved in the development of the power projects; the sovereign governments and the local developers which receive Chinese finance build and own the power projects. A second mechanism is foreign direct investment (FDI) made by Chinese power companies into new power projects in developing countries as project developers and owners. In this mechanism, Chinese power companies provide equity finance and directly own part or all of a project. For Chinese DF, the Chinese major state-owned policy banks—the China Development Bank and the Export-Import Bank of China—provide the vast majority of Chinese development finance. For Chinese FDI, Chinese state-owned enterprises are involved in 85% of all overseas power projects receiving Chinese FDI.

While significant work has been conducted to date that establishes the level of Chinese DF and FDI engagement in the power sector abroad, there is relatively less understanding of the determinants of Chinese energy finance. There have only been a handful of papers on the broad determinants of Chinese overseas finance across all sectors. Dreher et al., 2018 analyzed Chinese development finance to Africa from 2000 to 2012 and found the drivers of Chinese

development finance to be largely driven by the market forces of supply and demand, rather than the geopolitical drivers that many assumed. This finding is supported by a more recent study that compares Chinese development finance in 157 developing countries from 2000 to 2014 with development finance from the World Bank. This study also found that Chinese development finance is driven by market forces to a larger extent than World Bank financing (Morris et al., 2020). However, little research specifically examines Chinese overseas financing in the power sector. Kong and Gallagher (2019) developed a framework to qualitatively analyze various "push" and "pull" drivers of Chinese development finance in overseas coal power projects. Through field research in several case countries, Gallagher et al. (2020) argued that Chinese and other foreign financing can be heavily influenced by host country demand. They found domestic pull factors to be key drivers of such investment. Besides these qualitative studies, relatively little quantitative work has been conducted analyzing the drivers of Chinese overseas financing flows in developing countries' power sector.

To address this gap, we first compiled a comprehensive dataset which synthesizes previously collected data and includes all new power projects in developing countries receiving either Chinese DF or FDI from 2005 to 2018 (Li et al, 2020; Chen et al, forthcoming; Gallagher et al, 2020). Our newly created dataset covers 66.0 GW of new power projects which have received Chinese DF or FDI and were built from 2005 to 2018 in 35 developing countries. Compared with the total 369 GW of new power projects built in these 35 developing countries during the same period, Chinese overseas finance was involved in the development of 18% of power projects in these countries. Trends, energy mix and the overlap pattern of Chinese energy financing are included in Figures SI 1-5. Second, we developed an analytical framework based on Kong and Gallagher (2019) which includes a list of potential drivers for Chinese overseas financing in the

power projects of developing countries. Third, we deploy an econometric model to analyze the extent to which these push and pull factors explain the level and distribution of Chinese electric power financing. After presenting our results, we further discuss the most significant drivers of Chinese finance, and then consider how our results would inform a renewable energy transition in developing countries.

2. Materials and method

2.1 Analytical framework and potential drivers

We utilize the "push and pull" analytical framework of Kong and Gallagher (2019) to analyze the effects of different drivers on both types of Chinese financing, Chinese DF and Chinese FDI in the power sector. "Push" factors are described as Chinese domestic drivers that "push" Chinese finance out to overseas markets. We are particularly interested in four potential push factors. First, industrial overcapacity in the Chinese domestic market is often discussed as a push factor that drives Chinese finance overseas and is applicable to the power sector, particularly coal and hydropower generation (Kenderdine and Ling 2018; Kenderdine and Lan 2018; Pepermans 2019). Power generation in China grew rapidly between 2002 and 2007 with an average of 100 GW new generation brought on-line every year (Yuan et al., 2018; China Electricity Council 2019). As the number of new power projects increased, the Chinese electric power industry also increased technical capacity in power equipment manufacturing, project design and construction, as well as project financing capabilities (Jiang et al., 2010; Yue 2012). After 2007, the growth of new power projects in China gradually slowed, which led to

overcapacity in China's technical ability to build new power plants. Such a domestic overcapacity coincided with increasing Chinese overseas finance in the global power sector after the Global Financial Crisis (GFC) and recent qualitative analyse stipulate that Chinese finance was in part driven by a state objective to alleviate and export Chinese domestic overcapacity (Kong and Gallagher 2019). The second potential push factor is the Chinese incentive to use Chinese financing as leverage to gain influence and political alignment with host governments (Dreher and Fuchs 2015; Dreher et al., 2018). The third potential push factor on Chinese finance that we explore is the abundance of natural resources in the recipient country. Resource-seeking theory on foreign direct investment indicates that overseas finance could be driven by interests to secure strategic overseas assets, such as energy resources and we examine whether that applies to Chinese overseas finance (Foster et al., 2008; Lum et al., 2009). We also examine how Chinese finance has been driven by the magnitude of bilateral trade between China and the host country, as the fourth push factor.

"Pull" factors are host countries' demand that "pull" Chinese finance into their market. We examine three pull factors. The first pull factor is a host country's energy policies which usually determine the plan for new power projects for the next five to ten years, including total capacity, energy mix and even siting for large projects. Through a series of case studies of Chinese finance abroad, Gallagher et al. (2020) argued that foreign financing can be heavily influenced by local demand. They found domestic pull factors to be key drivers of such investment. Here we use the new power capacity built in host countries as a proxy for the local demand for new power projects. We also include local coal reserves, gas reserves and hydropower potential as the second pull factor to explain the different technology choices made by Chinese financiers. For

the overall economy, we examine the effect of gross domestic product (GDP) per capita as the third pull factor on Chinese finance (indicating total aggregate demand in the host country).

In addition to the push and pull factors, we also control for a number of other factors, including population, institutionalized democracy, the signing of a BRI memorandum of understanding (MOU) with China, existing trade with China in power equipment and power engineering services, and existing trade with major developed countries in power equipment and power engineering services.

2.2 Econometric model

We use a multivariate fixed-effect regression model to understand the effects of different independent variables on each type of Chinese finance (development finance, DF and foreign direct investment, FDI) in each developing countries' power sector. The model is given as:

$$\text{Chinese development finance}_{ijt} = \beta_0 + \beta_1 push_{ijt} + \beta_2 pull_{ijt} + \beta_3 control_{ijt} + \eta_t + \tau_t + \varepsilon_{it}$$

$$\text{Chinese foreign direct investment}_{ijt} = \beta_0 + \beta_1 push_{ijt} + \beta_2 pull_{ijt} + \beta_3 control_{ijt} + \eta_t + \tau_t + \varepsilon_{it}$$

Chinese development finance or foreign direct investment are the two different mechanisms of Chinese overseas financing to country i in technology j in year t; $push_{ijt}$ is a vector of four push factors (overcapacity; voting distance; trade with China; resource rent); $pull_{ijt}$ captures the three

pull factors (new power demand; GDP per capita; power resource potential); $control_{ijt}$ stands for the five controlled variables (population; BRI; the level of instutionalized democracy; trade with China in the power sector; trade with other countries in the power sector); η_t and τ_t stands for the year- and country-fixed effect, respectively,and ε_{it} is a stochastic error term. Data sources and description for each variable is shown in the Data collection section below.

We converted the project-level data on Chinese finance and the potential driving factors (independent variables) into a panel dataset covering 35 countries from 2005 to 2018 for three power technologies (coal, gas and hydropower). For Chinese development finance, we measure it by both project capacity (MW) and monetary value (million US dollar). For Chinese foreign direct investment, we measure it by project capacity only due to a lack of monetary value information. We also ran the Hausman test to determine whether the fixed effect or random effect model is more appropriate for our data set and thus chose the fixed effect model.

2.3 Data collection

We use the Boston University Chinese Global Power database as our source for Chinese development finance (Gallagher et al, 2020), and Li et al.(2020) as our source for Chinese foreign direct investment data. For Chinese development finance, we have information on project capacity (MW) and monetary value (US $). We run two sets of regressions using for both. For Chinese foreign direct investment, we only have complete information on project capacity and we do not run regressions using Chinese foreign direct investment in monetary value. Independent variables are described below with a detailed list of their sources in the Supplementary Information.

2.3.1 Push factors

For overcapacity, we use the peak year method to measure excess capacity in the Chinese domestic power industry. We collect the annual added power capacity in China from 2005 to 2018 for coal, gas and hydropower plants through the Platts database (Platts 2015). The key assumption is that Chinese industrial capacity to build new power projects stays the same after the peak year of installment for each of the technologies. Therefore, the amount of overcapacity can be quantified as the difference between the peak year installment and the new capacity installed in a given year. For voting distance, we use the dataset developed by Bailey et al., (2017) based on the United Nations General Assembly voting database. The voting distance measures how the recipient countries's vote align with the Chinese vote for all votes taken at the United Nations. We use its log form in our model. For total bilateral trade data, we collected both import and export data reported by China from the International Trade Statistics Database developed by UN Comtrade (UN 2019). We use its log form in our model. For resource rent, the value gained from the sales of natural resources after all monetary costs have been accounted for, we use the natural resource rent indicator developed by the World Bank's World Development Indicators (WDI), which measures the total natural resource rent as a share of gross domestic product (GDP) in a given country (World Bank 2019).

2.3.2 Pull factors

For new power capacity, we collect new power capacity additions for coal, hydro and gas power plants in 35 host countries from 2005 to 2018 from Platts. We use its log form in our model. We

collect GDP per capita from the World Bank's World Development Indicators (World Bank 2019). For potential power resource, we collect coal and gas reserves from the BP Statistical Review and use its log form in our model. We collect hydropower potential based on Zhou et al. (2015) and assume the potential remains the same from 2015 to 2018. We use the log form for all three technologies. We do not analyze solar or wind resources in this analysis.

2.3.3 Control factors

For existing trade in power equipment and engineering services with China and other developed countries, we use Platts to trace the source country of key power equipment and engineering services in all power projects globally. For power equipment, we include steam supply systems, turbines and generators and source their manufactures through the abbreviation list provided by Platts. For engineering services, we include primary construction contractors and primary architecture/engineering firms and source their country of origin through the abbreviation list. For developed countries, we include Japan, Germany, US. We use the log form by capacity of the power projects examined in our model. We collect population from the World Bank database and use its log form in our model. For the level of institutionalized democracy, we use the Polity2 variable developed by the Polity IV project (Marshall et al., 2014) which scales from +10 (consolidated democracy) to -10 (hereditary monarchy). For BRI, we collected records of MOU signatures from the Belt and Road Portal website supported by the Chinese government (Belt and Road Portal 2020).

Table 1 List of variables

Variable name	Definition	Source
Dependent variables		

Chinese development finance (log, unit:MW)	Chinese development finance in developing countries‘ power sector by capacity	Gallagher et al., 2020
Chinese development finance (log, unit: million US $)	Chinese development finance in developing countries‘ power sector by 2015 US dollar	Gallagher et al., 2020
Chinese_FDI (log, unit:MW)	Chinese FDI in developing countries‘ power sector by capacity	Li et a., 2020
Push factors		
Overcapacity (log, unit:MW)	Excess capacity in Chinese power manufacturing firms and engineering companies	Platts and peak year method
Voting distance	Alignment of voting behavior in the United Nations between China and the recipient countries.	Bailey at al., 2017 & UN General Assembly
Chinese_trade (log, unit:USD)	Chinese outgoing trade in developing countries' power sector	UN Comtrade
Resource rent (unit: %)	Natural resource rent as percentage of recipient countries' GDP	World Bank Database
Pull factors		
New power capacity (log, unit:MW)	Added power capacity in recipient countries' power sector	Platts
GDP per capita (log, unit:USD)	GDP per capita in recipient countries	World Bank Database
Power resource potential (log, unit:MWh)	Resource potential for power generation, coal/gas reserve for coal and gas plants, hydropower potential for hydropower plants, fixed all year for a given country	BP, Zhou et al., 2015
Control Variables		
Population (log)	Population in recipient countries	World Bank Database
Polity2	Regime authority of 21-point scale ranging from +10 (consolidated democracy) to -10 (hereditary monarchy)	Polity IV (Marshall et al., 2014)
BRI	1 for BRI signature year and each year thereafter since the country signed a BRI MOU with China and 0 before signing BRI MOU with China	China’s government website
Trade with China in the power sector (log, unit:MW)	Added power capacity in the last 5 years utilizing EPC or equipment from China	Platts
Trade in the power sector with US, Japan and Germany (log, unit:MW)	Added power capacity in the last 5 years involved with EPC or equipment from major players in global power industry (US, Japan and Germany)	Platts

3. Results and discussion

3.1 Econometric analysis on potential drivers and summary of regression results

We conduct an econometric analysis on the potential drivers described above using our newly created panel dataset which includes all power projects receiving Chinese development finance (DF) or Chinese foreign direct investment (FDI) during 2005-2018 in 35 recipient countries. Using the models we describe above, we measure the effects various driving factors have on both variants of Chinese finance during 2005-2018. We ran two sets of regressions, for Chinese DF and FDI respectively, with results shown in table 2. For each driving factor, or independent variables in econometric terms, there are two values we obtain from the regression model. The first value, without parenthesis, is the coefficient shown in the first row for each independent variable, describing the level and direction of the effect the independent variable has on Chinese financing with positive (negative) values indicating correlation (anti-correlation). The p value is shown in parentheses in the second row for each independent variable and describes the possibility that we reject the null hypothesis that the independent variable has no effect on Chinese financing. There are three thresholds for p values to describe the level of significance, 0.05, 0.01 and 0.001. The smaller the p value, the more likely the independent variable is significantly correlated with our dependent Chinese financing variables.

For some of the driving factors in our model, there are endogeneity concerns where it is difficult to infer the direction of the causality in our regression results. For instance, if we find that the amount of power capacity receiving Chinese development finance is strongly related to new power capacity in recipient countries, it is difficult to tell if a fast-growing electric power market

in recipient countries drives Chinese financing as a demand pull or if Chinese financing drives the local electric power market's growth. To avoid such a concern, we lag three such driving factors (new power capacity in host country, added power capacity in the last 5 years involving engineering services or equipment from China in host country, and added power capacity in the last 5 years involving engineering services or equipment from US, Japan and Germany in host country) by one year where we use the values of these various factors during 2004-2017 instead of 2005-2018. The underlying assumption is that although Chinese financing practices in a given year could drive new power capacity additions in that same year, they are not likely to have driven new power capacity additions the year before. Such lag regression practices have also been applied in other development finance and energy literature (Dreher et al., 2017; Dreher et al., 2018; Springer 2020). Table 3 presents the results when the three variables are lagged by one year while the other variables remain the same. We have also tested regressions with two-year and three-year lags on these variables and the results are shown in table S1 and table S2. Descriptive statistics for all variables are shown in table S3.

