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BILATERAL FINANCING OF THE POWER SECTOR AND IMPLICATIONS FOR THE GLOBAL LOW CARBON ENERGY TRANSITION

Chen, Xu

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BILATERAL FINANCING OF THE POWER SECTOR AND IMPLICATIONS FOR THE GLOBAL LOW CARBON ENERGY TRANSITION

Xu Chen

A DISSERTATION

PRESENTED TO THE FACULTY

OF PRINCETON UNIVERSITY

IN CANDIDACY FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

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Adviser: Denise L. Mauzerall

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Abstract

The Paris Agreement climate target entails a rapid decarbonization of the global power generation sector by mid-century. This requires a fundamental redirection of international finance from fossil fuel infrastructure towards low carbon technologies. To date, most research on the power sector transition has focused on domestic and multilateral finance. Bilateral finance also plays an important role in fueling global power infrastructure development. However, understanding of its influence is limited. This dissertation fills this knowledge gap by evaluating the impact of bilateral financing on global power technology deployment as well as its implications for future CO_2 emissions.

Chapter 2 focuses on the globally active Chinese development finance institutions (DFIs) and compares their overseas power generation financing with multilateral development banks (MDBs) as well as other East Asian national DFIs. I find that China's two DFIs have dramatically increased their financing of overseas power projects since 2000. In the late 2010s, their power financing surpassed the major MDBs' collective financing. As the MDBs stepped away from coal power financing, East Asian DFIs have filled this gap by continuing to finance overseas coal plants.

Chapter 3 analyzes bilateral financing of fossil fuel and renewable power technologies from the three biggest economies – China, Japan and the United States. I find that these three countries' overseas financing between 2000 and 2018 through their development finance and greenfield foreign direct investment facilitated 233 GW power capacity additions globally. However, the

majority of the facilitated capacity additions are coal, gas and hydroelectric power plants, while less than 10% are in non-hydro renewable technologies.

Chapter 4 analyzes Southeast Asia's current power generation pipeline and its implications for long-term CO_2 emissions and short-term electricity generation. I find that power plants which were under construction and planned as of mid-2020 will more than double Southeast Asia's fossil fuel power generation capacity. As a result, Southeast Asia's current power generation pipeline will commit 53 Gt CO_2 emissions in the long term. In the short term, continued reliance on fossil fuel power generation in Southeast Asia may result in stranded assets of fossil fuel power and crowd out renewable technology deployment.

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Chapter 1: Introduction

Electricity and heat generation is the most significant source of global CO_2 emissions. It accounted for over 40% of global energy related CO_2 emissions in 2018 and contributed one-fourth of global greenhouse gas (GHG) emissions out of all economic sectors (Edenhofer et al., 2014; International Energy Agency, 2020a). Electricity and heat generation from coal fired power plants, in particular, accounted for 30% of global energy related CO_2 emissions in 2018 (International Energy Agency, 2019a). Global electricity demand is projected to further increase through 2040 (International Energy Agency, 2020b). In developing countries, electricity demand continues to grow due to rapid population growth and increased economic activities (International Energy Agency, 2020b). Additionally, electrification of other economic sectors such as industry, buildings and transport sectors plays a key role in facilitating economy wide decarbonization (Davis et al., 2018; Rogelj et al., 2018). Therefore, decarbonizing the electric power sector is crucial in the global low carbon energy transition.

The Paris Agreement requires the global economy to decarbonize by mid-century (Millar et al., 2017; Rogelj et al., 2015, 2018). To achieve this target, power sector decarbonization needs to happen more rapidly than that of other energy end-use sectors in cost-effective mitigation pathways (Edenhofer et al., 2014). Limiting global average temperature increase to 1.5^{o}C above the pre-industrial level allows little or no further planning of CO_2-emitting power plants. Moreover, some of the existing plants will need to be underutilized, retire years before the end of their economic lifetimes, or be retrofitted with costly carbon capture and storage (CCS) technologies (Cui et al., 2019; Fofrich et al., 2020; Pfeiffer et al., 2018; Tong et al., 2019). In

other words, new and some of the existing power generation infrastructure will become stranded assets (Binsted et al., 2020; Pfeiffer et al., 2018). Otherwise, a delayed phase out of fossil fuel power infrastructure will jeopardize the mid-century decarbonization target and reduce the likelihood of achieving the Paris climate target.

Fossil fuel power generation, especially coal power, still holds a prominent place in the developing countries' power sector. According to the Global Coal Plant Tracker (Global Energy Monitor, 2020), global coal power generation capacity has grown continuously since the 1950s. From 2000 to 2019, the global coal power capacity nearly doubled from 1,066 GW to 2,045 GW, with the most of new capacity added in China (806 GW) and India (167 GW) (Global Energy Monitor, 2020). More recently, the global coal capacity growth has slowed down since 2015. This is largely due to the slowing coal capacity growth in China and India, as well as coal power plant retirements in the U.S. and Europe (Shearer et al., 2020).

As developed countries transition away from coal power and China and India slow down their additions of new coal plants, Southeast Asia now has the fastest coal capacity expansion rate in the world. Since 2000, the share of coal power in Southeast Asia's electricity generation mix has increased from around 20% to over 40% (International Energy Agency, 2019b). As of 2018, Southeast Asia was one of the few regions in the world with an expanding coal power fleet as well as a growing share of electricity generation from coal (International Energy Agency, 2019b). Southeast Asia's expanding power sector backed by fossil fuel generation contributed to a growing trend of regional CO_2 emissions, which increased from 1 Gt in 2010 to 1.4 Gt in 2018. International Energy Agency (IEA) projects that Southeast Asia's fossil fuel consumption will

grow until 2040 based on current policies and announced plans, which will further increase regional CO_2 emissions to 2.4 Gt in 2040 (International Energy Agency, 2019b). The share of Southeast Asia's total CO_2 emissions from the power sector will increase to over 50% in 2040 when the share of power sector emissions decline in most other countries in the world, even with electrification of other economic sectors (International Energy Agency, 2019b). Southeast Asia had a large number of coal power plants under construction and being planned as of 2020, which are mostly located in Indonesia, Vietnam and the Philippines. If no measures are taken to enable a low carbon transition, Southeast Asia's fossil fuel power fleet expansion will likely delay the global power sector decarbonization. If coal and natural gas plants continue to operate at utilization rates and economic lifetimes similar to levels of the past plants, they will commit large CO_2 emissions in the long-term as CCS technologies have not yet been commercialized in Southeast Asia due to the high costs. Coal fired power plants, in addition to their climate impacts, may also deteriorate ambient air quality by emitting air pollutants such as particulate matters, sulfur dioxide and nitrogen oxides, if they are not equipped with end-of-pipe emission control technologies.

For developing countries with limited financial resources for low-carbon infrastructure investment, international investment through multilateral financing and bilateral financing can facilitate a clean energy transition (Granoff et al., 2016; Steffen & Schmidt, 2018). Financial commitments from development finance institutions (DFIs), in particular, can mitigate investment risks and facilitate financing beyond their commitment levels by attracting additional public and private co-financing (Geddes et al., 2018; Hainz & Kleimeier, 2012). Multilateral financing, from multilateral development banks (MDBs), has supported global power generation

infrastructure development for over half a century, during which time the MDBs transitioned from mostly development-oriented institutions to becoming also important providers of climate finance (Delina, 2011, 2017; Martinot, 2001; World Bank, 1993). Since the 2010s, a number of the MDBs have gradually shifted their power financing from fossil fuel technologies towards renewable technologies (Steffen & Schmidt, 2018). More recently, most MDBs have announced policies to restrict financing of coal power as well as upstream oil and gas extraction since the Paris Agreement (Buckley, 2019). The major MDBs declared in 2017 to align their financial commitments with the Paris Agreement and in 2018 they jointly announced a framework to reinforce this goal (The MDBs, 2018). Currently all the major MDBs no longer finance new coal power plants virtually.

In the meanwhile, bilateral financing has also been fueling global power infrastructure development (Tirpak & Adams, 2008). G7 countries provided US$30 billion public finance to coal fired power plants around the world between 2007 and 2015, with the largest contributions from Japan, Germany and the United States (Chen et al., 2016; Schmidt, 2013). Meanwhile, China also became a significant source of public finance for overseas coal plants (Chen & Schmidt, 2017; Ueno et al., 2014). Between 2013 and 2016, public finance institutions from G20 countries committed US$38 billion to overseas coal power projects and US$25 billion to overseas solar, wind and geothermal projects (Chen & Schmidt, 2017). Chinese DFIs committed the largest amount of coal power finance among the G20 countries. However, comprehensive analyses that cover financing of other power technologies, such as hydroelectric and gas power plants, are absent. Since late 2000s, China's two DFIs, China Development Bank (CDB) and the Export-Import Bank of China (CHEXIM), have emerged and become the most prominent

sources of development finance on the international stage. CDB and CHEXIM have committed more financing to developing economies than the collective contributions from the Western-backed MDBs since 2000, as well as more financing to the energy sector in particular (Chin & Gallagher, 2019; Gallagher et al., 2018). Out of CDB's and CHEXIM's financing commitments to overseas power generation projects, coal power projects accounted for the largest share (42%) and hydroelectric projects were the second largest (38%) (Gallagher et al., 2018). However, the impact of CDB's and CHEXIM's overseas finance on global fossil fuel and renewable technology capacity additions remains unclear.

Understanding of bilateral financing through commercial investment is also limited due to the lack of disaggregated statistics. While a number of commercial banks announced plans to eliminate coal power financing (Buckley, 2019), recent evidence shows that commercial banks and investors from China, the U.S. and Japan are still among the largest financiers of overseas coal power projects (Urgewald, 2019). Nevertheless, information regarding financing of non-coal technologies is limited. Despite recent research that tracks China's foreign direct investment (FDI) of all power technologies (Li et al., 2020), a full picture of global commercial financing of the power sector is missing. Overall, in contrast to extensive efforts that track climate and energy finance from the MDBs, systematic analyses of bilateral financing are lacking. To align international financing with the Paris Agreement, a better understanding of bilateral financing's impact on power technology deployment as well as the associated climate consequences is needed.

This dissertation fills the knowledge gap in bilateral financing of the power sector and advances our understanding about its implications for the global energy transition. In order to unravel bilateral financing's role in the power generation sector, in **Chapter 2** and **Chapter 3** I first fill the data gap by developing the first database of bilateral financing from China, Japan and the U.S. Using the newly constructed database, these two chapters comprehensively evaluate the impact of bilateral financing on fossil fuel and renewable power capacity expansion in the recipient countries as well as the resulting CO_2 emissions. **Chapter 4** turns to the recipient countries of bilateral financing of the power sector – Southeast Asian countries. In this chapter I analyze the implications of Southeast Asia's current power generation pipeline for long-term CO_2 emissions and short-term electricity generation.

In **Chapter 2**, I construct a new dataset of overseas power development finance from China's two DFIs, CDB and CHEXIM. I analyze the technology portfolio of their financing commitments between 2000 and 2018 and quantify their impact on fossil fuel and renewable power generation capacity additions in the recipient countries. I compare China's two DFIs as well as other East Asian national DFIs with the major MDBs and find that, after the MDBs stopped financing new coal power plants, East Asian national DFIs have filled the gap left by the MDBs and further expanded coal power financing. As a result, the East Asian national DFIs' overseas power plant financing committed before 2018 has fueled a new generation of coal power plants currently in operation, under construction or being planned, which will emit over 16 Gt CO_2 over their lifetime. As the East Asian countries announced their domestic carbon neutrality goals in 2020, it is imperative that they decarbonize overseas development financing as well.

Chapter 3 expands the analyses in **Chapter 2** and includes two mechanisms of bilateral financing: development finance through national DFIs and commercial investment in the form of greenfield FDI. In this chapter, I compile the first database of bilateral financing of power generation projects from Japan and the U.S. through systematic analyses of their DFIs' annual reports, press releases and project evaluation reports as well as their FDI activities at the power plant level. I find that bilateral financing from these three economies have played an important role in expanding power generation capacity in the recipient countries. Their overseas financing between 2000 and 2018 facilitated 233 GW power capacity additions globally. However, the majority of facilitated capacity additions in recipient countries are coal, gas and hydroelectric power plants, whereas less than 10% are in non-hydro renewable technologies. This chapter shows that bilateral financing follows the recipient countries' energy development strategies and is not yet leading a low carbon transition in the recipient countries.

Chapter 4 turns to the recipient countries of bilateral financing. Through analyzing Southeast Asia's past and current power generation pipeline, this chapter makes three contributions to understanding the short-term and long-term implications of its expanding fossil fuel power fleet. First, power plants that were under construction and being planned as of 2020 in Southeast Asia will more than double its current fossil fuel power generation capacity. I quantify the realized and remaining committed CO_2 emissions from Southeast Asia's fossil fuel plants and find that power plants that are under construction and being planned will significantly increase Southeast Asia's power sector CO_2 emissions. Second, I analyze the planning and construction time of Southeast Asia's coal, gas and hydroelectric power plants using empirical data. I find coal and

hydroelectric plants in Southeast Asia on average required 4 years of planning and 3 years of construction, which is much longer than that of renewable projects, which suggests a challenge of meeting near-term electricity demand increase with new coal and hydroelectric plants. Third, I evaluate the implications of current power generation pipeline for future electricity generation and renewable deployment in Indonesia, Vietnam and the Philippines. I find dependence on fossil fuel power sources in these three countries will lead to electricity oversupply or stranded assets of fossil fuel power infrastructure, and may crowd out renewable technology deployment.

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Chapter 2: Chinese Overseas Development Financing of Electric Power Generation: A Comparative Analysis

1. Introduction

To meet the United Nations Sustainable Development Goals and the Paris Agreement on climate change, net global carbon dioxide (CO_2) emissions must approach zero by mid-century (Millar et al., 2017; Rogelj et al., 2015, 2018). To meet this goal, the global power sector must rapidly decarbonize (Davis et al., 2018; Rogelj et al., 2015, 2018). Development finance institutions (DFIs) – publicly sponsored finance institutions with the official mission of promoting public policy objectives – can provide and catalyze financing to facilitate this transition (EPG, 2018; Larsen et al., 2019; Xu et al., 2019). To date, most attention on DFIs has focused on established, Western-led multilateral development banks (MDBs) (Christianson et al., 2017; Larsen et al., 2019; Nakhooda, 2011; Steffen & Schmidt, 2018; Wright et al., 2017, 2018). Since 2013 MDBs have reduced their fossil fuel power generation financing in developing countries, discouraged financing of upstream oil and gas extraction and coal-fired power plants, and prioritized financing of renewable energy (Buckley, 2019; Larsen et al., 2019; Steffen & Schmidt, 2018). Between 2007 and 2015, ten major MDBs facilitated 118 GW (57 GW of fossil fuel and 53 GW of renewable generation) of additional power generation capacity globally with the fraction of renewable financing increasing over time (Steffen & Schmidt, 2018). However, national DFIs that promote national public policies through domestic and foreign markets collectively hold more assets globally than the MDBs (Kring & Gallagher, 2019). Between 2007-2016, Chinese banks and funds provided equivalent development finance for overseas energy-related projects as

all major Western-backed MDBs (Gallagher et al., 2018). In the power generation sector, Chinese, Japanese and South Korean DFIs have become prominent sources of overseas financing for coal power plants at a time when decarbonization must be a priority (Chen et al., 2016; Chen & Schmidt, 2017; Hervé-Mignucci & Wang, 2015; Ueno et al., 2014). However, little is known about the impact of their financing on power generation capacity across technology types. Power generation infrastructure investments today financially commit future generations (Thacker et al., 2019). Additionally, fossil fuel-based power plants emit air pollutants and challenge climate targets (Pfeiffer et al., 2018; Tong et al., 2018, 2019). Despite DFIs' critical roles in global power infrastructure development, quantitative analyses of their actual impacts are limited.

For the first time, we quantify the contribution of DFI financing to fossil fuel and renewable technology capacity additions around the world by constructing a new database. We utilize comprehensive power financing data available from 2000 through 2018 (Chen & Schmidt, 2017; Gallagher, 2019; Steffen & Schmidt, 2018) and map DFI power financing to individual power plant. We examine power generation capacity additions facilitated by overseas financing from two Chinese national policy banks, China Development Bank (CDB) and the Export-Import Bank of China (CHEXIM), as well as their Japanese and South Korean DFI counterparts, including the Japan Bank for International Cooperation (JBIC), Japan International Cooperation Agency (JICA), Korea Development Bank (KDB), and the Export-Import Bank of Korea (KEXIM). We further expand our analyses of coal power financing to investigate the extent to which the East Asian national DFIs support their domestic coal power industry to operate abroad. Additionally, we assess the efficiency and installation of air pollutant emission control

devices of new coal power plants financed by the national DFIs and the MDBs. Finally, we evaluate the lifetime CO_2 emissions that result from DFI financed new power generation.

We find that new overseas power generation facilitated by DFI financing committed between 2013 and 2015 from China, Japan and South Korea is larger than the contribution of major MDBs. Since 2015 Chinese DFI financing has continued to increase while Japanese and South Korean DFI financing remained stable. While the MDBs' overseas power financing portfolio has become increasingly focused on renewables, East Asian national DFIs still largely finance coal power plants. We identify this difference through comparative analyses of Chinese DFIs and other major DFIs. In the following sections we present our findings and conclude with policy implications.

2. Results

2.1 Assessing DFIs' financing of global power generation

DFIs, unlike commercial banks with profit maximization goals, are established by governments to fulfill public policy objectives. As mandated by the governments, DFIs facilitate the development of key sectors such as infrastructure and trade by offering a variety of financial instruments such as loans, guarantees, and equity (Xu et al., 2019). Due to government backing, DFIs are instrumental in mitigating perceived political risks (Hainz & Kleimeier, 2012) and as a result attract additional public and private investments that might not otherwise occur.

Both multilateral and national DFIs provide significant financing of global power generation development. Here we analyze CDB and CHEXIM, the two policy banks designated by the Chinese government for overseas development financing and promoting global strategies. We compare CDB and CHEXIM with two groups of DFIs. The first group comprises the ten MDBs examined in Steffen & Schmidt (2018), covering all relevant MDB financing of global power generation between 2006-2015. These ten MDBs include the World Bank (WB), the International Finance Corporation (IFC), the Multilateral Investment Guarantee Agency (MIGA), the African Development Bank (AfDB), the Asian Development bank (AsDB), the European Bank for Reconstruction and Development (EBRD), the European Investment Bank (EIB), the Inter-American Development Bank (IADB), the Development Bank of Latin America (CAF), and the Islamic Development Bank (IsDB). The second group comprises CDB and CHEXIM's East Asian counterparts, namely the Japanese and South Korean national policy institutions which provide overseas financing, including JBIC, JICA, KDB, and KEXIM.

MDBs have been financing power plants around the world for over 50 years (World Bank, 1993), whereas national DFIs are newcomers to the global power generation financing stage. In their first decades the MDBs invested heavily in fossil fuel intensive power generation projects (Rich, 1994, 2009), but began to shift their positions just over a decade ago (Steffen & Schmidt, 2018). National DFIs from developed East Asian economies, Japan and South Korea, have been active power plant financiers since the 1990s, especially for overseas coal plants (Chen et al., 2016; Rich, 2009; Schmidt, 2013). In contrast, CDB and CHEXIM became globally active starting in the 2000s, with power finance primarily concentrated in coal and hydroelectric plants (Hervé-Mignucci & Wang, 2015; International Rivers, 2012; McDonald et al., 2009; Strange et

al., 2013; Ueno et al., 2014). CDB and CHEXIM have become among the largest DFIs in the world economy with total assets of US$2.4 trillion and US$0.6 trillion in 2018, respectively (CDB, 2019; CHEXIM, 2019). Japanese and South Korean DFIs' total assets are all less than US$0.3 trillion (JBIC, 2019; JICA, 2019; KDB Bank, 2018; SEC, 2018). Total assets of the ten MDBs, in comparison, are US$1.5 trillion (calculated based on individual MDB's total assets; data collected from the banks' websites and/or annual reports (AfDB, 2019; AsDB, 2018; CAF, n.d.; EBRD, 2019; EIB, 2019; IDB, 2019; IsDB, 2018; The World Bank, n.d.)). CDB and CHEXIM also differ from other DFIs in aspects of financing instruments and investment recipients. Financing instruments from MDBs and Japanese and South Korean DFIs include loans, equity, grants and guarantees, whereas CDB and CHEXIM only provide loans and grants to overseas projects and are less apt to provide guarantees or equity financing. As for recipients of DFIs' financing support, MDBs and Japanese and South Korean DFIs lend both to public and private sectors, whereas lending from Chinese DFIs is largely to public institutions, such as governments and stated owned enterprises.

DFIs' overseas financial involvement in the power generation sector ranges from providing export credit to support international trade to financing the entire capital cost of a power plant. Whether providing partial or full financing to the power project, their involvement can be pivotal in enabling the plant's commissioning. In view of this instrumental role of DFIs financing, we evaluate their impact on new power generation capacity by accounting for the total nameplate generation capacity of new power plants with DFI's financing involvement, regardless of the amount of financing provided. We label this impact on power generation capacity as "facilitated generation capacity additions".

2.2 Contribution to global generation capacity additions

CDB and CHEXIM's overseas financing of power generation has grown rapidly since the late 2000s. In 2008, CDB and CHEXIM together surpassed the WB and its regional counterparts to annually become among the largest global power generation financiers. Between 2008 and 2015 their financing exploded – annually increasing from twice (US$3 billion) to ten (US$21 billion) times the financing of any other DFI (Figure S1). Japanese and South Korean DFIs have also been influential sources of power generation finance, annually contributing about US$1 billion and US$0.4 billion, respectively, to overseas coal power plants between 2013 and 2017.

We construct a power plant level database of CDB and CHEXIM's overseas power financing by mapping their financing commitments to individual power plant in the global power plant inventory – the World Electric Power Plants Database (WEPP) (S&P Global Market Intelligence, 2020). We quantify the facilitated generation capacity additions from CDB and CHEXIM's overseas financing and compare them to the MDBs and Japanese and South Korean DFIs. Data for MDBs' financing commitments is available for 2006-2015, for all technologies including renewables and non-renewables (Steffen & Schmidt, 2018). Data for Chinese DFIs is available for 2000-2018, also including all technologies (Gallagher, 2019). Data for Japanese and South Korean DFIs is available from January 2013 to August 2017, and only for coal, solar, wind and geothermal plants (Chen & Schmidt, 2017), thus their contributions to other technologies such as hydro, gas, oil and nuclear plants are unknown. Therefore when comparing CDB and CHEXIM with MDBs, we use the time interval 2006-2015 when data is available for both groups. When

comparing Chinese, Japanese, and South Korean DFIs with MDBs, we use the three-year time interval 2013-2015 because this is the only interval for which data is available for all the DFIs.