Based on the regression results in tables 2 and 3, we are able to quantitatively estimate how significant the relationship of each independent variable is on the two dependent variables of Chinese overseas financing. For the push factors we examine, overcapacity in Chinese domestic market is the only push factor we found to have a significant correlation with Chinese overseas financing and such correlation is only applicable to Chinese development finance and not FDI. Our results indicate that an overcapacity in the Chinese domestic market pushes more Chinese development finance to other developing countries. For the other push factors (UN voting alignment between host country with China, resource rent in host country, or trade value), we do not find any significant correlation with Chinese overseas financing. For the pull factors we

examine (see table 2), we find the new power capacity additions in host countries to be significantly correlated with the amount for both mechanisms of Chinese financing. When we lag the new power capacity additions by one year as well as the other two control variables (see table 3), we find that new power capacity additions in host countries only have a significant correlation with Chinese foreign direct investment. The lagged results are more credible as the endogeneity issue could threaten the results in table 2. We also find power resource potential to have a significant and positive correlation with Chinese development finance. For GDP per capita, it has no significant correlation with Chinese overseas financing. For the control factors we examine, we find that the added power capacity in a given host country involving China in EPC or equipment supply in the last five years has a significant and positive correlation with the amount of both types of Chinese financing in the same country. We also find that added power capacity in a given host country involving EPC or equipment supply from U.S., Japan and Germany has a significant and negative correlation with Chinese foreign direct investment and Chinese development finance measured in dollar value. For the rest of the control variables (signing of a BRI MOU with China or the level of institutionalized democracy), we find them to have no significant correlation with Chinese overseas financing. We discuss the significant drivers in more detail in the following section.

Table 1 Regression results. *(single asterisk indicates p<0.05, double asterisk indicates p<0.01, triple asterisk indicates p<0.001; p-value in parentheses)*

Independent Variables	Chinese Foreign Direct Investment (log, MW)	Chinese Development Finance (log, MW)	Chinese Development Finance (log, US$)
Push factors			
Overcapacity in China (log)	-0.003	0.030***	0.028**
	(0.631)	(<0.001)	(0.004)
UN voting alignment with China	-0.030	0.432	0.313
	(0.953)	(0.467)	(0.708)

Resource rent in host country (log)	0.006 (0.276)	-0.002 (0.949)	-0.001 (0.932)
Trade value between host country and China (log)	0.060 (0.056)	-0.022 (0.699)	-0.029 (0.575)
Pull factors			
New power capacity in host country (log)	0.106*** (<0.001)	0.182*** (<0.001)	0.164*** (<0.001)
Power resource potential (log)	0.013 (0.095)	0.027* (0.020)	0.035** (0.007)
GDP per capita in host country (log)	0.025 (0.290)	-0.004 (0.904)	-0.003 (0.939)
Control factors			
Added power capacity in the last 5 years involving EPC or equipment from China (log)	0.053*** (<0.001)	0.128*** (<0.001)	0.164*** (<0.001)
Added power capacity in the last 5 years involving EPC or equipment from US, Japan and Germany (log)	-0.045*** (<0.001)	-0.015 (0.398)	-0.043* (0.031)
Population in host country (log)	0.180 (0.722)	-0.562 (0.435)	-0.827 (0.319)
BRI (0 before signing BRI MOU and 1 afterwards)	0.091 (0.369)	0.051 (0.825)	0.007 (0.968)
Polity (Institutionalized democracy)	0.004 (0.792)	-0.005 (0.802)	-0.004 (0.839)
Country Fixed Effect	**Yes**	**Yes**	**Yes**
Year Fixed Effect	**Yes**	**Yes**	**Yes**
R-squared	**0.21**	**0.28**	**0.27**
Number of countries	**35**	**35**	**35**
Number of technologies	**3**	**3**	**3**
Number of observations	**1464**	**1464**	**1464**

Table 2 *Regression results. One-year lag for new power capacity in host country, added power capacity in the last 5 years involving EPC or equipment from China, added power capacity in the last 5 years involving EPC or equipment from U.S. Japan and Germany (single asterisk indicates p<0.05, double asterisk indicates p<0.01, triple asterisk indicates p<0.001; p-value in parentheses)*

Independent Variables	Chinese Foreign Direct Investment (log, MW)	Chinese Development Finance (log, MW)	Chinese Development Finance (log, US$)
Push factors			

Overcapacity in China (log)	-0.005	0.025**	0.024*
	(0.437)	(0.007)	(0.021)
UN voting alignment with China	0.116	0.775	0.715
	(0.826)	(0.331)	(0.398)
Resource rent in host country (log)	0.006	0.003	0.004
	(0.279)	(0.747)	(0.606)
Trade value between host country and China (log)	0.067	-0.005	-0.009
	(0.41)	(0.917)	(0.837)
Pull factors			
New power capacity in host country (log)	0.046***	0.022	0.028
	(<0.001)	(0.245)	(0.197)
Power resource potential (log)	0.016	0.045***	0.053**
	(0.051)	(<0.001)	(<0.001)
GDP per capita in host country (log)	0.022	-0.013	-0.011
	(0.374)	(0.721)	(0.656)
Control factors			
Added power capacity in the last 5 years involving EPC or equipment from China (log)	0.065***	0.108***	0.124***
	(<0.001)	(<0.001)	(<0.001)
Added power capacity in the last 5 years involving EPC or equipment from US, Japan and Germany (log)	-0.0254	0.011	-0.001
	(0.069)	(0.590)	(0.961)
Population in host country (log)	0.168	-0.403	-0.655
	(0.748)	(0.610)	(0.786)
BRI (0 before signing BRI MOU and 1 afterwards)	0.070	0.067	0.006
	(0.508)	(0.674)	(0.974)
Polity (Institutionalized democracy)	0.008	0.005	0.007
	(0.573)	(0.811)	(0.775)
Country Fixed Effect	**Yes**	**Yes**	**Yes**
Year Fixed Effect	**Yes**	**Yes**	**Yes**
R-squared	**0.15**	**0.14**	**0.13**
Number of countries	**35**	**35**	**35**
Number of technologies	**3**	**3**	**3**
Number of observations	**1464**	**1464**	**1464**

3.2 Push Factor: Domestic overcapacity in China

We measured the amount of excess technical capacity in the Chinese domestic market to build new coal, gas and hydropower projects by comparing the annual new power capacity additions with the historical peak year record. For the Chinese coal power industry, we found that overcapacity emerged in 2007 and grew to be around 40 GW per year after 2013. As shown in Figure 1, the trend of Chinese domestic overcapacity in coal matches the trend in Chinese overseas finance in coal projects. We also found that about 10 GW of overcapacity in Chinese hydropower occurred around 2010 and remained constant each year after 2015. For the Chinese gas power industry, overcapacity occurred in 2015 and the scale was much smaller - around 2 GW.

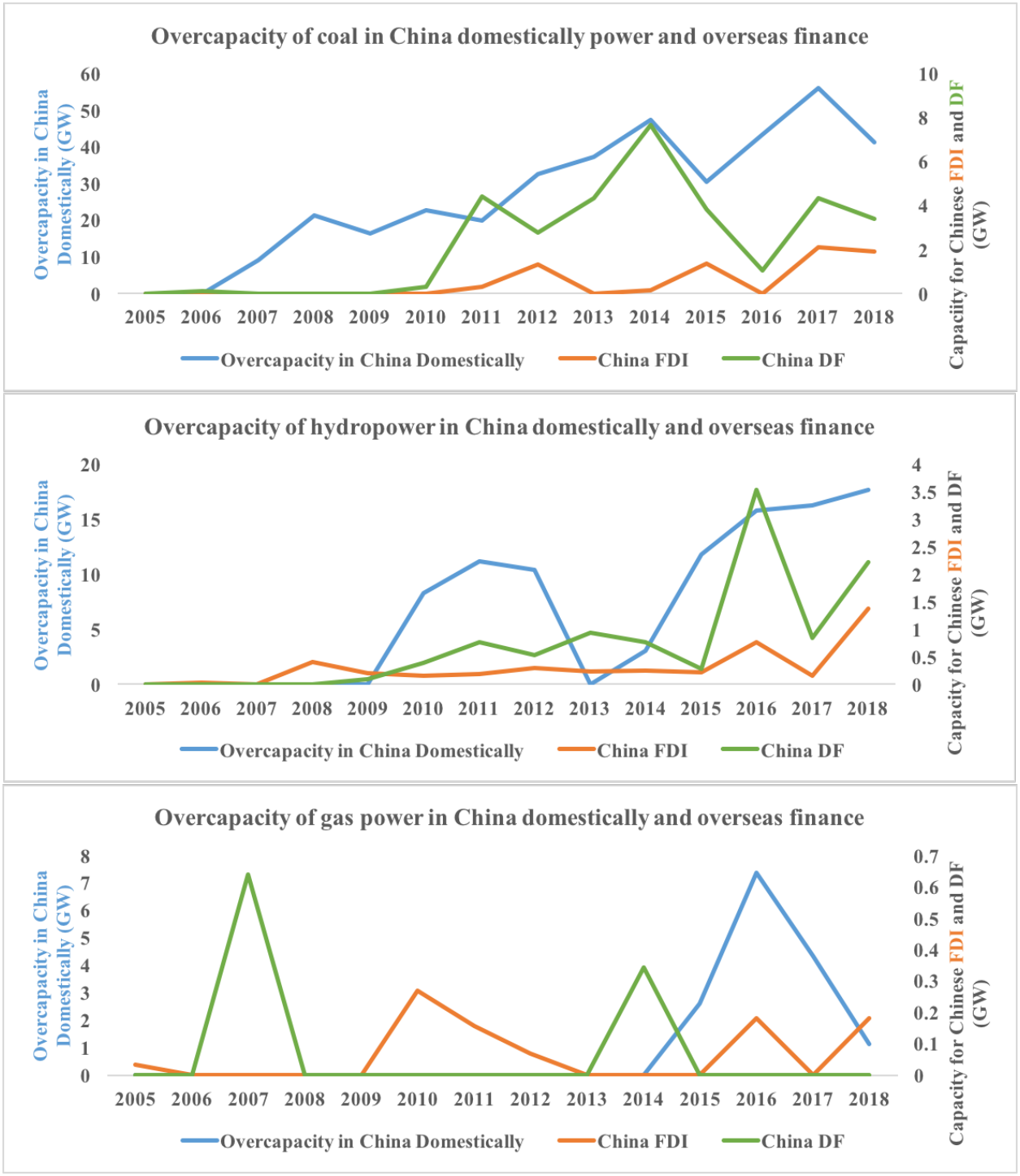


Figure 7 Measured overcapacity in Chinese domestic power industries (left axis) and Chinese overseas finance in coal, gas and hydropower projects (right axis) from 2005 to 2018.

Our multivariate econometric models suggest that overcapacity in the Chinese domestic market could explain Chinese overseas development finance with statistical robustness but not in the

case of Chinese foreign direct investment. Our results are consistent with case study research which found that China's development finance supported state objectives to export domestic overcapacity. These findings are especially true in the case of coal power and hydropower projects (Kong and Gallagher, 2020). In the case of Chinese foreign direct investment, such incentives are less important. As a complementary piece of evidence, we also observed a higher utilization rate of Chinese power equipment and engineering services in power plants receiving Chinese development finance than in power plants receiving Chinese foreign direct investment. Out of the 56 GW of power projects receiving development finance from China, 42 GW (75%) utilize power equipment manufactured by Chinese companies, and 49 GW (87%) utilize engineering services provided by Chinese companies for project construction or project design. In comparison, out of the 20 GW of power projects receiving FDI from China, 11 GW (57%) utilize power equipment manufactured by Chinese companies, and 14 GW (69%) utilize engineering services provided by Chinese companies for project construction or project design.

Pull Factor: Demand for new power capacity in host countries

From table 2, we observe that new power capacity additions in host countries has are strongly correlated ($p<0.001$) with the size of Chinese overseas finance (both DF and FDI). This is also seen in figure 2. Installation of new coal projects increased substantially in developing countries starting in 2009 and Chinese finance of coal grew starting in 2010. In the case of hydropower, the capacity of new hydropower projects in developing countries remained constant during 2005-2015 and increased after 2015, which also coincided with growth of Chinese development finance in overseas hydropower projects. There are two potential causal mechanisms to explain such correlations. The first is that Chinese finance is pulled by the growing markets in

developing countries. The second explanation is that the increasing new demand in developing countries is pushed by Chinese finance and the higher growth rate would not appear without it. If this is the case, a question remains as to what is causing the push. To avoid the endogeneity concern in the second explanation, we lagged new power capacity by one year and examine the effects of new power capacity additions in developing countries from 2004 to 2017 on Chinese overseas finance from 2005 to 2018. The results are shown in table 3. Although in the no-lag scenario shown in table 2, both Chinese development finance and Chinese foreign direct investment are found to be positively correlated with market demand in host countries, in the lagged scenario shown in table 3, only Chinese foreign direct investment is found to be significantly correlated with market demand in host countries. Since Chinese finance is not likely to have an effect on new power capacity additions the year before financing is provided, such results suggest that Chinese foreign direct investment, instead of Chinese DF, is more likely to follow a growing market, rather than creating a new market. This supports the profit-seeking nature of foreign direct investment when compared with development finance.

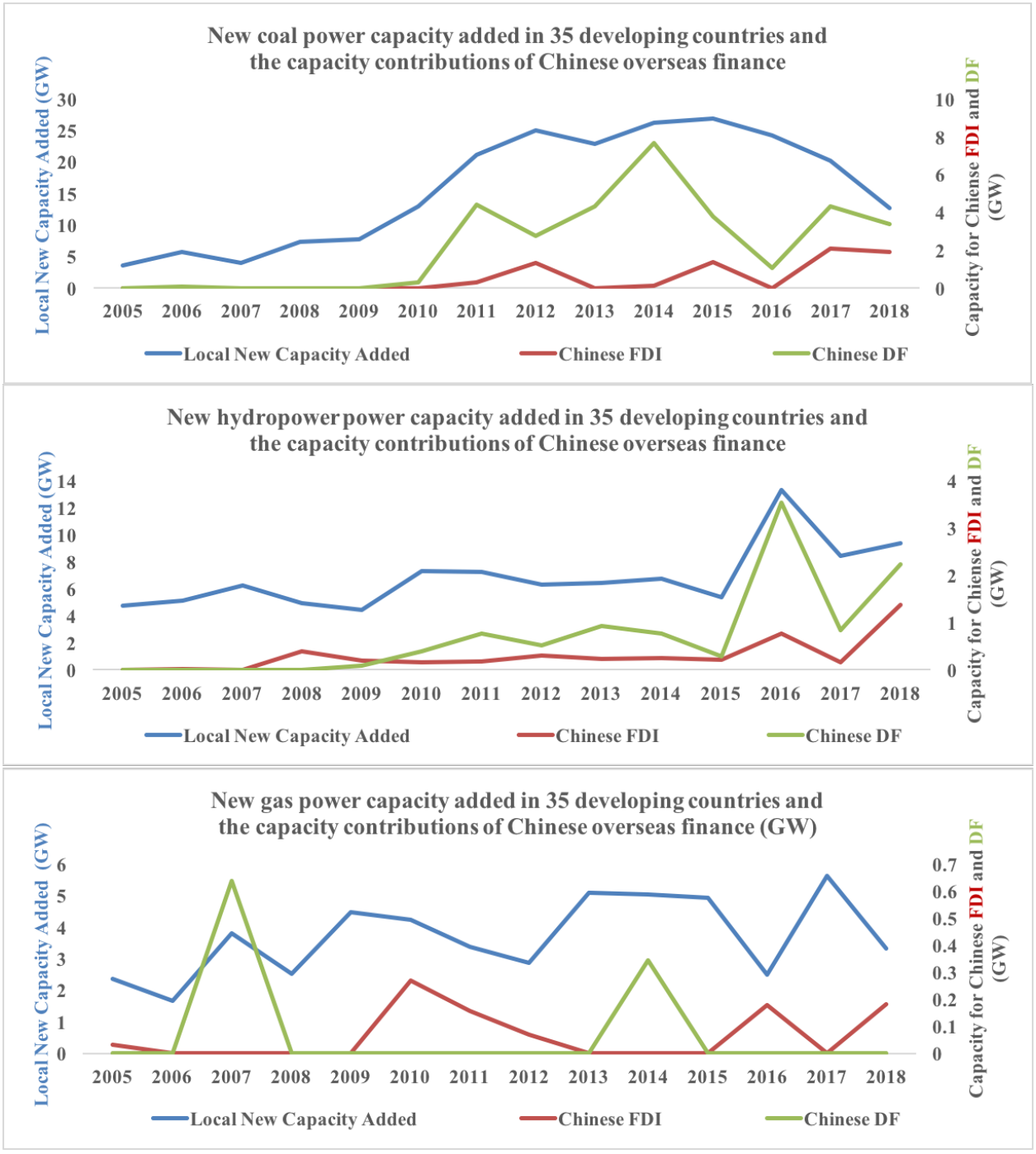


Figure 8 Local new capacity (left axis) measured as added new power capacity in 35 developing countries receiving Chinese finance and Chinese overseas development finance and foreign direct investment (right axis) in coal, gas and hydropower projects from 2005 to 2018

3.3 Pull factor: Power resource potential in host countries

From our econometric analysis, we observe a positive and statistically significant coefficient for host country power resource potential on Chinese development finance but not on Chinese

foreign direct investment. As described in the methodology section, we measure power resource potential as the coal and gas fuel reserves and hydropower potential in a given country. This result suggests that abundant local power resources are an important pull factor for Chinese development finance. In a mature power market, the abundance of local coal and gas, and hydropower potential are important factors determining the feasibility and bankability of individual power projects. Abundant local resources in coal, gas or hydropower would attract investment in the corresponding type of power projects. However, among the poorest developing countries, the low demand for electricity and poor transmission infrastructure results in non-bankable power projects under market conditions, despite abundant local resources. Our results indicate that Chinese development banks could be important sources of finance for power sector development in such cases. For example, in Africa, Chinese development banks have been important sources of finance for new hydropower projects. Out of the 35 developing countries we examine, Democratic Republic of Congo and Republic of Congo have the largest hydropower potential and represent 39% of the hydropower resources in these 35 countries. In Democratic Republic of Congo and Republic of Congo, there is no hydropower project receiving finance from Chinese power developers or other major international power developers in the form of foreign direct investment, although the local hydropower resource is very abundant. However, Chinese development finance has contributed to 68% of all new hydropower capacity, or 35% of all new power capacity from 2005 to 2018 in these two countries. Another 240 MW hydropower project in Democratic Republic of Congo financed by Chinese ExIm Bank is also in the pipeline. Chinese development finance and engineering companies have been involved in electricity transmission projects as well and since 2005 electricity access in these two countries has greatly improved.

3.4 Push and Pull: Building a customer base

Our most robust and intriguing finding is that Chinese finance tends to flow where it has been concentrated in the recent past, and to some extent where Western (US, Japan or Germany in this study) finance is not flowing. The "added capacity over the past five years involving power equipment or engineering services provided by Chinese companies in the host country" variable stays consistently significant regardless of whether we test for FDI or DF and whether variables are lagged or not. As the tables show, for both FDI and DF there is a statistically significant correlation showing that as China increases its export of power equipment and engineering services to a given country, there tends to be a positive effect resulting in continually increasing Chinese finance to power plant projects. For the FDI variable, we find a negative correlation for countries that have had a significant growth in import of power equipment and engineering services from non-Chinese countries, indicating a negative effect of increasing power equipment imports from non-Chinese countries on Chinese finance of power plant projects.

As reported by earlier researchers, Chinese involvement in the developing countries' power sector includes not only finance but also export of power equipment and power engineering services (Hannam et al., 2015; Ren et al., 2017). From 2005 to 2018, we found such Chinese trade practices to be involved in 173 GW of projects in 58 developing countries, which suggests that Chinese export of power equipment and power engineering services have been a important form of Chinese involvement in the power sector of developing countries.

To avoid endogeneity concerns in our regressions in this case as well, we also lagged existing Chinese trade by one year and obtained similar results. There are two potential mechanisms to

explain the facilitating effect of existing trade with China on Chinese finance in the power sector in the same country. First, existing Chinese business in the local power sector smooths interactions and reduces the transaction costs for Chinese financing. Since the early 2000s, most Chinese power equipment manufacturers and engineering companies have established a global office network to support their global business in power equipment sales and international contracting services. Such existing connections have been important sources of potential project information as well as local connections and market knowledge. In addition, there are also spillover effects where such information could be transferred from frontline companies to Chinese development banks and other power investors back in China. Secondly, greater trade with China in power equipment and engineering services is indicative of local acceptance of Chinese business and technical abilities to produce and deliver key equipment and engineering services. While there is a lack of data to support this assertion, knowledge from the field suggests that Chinese investors have a cost advantage over global competitors through their close alliance with Chinese power manufacturers and engineering companies.

3.5 Belt and Road Initiative: Not much of a pull yet, despite the push

Starting in 2013, dozens of countries signed memorandum of understanding with the Chinese government for bilateral cooperation under the Belt Road Initiative (BRI). Although in 2014, only nine developing countries signed MOU with China, in 2018 the number increased to more than 60. Infrastructure development is a key area for cooperation and many power projects receiving Chinese finance have been included in various BRI project lists. While many would expect that the development of BRI has been a strong driving factor pushing Chinese finance out

to overseas power projects, our results do not yet show a statistically significant correlation between signing a BRI MOU with China and the amount of Chinese finance received by a given country. The result is also consistent with knowledge from the field that most power projects secured Chinese financing before the host country signed the MOU. The projects listed in the MOU are simply a list of existing projects, rather than new commitments. It is important to note that we are only analyzing projects built from 2005 to 2018 and power projects usually have a long development cycle. Thus, it could take more time for the newly established BRI framework to have a visible effect on the quantity of Chinese overseas finance available to the developing countries' power sector.

4. Concluding Discussion

Combining two relatively new datasets from our previous work, we performed a statistical analysis to estimate the determinants of Chinese power plant finance in the developing world. We considered that such finance and investment would be a function of both the supply of Chinese finance—what we call 'push' factors, and the demand for such finance in host countries—what we call 'pull' factors. We deployed a fixed effect model to analyze a vector of push and pull factors on two different mechanisms of Chinese overseas finance in developing countries' power sector—foreign direct investment and development finance. The results shed light on some important factors driving Chinese development finance and Chinese foreign direct investment since 2005. With the expectation of a growing presence of Chinese finance in developing countries' power sectors, our findings enrich the discussion of energy development

pathways in developing countries from the perspective of international development finance and the renewable energy transition.

We find that Chinese FDI in the power sector is largely market driven, pulled by demand for electric power in developing countries. Development finance is naturally more driven by intermediate policy goals—to provide outlets for sectors that are facing overcapacity in mainland China, and to make inroads into countries that have abundant energy capacity but that are not yet market competitive. Although both Chinese development finance and Chinese foreign direct investment are driven by state actors, our analysis lends empirical support to observations that Chinese state-owned enterprises are largely profit seekers, instead of arms of the state. Our results also contribute to the discussion of whether China has been pushing finance outward or the host countries have been pulling finance inward. Our results found no statistical robust evidence to indicate that push factors are driving Chinese foreign direct investment outward. The pull factors, and market demand in particular, are the primary drivers for Chinese foreign direct investment. In the case of Chinese development finance, we have found both push and pull factors drive Chinese development finance in developing countries' power sector.

As Cabré et al., (2018) estimated there to be $800 billion dollar solar and wind investment potential based on the National Determined Contributions by all participating countries in the Paris Agreement, Chinese growing finance in developing countries could be important in realizing a share of this investment potential. Our results provide insights on how both mechanisms of Chinese finance could facilitate renewable energy transitions in developing countries. For Chinese FDI, our analysis suggests that a stronger demand pull from developing countries is more important in driving Chinese FDI inward and an existing distributing network

also facilitates Chinese FDI. As shown in data in figure S4, solar and wind projects represent 14% of all overseas power projects receiving Chinese FDI by capacity. This indicates that Chinese globally competitive renewable companies have already been investing in developing countries where they have established distribution networks or where the renewable power market is attractive. As the cost solar and wind power continues to decrease and becomes more economically competitive, there is an opportunity for developing countries to pull more Chinese FDI into their renewable projects. For Chinese DF, our analysis suggests that a push from Chinese overcapacity in domestic industries is important in driving Chinese DF outward, in case of coal and hydropower projects. While there has also been overcapacity in Chinese solar and wind industries since the early 2010s, only 2% of Chinese DF in the power sector has been devoted to renewable projects (as shown in figure S3), indicating the existence of other factors impeding Chinese DF flowing into overseas solar and wind projects. Moving forward, BRI is going to provide massive amount of development finance to infrastructure development in other developing countries. While these Chinese development finance could help other developing countries access affordable electricity for economic development, the newly built energy infrastructure would have multi-decade-long effect on global carbon emissions. As estimated by Tong et al., 2019, all existing and purposed energy infrastructure have already committed to more carbon emissions than the global carbon budget under the 1.5 degree target, or two-thirds of the global carbon budget under the two degree target. It is very important to substantially slow down or even stop Chinese development finance contribute to new carbon intensive power projects overseas. While Japan, as another important public financier for coal, has recently announced to stop approving loans to new overseas coal projects, Chinese development banks have not yet made explicit or effective announcement with the same level of commitment. From a non-climate perspective, coal power projects are also important sources of air pollution and

water pollution, which have already been severe public health concerns in many developing countries. Directing Chinese overseas finance away from coal plants would also bring substantial co-benefits.

Acknowledgements

An earlier version of Chapter 4 was presented at the the International Political Economy of Aid and Development hosted by Graduate Student International Political Economy Workshop on Dec. 1st, 2020. Zhongshu Li thanks the following co-authors of this chapter: Kevin P. Gallagher, Xu Chen, Denise L. Mauzerall.

References

"Belt and Road Portal ". Retrieved Feb. 20th, 2020, from https://www.yidaiyilu.gov.cn/xwzx/roll/77298.htm.

China's Global Power Database. K. P. Gallagher, Li, Zhongshu, Chen, Xu, Ma, Xinyue Global Development Policy Center, Boston University. (2020).

World development indicators 2019. World Bank (2019).

UN Comtrade database. In: UN Comtrade Online (2019).

China's Global Power Database. K. P. Gallagher, Li, Zhongshu, Chen, Xu, Ma, Xinyue Global Development Policy Center, Boston University. (2020).

Global Energy & CO2 Status Report 2019. International Energy Agency (2019).

Bailey MA, Strezhnev A, Voeten E. Estimating dynamic state preferences from United Nations voting data. Journal of Conflict Resolution 61, 430-456 (2017).

Davis SJ, Socolow RH. Commitment accounting of CO2 emissions. Environmental Research Letters 9, 084018 (2014).

Dreher A, Fuchs A. Rogue aid? An empirical analysis of China's aid allocation. Canadian Journal of Economics/Revue canadienne d'économique 48, 988-1023 (2015).

Dreher A, Fuchs A, Parks B, Strange AM, Tierney MJ. Apples and dragon fruits: the determinants of aid and other forms of state financing from China to Africa. International Studies Quarterly 62, 182-194 (2018).

Foster V, Butterfield W, Chen C. Building bridges: China's growing role as infrastructure financier for Africa. The World Bank (2009).

Gallagher KS, Rishikesh Ram Bhandary, Easwaran Narassimhan, and Nguyen Quy Tam. Drivers of Chinese Overseas Investments in Coal-Fired Power. (Under Review).

Gielen D. Perspectives for the Energy Transition Investment Needs for a Low-Carbon Energy System. (2017).

Hannam PM, Liao Z, Davis SJ, Oppenheimer M. Developing country finance in a post-2020 global climate agreement. Nature Climate Change 5, 983-987 (2015).

Jiang B, Sun Z, Liu M. China's energy development strategy under the low-carbon economy. Energy 35, 4257-4264 (2010).

Jun M, & Simon, Z. Decarbonizing the Belt and Road: A Green Finance Roadmap. Tsinghua University Center for Finance and Development, Vivid Economics and the Climateworks Foundation (2019).

Kenderdine T, Lan P. China's Middle East investment policy. Eurasian Geography and Economics 59, 557-584 (2018).

Kenderdine T, Ling H. International Capacity Cooperation—Financing China's Export of Industrial Overcapacity. Global Policy 9, 41-52 (2018).

Kong B, and Kevin P. Gallagher. The Big Push (and Pull): State finance and the Globalization of China's Overseas Coal Plants. Journal of East Asian Studies (Forthcoming).

Kong B, Gallagher Kevin P. Gallagher. Globalization as Domestic Adjustment: Chinese Development Finance and the Globalization of China's Coal Industry.

Kong B, Gallagher KP. Globalizing Chinese energy finance: the role of policy banks. Journal of Contemporary China 26, 834-851 (2017).

Li Z, Gallagher KP, Mauzerall DL. China's global power: Estimating Chinese foreign direct investment in the electric power sector. Energy Policy 136, 111056 (2020).

Lum T, Fischer H, Gomez-Granger J, Leland A. China's foreign aid activities in Africa, Latin America, and Southeast Asia. Russia China and Eurasia-Social Historicaland Cultural Issues 25, 175 (2009).

Lum T, Fischer H, Gomez-Granger J, Leland A. China's foreign aid activities in Africa, Latin America, and Southeast Asia. Russia China and Eurasia-Social Historicaland Cultural Issues 25, 175 (2009).

Marshall MG, Gurr TR, Jaggers K. Polity IV project: Political regime characteristics and transitions, 1800–2013. Center for Systemic Peace 5, (2014).