We find that CDB and CHEXIM's financing commitments between 2006-2015 facilitated 59 GW total capacity additions with the largest fraction devoted to coal, hydro and nuclear power. Their contribution together is larger than that of any individual MDB, and is equivalent to 42% of total power capacity additions collectively contributed by the ten major MDBs over the same time period (Figure 1; see also Table S1 for annual comparison). In contrast to CDB and CHEXIM's coal power dominated portfolio, the ten MDBs collectively, and most of them individually, have a more technologically diverse capacity portfolio. Among the MDBs, the largest share of facilitated capacity additions of AsDB and AfDB were devoted to coal power; WB, CAF, and MIGA to hydro power; and IsDB, EIB, and ERDB to gas plants. Collectively, between 2006-2015 the ten major MDBs' financing commitments facilitated substantial capacity additions in gas (39 GW) and hydroelectric generation (31 GW). Among the total 140 GW capacity additions facilitated by MDBs financing, 55 GW were through public lending and 84 GW through private lending. In contrast, all CDB and CHEXIM's financing commitments were to public borrowers except for one loan to a private company for a 100 MW wind farm in Pakistan. Therefore public lending from the two Chinese DFIs facilitated more power capacity additions, specifically more coal and nuclear plant capacity, than all ten MDBs' public lending combined.

During the period of analysis, Chinese, Japanese, and South Korean DFIs overtook the MDBs' role as the most important power generation financiers. Table S2 summarizes these DFIs'

facilitated capacity additions over various periods. While some of the MDBs have diversified their balance sheets towards cleaner energy, East Asian national DFIs have filled the coal financing gap by continuing to fund overseas coal plants. Between 2013-2015, ten MDBs together facilitated 42 GW power capacity additions, of which 12 GW were through lending to public borrowers. In comparison, CDB and CHEXIM's contributions were 32 GW (of which 17 GW were coal power), almost entirely to the public sector. Financing commitments between 2013-2015 from Japanese DFIs facilitated 10 GW coal power capacity additions and 1 GW solar, wind and geothermal capacity additions. Meanwhile, South Korean DFIs facilitated 2 GW coal, and 0.2 GW solar and wind power capacity additions. Together, even neglecting any contributions from Japanese and South Korean DFIs to potential hydro, gas, oil or nuclear plants, Chinese, Japanese and South Korean DFIs' overseas development finance between 2013-2015 facilitated more power generation capacity additions and more coal additions than the ten MDBs' total contributions.

2.3 Power capacity additions facilitated by Chinese DFIs

We unravel the technology mix and regional distribution of CDB and CHEXIM's overseas power financing since 2000 and its impact on generation capacity growth. Tracking CDB and CHEXIM's finance at the power plant level, we find these two Chinese policy banks committed US$112 billion to overseas power generation projects between 2000-2018. As a result, they facilitated past and expected future commissioning of 163 power plants with total capacity of 90 GW in operation, under construction, or planned (Table S3).

Figure 2 summarizes CDB and CHEXIM's annual financing commitments to overseas power plants since 2000, and their contribution to generation capacity additions. CDB and CHEXIM's financing commitments in the power sector increased greatly, rising from less than US$1 billion per year before 2006, to peak in 2015 at US$21 billion. In 2018 their financing commitments decreased to US$7 billion. This tremendous cumulative investment since 2000 led to 3 to 9 GW new power generation capacity additions overseas each year between 2011-2018 with coal and hydroelectric power plants making up the majority. In addition, CDB and CHEXIM financed a small amount of nuclear power and a smaller amount of gas, oil, solar, wind and biomass technologies. About 43 GW generation capacity is still in the pipeline (under construction or planned) as of March 2019, most of which is coal, hydro and nuclear power which is expected to commence operation within five years. According to the WEPP database, from 2011 to 2018 on average 82 GW of new power plants came online annually in non-OECD countries excluding China, so CDB and CHEXIM were involved in approximately 7% of these capacity additions. The vast majority of CDB and CHEXIM's overseas finance is to developing economies (87%) and countries that participate in China's Belt and Road Initiative (BRI) (87%) (Figure S2; see also Table S4 for a complete list of recipient countries).

CDB and CHEXIM's financing commitments typically provide a substantial fraction of the capital costs of their facilitated capacity additions. We find that they provide more than half of the total capital costs for the majority of the power plants they co-finance with other banks. The degree of their financial involvement, evaluated by the fraction of a power plant's capital cost that is financed by CDB or CHEXIM, varies by plant and by technology type (Figure S3). On average, CDB and CHEXIM's financing commitments support approximately 50% of the total

cost of coal power plants and 70% of the total cost of hydroelectric dams. Hydroelectric power plant's average capital cost per unit capacity is higher than that of coal power. Hence, CDB and CHEXIM's facilitated coal capacity additions are more than twice of their facilitated hydroelectric power capacity even though their financing to coal and hydroelectric plants are comparable.

Table 1 summarizes the regional distribution of CDB and CHEXIM facilitated generation capacity additions across technology types. CDB and CHEXIM's primary contribution to coal power capacity is concentrated in South and Southeast Asia where electricity demand is increasing rapidly with economic growth and industrialization. Their contributed hydropower capacity is concentrated in Africa where energy access is among the top development priorities and in African countries where water resources are abundant. The few projects of gas, oil, nuclear, solar, wind and biomass plants are scattered around the world.

CDB and CHEXIM's financing commitments between 2000-2018 facilitated the most capacity additions in Indonesia, Vietnam, South Africa, Pakistan, and India (Figure 3). Around 10% of each of these countries' total power generation capacity (except India at 2%) received some CDB or CHEXIM financing. In South Africa and Ecuador, almost 50% of their new generation capacity added since 2000 received some CDB or CHEXIM financing. CDB and CHEXIM's contributions to the top ten recipient countries are mostly coal, hydro, or nuclear power generation. These technologies appear to align with the recipient countries' energy resources and their domestic capacity portfolios, where coal and hydro power has long served the goal of expanding reliable and affordable electricity access (IEA, 2019b).

2.4 Coal power financing of the DFIs

In 2013, the World Bank announced it would no longer finance coal power except under exceptional circumstances (The World Bank Group, 2013) and other MDBs gradually adopted similar policies due to shareholder and stakeholder concerns about the impact of coal on global CO_2 emissions and climate change (Larsen et al., 2019). Meanwhile, East Asian national DFIs filled the resulting gap and further expanded coal power financing. Between 2013-2017, Chinese, Japanese and South Korean DFIs committed financing to 49 GW of coal power capacity overseas. Figure 4 shows the eight countries with the largest coal power generation capacity additions facilitated by financing commitments from the DFIs between 2013 and 2015. Chinese and Japanese DFIs' overseas financing dominates the facilitated coal power generation additions in the recipient countries with the MDBs contributing only to Pakistan and Morocco and South Korean DFIs only contributing to Vietnam.

CDB and CHEXIM's overseas finance supports Chinese firms to go abroad (Chin & Gallagher, 2019; Hannam et al., 2015; Kong & Gallagher, 2017). Japanese and South Korean DFIs are also by nature national development banks with the policy objective to globalize their firms. Our analyses of equipment manufacturer, construction contractor, and ownership of East Asian DFIs financed coal power plants confirm that these national DFIs' overseas coal power financing support the global expansion of their domestic coal power industry. Among CDB and CHEXIM financed overseas coal plants, 77% imported boilers, steam turbines, and/or generators from Chinese equipment manufacturers. 65% of these plants hired Chinese construction contractors, and 13% are majority or jointly owned by a Chinese project developer (Figure S5). Similar

dynamics are observed in the cases of Japanese and South Korean DFIs. The overseas expansion of Chinese coal power companies has been linked with their cost advantages in labor, technology, and financing, demand for coal plants from recipient countries, as well as China's domestic overcapacity in coal power (Hervé-Mignucci & Wang, 2015; Kong & Gallagher, 2019; Peng et al., 2017; Zhao & Alexandroff, 2019). Based on the linkage between CDB and CHEXIM's overseas coal power financing and Chinese coal power companies, studies such as Kong and Gallagher (2019) further advance that China's globalization of its coal industry through DFI financing is part of a "domestic adjustment" program to ease the industry of domestic overcapacity and environmental regulation.

2.5 Technology choices of DFI financed coal plants

The technology – subcritical, supercritical, ultra-super critical – used in a coal power plant influences the efficiency of coal burning and the resulting CO_2 and air pollutant emissions per unit electricity generated. We explore the technology choices of DFI financed coal plants by analyzing the technology configurations documented in the WEPP database. We find, of the DFIs, CDB and CHEXIM's finance has facilitated the largest capacity addition of subcritical coal fired power plants (Tables S5 and S6). Japanese DFIs have financed the largest fraction of more efficient supercritical (47%) and ultra-supercritical (45%) plants. South Korean DFIs also devoted over 90% of their facilitated capacity additions to supercritical and ultra-supercritical technology. MDBs' portfolio includes 35% subcritical coal technology capacity. In reality, we find that coal fired power plants can experience a lag of 1 to 9 years between the announcement of financing and commencement of plant operations. A coal plant's technological configuration

may evolve with technology improvements occurring during the project development period, especially for plants that are still in the planning stage.

Installing end-of-pipe emission control devices in coal power plants efficiently reduces emissions of air pollutants such as SO_2, NO_x, and particulate matter (PM) and the resulting ambient air pollution and associated adverse health impacts while slightly increasing CO_2 emissions due to the energy necessary to operate the control devices. However, there exists no comprehensive data on the installation of coal plants' pollution control devices worldwide, with WEPP being the only indicative source of such information. According to data reported to WEPP by electric power producers, coal power plants financed by East Asian national DFIs have installed less pollution control technology than the MDBs (Tables S5 and S6). This indicates either lower installation rates, less reporting of pollution controls, or lower availability of data. Compared with national DFIs, MDB financed plants either more frequently install pollution control devices or have a better and more transparent reporting system.

2.6 Committed CO_2 emissions from DFIs financed power plants

Fossil fuel-based power generation infrastructure will lock in CO_2 emissions for decades. Accounting for the committed emissions – CO_2 emissions expected over the power plants' lifetime – demonstrates the long-term consequences of past and current investment decisions. We quantify the total committed CO_2 emissions expected from coal, oil and gas power plants supported by the DFIs' financing commitments, assuming a 40-year lifetime (Table 2).

The power plants that CDB and CHEXIM committed to finance between 2000 and 2018 will emit 12 Gt of CO_2 between commencement of operations and closure. Most of these committed emissions will come from coal fired power plants. Over their lifetime these coal plants will emit as much CO_2 as the total annual emissions from all coal fired power plants in operation around the world in 2018. Over 90% of the emissions will occur in the future given that almost half of these plants are still in the pipeline (Table S7). The coal plants that Japanese and South Korean DFIs committed to finance between 2013 and 2017 will emit 3 Gt and 1 Gt of CO_2, respectively. Taking into account coal plants that were pending for Japanese and South Korean DFIs financing as of the end of 2017, another 3 Gt of committed CO_2 emissions will occur. The MDBs, although having financed more gas than coal power capacity additions between 2006-2015, have more committed CO_2 emissions from their facilitated coal than gas generation capacity. Among the recipient countries, India, Indonesia, Vietnam and South Africa have the most committed CO_2 emissions from power plants financed by the DFIs (Tables S7-S10).

3. Discussion

Our analyses of overseas development finance by CDB and CHEXIM (compared with Japanese and South Korean DFIs and the MDBs) and their contribution to power generation capacity additions, reveal the key role these institutions play in global power infrastructure development. Between 2013 and 2015, financing commitments from the Chinese, Japanese, and South Korean national DFIs together facilitated more generation capacity additions worldwide than the collective contribution of major MDBs. Over the last decade, ten major MDBs have financed a variety of power technologies with a growing share of renewable power generation (Steffen &

Schmidt, 2018). However, when juxtaposed with overseas financing from East Asian national DFIs, we find a different picture. The national DFIs' overseas power plant financing committed before 2018 fueled a new generation of fossil fuel power currently in operation or in the pipeline. Overseas financing by CDB and CHEXIM, committed between 2000-2018, facilitated 56 GW coal power, 23 GW hydro power and 7 GW nuclear generation capacity additions worldwide. Furthermore, as a result of financing committed between 2013-2017, Japanese and South Korean DFIs facilitated 15 GW and 4 GW overseas coal power capacity additions, respectively.

East Asian national DFIs have become public lenders of last resort for financing coal plants in developing countries after recipient countries' domestic sources have been utilized. In 2013 the U.S. government and the World Bank announced they would restrict lending for development of coal power plants out of concerns for climate impacts (The World Bank Group, 2013). Since then, over 100 global financial institutions have adopted coal power and/or coal mining financing restriction policies, including MDBs, European national DFIs, insurers, and some commercial banks (Buckley, 2019). In 2018, the MDBs and the International Development Finance Club (IDFC), of which CDB, JICA and KDB are members, declared that they would align member balance sheets with the Paris Agreement (GCF & IDFC, 2019; World Bank, 2018). In 2020, South Korea and Japan announced plans to further phase out public financing of new overseas coal plants. While CDB and CHEXIM have not yet moved to restrict overseas coal power financing, their overall energy financing overseas has decreased since 2017 due to a variety of domestic and global factors such as trade and financial instability on the mainland and debt sustainability concerns in borrowing countries, among others (Ma & Gallagher, 2020). Nevertheless, no policies have been announced by China, Japan or South Korea on divestment

from coal power plants that are already in the pipeline, which we show will commit large future CO_2 emissions.

These national DFIs' overseas financing commitments are inconsistent with a climate target of well below 2°C global average warming by the end of the century. To meet the Paris Agreement goals, little or no additional CO_2-emitting infrastructure can be commissioned and existing infrastructure will need to be retired early to reduce projected lifetime emissions (Tong et al., 2019). Of the coal power capacity that CDB and CHEXIM have committed to finance through 2018, half is expected to commence operations in the future with over 90% of their committed CO_2 emissions occurring after 2018. This will greatly reduce the potential to decarbonize the global power generation sector by mid-century. Reducing committed CO_2 emissions of new fossil power plants will require either major retrofits to permit carbon capture and storage or early retirement of operational plants – both of which are costly options. It is important that DFIs implement more restrictive policies on fossil fuel financing to ensure their overseas commitments are aligned with the Paris Agreement while serving other development goals such as infrastructure and trade.

In addition to the climate risks, East Asian DFIs' enormous capacity portfolios in coal power also expose them to financial risks. Costs of renewable technologies are decreasing rapidly. By 2028, in markets like Vietnam and Indonesia where coal power has long been prioritized, operating existing coal power plants will likely be more costly than building new solar power (Carbon Tracker, 2018). This may lead to DFIs having stranded coal power assets and thus trouble recouping their loans. Thus a critical evaluation of their fossil fuel investments versus

renewable energy options, to account for decreasing costs of renewable technologies and the possibility of future stranded coal power assets, will be valuable for the DFIs' financial security.

Our study, for the first time, illuminates Chinese DFIs' overseas power financing portfolio relative to other major DFIs and finds them to be the most significant international development financiers for power generation capacity expansion in developing countries. While we focus on DFI financing, commercial banks and institutional investors are also important financiers for global power generation. Though a number of commercial banks have introduced policies to cease lending to new coal power plants (Buckley, 2019), recent tracking by the NGO community revealed that commercial banks from Japan, Europe, U.S. and China have continued to provide significant support for coal power through direct loans and underwriting (Rainforest Action Network et al., 2020; Urgewald, 2019; Zhou et al., 2018). With profit maximization goals, commercial banks may still perceive coal plants in developing countries as steady sources of cashflow that generate greater returns than renewable technologies (Cloete, 2019). However, growing coal power generation capacity and increasing competitiveness of renewables are reducing utilization rates of existing coal plants (Carbon Brief, 2019), which in return undermines coal plants' profitability. To meet long term sustainable development goals and avoid committed CO_2 emissions from fossil fuel plants, a major increase in low carbon technology investment is needed (IEA, 2019a). Moreover, national determined contributions submitted by developing countries to the Paris Agreement suggest vast investment need for renewable energy in power generation (Cabré et al., 2018). DFIs can play pivotal roles in this regard. Redeployment of some coal power financing with renewable technologies has the potential to substantially increase renewable deployment.

Here we find national DFIs' overseas financing of power generation to be a prominent driver of fossil fuel generation capacity expansion globally and to have the potential to drive renewable power capacity expansion. However further questions remain regarding the political economy of how national DFIs make investment decisions on various technology options, what barriers they may face financing non-hydro renewable energy, and what approaches they may take to increase renewable energy financing. Future research that addresses these questions is needed as increased global investment in non-fossil energy is crucial for global sustainability and DFIs play an important role in facilitating power financing. In addition to DFI financing, power generation development in developing countries are influenced by a variety of other factors. Continuous research is required to understand how to steer the developing countries' power sector to a low carbon pathway and how DFIs can facilitate the transition. For example, we find that CDB and CHEXIM's overseas financing portfolio is typically aligned with the recipient countries' energy resources and domestic capacity portfolios. AsDB and AfDB, with many countries in their membership lists that have cheap coal resources and favor coal power projects, have also devoted higher portfolios to coal power capacity additions compared with other MDBs. This indicates a strong connection between DFI financing and the recipient countries' development priorities and demand for power capacity. In some developing countries where energy access and affordability are the top development priorities, or where subsidies and other incentives distort market prices, coal power may still appear to be the cheapest and most stable power source, although renewable energy is becoming increasingly competitive. Future research that examines the recipient countries' development strategies and energy policy and regulation is crucial to identify the bottleneck to shift global financing away from fossil fuel. Additionally, we find that

some of CDB and CHEXIM's coal power financing supports the expansion of Chinese coal power companies, including equipment manufacturers, construction contractors and project developers, into overseas coal power markets. To explain Chinese coal power companies' global expansion, hypotheses have been raised regarding their advantages in labor, technology and financing costs over international competitors (Hervé-Mignucci & Wang, 2015; Zhao & Alexandroff, 2019), China's domestic coal power overcapacity (Hervé-Mignucci & Wang, 2015; Kong & Gallagher, 2019), and "pull" factors from the demand side such as recipient countries' requests for coal power and high profitability of coal plants (Hervé-Mignucci & Wang, 2015; Kong & Gallagher, 2019; Peng et al., 2017). Yet questions remain about how CDB and CHEXIM interact with China's coal power companies and make financing decisions. While Chinese companies' overseas involvement in power generation has been coal-intensive (Hannam et al., 2015), they also have the potential to expand foreign markets for renewable technologies (Cabré et al., 2018; Steffen et al., 2018). To understand how to realize this potential, quantitative and case studies that utilize our database to further explore the relationship between Chinese overseas development financing and China's domestic power industry development will be valuable.

4. Method

4.1 Study scope and data sources

To analyze the impacts of CDB and CHEXIM's overseas power generation financing, we construct a new project level database that documents both the financing commitments of CDB and CHEXIM to overseas power plants and the corresponding nameplate generation capacity and

technology type of these plants. We choose CDB and CHEXIM because, out of China's three policy banks, they are two policy banks designated by the Chinese government for overseas development financing and promoting global strategies. The third policy bank, Agricultural Development Bank of China, is not included in our study because it does not provide overseas financing. China Export & Credit Insurance Corporation (Sinosure), though highly involved in Chinese companies' overseas power project investments, is not included in our study because it is an insurance company. Sinosure provides insurance against non-payment risks in China's foreign trade and investment, but does not provide direct lending. To construct the database for CDB and CHEXIM, we adopt a bottom up approach by utilizing project level financing data and plant level power generation and technology configuration data. National DFIs from China, Japan, and South Korea do not officially publish their project level financing data. Therefore, most existing studies on international power finance focus only on DFIs' financial flows to various technologies. Our study goes one step further by mapping the financial flows to individual power plants and quantifying new power generation capacity additions triggered by DFIs' financing commitments. With the newly constructed database, we further investigate DFI financed coal plants' technology efficiency (subcritical, supercritical, or ultra-supercritical), installation of these coal plants' air pollutant emission control devices, and DFI financed power plants' committed CO_2 emissions.

For project level financing data, we deploy the China Global Energy Finance Database (CGEF) (accessed in April 2019) from Boston University that documents CDB and CHEXIM's overseas financing of energy projects (Gallagher, 2019). The CGEF database is the most comprehensive document available of Chinese overseas energy finance and has coverage starting in 2000. We

select CDB and CHEXIM's financing of power generation projects in this database and exclude other types of energy financing such as those for transmission, mining, or irrigation projects. The CGEF database provides information including the recipient country, fuel type of financed power generation projects, year of financing commitments, US dollar amount of financing commitments and a brief description of the projects. It does not include the project's corresponding generation capacity, specific technology configurations (such as the efficiency or end-of-pipe air pollutant emission control technology of a coal plant), or the manufacturer, construction contractor or ownership information of the power plant.

To obtain plant level power generation and technology configuration data not available in CGEF, we exploit the World Electric Power Plant Database (WEPP, March 2019 version), which documents generation and technology information of the global power plant inventory. The process of mapping financing commitments to specific power plants in WEPP is as follows: for each entry of project financing in CGEF, we first screen WEPP by selecting the recipient country identified for the project by CGEF. We next search WEPP for the power plant(s) receiving the financing commitment based on CGEF's description. To facilitate the searching process, we develop a search tool based on two algorithms to identify the closest matches of power plants in WEPP: one built on the longest substring matching mechanism (Gusfield, 1997), another built on the Levenshtein distance mechanism (Levenshtein, 1966). The search tool allows for minor differences between a power plant's name described in CGEF and that documented in WEPP. The search tool returns the top matches of power plants it finds in WEPP; we then manually choose the correct one using additional information documented in CGEF including fuel type, location, and year of financing commitment. When the search tool does not return the correct

power plant, we manually search for the power plant in WEPP after a web search for additional information about the project finance (about 10% of the entries). We further manually code 4 power plants with fuel type and generation capacity because there are multiple web sources confirming the existence of these power plants which WEPP fails to document. 5 (3%) of CGEF's power generation financing projects do not have sufficient information to identify the power plant or generation capacity. Thus our estimation of total associated generation capacity is conservative. There are cases when several financing commitments documented in CGEF are devoted to the same power plant. By mapping financing commitments to power plants in WEPP, we avoid double counting when calculating generation capacity additions facilitated by CDB and CHEXIM's financing. The constructed database combining CGEF and WEPP provides complete information of CDB and CHEXIM's financing commitments, the corresponding power plants, the technology choices, air pollutant emission control device installation, equipment manufacturer, construction contractor and plant ownership.

We use published databases for Japanese and South Korean national DFI and MDB financing. We use the Consolidated Coal and Renewable Energy Database[19] (Chen & Schmidt, 2017) that covers Japanese and South Korean DFIs' financing commitments in overseas power generation projects from January 2013 to August 2017. This database only includes coal, solar, wind, and geothermal power technologies. Therefore our analysis of Japanese and South Korean DFIs does not include their potential financing to overseas oil, gas, hydro, nuclear, or biomass plants. The Consolidated Coal and Renewable Energy Database provides estimated share of plant capacity associated with financing from JBIC, JICA, KDB, and KEXIM, but does not document the total nameplate generation capacity of associated power plants. We locate Japanese and South Korean

DFI financed power plants in the WEPP database using the same searching method as we do for CGEF, and obtain the nameplate generation capacity of these power plants, as well as other information documented in WEPP.

We use the MDB power generation financing database from Steffen and Schmidt (2018) which includes ten major MDBs' financing between 2006-2015 (Steffen & Schmidt, 2018). This database documents both the financing commitments of the MDBs and the capacity of the power plants. It does not document the technology or ownership information of coal plants. Therefore we use this database for financing commitments and generation capacity but apply the search tool for MDB financed coal power plants to obtain information about the technology, air pollutant emission control devices, manufacturer, construction contractor and plant ownership.

4.2 Inflation/deflation

Financing commitments in three databases – CGEF, the Consolidated Coal and Renewable Energy Database, and the MDB database from Steffen and Schmidt (2018) are documented in US dollars. To convert the financing over a variety of years to 2015 US dollars, we use the International Monetary Fund's International Financial Statistics on Consumer Price Index of the United States.

4.3 DFIs' contribution to power generation capacity additions

We quantify DFIs' contribution to power generation capacity additions around the world by accounting for the nameplate generation capacity of all the power plants with partial or full financing from the DFIs. In cases where the DFIs devote multiple financing commitments to one power plant, we only account for the capacity additions once to avoid double counting. We focus on incremental generation capacity associated with financing so we do not account for the capacity additions in retrofitting or revamping projects (projects which improve an existing power plant) but account for the capacity additions in rehabilitation projects (projects which return retired power plants to operation). Often DFIs co-finance power plants together with local banks or local governments in the recipient country. Under this circumstance the DFI provides partial financing less than the total capital cost of the power plant. Whether CDB and CHEXIM provide partial or full financing to overseas power plants, their commitments can be pivotal in enabling the commissioning of a power plant. To better understand the degree of CDB and CHEXIM's financing involvement in power generation, we estimate their financial contributions relative to the total capital costs of the power plants by quantifying the fraction of financing that originate with CDB or CHEXIM. Because information about the total capital costs of the power plants is not available, we estimate the power plants' capital costs assuming an average capital cost per kW for each fuel type following Li et al. (2020). For each fuel type, a power plant's actual capital cost per kW is determined by many technological and non-technological factors. For example, the cost varies by specific technology configuration: ultra-supercritical and supercritical coal plants have higher capital costs per kW than subcritical coal plants; the cost of a coal plant's boiler depends on its temperature and pressure configurations; installation of advanced pollution control devices increases the cost of coal plants; etc. Furthermore, a power plant's total capital cost depends on its location (e.g. construction and labor costs vary with the

location of the power plants), varies by its equipment manufacturer and construction contractor (e.g. Chinese coal power manufacturers and contractors are reported to have lower costs (Hervé-Mignucci & Wang, 2015; Zhao & Alexandroff, 2019)), and changes with construction time (costs of renewable technologies have decreased rapidly with time). Moreover, the political and economic environment may also influence the plant's capital costs. Because the actual capital cost per kW may vary largely across power plants, our estimations of the power plants' capital costs and the fraction of CDB and CHEXIM's financing contribution are indicative of the degree of CDB and CHEXIM's financial involvement across fuel types on average, but not definitive. A detailed description of our estimation and uncertainty is presented in Figure S3 and Table S11.

4.4 Top recipient countries with the most facilitated generation capacity additions by all examined DFIs

In Figure 4 we rank the recipient countries by facilitated generation capacity additions contributed by financing commitments from DFIs. This order differs from the ranking of countries receiving the most financing commitments due to differences in generation cost by technology type and in distribution of financing. Most DFIs have committed finance to different power plants in the recipient countries and their facilitated capacity additions directly add up to total facilitated capacity additions contributed by all examined DFIs. However, in Vietnam, DFIs from China, Japan, and South Korea have co-financed the same coal plant so they all facilitated commissioning of this power plant. To avoid double counting of capacity additions, we separate the capacity additions of this power plant weighted by financing commitments from the DFIs and label them as facilitated capacity additions contributed by each DFI. Via this step, total

facilitated capacity additions in Vietnam reflect the actual additional generation capacity contributed by all DFIs. Another coal plant in Vietnam is co-financed by JBIC and KEXIM and a plant in Morocco is co-financed by JBIC and IsDB. We process the facilitated capacity additions for these two plants following the same procedure.

4.5 National DFIs' financial support of coal fired power plants

We analyze whether and how national DFIs make financing commitments to overseas coal power plants to support the DFI country's domestic coal power industry by examining the equipment manufacturer, construction contractor, and plant ownership of the financed coal plants. WEPP labels coal power plants with the companies that produce the main components (steam turbines, boilers and engines), the contractors that construct the power plant, and the parent companies that hold majority or joint ownership of the power plant. WEPP also documents the nationality of all manufacturing and construction companies. We conduct web searches and manually label the nationality of the parent companies. Combining information of company names and their nationalities, we then label whether a coal plant financed by a national DFI (e.g. CDB or CHEXIM) has imported equipment (steam turbine, boiler and engine) manufactured by a Chinese company, whether the plant has hired a Chinese construction contractor, and whether the plant is majority or joint owned by a Chinese firm. When a coal plant has imported at least one component among the steam turbine, the generator, and the boiler from a Chinese manufacturer, we label it as utilizing equipment manufactured in China.

4.6 Coal fired power plant technologies

We use information documented in WEPP to analyze DFI financed coal fired power plants' technology (subcritical, supercritical or ultra-supercritical) and end-of-pipe air pollutant emission control technology (SO_2, NO_x, and PM control). For a large number of power plants worldwide, WEPP is the only compiled database documenting these technologies although it does not have perfect data coverage. WEPP has 100% data coverage on the technology for coal plants financed by non-Chinese DFIs but only 85% coverage for coal plants financed by CDB and CHEXIM. This is likely due to the recently planned coal plants financed by CDB and CHEXIM for which the technology is unknown or unclear. WEPP collects data based on self-reported surveys, interviews with manufacturers, as well as documents about the power plants. In many cases entries of installed pollution devices are left blank or are marked with 'NA' in WEPP. In both cases we interpret it to mean that no information is available and cannot determine in which of these cases pollution devices are actually installed. We make the heuristic assumption that missing data in WEPP corresponds to a lack of reporting of pollution control installation. We note that WEPP is likely underestimating installation rates of SO_2, NO_x, and PM control technologies in coal power plants because of imperfect access to information. Various technologies exist to remove each of the key pollutants emitted from coal fired power plants. Each of these technologies results in different removal rates for these pollutants. We do not differentiate between these technologies in this study but instead focus on whether any control device for SO_2, NO_x, or PM is in place.

4.7 Committed carbon dioxide emissions

DFI financed power plants examined in this study have mostly been built over the past decade or will be built in the future. No comprehensive data of these power plants' actual CO_2 emissions or emission intensity is available. To calculate the committed CO_2 emissions of these DFI financed power plants, we estimate each power generator's annual emission based on their nameplate generation capacity, burned fuel, and country following the method in Davis and Socolow (2014)[72], assume a 40-year lifetime for all power plants and assume their annual emissions will stay the same following previous studies (Davis & Socolow, 2014; Edenhofer et al., 2018; Tong et al., 2019). Committed CO_2 emissions of each fossil fuel based power plant is calculated based on the following equation:

$$E_p = G_p \times CF_p \times h \times I_p \times y \quad (1)$$

where p represents the power plant or power generator. E_p is lifetime committed emissions, G_p is generation capacity (unit: MW), CF_p is capacity factor which can be interpreted as the fraction of hours that the power plant operates in one year, h is the number of hours in one year, which is 8,760 hours, I_p is emission intensity (unit: Gt CO_2/MWh), and y is the power plant/generator's lifetime in years, which equals 40 in our estimation. The emission intensity, I_p, of a power plant is determined by its efficiency or heat rate (heat rate is inversely related to efficiency) and its emission factor (determined by the carbon content of consumed fuel).

Our estimation relies on the WEPP database and the Carbon Monitoring for Action (CARMA) database (v3.0) (Center for Global Development, 2012). For each DFI financed power plant, we estimate its capacity factor and emission intensity based on the same or similar power plants

documented in CARMA (see Supplemental Method for a more detailed description). After calculating total committed CO_2 emissions for each power plant, we then separate them into realized emissions (CO_2 emitted before the end of 2018) and remaining committed emission (future emissions after 2018) based on the plants' commencement of operation year. The commencement year is available from WEPP for national DFI financed power plants. The information is not available for MDB financed power plants. Thus we follow Steffen and Schmidt (2018) and assume MDB financed power plants would commence operation two years after the financing commitment (Steffen & Schmidt, 2018).

CO_2 emissions from power plants that use the same type of fuel are aggregated in Table 2 and Tables S7-S10. "Coal" plants include power plants that use anthracite coal, bituminous coal, lignite, or sub-bituminous coal as fuel. "Gas" plants include plants that use conventional gas, liquefied natural gas, or liquefied petroleum gas. "Oil" plants include plants that use conventional oil or oil shale.

The average estimated capacity factor and emission intensity of power generators or power plants covered in this study are in good agreement with estimates in other studies (Table S12). Nevertheless, the estimation of committed CO_2 emissions is subject to uncertainties and limitations beyond capacity factor and emission intensity. A power plant's annual emissions will likely vary throughout its lifetime, depending on the actual future utilization rate and energy efficiency (Pfeiffer et al., 2018; Tong et al., 2019). With decreased cost of renewable technologies, fossil fuel based power plants may run fewer hours in a year in the future than power plants did in 2009 as documented in CARMA, leading to lower emissions than those

calculated based on the assumptions above. If the power plants retire earlier than has been the case in the past, it will also result in lower emissions. For gas plants, we only consider their CO_2 emissions in this study but not emissions of other greenhouse gases like methane leakage during gas extraction process (Riddick et al., 2019). Therefore, the climate impact from the gas plants is likely underestimated.

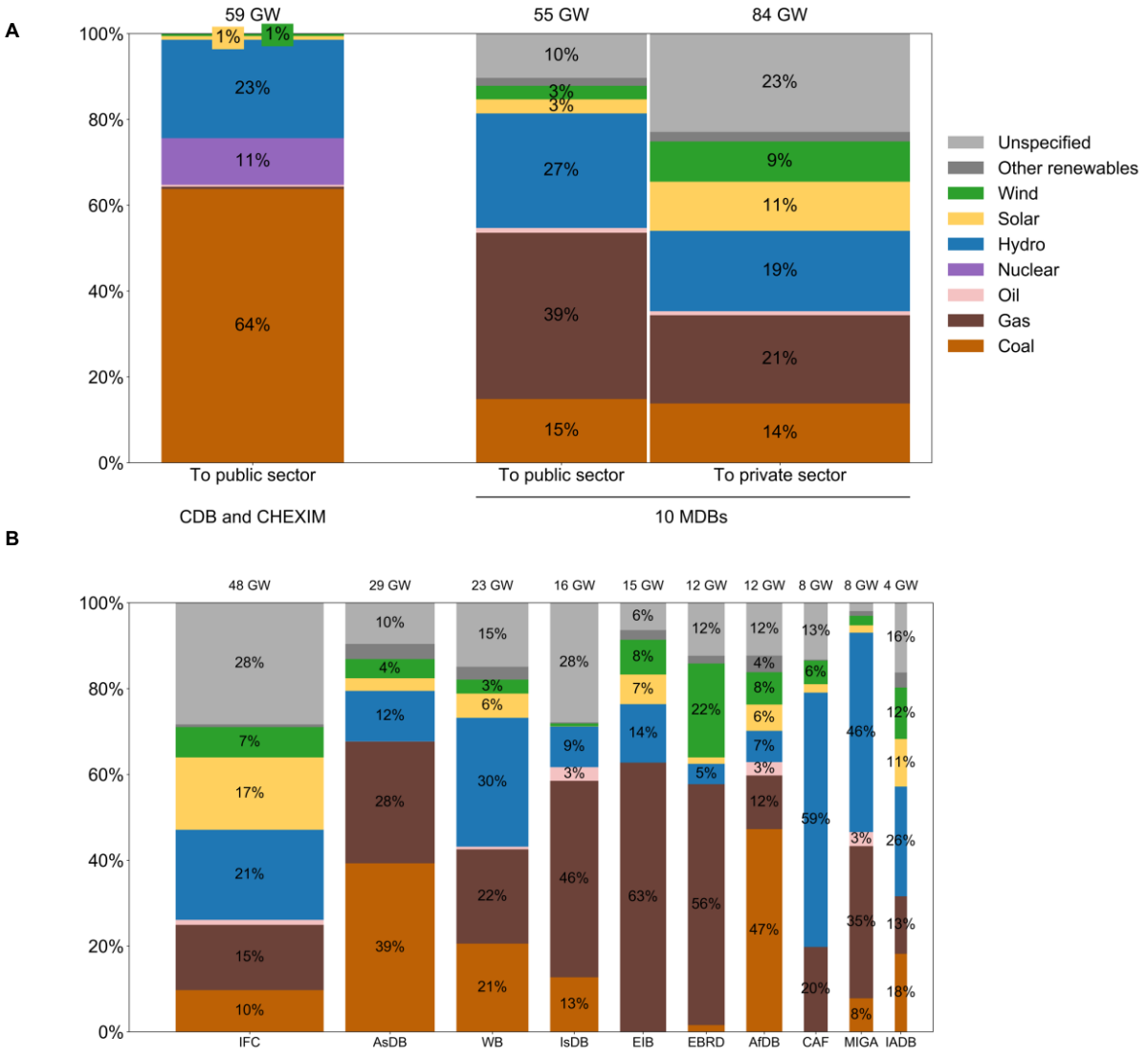


Figure 1. Power generation capacity additions facilitated by financing committed between 2006-2015 by two Chinese DFIs – CDB and CHEXIM and by ten major MDBs. Abbreviations for Chinese DFIs and the MDBs in figure: China Development Bank (CDB), the Export-Import Bank of China (CHEXIM), the International Finance Corporation (IFC), the Asian Development bank (AsDB), World Bank (WB), the Islamic Development Bank (IsDB), the European Investment Bank (EIB), the European Bank for Reconstruction and Development (EBRD), the African Development Bank (AfDB), the Development Bank of Latin America (CAF), the Multilateral Investment Guarantee Agency (MIGA), and the Inter-American Development Bank (IADB). Contribution by CDB and CHEXIM to the public sector

is presented because their contribution to the private sector is negligible. Contributions by the MDBs are: **A**, divided into public and private sectors, and **B**, shown individually for each MDB. The colors and percentages represent each fuel type. “Other renewables” include geothermal, biomass, and waste-to-energy. Numbers on top of the columns indicate the facilitated capacity additions (unit: GW). The widths of the columns are proportional to the facilitated capacity additions. Data sources: CDB and CHEXIM data constructed from China Global Energy Finance Database from Boston University (Gallagher, 2019) and the World Electric Power Plants Database (WEPP) (S&P Global Market Intelligence, 2020); MDB data from Steffen & Schmidt (2018).

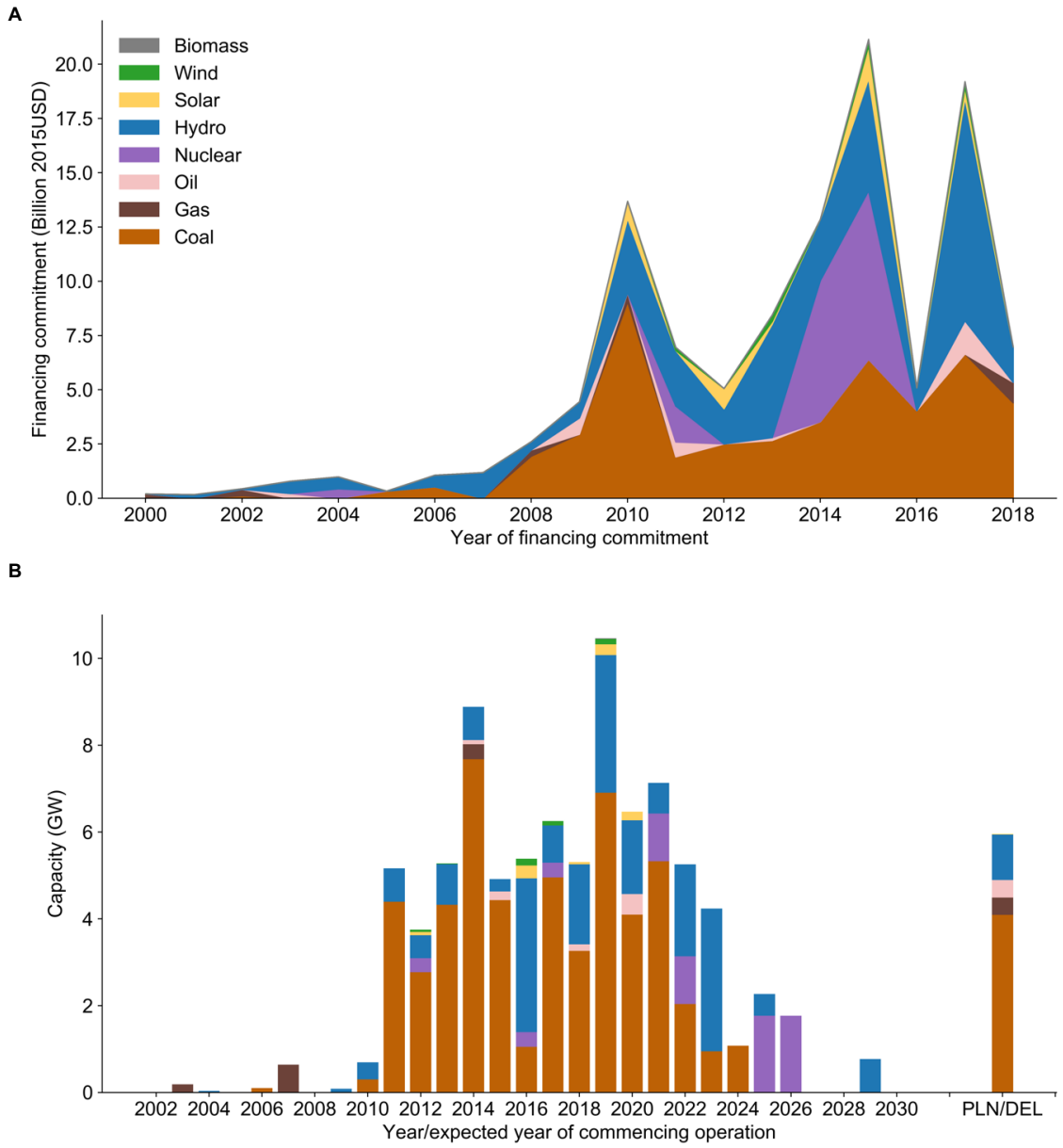


Figure 2. CDB and CHEXIM's annual financing commitments and facilitated capacity additions in overseas power generation. **A**: CDB and CHEXIM's overseas financing commitments in the power generation sector by technology type from 2000 to 2018 (year corresponds to when financing commitment is made). CDB and CHEXIM's overseas financing is counted in the year in which financing commitment was made rather than spread out and allocated across years of investment. Variation of their financing commitments across years is influenced by the number of newly approved projects and the financing amounts of these projects each year. In reality, annual financial flows are smoother than appear

in the figure because the bank's total commitment is allocated across years and distributed by the bank each year. **B**: CDB and CHEXIM facilitated overseas power generation capacity additions by year (year corresponds to commencement or expected commencement of operation year). PLN/DEL: planned or delayed power plants that do not yet have an estimated commissioning year.

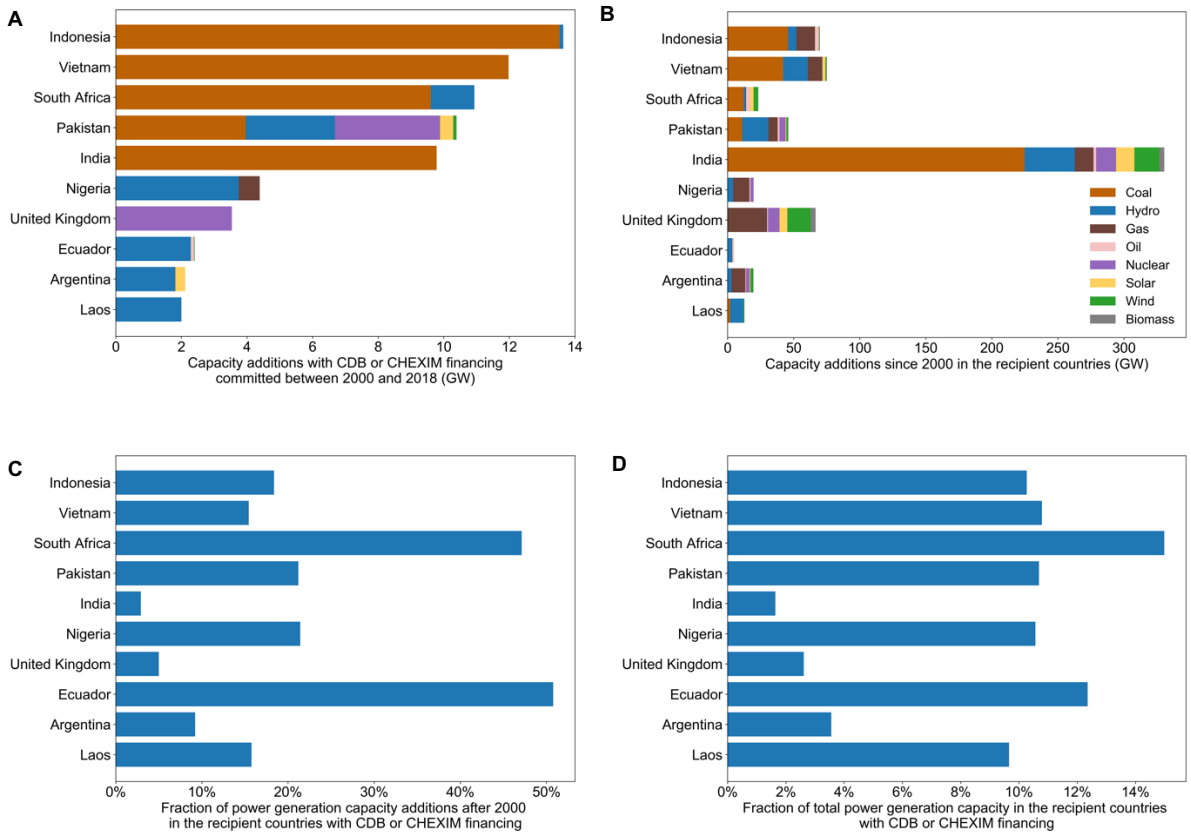


Figure 3. Ten recipient countries with the most power capacity additions facilitated by CDB and CHEXIM financing. **A**: Capacity additions facilitated by CDB and CHEXIM's financing commitments between 2000 and 2018 (in operation, under construction and planned; see also Figure S4 for each category separately). **B**: Power generation capacity added in or after 2000 in the ten recipient countries (that are currently in operation, under construction and planned). **C**: Fraction of the recipient countries' power generation capacity additions in or after 2000 that received at least partial financing from CDB or CHEXIM. **D**: Fraction of the recipient countries' total power generation capacity (that are currently in operation, under construction and planned) that received at least partial financing from CDB or CHEXIM. The colors in panel **A** and **B** indicate technology types.