Morris S, Parks B, Gardner A. Chinese and World Bank Lending Terms: A Systematic Comparison Across 157 Countries and 15 Years. (2020).

Peng R, Chang L, Liwen Z. China's involvement in coal-fired power projects along the Belt and Road. Global Environmental Institute, 1 (2017).

Pepermans A. Economic Nationalism in All Its Variety: The Case of China's Construction-and Railway Equipment Industry. Journal of Contemporary China 29, 431-453 (2020).

Platts S, Global P. World electric power plants (WEPP) database. (2016).

Steffen B, Schmidt TS. A quantitative analysis of 10 multilateral development banks' investment in conventional and renewable power-generation technologies from 2006 to 2015. Nature Energy 4, 75-82 (2019).

Strange AM, Dreher A, Fuchs A, Parks B, Tierney MJ. Tracking underreported financial flows: China's development finance and the aid–conflict nexus revisited. Journal of Conflict Resolution 61, 935-963 (2017).

Tao Y, Liang H, Celia MA. Electric power development associated with the Belt and Road Initiative and its carbon emissions implications. Applied Energy 267, 114784 (2020).

Yuan J, Na C, Lei Q, Xiong M, Guo J, Hu Z. Coal use for power generation in China. Resources, Conservation and Recycling 129, 443-453 (2018).

Yue L. Dynamics of clean coal-fired power generation development in China. Energy Policy 51, 138-142 (2012).

Zhou L, Gilbert S, Wang Y, Cabré MM, Gallagher KP. Moving the green belt and road initiative: from words to actions. World Resources Institute and Global Development Policy Center (2018).

Chapter 5: Conclusion

Facilitating renewable energy transition in developing countries' power sectors is critical to meet our climate targets. Since the early 2000s, China has been actively engaged with the power sector development in many developing countries through multiple forms of cross-border activities, including exporting power equipment and engineering services and providing foreign direct investment and development finance. As the Belt and Road Initiative further expands China's overseas impacts, Chinese climate policies can have significant impacts on global carbon emissions not only through governing Chinese domestic activities but also through governing Chinese overseas activities. While China has already been one of the most important players among other developed countries, there have been a lack of academic efforts yet made to understand the scale and mechanisms of Chinese overseas activities. To help direct China's overseas activities to facilitate renewable energy transition in other developing countries, my dissertation improves the understanding of Chinese overseas activities in the global power sector from three key perspectives.

Chapter 2 provides the first quantitative estimation of Chinese foreign direct investment in the global power sector. I 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. I 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. 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. The analysis indicates that Chinese investors have utilized more efficient coal technologies with more end-of-pipe controls than non-Chinese firms.

Chapter 3 expands the quantitative analysis to all major forms of cross-border activities China has been engaged with in the global power sector, including provision of development finance and foreign direct investment, and export of power equipment and engineering services to other developing countries. From 2005 to 2018, I find that China was involved in 246 GW of new overseas power projects in other non-OECD countries with a diverse technology portfolio that includes coal (41%), solar (25%), and hydropower (19%) measured by capacity. The 246 GW is equivalent to 20% of all new power projects in other non-OECD countries or 22% of all new power projects in China by capacity built between 2005 to 2018, inclusive. I also develop nine future scenarios and estimate the future committed carbon emissions from 2019-2079 from these overseas coal plants involving China. The analysis finds that, depending on the future scenario examined, the existing and expected future coal plants built before 2040 in other developing countries involving China would emit 9-77 Gton CO_2 over their lifetime, which adds 11-40% to China's power sector carbon emissions.

Chapter 4 focuses on the determinants of Chinese overseas financing in the global power sector. I conduct an econometric analysis on the potential drivers using our newly created panel dataset

which includes all coal, hydropower and gas power projects receiving Chinese development finance (DF) or Chinese foreign direct investment (FDI) during 2005-2018 in 35 recipient countries. The potential drivers examined include a number of 'push factors' –incentives in China that facilitate investment abroad—and 'pull factors' –incentives in host countries that facilitate Chinese investment into their own countries. On the push side, I find that overcapacity in China's domestic coal and hydro power industries to be significantly associated with the size of Chinese development finance. This indicates that exporting domestic overcapacity to overseas market could be an important driver for Chinese development finance in the power sector. On the pull side, I find that local demand for new power capacity to be significantly associated with the size of Chinese foreign direct investment in the power sector. This indicates that Chinese outward investment in overseas power projects could be driven by local pull from recipient countries. For other factors, I find that existing Chinese involvement in past power projects in recipient countries to be significantly associated with both types of Chinese overseas financing. This indicates that Chinese existing activities in the local power sector could facilitate future DF and FDI in recipient countries.

Based on the findings from these three chapters, I make the following suggestions for future endeavors to direct China's overseas activities towards facilitating renewable energy transition in other developing countries:

1. Improving the current reporting system for energy data

Future efforts on data collection should aim to build a more comprehensive global reporting system for energy related data with updating mechanisms and advocate for multilateral cooperation. This could be done to expand the scope of the monitoring, verification and monitoring (MRV) mechanism built in the United Nations Framework Convention on Climate

Change (UNFCCC). The current mechanism only includes report of direct greenhouse gas emissions and exclude the report of global trade of fossil fuels and other energy related commodities, and the reports of cross-border finance on key carbon emitting industries. There is also potential for other multilateral platforms to improve their reporting mechanism for climate related data. For instance, the United Nations Conference on Trade and Development (UNCTAD) has been collecting data on international trades and cross-border finance for decades. The current data reporting guidelines could be improved to better monitor energy-related activities, especially the trade and cross-border finance of renewable energy technologies.

2. Analyzing the barriers for Chinese renewable energy industries to access state-led financing

My analysis in Chapter 3 identifies a lack of state-led financial support for Chinese private-owned solar industry in the overseas market. Understanding and overcoming the underlying barriers is important to help China facilitate the renewable energy transition in other developing countries. There are a number of potential market factors and non-market factors. For instance, a high debt to asset ratio among Chinese solar manufacturers can be an important market factor that limits their access to further financing. A smaller project size in terms of monetary value for typical solar projects when compared to coal power projects can be another market factor, as Chinese banks and investors usually prefer larger projects. Non-market factors can include a lack of support from central government to solar companies and these factors should be identified and examined more carefully.

3. Evaluating the role of local interest groups in determining Chinese outward finance

For the power projects China have been involved in overseas power projects, China interacted and cooperated with a variety of local interest groups throughout the developing processes. For instance, local power developers provide important project information to China and they usually sell the early-phase project or co-develop with Chinese companies. Local mining companies are supplier of coal to Chinese coal power plants and they can be involved in very early phase of the project and provide strong local support. The impact these local interest groups have on Chinese finance could vary greatly across different regions and conducting regional case studies are important venues to fill up the knowledge gap.

Appendix for Chapter 2

China's Global Power: Estimating Chinese Foreign Investment in the Electric Power Sector

1. Unit-level database

Our database is available online at GoogleSheet[5]. Since some of the intellectual property rights are owned by Platts, we only expose information we have collected and pair it with a Platts unit ID. Anyone who has access to the Platts database can link our database with Platts using the unit ID. The units in the database are listed by capacity from largest to smallest. For most of the units, there is a webpage link where the information can be verified.

2. Technological and spatial distribution.

Figure S1 shows the technological mix and spatial distribution of Chinese overseas power investment.

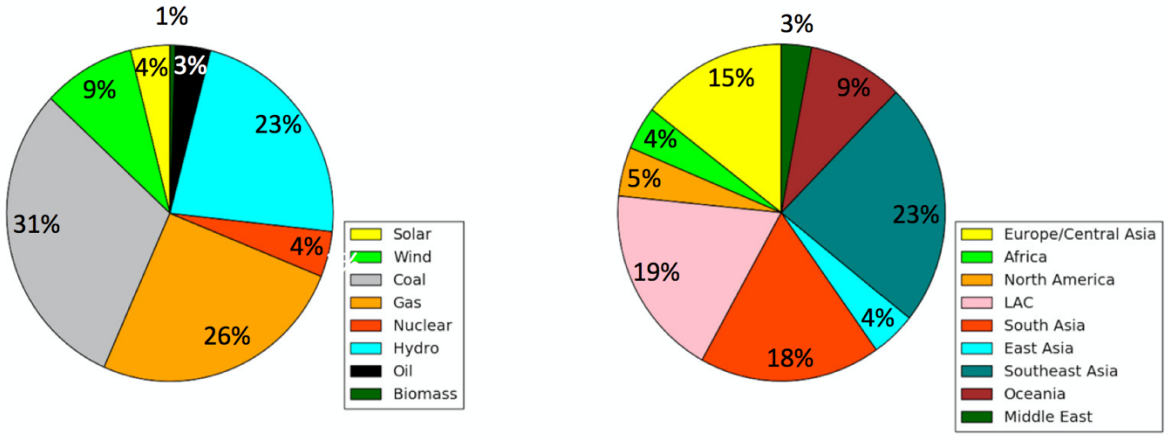


Figure S1. Technological mix (left) and spatial distribution (right) of Chinese overseas power projects. The percentage is calculated by capacity (MW). LAC: Latin American countries.

3. Capital cost

Table S1 shows the capital costs of various electricity generation technologies that we use to estimate Chinese investment. The estimates are based on IEA and IRENA estimates[6][7].

[5] https://docs.google.com/spreadsheets/d/1jPyn4unb06lx0trME4X-BhksiUUJGPSIoLpzLDAelps/edit#gid=0

[6] IRENA 2017. Renewable Power Generation Costs in 2017. Available at https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf

[7] IEA 2015. Project costs of electricity generation. Available at https://www.oecd-nea.org/ndd/pubs/2015/7057-proj-costs-electricity-2015.pdf

Table S4. Capital costs for various energy technologies used to estimate value of Chinese energy investments

Technology	Capital Cost
Wind	$2354/kW
Hydro	$2186/kW
Coal	$1500/kW
Gas	$1000/kW
Solar	$2500/kW
Nuclear	$4756/kW
Oil	$1000/kW
Geothermal	$3680/kW
Biomass	$4200/kW

4. Coal technology comparison

Table S2. Summary of Chinese Overseas Coal Plants and Recipient Countries' Coal Plants Developed by non-Chinese entities (based on Chinese net capacity).

	Chinese Greenfield Investment[8]	Non-Chinese Greenfield Investment[9]	Chinese M&A Investment[10]
Recipient Countries	Indonesia, Pakistan, Vietnam, Cambodia, India	Indonesia, Pakistan, Vietnam, Cambodia, India	Australia, Singapore, Malaysia
Time Period[11]	2011-2017	2011-2017	2003-2016
Total Net Capacity of Coal Plants	4.3 GW (100%)	145.8 GW (100%)	5.7 GW (100%)

[8] Direct investment by China in new coal power plants which became operational between 2011-2017. 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.

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

[10] 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.

[11] 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.

Capacity of Subcritical Plants	1.3 GW (30%)	96.0 GW (66%)	4.5 GW (79%)
Capacity of Supercritical Plants	3.0 GW (70%)	49.8 GW (34%)	1.2 GW (21%)
Capacity of Plants with Sulfur Controls	4.0 GW (93%)	123.6 GW (85%)	3.6 GW (63%)
Capacity of Plants with NOx Controls	2.6 GW (60%)	12.0 GW (8%)	1.2 GW (21%)
Capacity of Plants with Particle Controls	3.6 GW (84%)	130.8 GW (90%)	5.5 GW (97%)

Table S3. Summary of Chinese Overseas Coal Plants and Recipient Countries' Coal Plants Developed by non-Chinese entities (India excluded)

	Chinese Greenfield Investment	Non-Chinese Greenfield Investment
Recipient Countries	Indonesia, Pakistan, Vietnam, Cambodia, India	Indonesia, Pakistan, Vietnam, Cambodia, India
Time Period	2011-2017	2011-2017
Total Capacity of Coal Plants	4.4 GW (100%)	25.4 GW (100%)
Average Unit Size	335 MW	165 MW
Capacity of Subcritical Plants	2.4 GW (55%)	21.1 GW (84%)
Capacity of Supercritical Plants	2.0 GW (45%)	4.1 GW (16%)
Capacity of Plants with Sulfur Controls	4.1 GW (93%)	20.2 GW (79%)
Capacity of Plants with NOx Controls	1.3 GW (30%)	3.3 GW (13%)
Capacity of Plants with Particle Controls	3.6 GW (82%)	18.9 GW (74%)

Table S4. List of Chinese greenfield investment in coal power plants from 2011 to 2017

Online Year	Recipient Country	Name	Capacity (MW)	Steam Engine	Particle Control	SO_2 Control

2011	Indonesia	SIMPANG BELIMBING 1	150	Subcritical	No	No
2011	Indonesia	SIMPANG BELIMBING 2	150	Subcritical	No	No
2012	India	MAHATMA GANDHI 1	660	Supercritical	Yes	Yes
2012	India	MAHATMA GANDHI 2	660	Supercritical	Yes	Yes
2014	Cambodia	SIHANOUKVILLE CIIDG 1	135	Subcritical	Yes	Yes
2015	Indonesia	CELUKAN BAWANG 1	142	Subcritical	No	Yes
2015	Indonesia	CELUKAN BAWANG 2	142	Subcritical	No	Yes
2015	Indonesia	CELUKAN BAWANG 3	142	Subcritical	No	Yes
2015	Vietnam	MONG DUONG-II NO 1	621	Subcritical	Yes	Yes
2015	Vietnam	MONG DUONG-II NO 2	621	Subcritical	Yes	Yes
2015	Cambodia	SIHANOUKVILLE CIIDG 2	135	Subcritical	Yes	Yes
2017	Pakistan	PORT QASIM THERMAL 1	660	Supercritical	Yes	Yes
2017	Pakistan	SAHIWAL PROJECT 1	660	Supercritical	Yes	Yes
2017	Pakistan	SAHIWAL PROJECT 2	660	Supercritical	Yes	Yes
2017	Cambodia	SIHANOUKVILLE CIIDG 3	135	Subcritical	Yes	Yes

Table S5. List of Chinese M&A deals in coal power plants from 2003 to 2016

Deal Year	Recipient Country	Online Year	Capacity	Steam Engine
2003	Australia	2001	460	Supercritical
2003	Australia	2001	460	Supercritical
2003	Australia	2002	440	Supercritical
2003	Australia	2003	440	Supercritical
2008	Singapore	2013	102	Subcritical
2008	Singapore	2014	60	Subcritical
2012	Australia	1993	700	Subcritical
2012	Australia	1996	700	Subcritical
2012	Australia	1973	360	Subcritical
2012	Australia	1975	360	Subcritical
2012	Australia	1981	380	Subcritical
2012	Australia	1982	380	Subcritical
2016	Malaysia	2009	752.5	Subcritical
2016	Malaysia	2009	752.5	Subcritical

Table S6. Average and Median Size of subcricital/supercricital operation coal plants globally

	Subcritical	Supercritical
Average Plant Size	169 MW	564 MW
Median Plant Size	110 MW	600 MW

5. Matching algorithms.

Table S7 lists Chinese companies we use for direct and indirect matching. For direct matching, the three keywords that are used are shown in the columns. When words are duplicated, they are used to fit the matching code when less than three keywords are necessary.