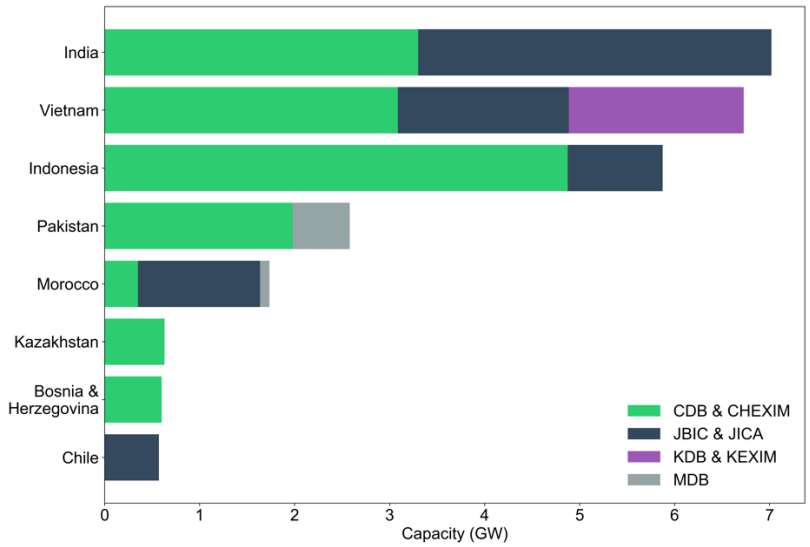


Figure 4. Recipient countries with the most coal power capacity additions facilitated by financing from the national and multilateral DFIs. Financing committed between 2013-2015. Bar color indicates financing country.

Table 1. Summary of regional distribution of facilitated generation capacity additions by CDB and CHEXIM across technology types between 2000-2018 (Unit: MW). The capacity additions include power plants that are currently in operation, under construction, and planned.

Technology type	Africa	Europe and Central Asia	Latin America and Caribbean	Middle East	South Asia	Southeast Asia	Total	BRI % as of 2019
Coal	10,850	3,180	350	0	15,960	26,106	56,446	99%
Gas	829	343	0	0	400	0	1,572	100%
Oil	200	0	100	470	0	156	926	100%
Nuclear	0	3,540	0	0	3,205	0	6,745	48%
Hydro	10,214	375	4,808	0	3,809	4,140	23,345	88%
Solar	55	85	368	0	400	0	908	61%
Wind	324	0	17	0	99	0	440	100%
Biomass	0	0	20	0	0	0	20	0%
Total MW	**22,472**	**7,523**	**5,663**	**470**	**23,873**	**30,402**	**90,401**	**92%**
% by region	**25%**	**8%**	**6%**	**1%**	**26%**	**34%**	**100%**	

Table 2. Committed CO_2 emissions from power plants with partial or full financing from the DFIs (unit: Gt CO_2). Financing commitments over various available time intervals. Data for Japanese and South Korean DFIs' financing of oil and gas plants is unavailable and are therefore not included. See also Tables S7-S10 for the breakup of committed emissions into realized emissions and remaining committed emissions and the breakup of emissions by country for the DFIs separately.

DFIs and year of financing commitments	Chinese DFIs (2000-2018)	Japanese DFIs (2013-2017)	South Korean DFIs (2013-2017)	10 MDBs (2006-2015)
Committed CO_2 emissions by fuel type				
Coal	11.81	3.25	1.20	5.00
Oil	0.14	NA	NA	0.15
Gas	0.08	NA	NA	3.41
Total	**12.03**	**-**	**-**	**8.56**

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Chapter 3: Bilateral Financing of Power Generation Technologies: A Comparative Study of China, Japan, and the U.S.

1. Introduction

To stabilize global average temperature increase at less than 2°C in order to avoid catastrophic outcomes from climate change, it is critical to rapidly decarbonize the global economy and approach net zero carbon emissions by mid-century (Davis et al., 2018; Millar et al., 2017; Rogelj et al., 2015, 2018). At present, electricity and heat generation contributes one-fourth of global anthropogenic greenhouse gas (GHG) emissions and is the largest emission source among all economic sectors (Edenhofer et al., 2014). Despite the demand reduction in 2020 due to COVID-19, global electricity demand is projected to recover in 2021 and grow further through 2040 (IEA, 2020). In developing countries, growing population and economic activities contribute to increasing electricity demand. Additionally, electrification is a key strategy for decarbonizing other end-use sectors, particularly transport and buildings (Davis et al., 2018; Elzinga et al., 2014; Kennedy, 2015; Knobloch et al., 2020; Rogelj et al., 2018). Hence it is crucial to decarbonize the power sector in order to fully decarbonize the economies of both developed and developing countries. This requires a rapid and fundamental redirection of global finance away from fossil fuel infrastructure towards low carbon technologies.

International investment through bilateral and multilateral financing has been facilitating power infrastructure development in developing countries (Steffen & Schmidt, 2018; Tirpak & Adams, 2008) and can play a pivotal role in the clean energy transition (Granoff et al., 2016). Among

international financiers, multilateral development banks (MDBs) have been financing power generation projects around the world for over half a decade (World Bank, 1993). Before the 2010s, MDBs mainly invested in coal, gas, and large hydroelectric power plants (Steffen & Schmidt, 2018; Tirpak & Adams, 2008). With the negotiations of international climate agreements, MDBs began formulating strategies to increase low carbon technology financing starting around 2000 (Delina, 2011, 2017; Martinot, 2001). Since the 2010s, a number of MDBs have gradually shifted their financing portfolios away from fossil fuel power projects towards renewable projects (Steffen & Schmidt, 2018). In 2017, the major MDBs declared jointly with members of the International Development Finance Club (IDFC) to align financing activities with the Paris Agreement and in 2018 further reinforced this commitment (IDFC & The MDBs, 2017; The MDBs, 2018). After 2017, none of the major MDBs finance coal-fired power plants any longer.

Meanwhile, bilateral financing has also been fueling power generation development globally. Advanced economies such as Japan have long provided financing and technologies for power sector development in developing countries, including China (Tirpak & Adams, 2008). Beginning in the late 2000s, China emerged as a prominent source of international finance for global power generation (X. Chen et al., 2020; Li et al., 2020). In contrast to extensive research efforts that track MDBs' climate and energy finance, structured analyses of bilateral financing of the power generation sector is limited. Existing evidence indicates that China, the United States, Japan, Germany, and South Korea have provided significant public finance for overseas coal fired power plants (H. Chen et al., 2016; H. Chen & Schmidt, 2017; Schmidt, 2013). Yet information is dispersed and comprehensive analyses that cover all types of power technologies

is absent. Furthermore, there has been limited tracking of bilateral financing through commercial investment. Although a number of global commercial banks announced plans to exit coal financing after the Paris Agreement, recent evidence suggests that other commercial banks and companies are still financing the global coal power fleet expansion (Urgewald, 2019). Specifically, lenders and investors from China, the U.S. and Japan have been identified as among the largest financiers for overseas coal power projects (Urgewald, 2019). Nevertheless, understanding of Japanese and U.S. overseas financing of non-coal power technologies is lacking. Except for recent research that sheds light on China, the impact of bilateral financing on fossil fuel and renewable power adoption and thus implications for global power sector decarbonization remains unclear.

We seek to fill this gap in the understanding of bilateral power finance. To systematically track the contribution of bilateral financing to power generation development, for the first time we compare overseas power financing by China, Japan, and the U.S. to the rest of the world from 2000 to 2018. We analyze two channels of financing from these three countries: public financing from their national development finance institutions (DFIs) and commercial financing in the form of greenfield foreign direct investment (FDI). This study draws on recently developed datasets of China's overseas power finance and a newly constructed project level database of Japanese and U.S. overseas power finance. We compile the new database based on analyses of press releases and annual reports from Japanese and U.S. DFIs. Additionally, in this database we track Japanese and U.S. greenfield FDI in overseas power plants using the World Electric Power Plant database (WEPP) from S&P Global Market Intelligence. We evaluate the contribution of Chinese, Japanese, and U.S. financing to the global power generation sector and distill their role

with respect to the deployment of fossil fuel and renewable power technologies, in different regions, and through DFI financing and greenfield FDI. We further highlight the long-term consequences of CO_2 emissions resulting from their overseas finance commitments.

The paper is structured as follows: in Section 2 we review bilateral financing in the power generation sector and relevant policy arrangements; in Section 3 we define the research boundary, introduce the data source and methodology, and discuss potential limitations; in Section 4 we discuss results and findings from multiple perspectives; finally in Section 5 we conclude with policy implications for global decarbonization of the power generation sector.

2. Bilateral financing in the power generation sector by the U.S., China and Japan

Bilateral financing is overtaking the role of multilateral lending in global power generation development (X. Chen et al., 2020; Gallagher et al., 2018). Bilateral financing occurs in the commercial sector through FDI and increasingly through national DFIs, in addition to traditional official development assistance (ODA). FDI is mainly driven by commercial motives. Through FDI, electric power companies invest in another country's power plants and hold a controlling ownership of the power plants, with the expectation that they will profit from the operation of the plants. In contrast, national DFIs are established by national governments to fulfill public policy goals. They promote development of key sectors as mandated by the governments, such as electricity generation infrastructure and power technology export. Given that there is no universal definition of DFI, in this study "DFI" is used broadly to include both national development banks and export credit agencies (ECAs).

Here we focus on bilateral financing of global power generation from the world's three biggest economies – the U.S., China, and Japan. Among the three economies, overseas finance from the U.S. and Japan have been fueling power generation development around the world for decades, whereas China only emerged in the 2000s as a major source of finance and became a significant international financier in the 2010s. In the 1990s, annual outward direct investment from the U.S. to electric and gas services grew from around US$1 billion to US$20 billion. Since then its contribution to the overseas electric power sector (including generation, transmission and distribution) has been around US$10-20 billion annually. At the same time, public finance institutions from the U.S., such as the Overseas Private Investment Corporation (OPIC) and the Export-Import Bank of the United States (US-EXIM), have also been active globally. OPIC began operation in 1971 and has mobilized private capital to support U.S. businesses and advance U.S. foreign policy and national security objectives. It provided political risk insurance and investment guarantees in the early years and expanded its business to offer direct loans later. In the electricity generation sector, OPIC has supported off-grid and utility scale power projects around the world. Prominently, through partnership in the U.S. Power Africa Initiative, OPIC has supported more than 30 power projects since 2013. In 2019 OPIC merged with the Developed Credit Authority in the U.S. Agency for International Development (USAID) and formed the new U.S. International Development Finance Corporation (DFC), which further added equity investment to its financing toolkit. US-EXIM, founded in 1934, is the official U.S. ECA. US-EXIM has been facilitating U.S. export of goods and services through offering export credit insurance, working capital loan guarantees, medium- and long-term loan guarantees, direct loans, and finance lease guarantees. US-EXIM's participation in the overseas power sector ranges from

financing the export of U.S. manufactured gas turbines to financing the construction of foreign power plants. Notably, US-EXIM did not engage in new finance between 2015 and 2019 due to a lapse in Congressional authorization. It resumed operation in 2019.

Japanese finance has also played a significant role in the global power sector, both through overseas expansion of Japanese electric power companies and through Japanese DFIs. Japanese FDI has grown steadily since 1985, from US$6 billion in 1985 to US$45 billion in 2000 and a peak of US$249 billion in 2019 (World Bank, n.d.). Japanese electric power companies, which hold large domestic power generation assets, such as Mitsubishi Corporation, have successfully expanded to overseas power sector as power plant investors and/or major equipment suppliers. Additionally, Japanese DFIs, such as Japan Bank for International Cooperation (JBIC) and Japan International Cooperation Agency (JICA), have been supporting overseas power infrastructure development through both commercial loans and ODA. Specifically, JBIC and JICA have been among the largest public financiers for overseas coal fired power plants since 2000s. JICA was first formed in 1974 as a semi-governmental organization and was re-launched in 2003 as an independent administrative institution. JBIC was first created in 1999 via the merger of Export-Import Bank of Japan and Overseas Economic Cooperation Fund. In 2008 the former JBIC was divided into Japan Finance Corporation (JFC) and the new JICA, when the new JICA succeeded operation of ODA loans previously managed by the former JBIC and part of the grant aid dispersed by Japan's Ministry of Foreign Ministry. At the same time, JBIC became the international wing of JFC with domestic finance managed by the rest of JFC units. In 2012 the new JBIC was established with the mission of securing natural resource import, supporting Japanese industries, preserving global environment, as well as

preventing financial market disruptions. JBIC's financial instruments include loans, guarantees and equity participation. Its loans extend from those for export, import and overseas investment, to untied government loans. In the power sector, JBIC may use loans to support Japanese power equipment export or Japanese FDI. Under its "Global action for Reconciling Economic growth and ENvironmental preservation" (GREEN) operations, JBIC supports overseas renewable energy as well as energy efficiency projects, among other environmental conservation projects. JICA, one of the world's largest bilateral aid agencies, is mainly in charge of Japan's ODA and provides assistance including loans, grants and technical cooperation. Additionally, JICA also offers private-sector commercial finance, therefore it is included here as a DFI. Via its ODA loans, JICA has financed power plant development around the world for decades since its first operation in the 1970s. Especially in Asia, it has greatly facilitated power generation development in developing countries such as Indonesia and India, as well as China before early 2000s.

China's overseas financing of power plants has burgeoned since the late 2000s. Before 2000, China was a major destination of FDI with around US$40 billion FDI inflows and less than US$5 billion outflows. Encouraged by the "Going Abroad Strategy" initiated in 1999 and subsequently the "Belt and Road Initiative" (BRI) adopted in 2013, Chinese FDI outflow grew significantly from US$17 billion in 2007 before the global financial crisis to a peak of US$216 billion in 2016. It fell after to US$98 billion in 2019. Chinese power companies have also increasingly integrated with the global economy, leading to rapid increase of FDI in overseas power generation. As a result, by 2017 Chinese companies held around US$115 billion foreign power generation assets (Li et al., 2020). Meanwhile, China emerged as a prominent financier in

international development finance, which has long been dominated by DFIs from developed countries. In 2018 China's policy banks held more assets than major Western-backed MDBs combined (Gallagher et al., 2018). Two Chinese DFIs, China Development Bank (CDB) and the Export-Import Bank of China (CHEXIM), now provide more financing to overseas power plants than the combined financing of major MDBs (X. Chen et al., 2020). Founded in 1994, CDB has facilitated the implementation of national strategies both domestically and globally. Guided by the Going Abroad Strategy and BRI, CDB supports cooperation between China and foreign entities by offering loan financing as well as equity investment through multilateral platforms under CDB. With US$2.4 trillion assets in 2018, CDB is now the largest DFI in the world. Also established in 1994, CHEXIM is dedicated to facilitating both China's foreign trade and international investment. Other than offering export credit for trade and loans for China's overseas investment and contracting, CHEXIM also facilitates international economic cooperation by granting loans to eligible projects that may not involve Chinese companies.

Despite the significant role of bilateral financing in global power generation development, information about its contribution to the deployment of various power technologies is dispersed and hard to compare. Countries publish annual FDI data with different categorization standards. Moreover, statistics for the power generation sector are often merged with other sectors such as power transmission and distribution. A transparent and consistent disclosure of national DFIs' financial commitments is also absent. Although national DFIs publish press releases and annual reports, detailed information about their contribution to generation capacity additions lack completeness. Overall, a comprehensive documentation of bilateral financing of power plants at the project level is missing.

Despite this lack of transparency, the technology choices of bilateral finance have great implications for the recipient countries' power generation development pathways and thus global decarbonization and future climate change. Policies regarding the alignment of bilateral financing with climate goals are currently limited. The OECD Arrangement on Officially Supported Export Credits (the "Arrangement") places environmental regulation on export credit; however emerging countries such as China are not bound by it. Participants to the Arrangement, including the U.S. and Japan, agreed in 2015 to restrict official export credits for low-efficiency coal-fired power plants; nevertheless, it remains a "gentlemen's agreement" with no formal enforcement mechanism (Hopewell, 2019). The IDFC, of which JICA and CDB are members, are committed to implementing the Sustainable Development Goals and the Paris Agreement, but it does not yet enforce any restrictions or formal obligations. National level policies regarding overseas fossil fuel power financing are also absent. The Obama Administration announced in 2013 that the U.S. would stop providing public finance to overseas coal plants, but it has not restricted commercial banks or investors nor public financing of gas plants. Japan announced plans in 2020 to reach carbon neutrality domestically by 2050 and to halt financing of overseas coal plants. However specific measures regarding its overseas finance remain vague and loopholes exist – for example, it still allows financing of ultra-supercritical coal plants. The governor of JBIC was quoted as stating in an interview with the media in April 2020 that it will "no longer accept loan applications for coal-fired power generation projects" but following up verification of this quote has failed (Sheldrick, 2020). China, with the largest overseas financing volume, announced in September 2020 that it would peak domestic carbon emissions before

2030 and reach carbon neutrality domestically by 2060; however it has not yet announced or implemented any policy regarding overseas finance.

3. Methods and data

3.1 Research subjects and boundary

To analyze and compare the impact of bilateral financing from China, Japan, and the U.S. on global power technology deployment, we utilize power project level datasets – both the recently published datasets on China's overseas power finance (X. Chen et al., 2020; Li et al., 2020) as well as a new database of Japanese and U.S. overseas finance we construct for this work. Chen et al. (2020) and Li et al. (2020) compile Chinese overseas DFI financing and FDI at the power plant level. However parallel datasets for Japan and the U.S. did not exist before this study. Existing datasets either only include select power technologies such as coal, wind, solar and geothermal (H. Chen & Schmidt, 2017) without information about other technologies like gas or hydroelectric power, or only provide aggregate numbers for financial flows (Estes & Landers, 2020) without revealing power plant level details such as technology type or generation capacity.

To compare bilateral financing from Japan and the U.S. with financing from China, in our new database we track Japanese and U.S. national DFIs' overseas power financing commitments between 2000 and 2018 as well as Japanese and U.S. greenfield FDI in overseas power plants by the end of 2018. National DFIs, which can catalyze additional public and private investment beyond their financial commitments, are the most important national public institutions that facilitate overseas power sector development. In this study we examine two national DFIs from

China, Japan, and the U.S. respectively, namely CDB, CHEXIM, JBIC, JICA, OPIC and US-EXIM, because they are the largest analogous national DFIs from the three countries. CHEXIM and US-EXIM are Chinese and U.S. official ECAs. JBIC, while being a national development bank, also plays the role of an ECA. CDB, JBIC and OPIC (now DFC) are all national development banks or institutions that are responsible for overseas development financing. JICA, though mainly providing ODA, also offers commercial loans and hence qualifies as a DFI. Additionally, JICA is analogous to CHEXIM as CHEXIM is also the Chinese government's vehicle to provide Two Concessional Facilities (including Chinese Government Concessional Loan and the Preferential Export Buyer's Credit). Concessional loans provided by the Developed Credit Authority of USAID are not included in this study because we examine finance committed by national DFIs between 2000 and 2018 whereas the Developed Credit Authority merged with OPIC after this period in 2019.

We focus on select bilateral financing mechanisms and evaluate the contribution of bilateral financing to overseas generation capacity expansion. For commercial investment, we examine greenfield FDI where the investors build new power plants from the ground up. We do not include FDI through mergers and acquisitions (M&A), where power plants often are already built at the time of investment. In M&A, investors have a much smaller influence in enabling the development of new power plants. We also do not consider foreign portfolio investment where investors do not directly affect power plant development. As discussed in Section 2, national DFIs offer a variety of financial instruments in the power generation sector, including sovereign loans, guarantees, export credit, as well as equity investment. For purposes of evaluating the impact of DFI financing on power plant development, in this study we quantify their

contributions to generation capacity expansion through direct loans and export credit. Their contributions through guarantees and portfolio investments are not examined here because national DFIs do not directly fund the power plants in these two financing mechanisms. Similarly, national insurance agencies which offer political or commercial insurance rather than direct financing, such as China Export & Credit Insurance Corporation, are outside the scope of this study.

3.2 Data and methodology

In the process of compiling the dataset, we find that the examined national DFIs lack full transparency when disclosing their overseas financing activities. With the exception of JICA, no structured database exists for any of the other five national DFIs examined here that fully documents their past financing commitments. To capture the Japanese and U.S. national DFIs' financing commitments at the project level, we adopt a bottom-up approach and analyze the archived press releases and annual reports of the DFIs. Among the four Japanese and U.S. DFIs, JBIC archives its past press releases back to 2004 and US-EXIM archives its press releases back to 1996. Utilizing the press release archives, annual reports, the WEPP database, together with web searches, we construct JBIC's and US-EXIM's project level financing data following the procedure below.