Table S7. List of companies and corresponding key words used for matching

Company Name	Keyword1	Keyword2	Keyword3
A-Power Energy Generation Systems	A-POWER	A-POWER	A-POWER
A-TECH Wind Power (Jiangxi) Co Ltd	A-TECH	A-TECH	A-TECH
Advanced Technology & Materials Co Ltd	ADVANCED TECH	ADVANCED TECH	ADVANCED TECH
Alpha Energy Storage Solution	ALPHA ESS	ALPHA ENERGY STORAGE	ALPHA-ESS
Aluminium Corporation of China (Chinalco) (Chalco)	ALUMINIUM CORPORATION OF CHINA	CHALCO	CHINALCO
Asia Pacific Generation	ASIA PACFIC GENERATION	ASIA PACFIC GENERATION	ASIA PACFIC GENERATION
Asia Tiger Group Ltd	ASIA TIGER	ASIA TIGER	ASIA TIGER
Aviation Industry Corporation of China	CHINA AVIATIOIN IND	AVIATION INDUSTRY CORPORATION OF CHINA	AVIATION INDUSTRY CORPORATION OF CHINA
Beijing DQY Agriculture Technology	DQY	DEQINGYUAN	DEQINGYUAN
Beijing Enterprises Holdings Ltd	BEIJING ENTERPRISES	BEIJING ENTERPRISES	BEIJING ENTERPRISES
Beijing Fuxing Xiaocheng Electronic Technology Stock	FUXING XIAOCHENG	FUXING XIAOCHENG	FUXING XIAOCHENG
Beijing Jingneng Clean Energy Co Ltd	JINGNENG	JINGNENG	JINGNENG
Beijing Ruichi Power Technology	RUICHI POWER	BEIJING RUICHI	RUICHI POWER
Boretech	BORETECH	BORETECH	BORETECH
Boyuan Construction Group Inc	BOYUAN	BOYUAN	BOYUAN
BYD	BYD	BYD	BYD

Canadian Solar Inc	CANADIAN SOLAR	CANADIAN SOLAR	CANADIAN SOLAR
Changzhou Almaden	CHANGZHOU ALMADEN	CHANGZHOU ALMADEN	CHANGZHOU ALMADEN
Chaozhou Three-Circle Group Co Ltd	CHAOZHOU THREE	CCTC	THREE-CIRCLE
China Aerospace Science and Technology Corporation	CHINA AEROSPACE	CHINA AEROSPACE	CHINA AEROSPACE
China CAMC Engineering	SINOMACH	CAMC	CAMC
China Certification & Inspection (CCIC)	CHINA CERTIFICATION	CCIC	CHINA CERTI
China Crystal Technologies	CHINA CRYSTAL TECH	CHINA CRYSTAL TECH	CHINA CRYSTAL TECH
China Development Bank Corp	CDB	CHINA DEVELOPMENT BANK	CHINA DEVELOPMENT BANK
China Energy Conservation and Environmental Protection Group (Cecep)	CECEP	CHINA ENERGY CONS	CHINA ENERGY CONS
China Everbright Group	CHINA EVERBRIGHT	CHINA EVERBRIGHT	CHINA EVERBRIGHT
China General Nuclear Power Corporation (China Guangdong Nuclear Power Holding)	GENERAL NUC	CGNPC	CHINA GENERAL NUC
China General Technology Group	CHINA GENERAL TECH	CHINA GENERAL TECH	CHINA GENERAL TECH
China Gezhouba (CGGC)	GEZHOUBA	CGGC	GEZHOUBA
China Guodian Corporation	GUODIAN	GUODIAN	GUODIAN
China Huadian Corporation	HUADIAN	HUADIAN	HUADIAN
China Huaneng	HUANENG	HUANENG	HUANENG
China International Trust & Investment Corp - CITIC	CITIC	CITIC	CITIC
China Investment Corp	CHINA INV	CHINA INV	CHINA INV
China Juli Group	CHINA JULI	JULI GROUP	JULI GROUP

China Longyuan Power Group Corp Ltd	LONGYUAN	LONGYUAN	LONGYUAN
China Machinery Engineering Corp	CMEC	CHINA MACHINERGY	CHINA MACH ENG
China Metallurgical Group Corporation (MCC)	CHINA METALLURGICAL	MCC	CHINA METAL
China Ming Yang Wind Power Group	MINGYANG	MINGYANG	MINGYANG
China Minsheng Investment Corp	MINSHENG	MINSHENG	MINSHENG
China National Building Material Group Corporation (CNBM)	CHINA NATIONAL BUILDING MATERIAL	CNBM	CHINA NATL BUILD
China National Chemical (ChemChina)	CHINA NATL CHEM	CHINA NATIONAL CHEM	CHEMCHINA
China National Electric Engineering	CHINA NATIONAL ELECTRIC ENG	CHINA NATL ELEC	CNEEC
China National Machinery Industry	CHINA NATIONAL MACH	SINOMACH	CHINA NATL MACH
China National Materials Company	CHINA NATL MAT	CHINA NATIONAL MAT	CHINA NATIONAL MAT
China National Nuclear Corporation	CHINA NATL NUC	CNNC	CHINA NATIONAL NUC
China National Offshore Oil Corporation (CNOOC)	CHINA NATIONAL OFFSHORE OIL	CNOOC	CHINA NATL OFFSHORE
China National Overseas Engineering (Covec)	CHINA NATIONAL OVERSEAS ENGINEERING	COVEC	CHINA NATL OVERSEAS ENG
China National Petroleum (CNPC)	CHINA NATIONAL PETROLEUM	CNPC	CHINA NATL PETRO
China National Seed Group	CHINA NATIONAL SEED	CHINA NATIONAL SEED	CHINA NATIONAL SEED
China Natural Gas	CHINA NATURAL GAS	CHINA NATURAL GAS	CHINA NATURAL GAS
China Oceanwide Holdings Ltd	OCEANWIDE	OCEANWIDE	OCEANWIDE
China Petroleum and Chemical (Sinopec)	CHINA PETRO	SINOPEC	SINOPEC
China Poly	CHINA POLY	CHINA POLY	POLY GROUP
China Power Investment	CHINA POWER INVESTMENT	CHINA POWER INV	CPI

China Railway Construction Corporation	CHINA RAILWAY CONS	CRCC	CHINA RAIL CONS
China Solar Photovoltaic	CHINA SOLAR PV	CHINA SOLAR PHOTO	CHINA SOLAR PV
China Southern Power Grid	CHINA SOUTHERN POWER GRID	CHINA SOUTHERN POWER GRID	CHINA SOUTH POWER GRID
China Sunergy	CHINA SUNERGY	CHINA SUNERGY	CHINA SUNERGY
China Three Gorges Corporation	THREE GORGES	THREE GORGE	THREE GORGE
China Wanhe Investment Ltd	WANHE	WANHE	WANHE
China Western Power Industrial	CHINA WESTERN POWER	CHINA WESTERN POWER	CHINA WESTERN POWER
Chinaland Solar Energy	CHINALAND	CHINALAND	CHINALAND
Chint Group	CHINT	CHINT	CHINT
Clenergy International	CLENERGY	CLENERGY	CLENERGY
CNPV Solar Power (CNPV)	CNPV SOLAR	CNPV	CNPV
Cochran International Holdings	COCHRAN INT	COCHRAN INT	COCHRAN INT
CSEIC	CHINA SINOGY ELECTRIC	CSEIC	CSEEC
Daqo New Energy	DAQO	DAQO	DAQO
Datang International Power Generation	DATANG	DATANG	DATANG
Divine Aid Enterprise Tianjin International Trade	DIVINE AID	TIANJIN INT	DIVINE AID
Dongfang Electric (DEC)	DONGFANG ELECTRIC	(DEC)	DONGFANG ELEC
Dongfang Electrical Machinery	DONGFANG ELECTRIC MACHINERGY	(DEFM)	DONGFANG ELECTRIC MACHINERGY
Dragon Power	DRAGON POWER	DRAGON POWER	DRAGON POWER
ELL Environmental Holdings Ltd	ELL ENV	ELL ENV	ELL ENV
ENN Group	ENN GROUP	ENN GROUP	ENN GROUP
Envision Energy	ENVISION ENERGY	ENVISION ENERGY	ENVISION ENERGY
Eoplly New Energy Technology	EOPLLY	OUBEI	EOPLLY
Erjin Solar Energy Equipment Making	ERJIN SOLAR	ERJIN SOLAR	ERJIN SOLAR

ET Solar	ET SOLAR	ET SOLAR	ET SOLAR
Excel Fortune	EXCEL FORTUNE	EXCEL FORTUNE	EXCEL FORTUNE
Flat Glass Group	FLAT GLASS	FLAT GLASS	FLAT GLASS
Focusic	FOCUSIC	FOCUSIC	FOCUSIC
Fortunate Solar Technology	FORTUNATE SOLAR	FORTUNATE SOLAR	FORTUNATE SOLAR
GC China Turbine Corp	GC CHINA	GC CHINA	GC CHINA
GCL New Energy Holdings Ltd	GCL	GCL	GCL
GCL-Poly Energy Holdings Ltd	GCL-POLY	GCL-POLY	GCL-POLY
GI Technologies (Beijing)	GI TECH	GI TECH	GI TECH
Gingko Tree Investment Ltd	GINGKO	GINGKO	GINGKO
Golden Jumping Group	GOLDEN JUMPING	GOLDEN JUMPING	GOLDEN JUMPING
GS Solar	GS SOLAR	GS SOLAR	GS SOLAR
GSR Ventures; Dragontech Ventures Management Ltd	GSR VENTURE	DRAGONTECH VENTURE	DRAGONTECH VENTURE
Guangdong Aiko Solar Energy Technology Co Ltd	AIKO SOLAR	AIKO SOLAR	AIKO SOLAR
Guangdong Hengjian Investment Holdings Co Ltd	HENGJIAN INV	HENGJIAN INV	HENGJIAN INV
Guangxuan High-tech Group	GUANGXUAN	GUANGXUAN	GUANGXUAN
Guangzhou Devotion Thermal Technology	DEVOTION	DEVOTION	DEVOTION
Guangzhou Felicity Solar Technology	FELICITY	FELICITY	FELICITY
Guanxi Estates	GUANGXI ESTATES	GUANGXI ESTATES	GUANGXI ESTATES
Guanxi State Farm	GUANGXI STATE FARM	GUANGXI STATE FARM	GUANGXI STATE FARM
Halo International	HALO INT	HALO INT	HALO INT
Hanergy Holdings Group	HANERGY	HANERGY	HANERGY
Hanwha SolarOne (Solarfun Power)	HANWHA SOLARONE	SOLARFUN	SOLARFUN
Harbin Electric	HARBIN ELEC	HARBIN ELEC	HARBIN ELEC
Hareon Solar Technology	HAREON	SHENLONG	HAREON

Heilongjiang Lijing Industry Co Ltd	HEILONGJIANG LIJING	HEILONGJIANG LIJING	HEILONGJIANG LIJING
Hejian Solidkey Petroleum Machinery	HEJIAN SOLIDKEY	SOLIDKEY PETRO	SOLIDKEY PETRO
Hongua Group	HONGHUA	HONGHUA	HONGHUA
Hope Group (Beijing Hope Solar Power)	HOPE GROUP	HOPE SOLAR	BEIJING HOPE
Huapeng	HUAPENG	HUAPENG	HUAPENG
Huawei Technologies	HUANGWEI	HUANGWEI	HUANGWEI
Huayi Electric	HUAYI ELEC	HUAYI ELEC	HUAYI ELEC
JA Solar	JA SOLAR	JA SOLAR	JA SOLAR
Jetion Solar Holdings	JETION SOLAR	JETION SOLAR	JETION SOLAR
Jiangsu Baoli Asphalt	JIANGSU BAOLI	BAOLI ASP	JIANGSU BAOLI
Jiangsu Changbao Steel Tube	CHANGBAO	CHANGBAO	CHANGBAO
Jiangsu Hantong Group	JIANGSU HANTONG	HANTONG GROUP	HANTONG
Jiangsu Kaiyuan Group	JIANGSU KAIYUAN	JIANGSU KAIYUAN	JIANGSU KAIYUAN
Jiangsu Shunda Semiconductor Development	SHUNDA SEMICONDUCTOR	SHUNDA SEMICONDUCTOR	SHUNDA SEMICONDUCTOR
Jiangsu Sujia Group	JIANGSU SUJIA	JIANGSU SUJIA	JIANGSU SUJIA
Jiexiu Dexinglong Coal Gasification	JIEXIU DEXINGLONG	JIEXIU DEXINGLONG	JIEXIU DEXINGLONG
JinkoSolar	JINKOSOLAR	JINKOSOLAR	JINKOSOLAR
Jinpan International	JINPAN INTERNATIONAL	JINPAN INTERNATIONAL	JINPAN INTERNATIONAL
KINETIC POWER & ENERGY	KINETIC POWER	KINETIC POWER	KINETIC POWER
Kinglong New Energy Technology (KLNE) (Beijing Kinglong New Energy Technology)	KINGLONG	KINGLONG	KINGLONG
LDK Solar	LDK SOLAR	LDK SOLAR	LDK SOLAR
Lightway Solar	LIGHTWAY SOLAR	LIGHTWAY SOLAR	LIGHTWAY SOLAR
Linuo Group	LINUO	LINUO	LINUO
Mingyang Electric	MINGYANG ELECTRIC	MINGYANG ELECTRIC	MINGYANG ELEC
Nanjing Sunec Wind Generator Equipment Factory	NAJING SUNEC	NAJING SUNEC	SUNEC WIND