- First, we start with JBIC's press releases because they contain the most detailed project level information. We compile a list of financing commitments from JBIC to overseas power plants through screening its press release archive using key word searches. We use

key words including “power”, “plant”, “station”, “dam”, “farm” and “renewable” and obtain an exhaustive list of JBIC’s archived press releases indicating potential power plant financing.

- Second, we exclude from the compiled list non-power generation projects such as financing of coal mining or gas extraction infrastructure, power grid expansion projects, and power distribution projects.

- Third, we manually code power project level information embedded in JBIC’s press releases, including year of financing commitments, amount of financing commitments, description of financed power plants, technology or fuel used in the power plants, location of the plant, etc.

- Fourth, we use JBIC’s annual reports to verify the dataset that we compile from its press release archive and add financing commitments missing from the press release archive.

- Some press releases and annual reports do not include detailed information like the financed power plant’s technology or generation capacity. To address this issue, as the fifth step, we map the DFI financed power projects with corresponding power plants documented in the WEPP database, following the methodology in Chen et al. (2020). Through this process we obtain technology and capacity information of DFI financed power plants from the WEPP database. Moreover, we obtain information about these

power plants' equipment manufacturers and engineering and construction contractors from the WEPP database.

Through these five steps, we construct a complete plant-level database of JBIC's financing of overseas power plants from 2000 to 2018 with information about its financing commitments including which power plants it has financed.

We construct US-EXIM's project financing dataset following the same procedure. Because US-EXIM's annual reports list its total authorizations each year in the power generation sector, we are able to further constrain our results from the top-down. We find that part of US-EXIM's authorizations to power projects cannot be tracked to specific power plants. Therefore the US-EXIM dataset we construct is a conservative estimate of its contribution to the global power generation sector.

We construct JICA's plant level financing dataset using its ODA Loan Project Data, its press release archive, JICA's project evaluation reports and the WEPP database. JICA's ODA Loan Project database publishes the amount of JICA's ODA loan to specific projects, along with financial arrangements such as interest rates and repayment period. This ODA Loan Project database does not outline the technology or generation capacity of JICA financed power generation projects but includes a project URL for each loan agreement. To construct the complete dataset with power plant information, we start with JICA's ODA Loan Project database in the "Electric Power and Gas" sector. We review each loan using its project URL and associated ex-ante and ex-post evaluate reports when available, and construct a dataset for JICA

following step 2 and 3 described above. We further map JICA financed power plants with the WEPP database and obtain the final dataset with complete power plant information. JICA's Private-Sector Investment Finance projects are not included in our dataset because they are not disclosed publicly at project level. This is not a significant omission of JICA's financing commitments because ODA loans comprise the vast majority of JICA's operations. JICA's Private-Sector Investment Finance in 2019 is less than 5% of its ODA loans.

We construct OPIC's project level financing data using three data sources: OPIC's annual reports from 2000 to 2019, OPIC's Portfolio by Project as of 9/30/2018 (OPIC, 2018), and DFC's active projects dataset as of 6/30/2020. Press releases were not utilized when constructing the OPIC database because OPIC only archives its past press releases back to 2015. OPIC's annual reports document its investment activities by project each year. Based on the annual reports, we construct a dataset of OPIC financed power generation projects from 2000 to 2018, with information about each project's financing amount, project description, fuel type, generation capacity, U.S. sponsor, and borrower. Some of OPIC's investment activities are recorded vaguely in the annual reports with information about the fuel type or capacity missing. Therefore we merge our dataset with OPIC's Portfolio by Project dataset and DFC's active projects dataset and obtain additional information. All three source do not contain detailed information about the power plants (such as the plant's names) that allows mapping with WEPP. Therefore, our final constructed OPIC project financing dataset includes information about its financing commitments and the fuel type and generation capacity of financed power plants. But it does not include information about the financed power plants' equipment manufacturers and equipment/construction contractors.

Companies' FDI are considered commercial statistics and thus project level data are generally not publicly disclosed in a systematic way. We track Japanese and U.S. greenfield FDI in overseas power plants following the methodology in Li et al. (2020). We search through the WEPP database using a list of key words of Japanese and U.S. electric power companies and identify power plants that are partially or fully owned by a Japanese or a U.S. company. We then use public information from news, annual reports of listed companies, as well as company websites to verify the identified power plants which received Japanese or U.S. FDI. While information about the investment amount of FDI is generally unavailable, we obtain the generation capacity of invested power plants from WEPP and evaluate the power plants' distribution across technologies, countries and regions. Because the exact year of the investment decision of FDI is difficult to trace, the constructed dataset of Chinese, Japanese and U.S. FDI to the global power sector reflects all FDI which occurred before the end of 2018. In order to compare the impact of DFI financing and greenfield FDI on global power capacity additions (and exclude the impact of FDI occurring before 2000), we examine financed power plants with a commissioning year of 2005 or later. This way we allow for a 5-year lag between financing commitments and power plant commissioning, which is estimated based on DFI financing of power plants. Power plants examined in this paper through both DFI financing and greenfield FDI include plants that were in operation or under construction as of 2019.

Bilateral financing plays a pivotal role in enabling the commissioning of new power plants. National DFIs, in particular, mitigate risks and leverage additional investments that may not occur otherwise. Therefore, to evaluate the impact of bilateral financing on global power

generation capacity growth, we examine the total generation capacity of new power plants that received partial or full financing from China, Japan, and the U.S. Similar to the approach in Chen et al. (2020), we label this impact of bilateral financing on power capacity growth as "facilitated capacity additions".

We evaluate the lifetime committed CO_2 emissions from China, Japan, and the U.S. financed fossil fuel plants following the method described in Chen et al., (2020). Each coal, gas and oil plant's committed CO_2 emissions are estimated based on its generation capacity, capacity factor, emission intensity, and an assumed 40-year economic lifetime. Each power plant's capacity factor and emission intensity are estimated using the Carbon Monitoring for Action (CARMA) database (Center for Global Development, 2012).

4. Results and discussion

4.1 Development financing from China, Japan, and the U.S. to the global power generation sector

The national DFIs from China, Japan, and the U.S. have provided significant financing of global power generation development since 2000. Chinese DFIs specifically, despite being latecomers to international development financing, have committed US$112 billion, more than twice the overseas power finance than Japanese DFIs (US$46 billion), and five times that of U.S. DFIs (US$21 billion) between 2000 and 2018 (Figure 1). Japanese and U.S. DFIs have been steady sources of moderate finance over this period. Japanese DFIs provided up to US$5 billion annually to overseas power plants, while U.S. DFIs provided a lesser amount generally (Figure

S1). In contrast, overseas finance from Chinese DFIs has increased substantially from the late 2000s to late 2010s - from less than US$5 billion per year before 2010 to a peak of US$21 billion in 2015 (Figure S1). More recently, Chinese DFIs have scaled back its overseas finance since 2017.

The technology mix of Chinese, Japanese and U.S. DFIs' overseas power finance shows their commitments to various power generation technologies. The largest share of overseas development finance from all three countries went to non-renewable power generation, but the technology choices differed (Figure S2-S4). The most Chinese DFI financing was committed to coal (US$47 billion; 42%), with lessor amounts to hydro (US$38 billion; 34%) and nuclear power (US$16 billion; 15%) generation and limited financing of non-hydro renewables (US$5 billion; 4%). Japanese DFI financing was mostly committed to gas power (US$18 billion; 39%), followed by coal (US$13 billion; 27%) and hydroelectric power plants (US$5 billion; 11%). Its US$6 billion commitments to non-hydro renewables accounted for 14% of total finance, mostly to geothermal and wind power. Another US$3 billion was committed by JBIC to overseas renewable projects through its export credit lines and GREEN Operations. Besides US-EXIM's US$8 billion finance (39%) to nuclear power projects in China, the United Arab Emirates (UAE) and Bulgaria, most of the rest U.S. DFI financing was to gas (US$4 billion; 18%), solar (US$3 billion; 15%) and wind power (US$3 billion; 12%). OPIC contributed the vast majority of these solar and wind projects.

Looking back, the technology mix of Chinese, Japanese and U.S. DFIs' overseas power finance evolved from 2000 to 2018 although there was no fundamental shift among technologies (Figure

S1). All three countries' commitments to non-hydro renewables increased after 2010 when development and deployment of wind and solar technologies took off globally. Chinese and Japanese DFI finance to overseas coal plants also increased after 2010, possibly due to increasing demand of expanding electricity access in developing countries. Two U.S. DFIs have distinct financing portfolios. While the technology mix of US-EXIM didn't change significantly (mostly to non-renewable projects), OPIC's financing of solar and wind projects substantially increased after 2010. Notably, the first new financing from US-EXIM, after five years of not approving new projects from 2015 to late 2019, was a US$5 billion direct loan in 2019 to a liquefied natural gas plant in Mozambique.

Geographically, Chinese and Japanese DFIs have both committed the largest portion of their overseas finance to developing countries in Asia, whereas U.S. DFIs mostly financed power plants in other regions of the world (Figure S2-S4). Chinese and Japanese DFIs have both financed hotspot recipient countries like Indonesia, Vietnam, and India, mostly in support of their coal plants, where electricity demand grows rapidly. Other recipient countries, likely strategic or close partners of the financing countries, have received preferential finance from DFIs of one country. For example, Chinese DFIs have greatly supported power generation development in Pakistan and Nigeria. Japanese and U.S. DFIs contributed greatly to power plants in UAE. Together, development finance from China, Japan, and the U.S. has supported power sector development in all developing regions of the world. Their development finance to overseas power plants combined is more than the major MDBs' total commitments, doubling the available global development finance.

4.2 Contribution of Chinese, Japanese and the U.S. overseas finance to global power generation

We aggregate the contribution of bilateral financing through DFI financing and greenfield FDI from China, Japan, and the U.S. and show their impact on the global power generation capacity growth in Figure 2. The three countries' total overseas finance committed between 2000 and 2018 facilitated 233 GW new capacity added around the world since 2005 (with 225 GW located outside of the three financing countries). 2-25 GW new capacity were added annually in recipient countries with an increasing trend over time. Between 2005 and 2018, on average 70 GW of new generation capacity came online annually in non-OECD countries excluding China (S&P Global Market Intelligence, 2020). Thus, about one-fifth of capacity growth in non-OECD countries excluding China was facilitated by bilateral finance from China, Japan, and the U.S.

Respectively, Chinese, Japanese, and U.S. overseas finance facilitated 101 GW, 95 GW, and 47 GW generation capacity additions (including co-financed plants; Figure 2). Although overseas finance committed by Chinese DFIs is much larger than that of Japanese and U.S. DFIs, China's overall contribution to capacity additions is similar to that of Japan and only double that of the U.S. On the one hand, facilitated capacity additions per dollar of financial commitments made by Japanese and U.S. DFIs are larger than those of China. For one reason, Chinese DFIs financed more hydroelectric plants which generally have higher capital costs per GW than other technologies. Another possible reason is that Japanese and U.S. DFI financing leverages other financial resources more than China, whereas Chinese DFI financing is more concentrated and funds a larger portion of the power plant's total costs. On the other hand, Japanese enterprises

have contributed more overseas capacity additions through greenfield FDI than Chinese and U.S. enterprises.

All three financing countries facilitated far more fossil fuel power deployment than renewable technologies. The percentages of China, Japan, and the U.S. finance facilitated capacity additions in fossil fuel power are as high as 64%, 87%, and 66%, respectively. China's overseas finance contributed the most coal fired power generation, followed by hydroelectric power. Together coal and hydro power account for over 80% of China facilitated capacity additions. In comparison, China's involvement in overseas natural gas plants is limited, whereas Japan and the U.S. both contributed the most generation capacity additions to overseas gas power. Most of the capacity additions facilitated by Japanese finance were gas plants (54%); coal (27%) and oil plants (6%) follow. Gas power also takes the most, at 39%, of the capacity additions facilitated by U.S. finance, with coal (22%) and nuclear (17%) following. Overall, the three countries' contribution to non-hydro renewable technology deployment is limited, with the U.S. being the only one that devotes over 10% to non-hydro renewable power generation.

Disaggregating the contributions of bilateral financing from China, Japan, and the U.S. into DFI financing and greenfield FDI, it appears that the technology choices through these two financing mechanisms differ. Moreover, the difference in technology portfolios varies with the financing country. In the case of China, technology portfolio of capacity additions facilitated by its FDI is more diversified than its DFI financing. In addition to supporting coal, hydro and nuclear power, like Chinese DFI financing, Chinese FDI extends support to overseas gas plants as well as to more renewable projects including wind and solar plants. In contrast, the portfolio of Japanese

DFI financing is more diversified than its FDI. Japanese DFI financing has made a larger contribution to overseas coal plants and hydroelectric dams. The technology portfolio of Japanese FDI, on the other hand, is predominantly gas power. Setting aside the nuclear plants financed by US-EXIM, shares of capacity additions facilitated by U.S. DFI financing and FDI in non-renewable technologies are similar. Their difference comes from fossil fuel technology choices instead – U.S. DFI financing supported more gas power plants whereas U.S. FDI supported more coal plants.

The comparison of technology portfolios with respect to the financing countries and between their development finance and commercial investment indicate differences in their technology choices. Chinese, Japanese, and U.S. DFI financing portfolios reflect their distinct policy priorities. Two Chinese DFIs, CDB and CHEXIM, have supported the most large infrastructure projects such as coal and hydroelectric plants, which have high up-front costs and often face difficulty securing finance from the private sector or the MDBs after MDBs diverted away from coal power financing. U.S. DFIs are significantly different. Following the vision to support small and medium enterprises and catalyze private sector investment, OPIC is mostly engaged in financing wind and solar plants. US-EXIM's contribution to overseas gas, solar and wind plants is closely linked with its policy agenda to support U.S. export. JBIC supports Japanese businesses through its financing of overseas gas and coal plants which utilize Japanese FDI or equipment. Its financing of renewable projects is mainly through the GREEN Operations and export credit lines. JICA's ODA, in contrast, is mostly untied loan commitment.

The technology portfolios of overseas capacity additions facilitated by China, Japan, and the U.S. show that their overseas finance has lagged behind their domestic power sector transition, except for Chinese greenfield FDI. Compared with the 2000s, China, Japan, and the U.S. all added a larger fraction of renewable power capacity domestically in the 2010s (Figure 2). Between 2010 and 2018, 34%, 50% and 65% of new capacity additions (retirement and decommissioning of old generation capacity excluded) were wind and solar power in China, Japan and the U.S., respectively. Overseas capacity additions facilitated by the DFIs resemble the three financing countries' domestic capacity development between 2001-2009. Portfolio of Chinese greenfield FDI is similar to China's domestic development between 2010-2018. Portfolios of Japanese and U.S. FDI are much less "greened" than their domestic development in recent years.

To further examine the linkages between bilateral financing and the financing country's domestic power industry, we analyze the adoption of power equipment supplies as well as engineering and construction contractors in power plants supported by Chinese, Japanese, and U.S. overseas finance. We find that China, Japan, and the U.S. have used bilateral financing to support their equipment and service export (Figure 3). Among China, Japan and the U.S. financed power plants, 42%-53% deployed major equipment manufactured within the financing country. Naturally, DFI financing supports the financing country's equipment export to a larger extent than greenfield FDI. Besides equipment export, service export is another strategic area that receives DFI support and may be associated with FDI. Through analyzing the nationality of engineering and construction contractors hired in power plants financed by China, Japan, and the U.S., we find that 54% of China financed power plants hired a Chinese contractor. Chinese

engineering and construction contractors were mostly hired in power plants financed by CDB or CHEXIM. In comparison, around 35% of Japanese financed plants and 22% of those of U.S. hired a Japanese or U.S. contractor.

Moving from the financing countries to the recipient countries, in Figure 4 we summarize the top ten recipient countries with the most power capacity additions facilitated by bilateral finance from China, Japan, and the U.S. together. Bilateral finance from the three countries facilitated the most capacity additions in Indonesia, India, Vietnam, UAE and South Africa. Except for India and Saudi Arabia, bilateral financing from China, Japan, and the U.S. facilitated 35-62% of generation capacity added in these recipient countries since 2005. In all recipient countries, the technology mixes of facilitated capacity additions receiving bilateral finance align with these countries' power generation development. Bilateral finance facilitated the most capacity additions in coal power in Indonesia, India and Vietnam, where the majority of added generation capacity since 2005 were coal plants. In recipient countries like UAE and Thailand, which added the most capacity in gas power generation since 2005, bilateral finance has also contributed the most capacity growth in gas power. This suggests that bilateral financing follows the recipient countries' power sector development strategies, with limited or no role in leading an energy transition away from fossil fuel.

4.3 Committed CO_2 emissions associated with bilateral power financing from China, Japan, and the U.S.

Bilateral finance has significantly facilitated global power generation development, both through direct financing and instrumental influence in catalyzing additional investment. With a larger financing capacity than the MDBs, bilateral finance from China, Japan, and the U.S. fills the financing gap in developing countries' power infrastructure development and extends their impact to all regions of the world. However, their commitments have mostly been in coal and gas power generation, at a time when public finance needs to catalyze a low carbon transition and private finance needs to be mobilized for the uptake of renewable technologies.

Past financing commitments to fossil fuel infrastructure have a lock-in effect because fossil fuel power infrastructure often operate for decades. Continued financing of fossil fuel incurs climate consequences and may decrease opportunities for renewable technology deployment. To demonstrate the long-term commitments from fossil fuel power generation to CO_2 emissions*, we analyze* the lifetime CO_2 emissions expected from coal, gas and oil power plants that received overseas finance from China, Japan, and the U.S. (Figure 5). Power plants supported by bilateral finance and added since 2005, which were operating or under construction as of 2019, will emit 24 Gt CO_2 over an assumed 40-year lifetime. Over 90% of the emissions from these plants will occur after 2019. Because fossil fuel-based power generation infrastructure locks in large CO_2 emissions for multiple decades, it may interfere with the critical goal of decarbonizing the global power sector by mid-century as detailed in the Paris Agreement or result in stranded assets of prematurely decommissioned fossil power plants.

5. Conclusions and policy implications

Through tracking overseas finance from China, Japan and the U.S. to the global power generation sector between 2000 and 2018, our analyses reveal the key role that bilateral financing is playing in filling the infrastructure financing gap and supporting power capacity expansions in developing countries. Chinese, Japanese, and U.S. overseas finance between 2000 and 2018, respectively, facilitated 101 GW, 95 GW, and 47 GW of generation capacity added since 2005 around the globe. This accounted for one-fifth of generation capacity growth in non-OECD countries excluding China. However, while multilateral financing has shown signs of moving towards supporting renewable technologies in line with the Sustainable Development Goals and Paris Agreement, bilateral finance has lagged in this transition. We find that Chinese, Japanese, and U.S. overseas finance through their DFI financing and greenfield FDI has mostly contributed to fossil fuel power generation including coal and gas plants. Over 60% of China and U.S. facilitated capacity additions and over 80% of those facilitated by Japan are fossil fuel power infrastructure. Among their total facilitated capacity additions, less than 10% are non-hydro renewable technologies.

The commitments of bilateral financing to fossil fuel power infrastructure will pose long-term climate and financial risks. The goal of the Paris Agreement to limit global average temperature increases to less than 2^{o}C or preferably 1.5^{o}C requires that the global power generation sector fully decarbonize around mid-century. However, we find that a large number of overseas power plants financed by China, Japan, and the U.S. are still in the pipeline and the vast majority of their projected CO_2 emissions will occur after 2019. On the one hand, if these fossil fuel plants continue operating with similar capacity factors and for the number of operational years typical in the past, decarbonization of the global power sector by mid-century will be impossible. A

delayed decarbonization pathway implies both a heavier reliance on negative emissions technologies after mid-century and a larger likelihood of exceeding the 2°C climate target and resulting in catastrophic outcomes (Rogelj et al., 2018). On the other hand, with costs of renewable technologies such as solar and wind power decreasing rapidly, operating existing and new fossil fuel plants will soon be more costly than building and operating renewable power plants (Hodges, 2020), making past fossil fuel investments less profitable in the future. Moreover, in case of failing to meet the 1.5°C target, climate risks could materialize for financiers via physical damages to their assets as a result of climate change induced extreme events. Therefore, it is critical that bilateral financing commitments take into account the great potential of future renewable technology development and fully anticipate the risks and diminishing profits from investing in fossil fuel power assets.

In contrast to extensive domestic and multilateral mitigation efforts, bilateral fossil fuel infrastructure financing from China, Japan and the U.S. has faced little restriction. All the financing countries have outlined mid-century national decarbonization targets. United States rejoined the Paris Agreement in January 2021. However, limited climate policies exist regarding these countries' overseas finance. In this study, we find that DFI financing from China, Japan and the U.S. is closely related to supporting their domestic power industry. Nevertheless, the technology portfolios of capacity additions facilitated by overseas finance are not as "green" as the financing country's domestic power sector development, especially for Japan and the U.S. The climate implications of bilateral financing are not fully captured in current policy arrangements. Current national climate policies only account for GHG emissions produced domestically. Neither national nor international climate policies consider the impacts of

international financing on global GHG emissions. In order to clearly characterize the impacts of bilateral financing commitments on the climate, more transparency is needed. While all major multilateral DFIs have open data policies that allow scholars and stakeholders to download project level data, all three financing countries analyzed in this study lack comparable transparency. Therefore, a more transparent and consistent disclosure of the financing by national DFIs is crucial as a first step to evaluate the national DFIs' wider environmental impacts. Going forward, it is important that national DFIs divest away from financing overseas fossil fuel infrastructure and move towards financing a low-carbon power system.

We find that the technology choices of bilateral financing from China, Japan, and the U.S., rather than leading a low-carbon transition, align with portfolios of power sector development in the top recipient countries, which have mainly prioritized fossil fuel power development. Nevertheless, China, Japan, and the U.S. all have the potential to facilitate global power sector decarbonization. China has built a large renewable technology manufacturing capacity through its domestic renewable power development. In the process, the Chinese renewable power industry has also facilitated global renewable power development through its contribution to the manufacturing cost reduction of solar panels and wind turbines. Through the BRI, China has signed Memorandum of Understanding (MoU) with 138 countries as of March 2020. Although overseas finance from CDB and CHEXIM decreased in 2019 (Kynge & Wheatley, 2020), BRI stands as an umbrella of bilateral cooperation, through which CDB and CHEXIM may support renewable and sustainable businesses overseas in the future. Furthermore, President Xi's announcements to peak domestic emissions before 2030 and reach carbon neutrality by 2060 show China's determination to decarbonize its' domestic economy. In the 2020 new National

Determined Contribution (NDC) target, China further committed to increasing the share of non-fossil fuels in its primary energy mix to 25% by 2030. If China's domestic measures are extended overseas, it has the capability to facilitate renewable technology deployment globally and hence facilitate GHG emission reductions in recipient countries. With a domestic carbon neutrality goal by 2050, there is room for Japan to strengthen its policies regarding overseas financing too. Japan's current policy, which partially restricts overseas public coal power financing but still allows the financing of ultra-supercritical coal plants, has been criticized by environmental communities. If Japan completely bans public financing of coal plants, the Japanese government's climate policies and efforts to phase out domestic coal power will be more credible and face less pressure from local environmental groups. As the U.S. reentered the Paris Agreement, it also has the opportunity to adopt stricter policies regarding overseas financing. The Obama Administration's announcement in 2013 to stop public support for overseas coal power led several other banks to follow suit and adopt similar policies. If the Biden Administration extends this policy to also restrict financing of gas, U.S. policies would have larger climate benefits.

Our study is the first attempt to systematically track and evaluate the impact of bilateral financing on power technology deployment by analyzing national DFIs and greenfield FDI from China, Japan, and the U.S. Our methodology may be extended to analyze additional countries. For example, German and South Korean DFIs, although outside the scope of our study, also have large financial commitments to overseas coal plants (H. Chen & Schmidt, 2017). We have focused on DFI financing and its direct impact on power generation projects. However, national DFIs can also influence power sector development through guarantees or equity investment. For

example, besides US-EXIM's direct loans to gas power plants, it also provided large guarantees to overseas gas power projects to facilitate U.S. export. Such indirect support from DFIs to overseas fossil fuel infrastructure is worthy of future research. In future studies, continuous tracking of the impact of bilateral financing is needed. It is critical that national governments make DFIs transparent in their fossil fuel lending practices in order to understand the alignment of their balance sheets with climate goals and to facilitate decarbonization.

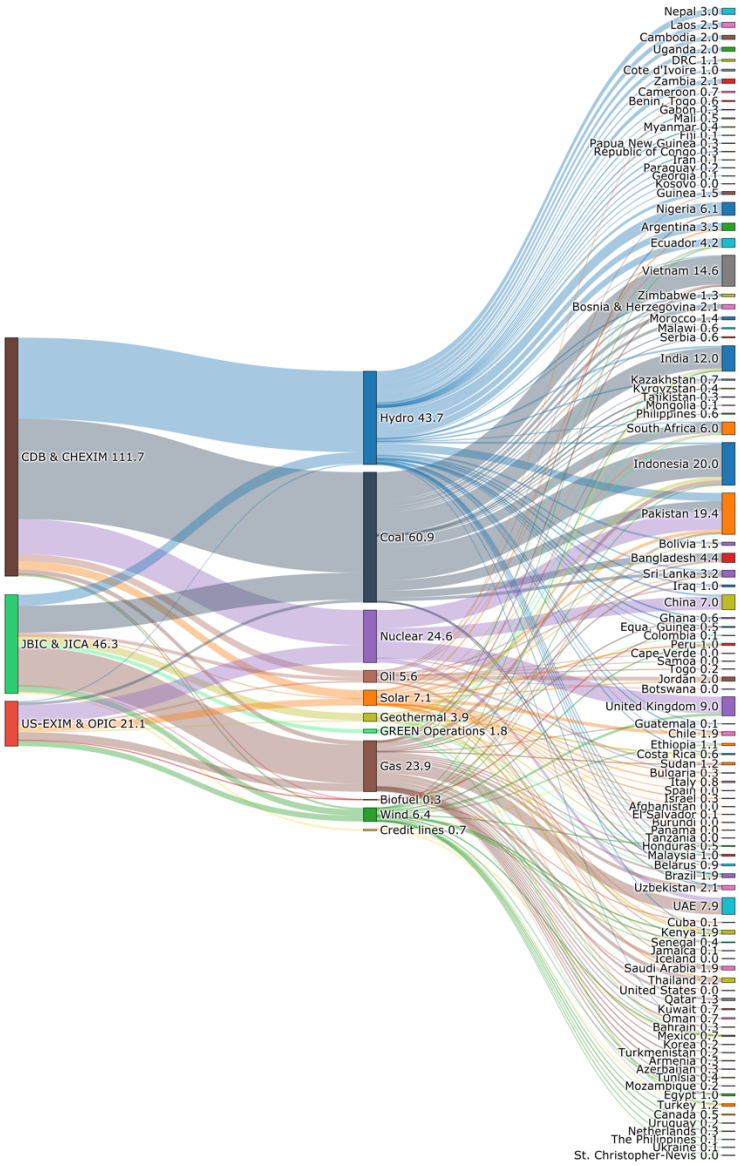


Figure 1. Total financing commitments from Chinese, Japanese and U.S. DFIs to recipient countries between 2000 and 2018, by technology type (unit: billion 2015USD). Colors of financing flow indicate different technology types. Numbers indicate financing commitments. Also see Figures S2-S4 for financial flows from Chinese, Japanese and U.S. DFIs to recipient countries, respectively.

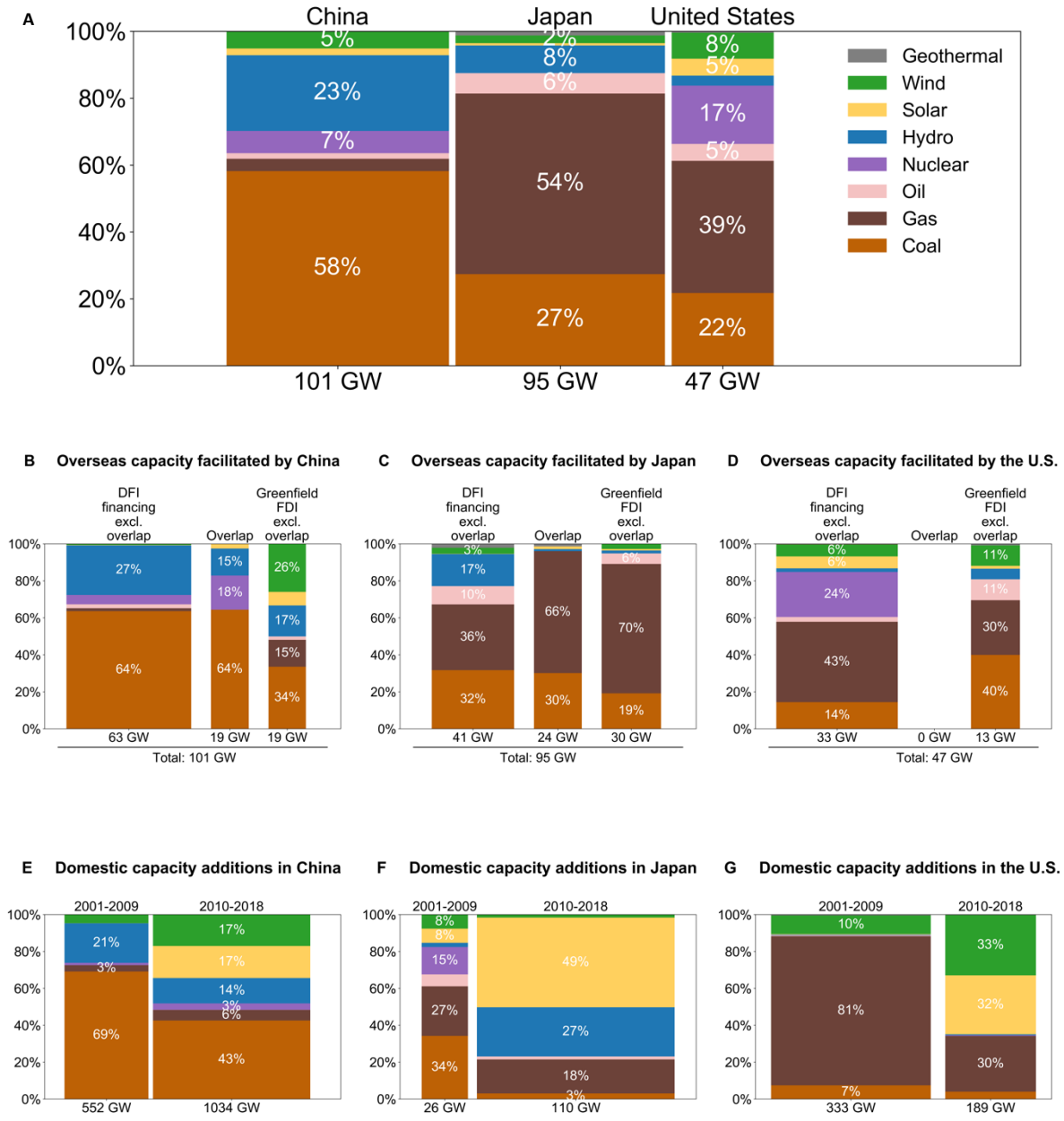


Figure 2. Total power generation capacity additions facilitated by Chinese, Japanese, and U.S. overseas financing between 2000-2018, by technology type (A). The facilitated capacity additions include power plants that were in operation or under construction as of 2019 which have a commissioning year of 2005 or after. Colors indicate different fuel/technology types. Widths of bars represent facilitated capacity additions (widths of bars are proportional to the facilitated capacity additions in each panel but are not proportional across panels). Panel **A** shows total capacity additions facilitated by bilateral

financing from China, Japan, and the U.S., respectively. The numbers in panel A do not add up because DFI co-financed in power plants occasionally. Panels **B-D** disaggregate capacity additions facilitated by each financing country, through their DFI financing and greenfield FDI. Because DFI financing and greenfield FDI may support the same power plants, their overlap in facilitated capacity additions is listed separately. Panels **E-G** show new generation capacity added domestically within China, Japan, and the U.S. between 2001-2009 and between 2010-2018, by technology (retired and decommissioned capacity not included).

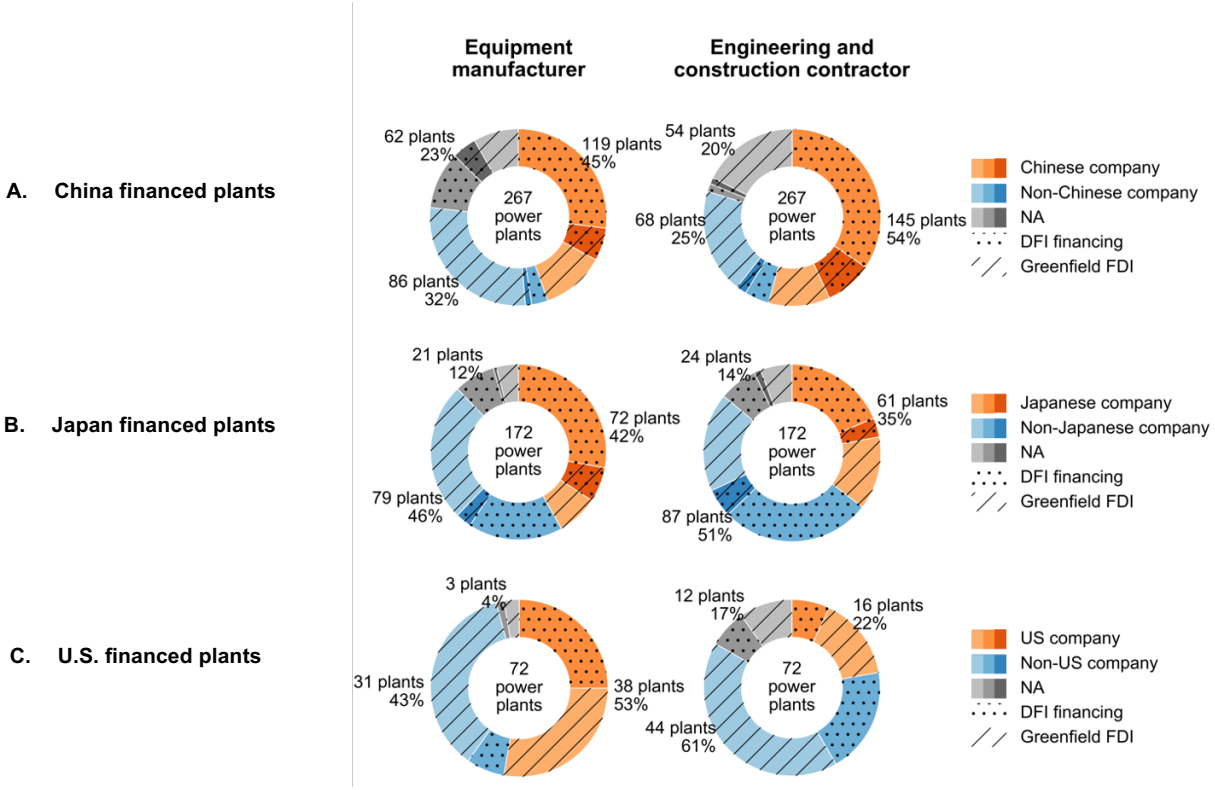


Figure 3. Nationality of manufacturers and contractors of power plants that received bilateral finance from China, Japan, and the U.S. The hollow circles and the numbers at the center of these circles represent number of power plants with overseas financing from (**A**) China, (**B**) Japan, and (**C**) the U.S. U.S. DFI financing only includes US-EXIM. The financed power plants include power plants that were in operation or under construction as of 2019 which have a commissioning year of 2005 or after. For each hollow circle, different colors indicate the origins of the equipment manufacturer and engineering or construction contractors for the power plants. Shaded patterns represent DFI financing and greenfield FDI.

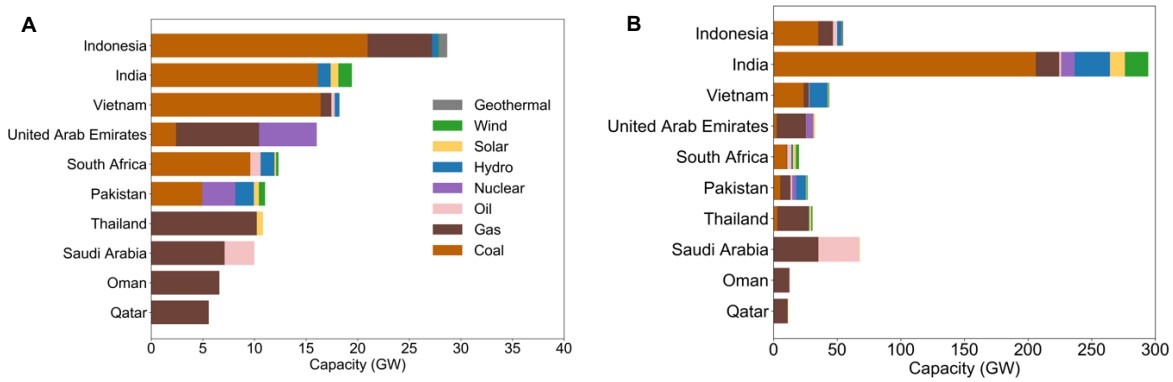


Figure 4. Ten recipient countries with the most power capacity additions facilitated by overseas finance from China, Japan, and the U.S. A: Capacity additions facilitated by Chinese, Japanese, and U.S. finance committed between 2000 and 2018. Facilitated capacity additions include power plants that were in operation or under construction as of 2019 which have a commissioning year of 2005 or after. **B**: Total power generation capacity added in or after 2005 in the ten recipient countries. Capacity added in recipient countries include plants that were in operation or under construction as of 2019. Colors indicate different technology types.

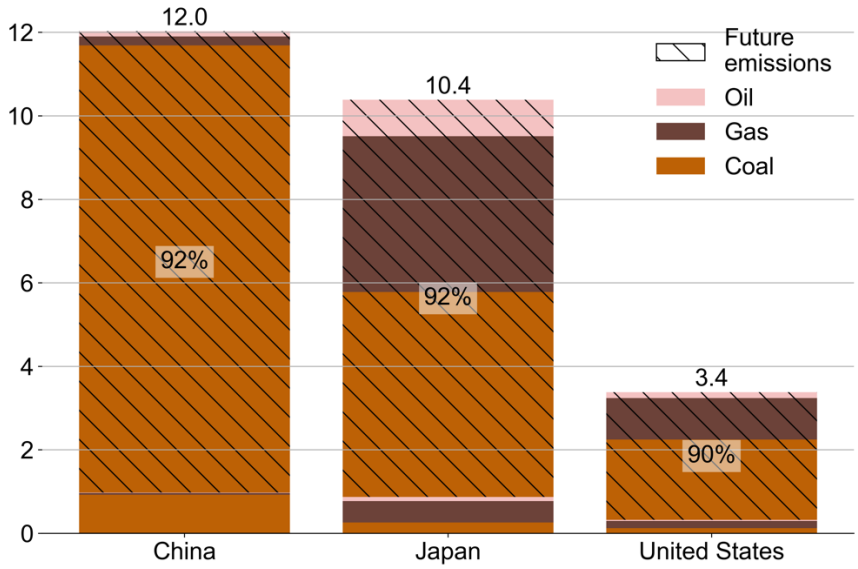


Figure 5. Committed lifetime CO_2 emissions from power plants with Chinese, Japanese, and U.S. overseas financing between 2000 and 2018. Emissions from power plants with a commissioning year of 2005 or after (which were in operation or under construction as of 2019) are shown. Numbers above each country bar indicate total committed lifetime CO_2 emissions from power plants financed by China, Japan and the U.S. respectively (unit: Gt CO_2). Numbers for each financing country do not add up to the total emissions because they have co-financed a few plants. Percentages over shaded areas indicate the fraction of future CO_2 emissions (emissions occurring after 2019) out of total lifetime emissions. Colors indicate different fossil fuel types.

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Chapter 4: The Expanding Coal Power Fleet in Southeast Asia: Implications for Electricity Generation and Future CO_2 Emissions

1. Introduction

Greenhouse gas (GHG) emissions from fossil fuel combustion have been the main cause of global temperature increase since pre-industrial time. Coal combustion for energy, among all fossil fuels, is the largest source of CO_2 emissions, making up 44% of global CO_2 emissions in 2018 (International Energy Agency, 2020). Two-thirds of the CO_2 emissions from coal combustion is used for electricity generation (around 30% of global CO_2 emissions) (International Energy Agency, 2019a). In order to reach the goals of the Paris Agreement to limit global average warming to well below 2°C and preferably under 1.5°C above pre-industrial levels, it is crucial to rapidly phase out coal fired power generation. Replacing coal fired power generation with low carbon technologies can substantially reduce CO_2 emissions. Furthermore, decarbonizing electricity generation is a key mechanism to facilitate economy wide decarbonization as industry, buildings and the transport sectors electrify (Edenhofer et al., 2014). However, global coal power fleet expansion is continuing, with the most capacity growth happening in developing countries, where electricity demand is rapidly increasing. Specifically, Southeast Asia is now poised for the fastest coal power capacity growth in the world, as China and India have recently slowed their growth in new coal power.

Indigenous resources and relatively low costs have granted coal a prominent role in Southeast Asia's power generation sector. The rapidly decreasing costs of renewable technologies globally

have made wind and solar technologies competitive with coal power in many regions of the world (IRENA, 2020). However, levelized cost of electricity (LCOE) for wind and solar are still higher than coal power in Southeast Asia (Zissler, 2019) as locally produced coal resources are cheaper than international prices and coal power has long been subsidized by the governments (IRENA, 2018; Minh Do & Sharma, 2011). From 2000 to 2018, the share of Southeast Asia's power generation from coal has increased steadily from around 20% to over 40% (International Energy Agency, 2019b). As of 2018, Southeast Asia is one of the few regions in the world with an expanding coal fleet in the power generation mix. As a result of the expanding power generation sector fueled by fossil fuels, CO_2 emissions in Southeast Asia have increased from 1 Gt in 2010 to around 1.4 Gt in 2018. As most countries in the world slow down their fossil fuel power generation growth, Southeast Asia is projected by IEA to continue to increase its fossil fuel consumption until 2040 based on current policies. Under the Stated Policies Scenario by IEA, Southeast Asia's CO_2 emissions will increase by 65% from 2018 to 2.4 Gt in 2040 with over half of the emissions coming from the power sector while the global emissions increase by 7% (to 36 Gt) over the same period (International Energy Agency, 2019b). If no measures are taken to decarbonize Southeast Asia's power sector beyond its current policies, its fossil fuel power capacity expansion will likely delay global power sector decarbonization as carbon capture and storage (CCS) technologies are costly and have not yet been commercialized or widely deployed in Southeast Asia or elsewhere.

Southeast Asia's continued reliance on fossil fuel power generation, especially coal power, will bring other environmental, financial and energy security issues beyond CO_2 emissions. Coal fired power generation, if not equipped with air pollution control technologies, emit air

pollutants including sulfur dioxide, nitrogen oxides, particulate matters as well as various heavy metals which result in ambient air pollution that adversely impacts human health and agricultural production. Fossil fuel power generation may also increase the financial burden on Southeast Asian country governments. With limited financial resources, Southeast Asian countries have resorted to international development finance institutions to fund their coal plants (Cornot-Gandolphe, 2016). As, starting in the 2010s, multilateral development banks (MDBs) adopted policies to stop financing coal plants, Southeast Asian governments have turned to national development finance institutions (DFIs) to finance their coal power (Chen et al., 2020). Over the past two decades, Vietnam has adopted the Build-Operate-Transfer (BOT) model with foreign financiers, which puts a great financial burden on the Vietnamese government because they provided sovereign guarantees for the financing. Although coal is relatively abundant in Indonesia, since the 2000s, countries other than Indonesia have increasingly relied on imported coal for their coal fired power generation (Cornot-Gandolphe, 2016).

Despite significant environmental and financial burdens as well as energy security risks associated with Southeast Asia's heavy reliance on fossil fuel power generation, the implications of Southeast Asia's power sector for CO_2 emissions and electricity generation remain understudied. Studies with a global focus find that existing fossil fuel-based power generation infrastructure will need to retire prematurely in emission mitigation scenarios consistent with the Paris goals (Cui et al., 2019; Tong et al., 2019). Coal fired power plants, in particular, will have only 20-35 years of operation (Cui et al., 2019) if the Paris goals are met, much shorter than their economic lifetimes. Power generation that is currently under construction or being planned will incur significant stranded assets; otherwise its' committed CO_2 emissions will be significantly

above levels consistent with the Paris climate goals (Pfeiffer et al., 2018a). Similar studies with a Southeast Asia focus do not exist. Because Southeast Asia's coal and gas power plants were mostly constructed over the past decade, the costs as well as political resistance to retire these coal plants prematurely will likely be significant. Studies with a regional focus have mostly focused on China and India in addition to developed regions (Binsted et al., 2020; Liu et al., 2019; Malik et al., 2020; Shearer et al., 2017; Yang & Urpelainen, 2019). Studies on Southeast Asia find that emissions from Southeast Asia's coal fired power plants will depend on their attrition rate, capacity factor and plant lifetime (Clark et al., 2020). The majority of Southeast Asia's fossil fuel power generation assets planning are incompatible with emission pathways consistent with the Paris Agreement (Caldecott et al., 2018). Nevertheless, understanding regarding long-term implications of the continued expansion of Southeast Asia's fossil fuel power pipeline for CO_2 emissions is limited. It is also unclear what Southeast Asia's current power generation pipeline implies for short-term electricity generation and renewable deployment.