Narada Power	NARADA POWER	NARADA POWER	NARADA POWER
New Sky (China) Environmental & Tech Co Ltd	NEW SKY	NEW SKY	NEW SKY
Ningbo Shentong Auto Decorations Ltd	SHENTONG	SHENTONG	SHENTONG
Niutech Environment Technology	NIUTECH	NIUTECH	NIUTECH
Oriental Energy	ORIENTAL ENERGY	ORIENTAL ENERGY	ORIENTAL ENERGY
Pansoft	PANSOFT	PANSOFT	PANSOFT
Polar Photovoltaics	POLAR PHOTO	POLAR PV	POLAR PV
Power Construction Corporation of China (PowerChina)	POWERCHINA	POWER CONSTR CORP	POWER CONSTRUCTION CORP
Powerway Renewable Energy	POWERWAY	POWERWAY	POWERWAY
Private Investor (Mr. Ko Chun Shun, Johnson)	PRIVATE INVESTOR	PRIVATE INVESTOR	PRIVATE INVESTOR
Profundo Technologies	PROFUNDO	PROFUNDO	PROFUNDO
Prudent Energy	PRUDENT ENERGY	PRUDENT ENERGY	PRUDENT ENERGY
PT Drive	PT DRIVE	PT DRIVE	PT DRIVE
Qingdao iTechene Technologies	ITECHENE	ITECHENE	ITECHENE
Qingdao Talent Tradiong	QINGDAO TALENT	QINGDAO TALENT	QINGDAO TALENT
Qunsheng Group	QUNSHENG	QUNSHENG	QUNSHENG
R.D. Green Source Chemical	R.D. GREEN SOURCE	GREEN SOURCE CHEMICAL	GREEN SOURCE CHEM
Recon Technology	RECON TECH	RCON TECH	RECON TECH
ReneSola	RENESOLA	RENESOLA	RENESOLA
Risen Energy	RISEN ENERGY	RISEN ENERGY	RISEN ENERGY
Sancon Resources Recovery	SANCON RESOURCES RECOVERY	SANCON RES	SANCON RES
Sany	SANY	SANY	SANY
Seraphim Solar System	SERAPHIM	SERAPHIM	SERAPHIM
Shandong Borun Process Industrial Technology	SHANDONG BORUN	BORUN HYDRO	SHANDONG BORUN

Shandong Hi-speed Group Co Ltd	SHANDONG HI-SPEED	SHANDONG HI-SPEED	SHANDONG HI-SPEED
Shandong Kerui Group	SHANDONG KERUI	SHANDONG KERUI	SHANDONG KERUI
Shangdong Auhua	SHANGDONG AUHUA	SHANGDONG AUHUA	SHANGDONG AUHUA
Shanghai Alex Solar Industry	ALEX SOLAR	ALEX SOLAR	ALEX SOLAR
Shanghai Alliance Investment Ltd; Valero Energy Corp; Bohemian Investment Corp; I2BF Venture Capital; Infield Capital; Southern Ute Alternative Energy LLC	SHANGHAI ALLIANCE	SHANGHAI ALLIANCE	SHANGHAI ALLIANCE
Shanghai Chaori Solar Energy Science & Technology	CHAORI	CHAORI	CHAORI
Shanghai Electric	SHANGHAI ELEC	SHANGHAI ELECTRIC	SHANGHAI ELECTRIC
Shanghai Guyuan Real Estate Development Co Ltd	GUYUAN	GUYUAN	GUYUAN
Shanghai Safbon Water Service	SAFBON	SAFBON	SAFBON
Shanghai Shangshi Energy Technology	SHANGSHI ENERGY	SHANGHAI SHANGSHI	SHANGHAI SHANGSHI
Shanghai Taisheng Wind Power Equipment	TAISHENG	TAISHENG	TAISHENG
Shanxi Coal International Energy Group	SHANXI COAL	SHANXI COAL	SHANXI COAL
Shenhua Group Corporation	SHENHUA	SHENHUA	SHENHUA
Shenyang Brilliant Elevator Co Ltd	SHENYANG BRILLIANT	SHENYANG BRILLIANT	SHENYANG BRILLIANT
Shenzhen Energy Group	SHENZHEN ENERGY	SHENZHEN ENERGY	SHENZHEN ENERGY
Shenzhen Nanshan Power Station Co Ltd	NANSHAN POWER	NANSHAN POWER	SHENZHEN NANSHAN
Shunfeng International Clean Energy Ltd	SHUNFENG	SHUNFENG	SHUNFENG

Simax (Suzhou) Green New Energy	SIMAX	SIMAX	SIMAX
Sinohydro	SINOHYDRO	SINOHYDRO	SINOHYDRO
Sinovel Wind	SINOVEL	SINOVEL	SINOVEL
State Development and Investment	STATE DEV	STATE DEV	SDIC
State Grid Corporation	STATE GRID	STATE GRID	STATE GRID
State Power Investment Corp	STATE POWER INV	STATE POWER INV	SPIC
Sungrow Power Supply	SUNGROW POWER	SUNGROW POWER	SUNGROW POWER
Sunlan Solar	SUNLAN SOLAR	SUNLAN SOLAR	SUNLAN SOLAR
SunSi Energies Inc	SUNSI	SUNSI	SUNSI
Suntech Power Holdings	SUNTECH	SUNTECH	SUNTECH
TBB Power	TBB POWER	TBB POWER	TBB POWER
Tebian Electric Apparatus (TBEA)	TEBIAN ELECTRIC	TBEA	TEBIAN ELE
Tellhow SCI-Tech Co Ltd	TELLHOW	TELLHOW	TELLHOW
The Hilong Group of Companies	HILONG GROUP	HILONG GROUP	HILONG GROUP
Tianjin Pipe	TIANJIN PIPE	TIANJIN PIPE	TIANJIN PIPE
Tianjin State Farms Agribusiness Group	TIANJIN STATE FARM	TIANJIN STATE FARM	TIANJIN STATE FARM
Tianjin Suli Cable Group	SULI CABLE	SULI CABLE	SULI CABLE
Titan Wind Energy	TITAN WIND	TITAN WIND	TITAN WIND
Tongfang (Tsinghua Tongfang)	TONGFANG	TONGFANG	TONGFANG
Topoint Photovoltaic	TOPOINT PHOTO	TOPOINT PV	TOPOINT PHOTO
Tri-Tech	TRI-TECH	TRI-TECH	TRI-TECH
Trina Solar Limited	TRINA SOLAR	TRINA SOLAR	TRINA
Union Resources & Engineering	UNION RES	UNION RES	UNION RES
United Photovoltaics Group Ltd	UNITED PHOTO	UNITED PHOTO	UNITED PHOTO
Upsolar	UPSOLAR	UPSOLAR	UPSOLAR
Wanxiang	WANXIANG	WANXIANG	WANXIANG
Winsun New Energy	WINSUN	WINSUN	WINSUN
Wiscom System Co Ltd	WISCOM	WISCOM	WISCOM
WSP Holdings Limited	WUXI SEAMLESS	WSP HOLD	WSP HOLD

Wuxi Guolian Development Group	GUOLIAN	GUOLIAN	GUOLIAN
Xi'an LONGI Silicon Materials	LONGI	LONGI	LONGI
Xiangtan Electric Manufacturing (XEMC)	XIANGTAN ELECTRIC	XEMC	XIANGTAN ELEC
Xin Gang Power Investments Ltd	XIN GANG	XIN GANG	XIN GANG
Xinfa Group	XINFA	XINFA	XINFA
Xinjiang Goldwind Science & Technology (Goldwind)	GOLDWIND	GOLDWIND	GOLDWIND
Xinjiang Guanghui Industry Investment (Group)	XINJIANG GUANGHUI	XINJIANG GUANGHUI	XINJIANG GUANGHUI
Xuzhou Superenergy Photoelectricity Technology	XUZHOU SUPERENERGY	SUPERENERGY PV	SUPERENERGY PHOTO
Yangden Solar Energy Holding	YANGDEN SOLAR	YANGDEN SOLAR	YANGDEN SOLAR
Yechiu Metal Recycling (China)	YECHIU	YECHIU	YECHIU
Yinchuan Tianjia Energy Technology	TIANJIA	TIANJIA	TIANJIA
Yingli Green Energy Holding Company Limited (Yingli)	YINGLI	YINGLI	YINGLI
Yunnan Water Investment Co Ltd	YUNNAN WATER	YUNNAN WATER	YUNNAN WATER
Zewox New Energy	ZEWOX	ZEWOX	ZEWOX
Zhefu Holding Group Co Ltd	ZHEFU	ZHEFU	ZHEFU
Zhejiang Glass	ZHEJIANG GLASS	ZHEJIANG GLASS	ZHEJIANG GLASS
Zhejiang Hengyi Group	ZHEJIANG HENGYI	HENGYI	HENGYI
Zhejiang Jiangnan Petrochemical Machinery (Zhejiang JNSH Machinery)	JIANGNAN PETROCHEMICAL	JNSH	JIANGNAN PETRO
Zhejiang Kaishan Compressor	KAISHAN	KAISHAN	KAISHAN
Zhejiang Kaishan Compressor Co Ltd	ZHEJIANG KAISHAN	ZHEJIANG KAISHAN	ZHEJIANG KAISHAN
Zhejiang Leye Photovoltaic Science & Technology	ZHEJIANG LEYE	LEYE PHOTO	LEYE PHOTO

Zhejiang Rongsheng Holding Group	RONGSHENG	RONGSHENG	RONGSHENG
Zhejiang Solar Best Energy Technology (Solarbest)	ZHEJIANG SOLAR BEST	SOLAR BEST	SOLAR BEST
Zhejiang Sunflower Light Energy Science & Technology (Sunowe)	ZHEJIANG SUNFLOWER	SUNOWE	SUNOWE
Zhenfa New Energy Science and Technology	ZHENFA	ZHENFA	ZHENFA
Zhongli SCI-Tech Group	ZHONGLI	ZHONGLI	ZHONGLI
ZKenergy Science & Technology	ZKENERGY	ZKENERGY	ZKENERGY
Znshine Group	ZNSHINE	ZNSHINE	ZNSHINE
ZTE	ZTE	ZONERGY	ZTE

Appendix for Chapter 3

Quantitative analysis of Chinese impact on non-OECD countries' power sector development

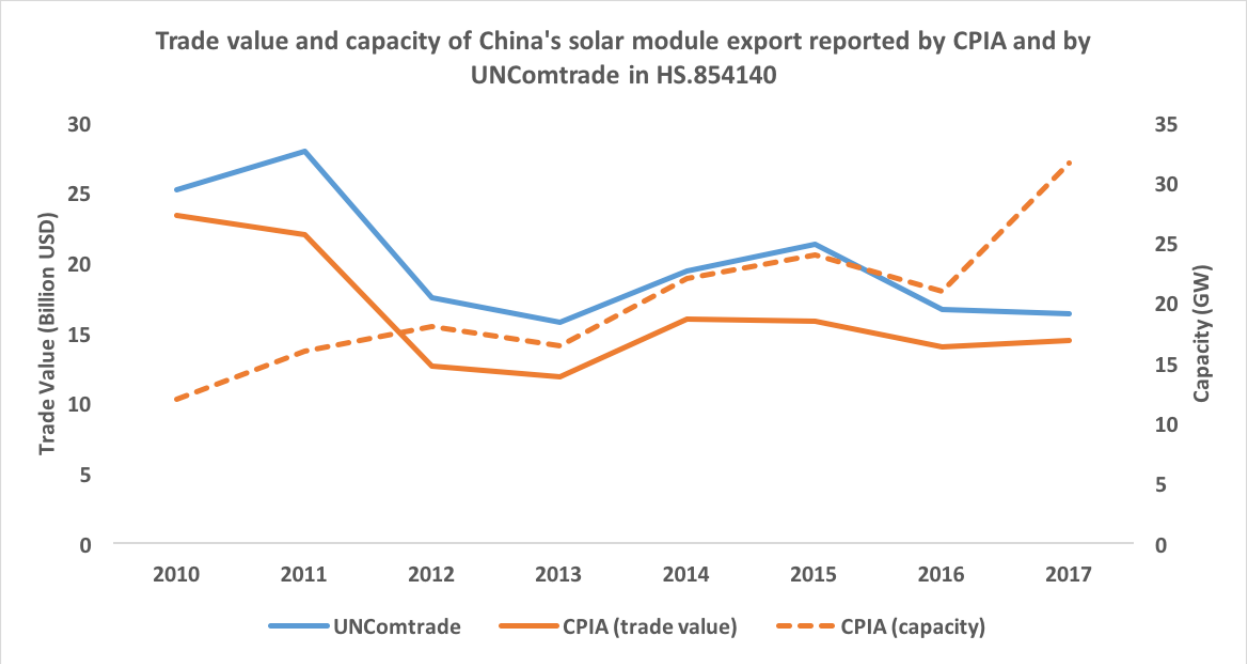


Figure S1. Trade value of solar modules reported by China Photovoltaics Industry Association (CPIA) and UN Comtrade in HS.854140 from 2010 to 2017

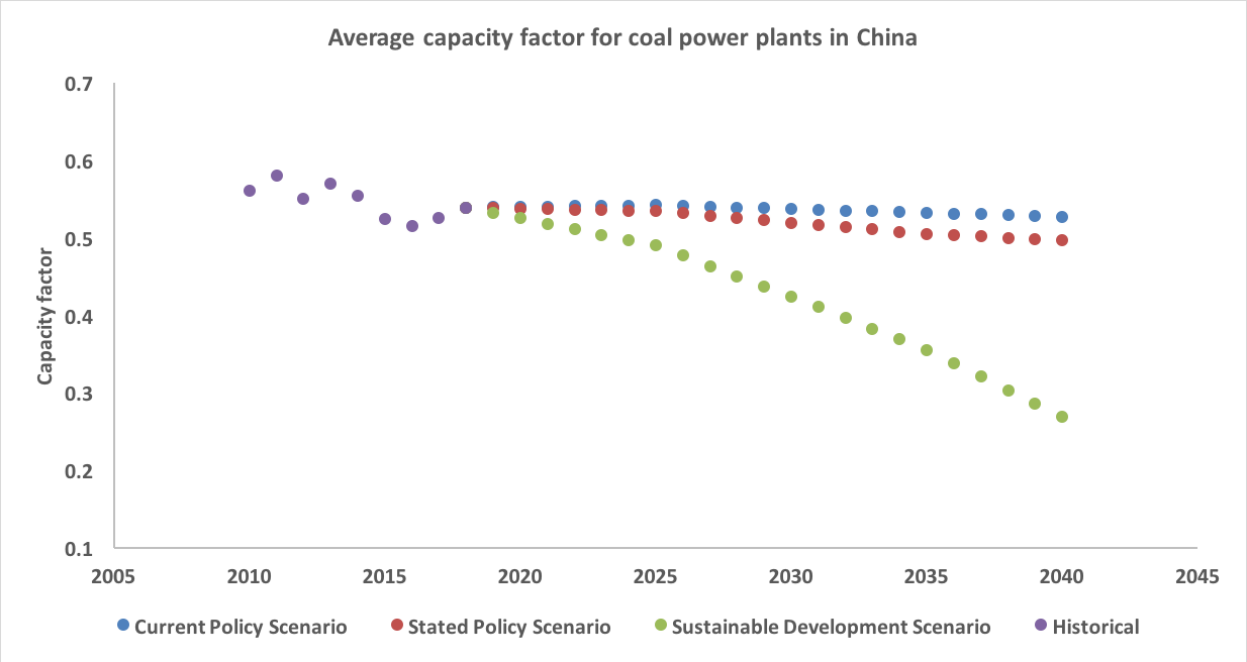


Figure S2. Average capacity factor for coal power plants in China for each IEA scenario we use in the paper (source: IEA World Energy Outlook 2012-2019).

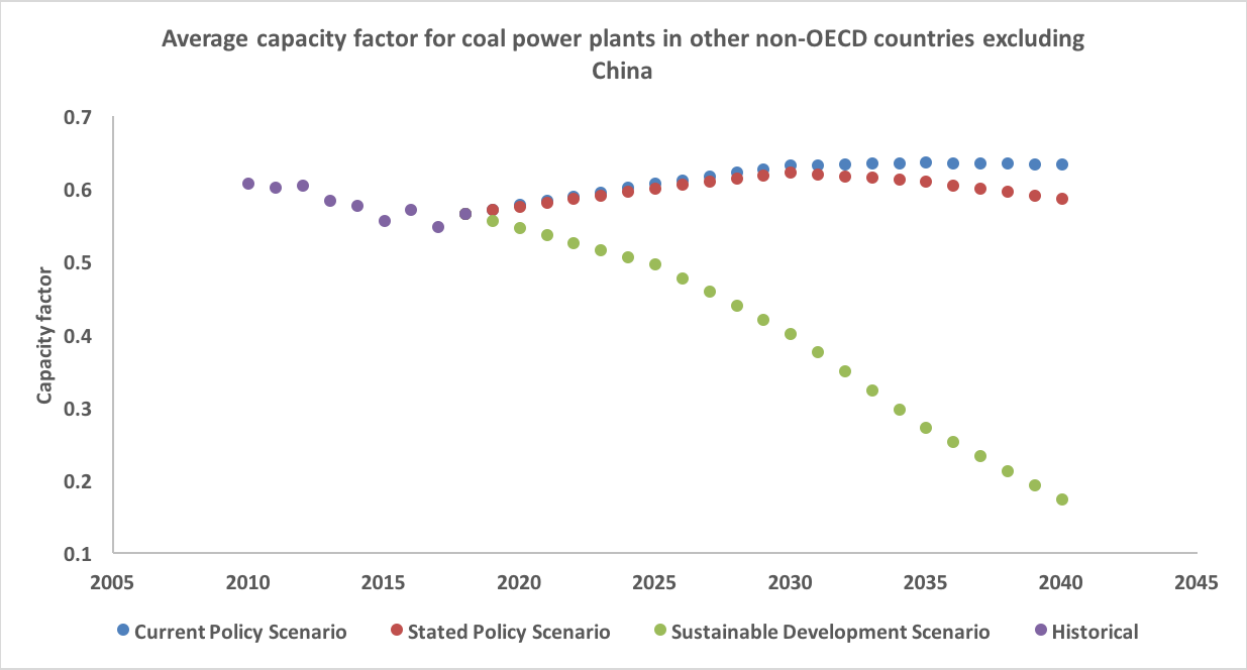


Figure S3. Average capacity factor for coal power plants in other non-OECD countries excluding China for each IEA scenario we use in the paper (source: IEA World Energy Outlook 2012-2019).

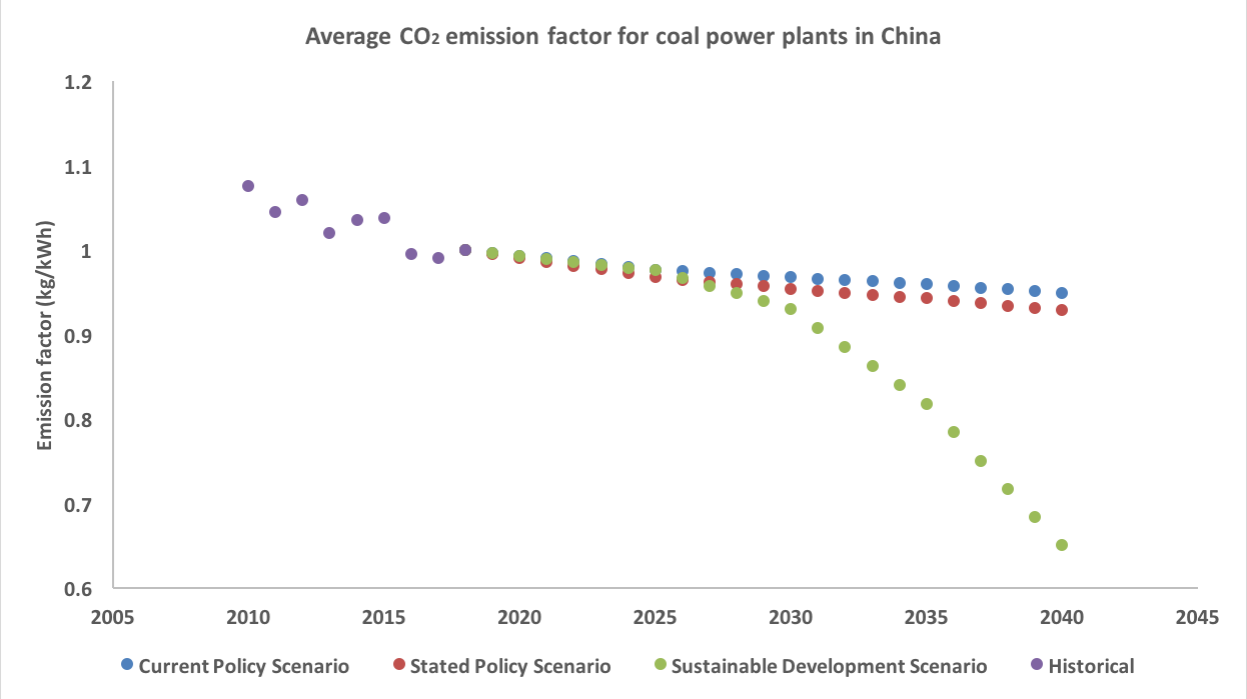


Figure S4. Average CO_2 emission factor for coal power plants in China for each IEA scenario we use in the paper (source: IEA World Energy Outlook 2012-2019).

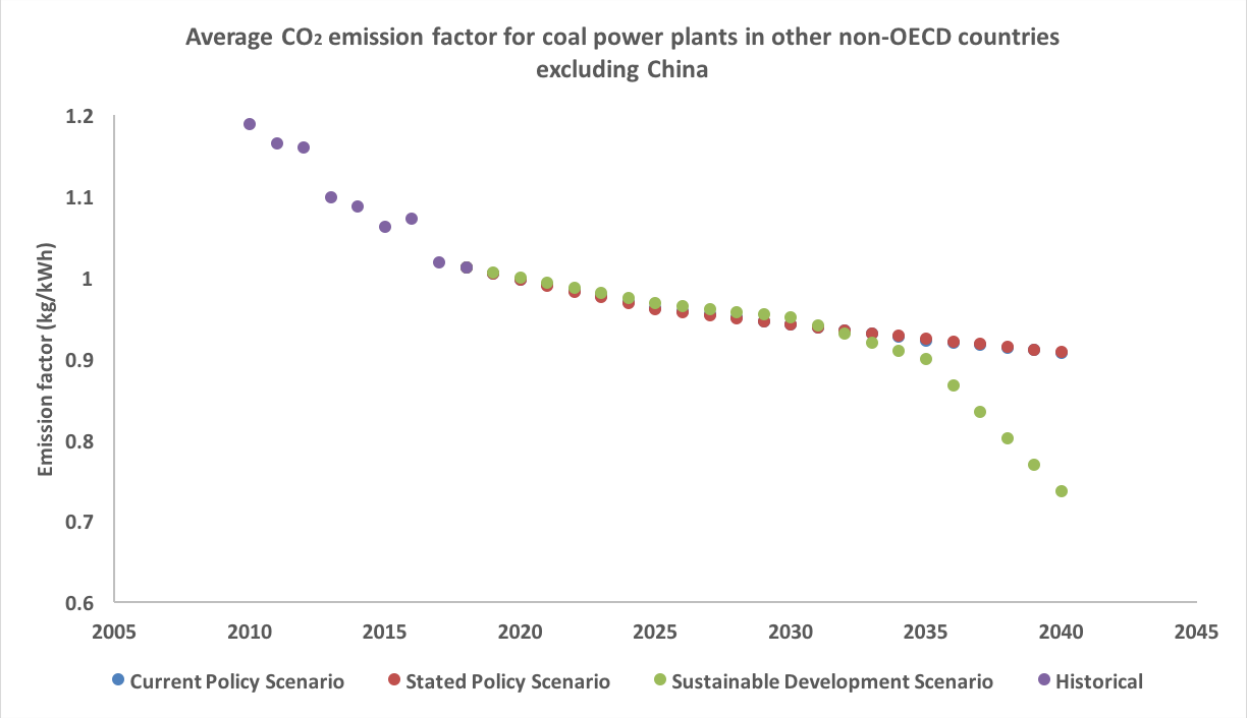


Figure S5. Average CO_2 emission factor for coal power plants in other non-OECD countries excluding China for each IEA scenario we use in the paper. Note order of plotting is purple, blue, red, green leading to the top color obscuring the one underneath. (source: IEA World Energy Outlook 2012-2019).

Appendix for Chapter 4

Determinants of Chinese Outbound Energy Finance to Developing Countries

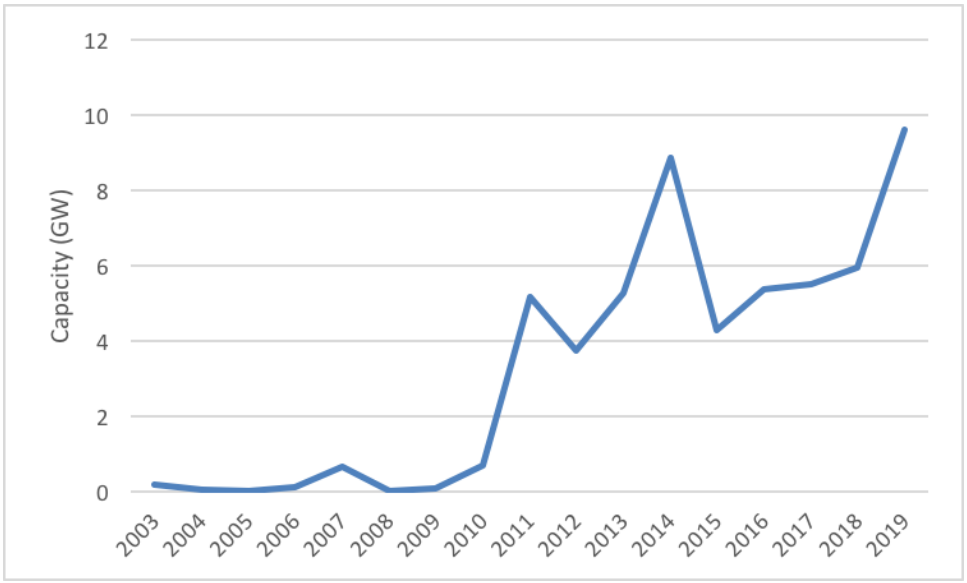


Figure S9 Trend of power projects receiving Chinese development finance in developing countries' power sector capacity from 2003 to 2019

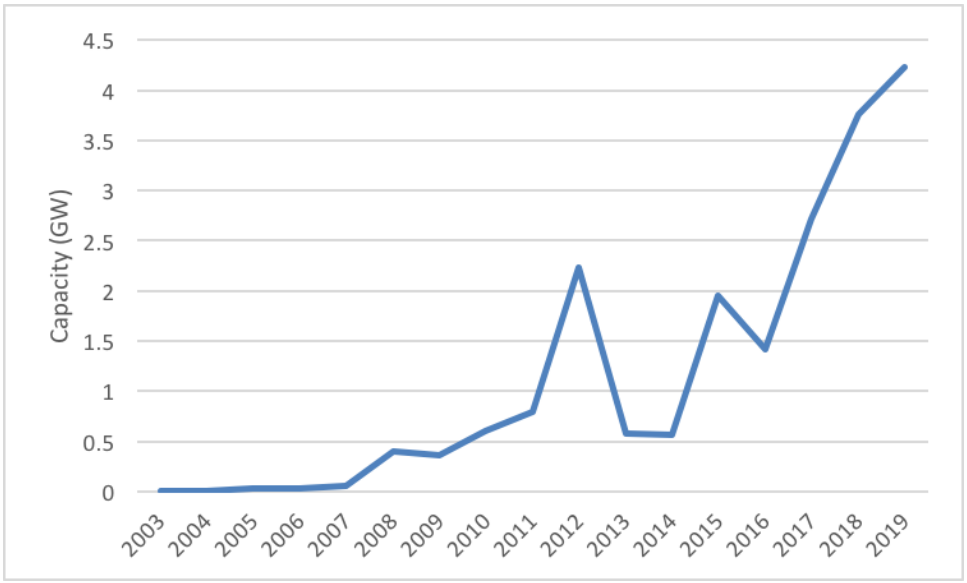


Figure S10 Trend of power projects receiving Chinese foreign direct investment in developing countries' power sector capacity from 2003 to 2019

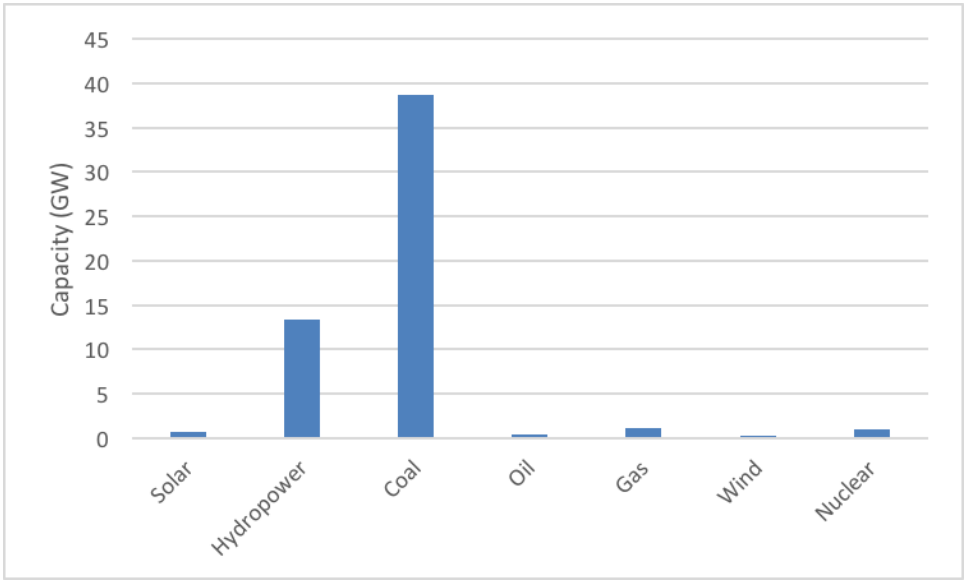


Figure S11 Energy mix of power projects receiving Chinese development finance in developing countries from 2003 to 2019