In this paper, we make three contributions to understanding Southeast Asia's current power generation development. First, we evaluate the long-term climate impact of Southeast Asia's current power generation pipeline by analyzing the power plants' lifetime committed CO_2 emissions. We evaluate the realized and remaining committed CO_2 emissions from operating fossil fuel plants in Southeast Asia as well as the committed emissions from plants that are currently under construction and being planned as of 2020. We further analyze the dependence of committed emissions from coal plants on their utilization rates in order to see how displacement of coal with non-fossil energy could reduce the committed CO_2 emissions and how

heavy reliance on coal power generation could increase the emissions. Second, to better understanding the implications of using new fossil fuel infrastructure to meet near-term electricity demand, we evaluate the planning and construction time of Southeast Asia's coal, gas and hydroelectric power plants. Anecdotal evidence indicates that coal fired power plants have experienced delays due to financial challenges in recent years. Here for the first time we systematically investigate coal, gas and hydroelectric plants' planning and construction time using a time-series dataset that we construct for this study. Third, we analyze the short-term implications of the current power generation pipeline for electricity generation and renewable deployment in Indonesia, Vietnam and the Philippines. We select Indonesia, Vietnam and the Philippines because these three countries have the largest coal power pipeline in Southeast Asia. Meanwhile, they all have quantitative capacity targets for renewable electricity. Ten member countries of the Association of Southeast Asian Nations (ASEAN) have collectively committed to increase renewable energy in their primary energy mix to 23% by 2030. However, a clear collective target for renewable electricity penetration is absent. ASEAN countries all have overarching renewable energy targets; however, only a small number of the countries have outlined quantitative electricity capacity targets for renewables. Through examining electricity generation from their current fossil fuel pipeline and targeted renewable capacity in the short-term, we analyze whether and how these countries' fossil fuel power pipelines influence their renewable deployment as well as their decarbonization goals.

In this paper we analyze ten ASEAN member countries for Southeast Asia, namely Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam. This paper is organized as follows: in Section 2 we introduce our methodology and

data sources. In Section 3 we present our analyses and results of the committed CO_2 emissions for Southeast Asia's power sector, historical planning and construction time for coal, gas and hydroelectric power plants, and the impact of current power generation pipeline on future electricity generation in Indonesia, Vietnam and the Philippines. Finally, we conclude with policy implications.

2. Method and Data

2.1 Southeast Asia's current power generation pipeline

Here we use "Southeast Asia's current power generation pipeline" to refer to power plants in ten ASEAN countries that are operating, under construction and being planned as of mid-2020. We construct a list of these plants using three datasets: World Electric Power Plants Database (WEPP; 2020 June Issue) (S&P Global Market Intelligence, 2020), Global Coal Plant Tracker Database (GCPT) (Global Energy Monitor, 2020) and Bloomberg New Energy Finance Database (BNEF) (BloombergNEF, 2020). WEPP is widely used for plant level analyses such as lifetime CO_2 emissions and retirement ages (Caldecott et al., 2018; Davis & Socolow, 2014; Jewell et al., 2019; Tong et al., 2019). It provides a global inventory of power plants at the generating unit level and tracks the operational status and holding company of individual plants. Moreover, the historical releases of WEPP offer valuable information regarding changes of power plants' planning, construction and operational status. WEPP has a comprehensive (>75%) to complete (>95%) coverage of power generating units for most technologies including coal, gas, oil, nuclear, hydroelectric and geothermal, and a representative (>50%) to comprehensive coverage of most wind and solar power facilities. For small wind and solar power generating units such as

solar PV that is less than 10 MW or wind power that is less than 0.1 MW, its coverage is considered adequate (less than majority). GCPT tracks the global coal plant pipeline and provides information on existing coal fired power plants larger than 30 MW as well as coal plants proposed since 2010. It does not include non-coal power plants, currently planned coal plants that were proposed before 2010, or coal plants smaller than 30 MW. GCPT has been widely used in studies with a focus on coal power plants (Clark et al., 2020, 2020; Pfeiffer et al., 2018b; Shearer et al., 2017; Yang & Urpelainen, 2019). BNEF tracks annual country level power capacity and generation data for all power generating technologies and is often utilized for its comprehensive statistics and extensive analyses regarding renewable technologies (e.g. Zissler, 2019). However, it does not have spatially disaggregated or detailed plant level information for Southeast Asia.

First, we merge WEPP data for coal, gas, oil, hydroelectric and geothermal power technologies with BNEF data for wind, solar, biomass and waste power to obtain Southeast Asia's operating power capacity by technology from 1980 to 2020. Nuclear power is not included in this study because there are currently no nuclear plants in operation or under construction in Southeast Asia. Countries like Indonesia once planned or considered nuclear power plants, however nuclear power's prospects are now unclear in Southeast Asia due to its high costs and associated safety and security concerns (Maulia & Venzon, 2020). Second, we include power plants of all technologies that are under construction or being planned as of mid-2020 using unit level data from WEPP. Third, we compare coal fired power plants documented in WEPP with GCPT and BNEF and synthesize WEPP and GCPT data at the plant level where there is discrepancy between these two sources at the aggregate level. As WEPP and GCPT are in good agreement on

coal power capacity for countries other than Indonesia and Vietnam, we use internet sources to verify plant level information and merge WEPP and GCPT for Indonesia's and Vietnam's coal plants. Finally, we compare our constructed list of Southeast Asia's power generation capacity with regional level data from IEA (International Energy Agency, 2019b). We find our results of Southeast Asia's generation capacity to be in good agreement with IEA statistics.

To analyze the impact of ten ASEAN countries' current power generation pipeline on their generation capacity growth in the near future, we determine each power plant's commissioning year and retiring year using the following procedure. We use the plant's commissioning year or planned commissioning year from WEPP or GCPT if such information is available. When such information is not available, we exclude coal, gas, hydroelectric and renewable power plants which have been in the planning stage for over 12, 10, 12, and 8 years, respectively, and the commissioning year remains unknown. The thresholds are determined based on the 95th percentile of power plants' planning time historically. We consider such plants unlikely to proceed without cancellation or further deferral. We determine the commissioning year of power plants with shorter planning times by assuming a commissioning year between 2020 and 2027 following the average planning and construction time based on historical data (see Section 2.3 and 3.2 for more detailed analyses). We determine each power plant's future retirement year using its commissioning year and an assumed expected lifetime based on its technology. The expected economic lifetime for each power technology is listed in Table S1. Currently operating plants with longer operational years than their expected lifetimes are assumed to retire randomly between 2020 and 2030. Here we focus on ASEAN countries' current power generation pipeline; therefore new fossil fuel and renewable projects initiated after mid-2020 are not included.

2.2 Committed CO_2 emissions from operating, constructed and planned fossil fuel plants

We evaluate the long-term climate consequences from Southeast Asia's current power generation pipeline by quantifying the committed CO_2 emissions expected over the fossil fuel plants' lifetime (Davis & Socolow, 2014). We use our constructed list of coal, gas and oil power plants in ASEAN countries and calculate each power plant's lifetime committed CO_2 emissions based on the function:

$$E_i = C_i \times CF_{f,k} \times 8760\ (hours) \times H_{f,t} \times EF_{f,j} \times L_f$$

where i, f, j, k, t represent power generating unit, fuel type (coal, gas or oil), fuel (anthracite, bituminous, lignite, etc), country, and power plant technology (subcritical, supercritical or ultra-supercritical coal power; steam turbine, simple-cycle gas turbine or combined cycle gas turbine). E (unit: kg CO_2) represents lifetime committed CO_2 emissions and measures the total CO_2 emissions expected over the power plant's economic lifetime; C (unit: MW) represents generation capacity; CF (unitless) is a capacity factor and represents the utilization rate of each plant; H represents heat rate (unit: Btu/MWh); EF represents emission factor (unit: kg/Btu); and L represents lifetime in years.

We calculate capacity factor between 2017 and 2019 for each fuel type in each ASEAN country using BNEF statistics of electricity generation (BloombergNEF, 2020) and use the average capacity factor in the past three years for each fuel type in each country. Because utilization rate

data at the plant level is not available, we assume that power plants of the same fuel type in the same country have the same utilization rates. In our base case scenario, we assume power plants' capacity factors vary by country but remain constant throughout the plants' lifetime as no information regarding the plants' future utilization rate is available. As each power plant's annual operating hours increase or decrease in the future, its CO_2 emissions will change accordingly. To evaluate how lifetime committed CO_2 emissions may change with power plant utilization rates (capacity factors), we conduct a sensitivity analysis examining how larger displacement of coal with non-fossil energy could reduce committed CO_2 emissions and how heavier utilization of coal power plants could increase committed CO_2 emissions.

We estimate the heat rates of power plant technologies based on various sources (MIT, 2007; Tong et al., 2018; U.S. Energy Information Administration, 2020). The heat rates and corresponding electricity generating efficiencies are listed in Table S2 and they agree with efficiencies in select ASEAN countries where data is available (Maruyama & Eckelman, 2009). We use emission factors of each fuel following the IPCC Guidelines for National Greenhouse Gas Inventories (Eggleston et al., 2006). After obtaining the total lifetime committed CO_2 emissions for each plant, we then divide them into the realized emissions through 2019 and remaining committed emissions from 2020 onwards.

2.3 Power plant planning and construction trends in Southeast Asia

We examine the planning and construction time of coal, gas and hydroelectric power plants in ASEAN countries by analyzing the progression of power generating units' operational status

using historical releases of WEPP. WEPP documents each power generating unit's development/operational status as one of the following ten categories: planned (PLN, meaning unit is "in development or design"), under construction (CON, meaning "physical site work is underway"), in operation (OPR), cancelled (CAN), delayed (DEL, meaning "constructed was started but later halted"), deferred (DEF, meaning unit is "no longer scheduled"), deactivated (DAC), retired (RET), shutdown (STN), or unknown (UNK, when "operating status is unknown"). WEPP is issued quarterly and its historical releases update the power generating unit's operational status as its status changes. In order to track individual power generating unit's development/operational status change over time, we obtain WEPP's past releases back to 2004 – the oldest release since consistent UNITIDs are used in WEPP for all the power generating units which allows tracking of power plants' updates across WEPP's releases. We obtain one WEPP release for each year from 2004 to 2020 and merge them using their UNITIDs into a time-series dataset with the status of each power generating unit for each year from 2004 to 2020.

We define the planning time of a power generating unit as the lag between when the entry first appears in the time-series as PLN and when the unit's status first changes to CON. We define the construction time of a power generating unit as the lag between when the unit's status first changes to CON and when the unit's status first changes to OPR. Among all the coal, gas and hydroelectric power generating units in ASEAN countries, we find the longest planning time to be 10-15 years and the longest construction time to be 5-10 years, depending on the technologies. To avoid omission bias from power plants which may have started planning or construction before 2004, we confine our results to power plants that began operation between

2014 and 2020. This way we allow a gap of ten years after the time-series' starting point in 2004. Power plants that began operation on or after 2014 likely started their planning and construction phase after 2004, which is captured by the time series we constructed.

2.4 Electricity generation and demand in Indonesia, Vietnam and the Philippines

We analyze electricity generation in Indonesia, Vietnam and the Philippines until 2030 based on their current power generation pipeline. For the base case we assume for each country that the capacity factor for each technology will remain the same as the historical capacity factor (as estimated in Section 2.2) and stay constant until 2030. Actual capacity factors depend on each power plant's or technology's utilization rate and thus can change with time. New plants may also have different capacity factors than existing power plants because of their location and/or the grid capacity. Therefore, our analyses are not forecasts of future electricity generation in the three countries. The three countries may also construct additional new power plants beyond their current pipeline which would add further electricity generation beyond our estimation.

We compare electricity generation estimated based on these three countries' current power generation pipelines with their future electricity demand projection. We estimate their future electricity demand based on the electricity consumption in Indonesia, Vietnam and the Philippines in 2018 and assume a range of annual electricity demand growth rates that reflect scenarios of low, medium and high electricity demand growth. In addition to electricity generation from the current pipeline based on historical capacity factors, we also investigate the possibility of an increased utilization rate of coal plants as well as the potential of increasing

renewable energy deployment. Potential renewable energy deployment in Indonesia, Vietnam and the Philippines are estimated based on their near-term (2025 or 2030) renewable energy capacity targets. We collect information about their renewable capacity targets from countries' national policies as well as IEA and IRENA's energy policy databases (International Energy Agency, 2019b; IRENA, 2018).

3. Results

3.1 Southeast Asia' current power generation pipeline and committed CO_2 emissions

Fossil fuels and hydroelectric power have long underpinned Southeast Asia's power generation development. Together, they made up over 95% of Southeast Asia's total generation capacity of 19 GW in 1980 and in 2019 still contributed over 85% of the total 280 GW capacity (excluding generation capacity from waste heat recovery system in combined cycle power plants). A total of 84 GW coal power, 77 GW gas power, 51 GW hydroelectric power and 25 GW oil power plants were in operation in Southeast Asia in 2019. Meanwhile, non-hydro renewable technologies played an insignificant role with only 21 GW total capacity in 2019. ASEAN countries have diverse portfolios of power generation given their distinct resources and energy development strategies. Most of the coal plants in Southeast Asia are located in Indonesia (32 GW), Vietnam (19 GW), Malaysia (13 GW), and the Philippines (10 GW) as of the end of 2019. Gas power plays the most important role in Thailand's and Singapore's power sectors, making up 53% (28 GW) and 63% (9 GW) of their total generation capacity in 2019. Meanwhile, Laos, Myanmar and Cambodia have prioritized hydroelectric power development, with 78% (7 GW), 49% (3 GW), and 61% (1 GW) of their generation capacity from hydroelectric in 2019, respectively.

Our analyses of Southeast Asia's current power generation pipeline show that coal, gas and hydroelectric power continue to play an important role in the near future (Figure 1). Power plants that were under construction or being planned as of mid-2020 will double the generation capacity of coal (with 100 GW added) and hydroelectric power (52 GW) in ASEAN countries from 2019 to 2029 and increase the generation capacity of gas power by almost 80% (60 GW). Most of the generation capacity growth is from power plants that are currently under construction or planned in Vietnam, Indonesia, and the Philippines. If all the plants that are under construction or planned are built, Vietnam will add another 40 GW of coal power plants, 19 GW gas plants, as well as 5 GW hydroelectric power to its generation mix. Indonesia will add 41 GW coal power, 12 GW hydroelectric power and 10 GW gas power. The Philippines will add 13 GW coal power, 8 GW hydroelectric power and 6 GW gas power. Additionally, 15 GW and 10 GW hydroelectric power will be added in Myanmar and Laos respectively; 13 GW and 8 GW gas plants will be added in Thailand and Malaysia. As our analyses do not include new power plants that may be initiated after mid-2020, Southeast Asia's future power generation projection will likely include additional power plants of various technologies. According to the projection by IEA based on Southeast Asian countries' stated policies (International Energy Agency, 2019b), over 90 GW of coal power and over 100 GW of gas power will be installed between 2019 and 2040.

However, Southeast Asia's power generation development does not have to lock itself into a future that is heavily reliant on fossil fuels. As the current generation pipeline only includes a limited number of non-hydro renewable projects (12 GW solar, 6 GW wind, 5 GW biomass and 4 GW geothermal around 2029), there is large potential to develop additional renewable power

in the coming years given Southeast Asia's considerable renewable resource potential (Kumar, 2016) and the rapidly decreasing costs of renewable technologies (Carbon Tracker, 2018). There is also flexibility to replace fossil fuel plants that are still at the planning stage with renewable energy technologies before additional fossil fuel power infrastructure is actually built.

Figure 2 shows CO_2 emissions expected from coal, gas and oil power plants that are currently in operation, under construction and being planned in ASEAN countries based on historical capacity factors. Currently operating fossil fuel plants have emitted 9 Gt CO_2 since 1980, with 5 Gt, 3 Gt and 1 Gt from coal, gas and oil plants respectively. Continuing to operate these existing power plants leads to an additional 18 Gt CO_2 committed emissions over the course of the rest of their lifetimes. The large number of coal and gas power under construction or being planned as of mid-2020 will further increase the total committed CO_2 emissions from Southeast Asia's power sector. Coal and gas plants that are under construction will emit 6 Gt and 1 Gt over their lifetimes. Moreover, currently planned coal and gas plants will emit another 13 Gt and 5 Gt, respectively. Together, Southeast Asia's fossil fuel power pipeline, which have not yet begun operation, will nearly double the committed CO_2 emissions from southeast Asia's power sector.

Future CO_2 emissions from coal, gas and oil plants will depend on how much they are utilized throughout their lifetimes – their capacity factors. Using Southeast Asia's coal power pipeline as an example, we show that an increase of capacity factor from its historical average level of 62% by 20% (to 75%) add 7 Gt committed CO_2 emissions (Figure 2). This corresponds to a heavier reliance on coal power for electricity generation, in which case average operating hours of coal plants increase from 5400 hours to 6600 hours annually. Conversely, with a deeper penetration

of renewable technologies to the power system and with decreasing LCOE from renewable sources, countries may displace coal with renewables and utilize coal power plants less in the future than they do now. In this case, a decrease of coal plants' capacity factor by 20% to 50% will reduce their committed CO_2 emissions by 6 Gt.

A small number of holding companies which operate and own the coal fired power plants in Southeast Asia contribute to the majority of committed CO_2 emissions (Figure 3). Out of all the 195 companies that operate and own coal plants, less than 10% of them contribute to 50% of the total CO_2 emissions. 25% of the companies contribute to 80% of total emissions.

3.2 Power plant planning and construction time in Southeast Asia

The average planning time of coal and gas plants as well as the average construction time of coal and hydroelectric power plants in Southeast Asia remained stable from early 2000s to 2020 (Figure 4). Out of the power plants that started construction before mid-2020, coal plants on average required 4 years of planning while gas plants required 2-3 years of planning. In contrast, average planning time of hydroelectric plants increased significantly in the same period, from 2 years to 5 years. Out of the power plants that started operation before mid-2020, construction of coal and hydroelectric plants took 3 years on average. Meanwhile, construction of gas plants got faster, with the average construction time reducing from 2 years around 2010s to 1 year in 2019.

Notably, a larger number of coal and hydroelectric plants in Southeast Asia now require longer time of planning than previously. Coal plants which started construction before 2017 generally

required 8 years or less of planning. More recently, a few coal plants experienced as long as 9-10 years of planning before their construction started. Moreover, a number of coal plants have been in the planning status for 10-14 years and still have not yet started construction by 2020. Similarly, a number of hydroelectric dams were in the planning status for 10 years or longer before their construction started. This is consistent with recent anecdotes about the increasing challenge of building new coal plants due to opposition from local communities. For example, the 2,000 MW Batang coal plant in Indonesia, which was initially scheduled to commence operation in 2016, faced strong protests from local villagers and environmental communities and thus experienced a long delay before its actual construction started in 2016 (Woods, 2017). Coal plants also face increasing difficulty in securing investment (Nangoy & Burton, 2019). As MDBs divested away from coal power since 2010s, Southeast Asian countries with limited domestic financial resources have to turn to banks from China, Japan and South Korea for financing (Chen et al., 2020). In 2020, Japan and South Korea both announced to stop public finance for overseas power plants. Going forward, financing of new coal plants in Southeast Asia is likely becoming more challenging.

3.3 Electricity Generation

Figure 5 shows future electricity generation expected from the current power pipeline in Indonesia, Vietnam and the Philippines, as well as future electricity generation when taking into account generation from each country's renewable capacity targets. All three countries demonstrate a focus on coal (and gas) power plant development. With 31 GW coal and 14 GW gas power plants in 2018, 84% of Indonesia's electricity generation comes from fossil fuels in

2018. Going forward, Indonesia's current power pipeline may result in potential electricity oversupply from its fossil fuel-based power system. If power plants in Indonesia continue operating with historical capacity factors, electricity generation from plants that were under construction or planned in 2020 will only be fully utilized after 2030. In 2016, the Indonesian Ministry of Energy and Mineral Resources (MEMR) drafted the National Electricity General Plan (RUKN) 2015-2034, which planned to install 45 GW renewable power generation capacity by 2025. If Indonesia meets this renewable target and operate the currently operational coal plants at 75% capacity factor, electricity generation from existing plants is sufficient to meet its electricity demand through 2026 even with relatively high demand growth rates. The 18 GW coal plants under construction will not be needed until 2026. The 24 GW coal plants that were planned in 2020 will not be needed until after 2030. Indonesia's electricity demand in recent years grew at a much slower rate than the government's expectation (Asmarini, 2020). If the trend of low demand growth continues, coal plants that were under construction in 2020 will not be needed until after 2028 and planned coal plants will not be needed until years after 2030.

However, Indonesia's recent power sector development, which has focused on the large number of coal plants under construction and planned, may crowd out its renewable development. Indonesia's long-term plans for power generation and grid development (such as the Electricity Supply Business Plan (RUPTL) issued by Indonesia's State Electricity Company - PT Perusahaan Listrik Negara, or PLN) often include detailed planning and outline specific projects for fossil fuel, hydroelectric and geothermal projects, where the same level of detail is lacking for non-hydro renewable projects. Furthermore, PLN's renewable targets in RUPTL are much lower than that in RUKN, which is not formally regulated, indicating that PLN's grid plans are

not designed to achieve the renewable targets in RUKN (IRENA, 2017a). If the construction and planning of new coal plants continue, the excess capacity of coal power may become "stranded assets". Coal plants will likely operate at lower utilization levels than expectation in the future, especially as PLN is already experiencing electricity oversupply (Asmarini, 2020). Meanwhile, Indonesia's National Determined Contribution (NDC) has put minimal restrictions on fossil fuel power expansion. Its first NDC allows for CO_2 emission increase through 2030 and Indonesia has no plan to update or strengthen it (Climate Action Tracker, 2020; UNDP, n.d.).