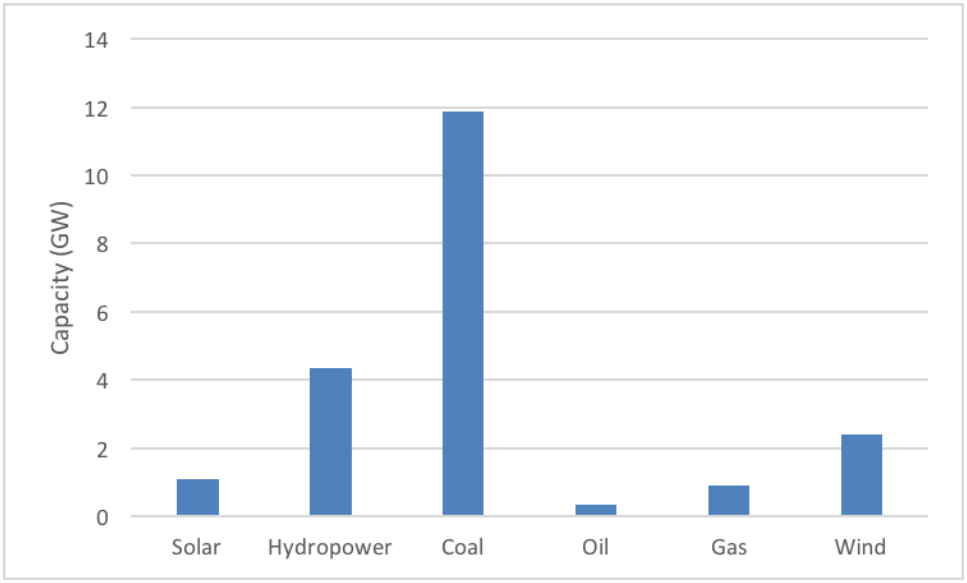


Figure S12 Energy mix of power projects receiving Chinese foreign direct investment in developing countries from 2003 to 2019

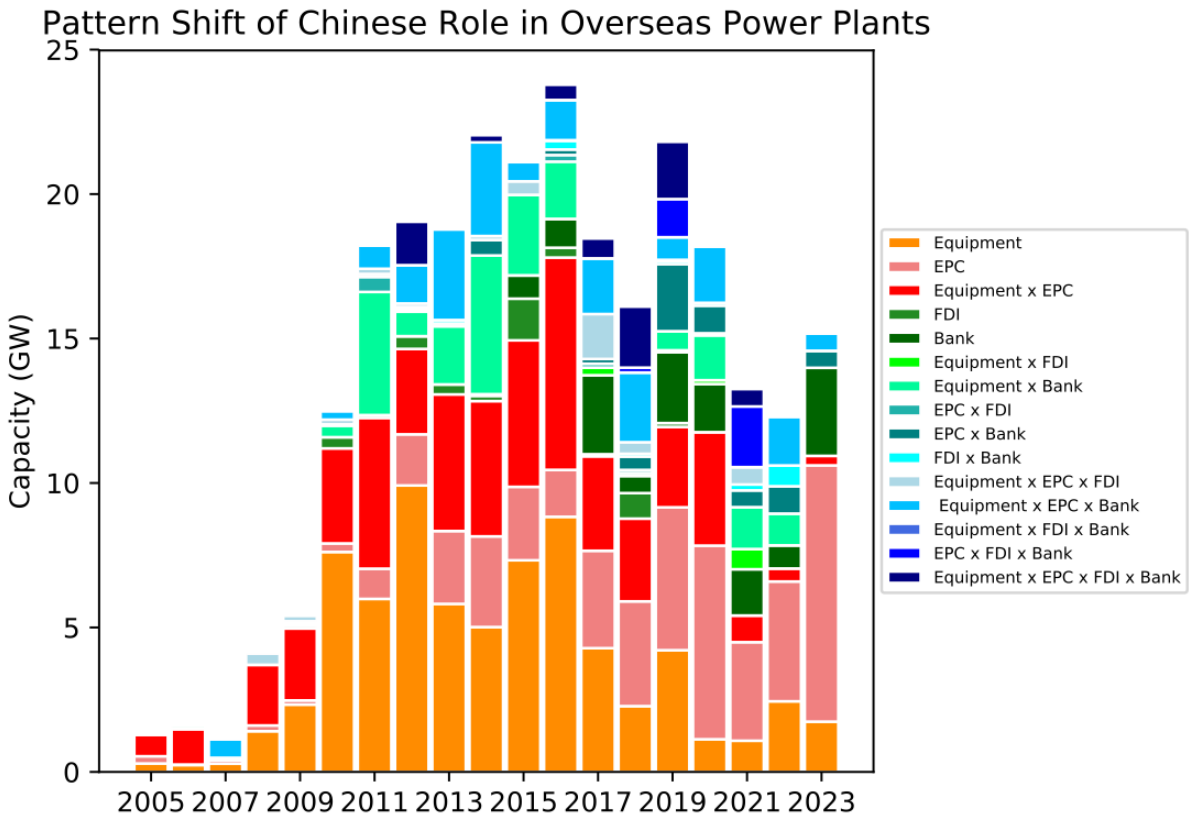


Figure S13 Pattern shift of all forms of Chinese involvement in developing countries' power sector since 2005

Table S1 *Regression results for Chinese FDI with different time lags for new power capacity in host country, added power capacity in the last 5 years involving EPC or equipment from China, added power capacity in the last 5 years involving EPC or equipment from U.S. Japan and Germany (single asterisk indicates p<0.05, double asterisk indicates p<0.01, triple asterisk indicates p<0.001; p-value in parentheses)*

Independent Variables	FDI (log amount, no lag)	FDI (log amount, 1-year lag)	FDI (log amount, 2-year lag)	FDI (log amount, 3-year lag)
GDP per capita (log)	0.0249	0.0216	0.0013	-0.0023
	(0.290)	(0.374)	(0.928)	(0.868)
Population (log)	0.1801	0.1678	-0.0022	-0.0117
	(0.722)	(0.748)	(0.908)	(0.542)
Resource Rent	0.0059	0.0060	-0.00246	-0.0022
	(0.276)	(0.279)	(0.222)	(0.268)
Trade with China (log)	0.060	0.0665	0.00146	0.0011
	(0.056)	(0.41)	(0.886)	(0.915)

Added power capacity in the last 5 years involving EPC or equipment from China (log, lagged by 3 year)	0.0526*** (<0.001)	0.0652*** (<0.001)	0.0855*** (<0.001)	0.0807*** (<0.001)
Added power capacity in the last 5 years involving EPC or equipment from US, Japan and Germany (log, lagged by 3 year)	-0.0453*** (<0.001)	-0.0236 (0.069)	-0.0269* (0.030)	-0.0293* (0.020)
UN voting alignment with China	-0.0297 (0.953)	0.1156 (0.826)	0.0845 (0.722)	0.1423 (0.549)
Power resource potential (log)	0.0133 (0.095)	0.0163 (0.051)	0.0141 (0.043)	0.0133 (0.056)
BRI (0 before signing BRI MOU and 1 afterwards)	0.0911 (0.369)	0.0694 (0.508)	0.0728 (0.445)	0.0714 (0.454)
Polity (Institutionalized democracy)	0.0035 (0.792)	0.0076 (0.573)	-0.0080 (0.174)	-0.0076 (0.200)
Overcapacity in China (log)	-0.0025 (0.631)	-0.00470 (0.437)	-0.00689 (0.267)	-0.00478 (0.442)
New power capacity in recipient country (log, lagged by 3 year)	0.1056*** (<0.001)	0.046*** (<0.001)	0.00354 (0.782)	0.02649* (0.042)
Country Fixed Effect	**Yes**	**Yes**	**Yes**	**Yes**
Year Fixed Effect	**Yes**	**Yes**	**Yes**	**Yes**
R-squared	**0.15**	**0.15**	**0.08**	**0.08**
Number of countries	**35**	**35**	**35**	**35**
Number of technologies	**3**	**3**	**3**	**3**
Number of observations	**1464**	**1464**	**1464**	**1464**

Table S2 *Regression results for Chinese DF with different time lags for new power capacity in host country, added power capacity in the last 5 years involving EPC or equipment from China, added power capacity in the last 5 years involving EPC or equipment from U.S. Japan and Germany (single asterisk indicates p<0.05, double asterisk indicates p<0.01, triple asterisk indicates p<0.001; p-value in parentheses)*

Independent Variables	DF (log amount, no lag)	DF (log amount, 1-year lag)	DF (log amount, 2-year lag)	DF (log amount, 3-year lag)
GDP per capita (log)	-0.0041 (0.904)	-0.0132 (0.721)	-0.0110 (0.597)	-0.0089 (0.674)
Population (log)	-0.562 (0.435)	-0.403 (0.610)	-0.0184 (0.515)	-0.0111 (0.696)

Resource Rent	-0.0015	0.0027	-0.0012	-0.0012
	(0.949)	(0.747)	(0.686)	(0.677)
Trade with China (log)	-0.0221	-0.0051	-0.00945	-0.00787
	(0.699)	(0.917)	(0.528)	(0.601)
Added power capacity in the last 5 years involving EPC or equipment from China (log, lagged by 3 year)	0.1282*** (<0.001)	0.108*** (<0.001)	0.1108*** (<0.001)	0.1152*** (<0.001)
Added power capacity in the last 5 years involving EPC or equipment from US, Japan and Germany (log, lagged by 3 year)	-0.0148 (0.398)	0.0106 (0.590)	0.0215 (0.239)	0.0248 (0.184)
UN voting alignment with China	0.4326	0.775	0.269	0.269
	(0.467)	(0.331)	(0.441)	(0.444)
Power resource potential (log)	0.0266*	0.0445***	0.0352**	0.0382***
	(0.020)	(<0.001)	(0.001)	(<0.001)
BRI (0 before signing BRI MOU and 1 afterwards)	0.0507	0.0666	0.0738	0.0825
	(0.825)	(0.674)	(0.598)	(0.558)
Polity (Institutionalized democracy)	-0.0046	0.00491	-0.0045	-0.0035
	(0.802)	(0.811)	(0.605)	(0.687)
Overcapacity in China (log)	0.0301***	0.0247**	0.0264**	0.0267**
	(<0.001)	(0.007)	(0.004)	(0.004)
New power capacity in recipient country (log, lagged by 3 year)	0.182*** (<0.001)	0.022 (0. 245)	0.0115 (0.540)	-0.0088 (0.646)
Country Fixed Effect	**No**	**No**	**No**	**No**
Year Fixed Effect	**Yes**	**Yes**	**Yes**	**Yes**
R-squared	**0.23**	**0.12**	**0.11**	**0.10**
Number of countries	**35**	**35**	**35**	**35**
Number of technologies	**3**	**3**	**3**	**3**
Number of observations	**1464**	**1464**	**1464**	**1464**

Table S3 Descriptive statistics

Variable name	Obs	Mean	Std. Dev.	Min	Max
Dependent variables					
Chinese development finance (log amount)	1470	0.28	1.27	0.00	8.10
Chinese_FDI (log amount)	1470	0.14	0.85	0.00	7.59
Explanatory variables					
Overcapacity (log amount)	1470	5.46	4.79	0.00	10.93
Voting distance	1470	0.78	0.17	0.00	1.00
Chinese_trade (log amount)	1470	20.08	4.19	0.00	25.41
Resource rent	1470	11.08	12.11	0.11	59.62

New power capacity (log amount, no lag)	1470	1.51	2.62	-5.81	9.91
New power capacity (log amount, 1-year lag)	1470	1.47	2.60	-5.81	9.91
New power capacity (log amount, 2-year lag)	1470	1.40	2.54	-5.81	9.91
New power capacity (log amount, 3-year lag)	1470	1.35	2.50	-5.81	9.91
GDP per capita (log amount)	1470	7.32	1.66	0.00	9.93
Power resource potential (log amount)	1470	4.46	3.79	0.00	13.68
Population (log amount)	1470	16.92	1.61	13.44	21.00
Polity2	1470	1.04	4.22	-8.00	9.00
BRI	1470	0.08	0.28	0.00	1.00
Trade with China in the power sector (log amount, no lag)	1470	1.31	2.48	-1.20	10.54
Trade with other major countries in the power sector (log amount, no lag)	1470	1.37	2.67	-5.30	9.10
Trade with China in the power sector (log amount, 1-year lag)	1470	1.31	2.48	-1.20	10.54
Trade with other major countries in the power sector (log amount, 1-year lag)	1470	1.25	2.55	-5.30	9.00
Trade with China in the power sector (log amount, 2-year lag)	1470	1.14	2.34	-1.20	10.54
Trade with other major countries in the power sector (log amount, 2-year lag)	1470	1.24	2.54	-5.30	9.00
Trade with China in the power sector (log amount, 3-year lag)	1470	1.00	2.19	-1.20	10.54
Trade with other major countries in the power sector (log amount, 3-year lag)	1470	1.23	2.52	-5.30	9.00

Table S4 Robustness check on dollar amount vs. project capacity. Both dollar amount and project capacity is used to estimate Chinese development finance. Everything else stays the same as in Table 1. *(single asterisk indicates p<0.05, double asterisk indicates p<0.01, triple asterisk indicates p<0.001; p-value in parentheses)*

Independent Variables	Chinese Development finance ($, log)	Chinese Development Finance (Project capacity, log)
Push factors		
Overcapacity in China (log)	0.0847**	0.0301***
	(0.004)	(<0.001)
UN voting alignment with China	1.165	0.4326
	(0.651)	(0.467)
Resource rent in host country (log)	0.0011	-0.0015
	(0.968)	(0.949)
Trade value between host country and China (log)	-0.097	-0.0221

	(0.540)	(0.699)
Pull factors		
New power capacity in host country (log)	0.5984***	0.1823***
	(<0.001)	(<0.001)
Power resource potential (log)	0.1154**	0.0266*
	(0.004)	(0.02)
GDP per capita in host country (log)	-0.0315	-0.0041
	(0.791)	(0.904)
Control factors		
Added power capacity in the last 5 years involving EPC or equipment from China (log)	0.4992***	0.1282***
	(<0.001)	(<0.001)
Added power capacity in the last 5 years involving EPC or equipment from US, Japan and Germany (log)	-0.1629**	-0.0148
	(0.009)	(0.398)
Population in host country (log)	-2.429	-0.562
	(0.791)	(0.435)
BRI (0 before signing BRI MOU and 1 afterwards)	0.347	0.0507
	(0.946)	(0.825)
Polity (Institutionalized democracy)	-0.0148	-0.0046
	(0.823)	(0.802)
Country Fixed Effect	**Yes**	**Yes**
Year Fixed Effect	**Yes**	**Yes**
R-squared	**0.27**	**0.28**
Number of countries	**35**	**35**
Number of technologies	**3**	**3**
Number of observations	**1464**	**1464**