Vietnam, among ASEAN countries, had the largest coal and gas power generation capacity under construction and planned in 2020. Driven by fast economic growth and electricity demand increase, Vietnam has expanded its fossil fuel power generation rapidly since 2000s. Specifically, the share of its electricity generation from coal power grew from 15% in 2010 to 41% in 2019. Vietnam continues to meet its fast electricity demand growth with a large number of coal and natural gas plants. However, it still faces power shortage due to the delayed construction of new plants (Lee, 2019; Vu, 2019). Based on Vietnam's current power generation pipeline, coal and gas power continue to dominate its future power generation mix. As shown in Figure 5, Vietnam relies on coal plants under construction to meet its near-term electricity demand. If Vietnam meets the renewable capacity targets as indicated by the Ministry of Industry and Trade (Thuc, n.d.) and operates existing coal plants at a higher capacity factor of 75%, coal plants under construction are sufficient to meet its electricity demand through 2024. Yet, planned coal and gas power will not be fully utilized until around 2030. In other words, either currently planned coal power or planned gas power (or both) will become stranded assets which operate at utilization rates below optimal levels, especially with future renewable power

development. Compared with fossil fuel power infrastructure, renewable projects like wind and solar power take less time to complete and can serve to fill its near-term electricity generation gap. Moreover, wind and solar projects will become cheaper than coal in the coming years (EREA & DEA, 2019). Replacing part of the planned fossil fuel capacity with renewable projects in Vietnam will help relieve the financial burden from building new coal plants. As Vietnam is now formulating its Power Development Plan (PDP IIIV) for the next ten years (2021-2030), it is important to take into account of renewable power as alternatives to new fossil fuel plants given renewable's advantages in shorter construction time and decreasing costs.

The Philippines' power sector development experienced several stages since the 1990s. In the early 1990s, after experiencing a number of severe power outages, the Philippines passed the Electric Power Crisis Act. This led to a rapid power capacity expansion in the late 1990s from 8 GW in 1990 to 18 GW in 2000. The expansion was facilitated by the private sector and mainly comprised of oil plants. In the 2000s, when electricity demand did not grow as forecasted, parts of the Philippines experienced excess capacity (Asian Development Bank, 2018). As a result, the Philippines' power generation capacity grew modestly between early 2000s and mid-2010s, from 18 GW in 2000 to 22 GW in 2015. As electricity demand grew and excess generation capacity decreased, its power sector started the second phase of rapid expansion since the mid-2010s. The Philippines' coal power capacity increased from 6 GW in 2015 to 10 GW in 2019, with 12 GW capacity under construction and planned as of 2020. Coal and gas power made up 72% of the Philippines' power generation in 2018 and continue to contribute the majority of its future electricity generation. The Philippines' renewable power generation is mainly from geothermal

and hydroelectric power plants. It built the first geothermal plant in 1977 and has the second largest geothermal power generation next to the U.S. (IRENA, 2017b).

The Philippines' planned coal and gas power plants have a large chance of becoming stranded assets, similar to Vietnam. With relatively slow electricity demand growth forecast, coal plants that were under construction in 2020 will be sufficient to meet the Philippines' demand through 2023. In 2011, the Philippines set a renewable target of 15.3 GW by 2030. With electricity output from its current power generation pipeline as well as this renewable target, a substantial fraction of its planned coal and gas power plants will be underutilized or will not be needed at all until 2030. Continuing to plan coal and gas power as scheduled will put the Philippines at the risk of having excess reserve margin like it did in 1990s. As the lockdown measures due to Covid-19 led to economic slowdown and electricity consumption decrease in 2020 in the Philippines (Asian Power, 2020), the need for new coal and gas plants to meet electricity demand will be further delayed or eliminated if more renewables are deployed. In late 2020, the Philippines government announced a moratorium to approving new coal plants in the Philippines (Farand, 2020). It is important to also consider possibilities to strengthen and scale up its renewable target as well as replace some of the planned coal or gas power plants.

4. Conclusions and discussions

As the developed economies transition away from coal fired power plants and the biggest developing countries such as China and India slowed their coal power capacity expansion rates, we find that Southeast Asia's fossil fuel power infrastructure including coal and natural gas

plants are expanding rapidly. Here we analyze Southeast Asia's current power generation pipeline, i.e. power plants that are operational, under construction and being planned as of mid-2020. We find that in 2019 Southeast Asian countries had 84 GW coal and 77 GW gas power generation capacity in operation. Power plants which were under construction and planned in 2020 will further add 100 GW coal and 60 GW gas power. Hydroelectric power also plays an important role, with 51 GW in operation and 52 GW under construction and planned. In contrast, non-hydro renewables remain a tiny portion (21 GW and 7.4% in 2019) of Southeast Asia's power capacity mix. The fossil fuel power infrastructure results in large committed CO_2 emissions over their lifetime. Coal, gas and oil plants which were operating in 2020 have emitted 9 Gt CO_2 and will commit another 18 Gt CO_2 emissions if they operate under historical capacity factor and emission intensity for 40 years. Fossil fuel infrastructure which were under construction and planned in 2020 will further double the total committed CO_2 emissions. Southeast Asia is experiencing rapid electricity demand growth. If Southeast Asian countries continue to rely on coal and gas power to meet their increasing demand without a transition towards renewable power alternatives, they will be locked into a future reliant on fossil fuel infrastructure.

As Southeast Asia meets its rapid electricity demand growth, it is critical to take into account the near-term and long-term risks of fossil fuel infrastructure. First of all, fossil fuel infrastructure such as coal plant development takes years of planning and construction before commissioning. We find that in the past coal plants have experienced 4 years of planning time and 3 years of construction time on average before they commission operation. In recent years a number of coal plants have experienced serious delays, which led to a lag of 8 years or longer before they started

construction. Difficulty in securing financing and oppositions from local communities due to environmental and ecological concerns are among the major factors that delay the planning and construction of coal plants (Chavez, 2020; Nangoy & Burton, 2019). Challenge of land acquisition, difficulty in securing long-term coal supply and delays in signing power purchase agreements may also lead to delays from months to years (Buckley & Shah, 2018). While countries rely on coal plants to bring large capacity to the grid, the risk of project delay or stagnation may disrupt the plan. Meanwhile, renewable projects can help relieve near-term power shortage because they take much shorter time to build. As the cost of renewable technologies decrease, planning renewable projects to meet future electricity demand growth will also be a cost-effective option. As we show in the electricity generation analyses for Indonesia, Vietnam and the Philippines, even modest renewable targets may delay or eliminate the need of new coal or gas plants.

Second, continued investment in coal plants in Southeast Asia may cause financial loss or crowd out non-hydro renewable energy development and deployment. LCOE of renewable projects such as wind and solar power have become lower than coal plants in many countries worldwide (IRENA, 2020). Even in Southeast Asia where coal has long been subsidized and renewable feed-in tariffs have been unfavorable, new solar and wind plants may be cheaper than investing in new coal plants in the coming years (Carbon Tracker, 2018). Furthermore, new solar and wind plants will be cheaper than running existing coal plants in late 2020s (Carbon Tracker, 2018). Renewable deployment and excess fossil fuel capacity planning will lead to low utilization rates of future coal plants, resulting in financial loss of investment. Otherwise, continued expansion of coal power fleet and reliance on coal power generation will hinder renewable development.

Finally, it is important to consider other environment and climate-related risks when investing in fossil fuel power infrastructure. Coal fired power plants cause short-term environmental risks other than its long-term CO_2 emissions. Without proper mitigation strategies such as end-of-pipe controls, coal plants emit air pollutants which cause ambient air pollution and adversely impact health and agricultural production. Additionally, fossil fuel plants in Southeast Asia are vulnerable to climate change. Because thermal power plants use water for cooling, changes in water resources and water temperature in Southeast Asia due to changes of the climate may constrain future electricity generation from coal plants (Wang et al., 2019). Therefore, integrating renewable sources such as wind and solar power into the electricity system brings multiple co-benefits alongside CO_2 emission mitigation, including air quality benefit and climate resilience.

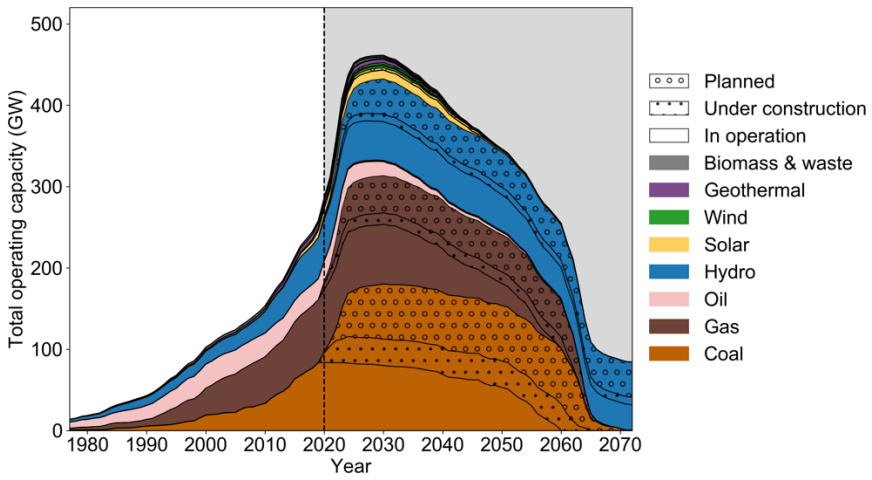


Figure 1. Power generation capacity in ten ASEAN countries, by technology type and by operational/development status as of mid-2020. The grey area to the right of 2020 indicates Southeast Asia's future power generation capacity based on power plants that are currently in operation, under construction and being planned. Additional fossil fuel or renewable power plants that may be initiated after 2020 are not included. Capacity from waste heat cogenerating units in combined cycle thermal plants is not included.

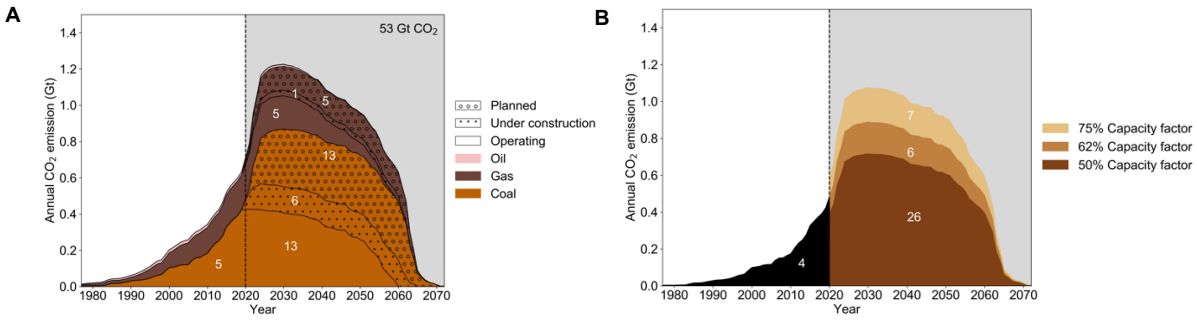


Figure 2. Annual and committed CO_2 emissions expected from fossil fuel power plants that are currently in operation, under construction and being planned (A) and coal plants specifically (B). Numbers in the panels indicate total committed CO_2 emissions – area left of 2020 are cumulative emissions through 2019 and area right of 2020 is projected remaining committed emissions over the remainder of the power plants' assumed 40-year lifetime.

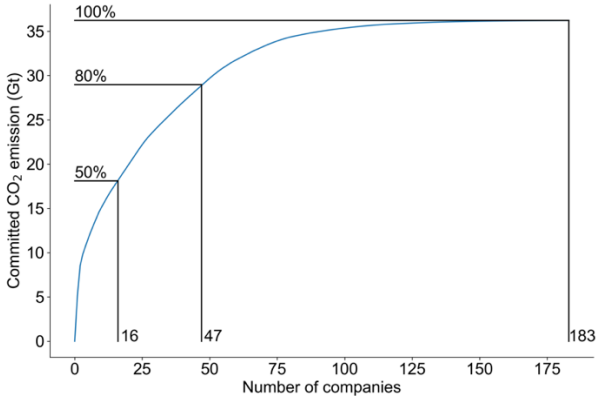


Figure 3. Committed CO_2 emissions contributed by the number of holding companies that operate/own the coal fired power plants in Southeast Asia.

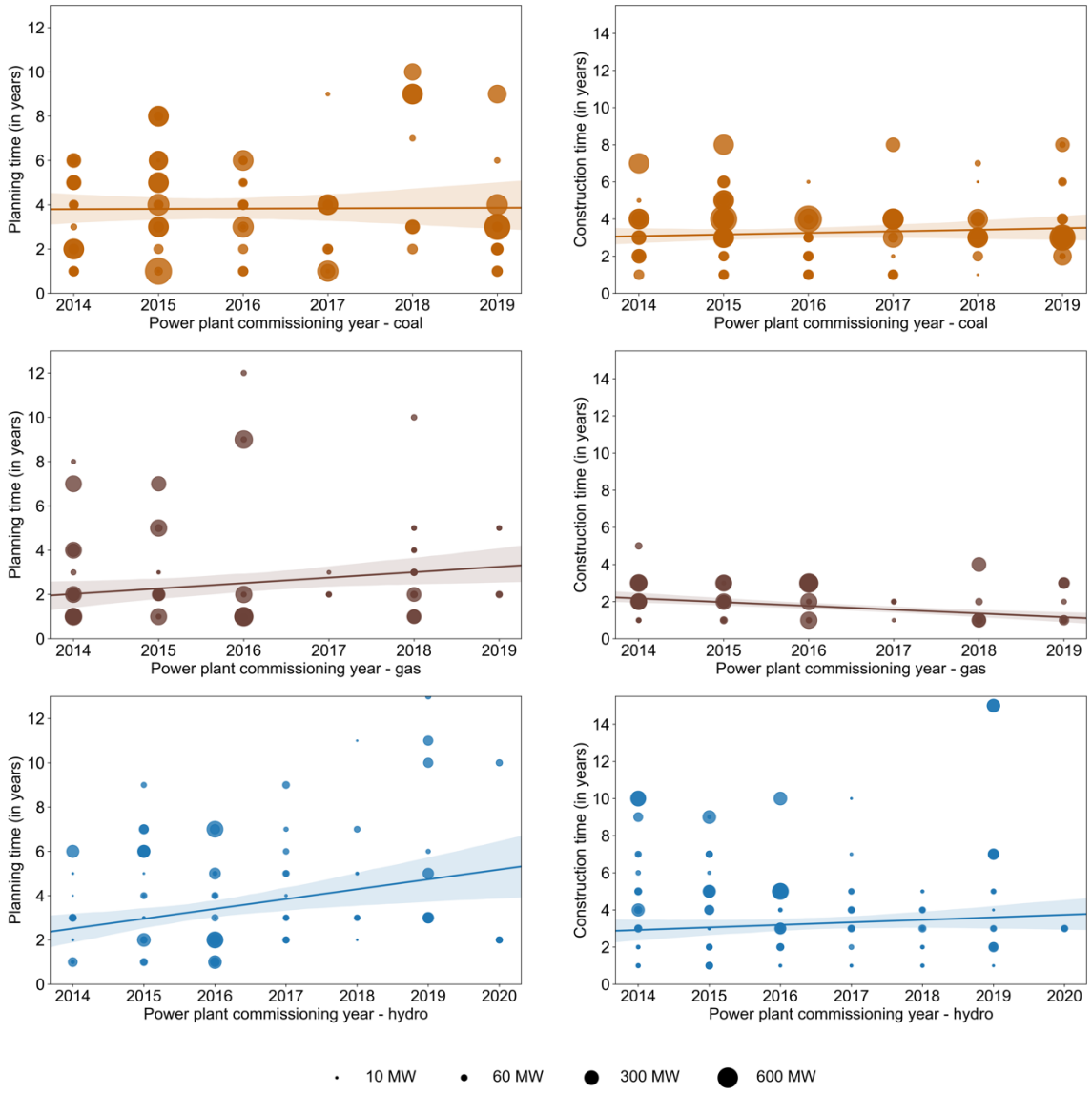


Figure 4. Planning and construction time for coal, gas and hydroelectric power plants in Southeast Asia. Power generation units that began construction or operation between 2014 and 2020 are shown. Circles represent data points of power generating units and size of the circles correspond to their generation capacity. The trend line and the bands represent time-dependent expectations of planning/construction time and the 5th and 95th percentile ranges.

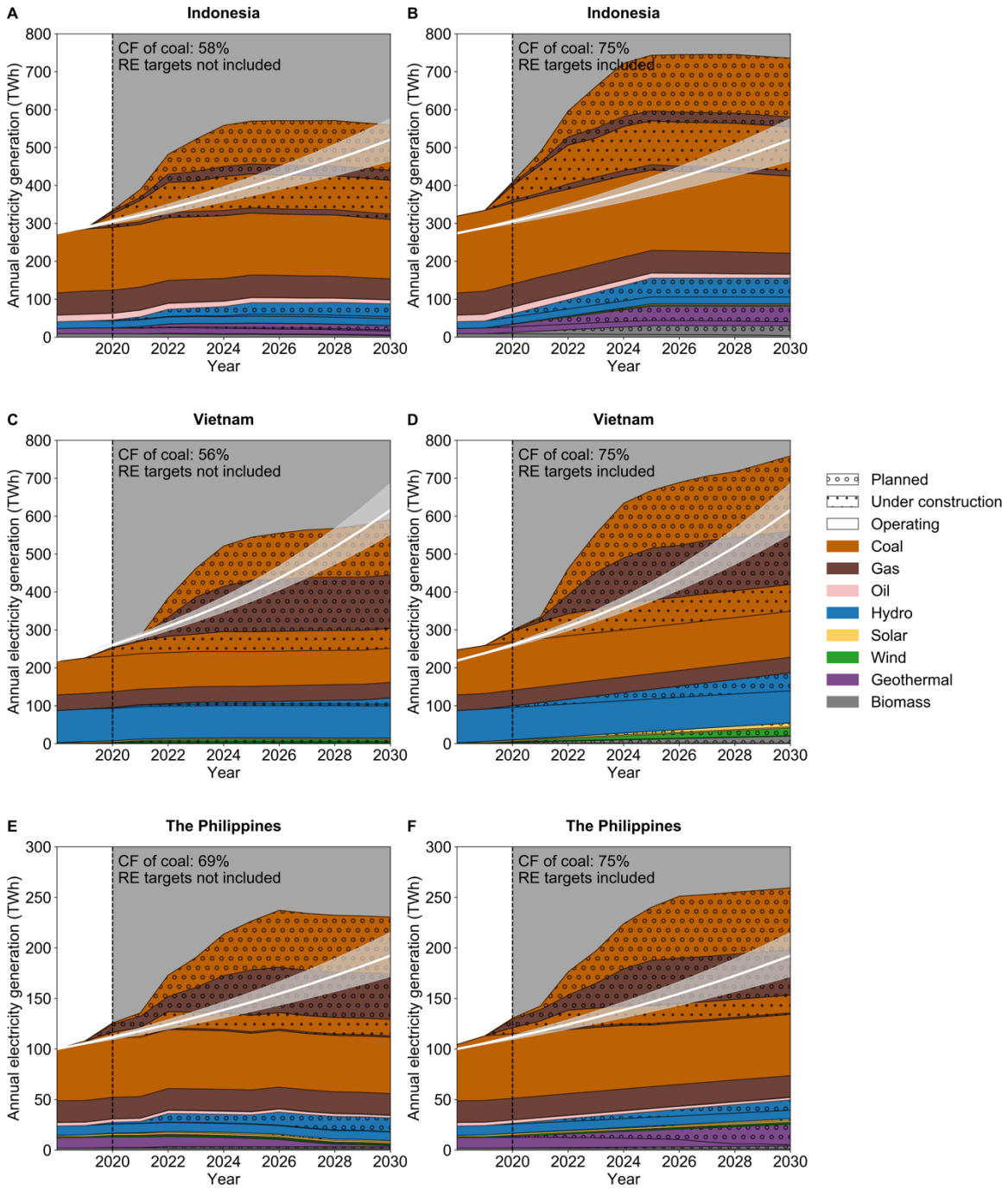


Figure 5. Projected annual electricity generation from Southeast Asia's power plants. Panel **A**, **C** and **E** project future electricity generation based on historical capacity factors of each technology in Indonesia, Vietnam and the Philippines and power plants that were in operation, under construction or being planned in 2020. Panel **B**, **D** and **F** project future electricity generation based on historical capacity

factors for non-coal technologies and 75% capacity factor for coal power (75% is the highest regional annual average capacity factor for coal historically) and each country's current power pipeline as well as their renewable capacity targets by 2025 (Indonesia) or 2030 (Vietnam and the Philippines). The light grey bands are projections of each country's national electricity demand estimated based on a range of low, medium and high annual demand growth rates. The growth rates for each country are: Indonesia – 4.5% (low), 5.5% (medium), 6.5% (high); Vietnam – 7% (low), 8% (medium), 9% (high); and the Philippines – 4.6% (low), 5.6% (medium), 7.6% (high).

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Chapter 5: Conclusions

Power generation infrastructure is essential to meeting increasing electricity demand and is the foundation to economy wide electrification. Power infrastructure development in developing countries requires tremendous investment from local and international sources. This dissertation reveals the key role that bilateral financing is playing in financing new power generation infrastructure and facilitating power capacity expansion globally. Since 2010s, MDBs have shown signs of moving away from financing new coal power towards supporting renewable technologies in line with the Sustainable Development Goals and Paris Agreement. However, when juxtaposed with bilateral financing from the largest economies, I find a different picture of international financing of the power sector.

Chapter 2 and **Chapter 3** show that bilateral finance has lagged in the low carbon energy transition behind the MDBs. **Chapter 2** highlights the key role that Chinese national DFIs play in global power infrastructure development. Chinese national DFIs have become globally active since the 2000s, from contributing negligible overseas finance in early 2000s to becoming the largest public financiers of power generation infrastructure in late 2010s. Overseas finance by CDB and CHEXIM committed between 2000-2018 facilitated 56 GW coal power, 23 GW hydro power and 7 GW nuclear generation capacity additions worldwide. Together with Japanese and South Korean DFIs, East Asian national DFIs have become public lenders of last resort for financing coal fired power plants in developing countries with limited domestic sources. East Asian national DFIs' overseas financing of coal plants is not aligned with the climate target of well below 2^{o}C global average warming by the end of the century. Of the coal power capacity

that CDB and CHEXIM committed to finance through 2018, half is expected to commence operation in the future and over 90% of their committed CO_2 emissions will occur after 2018. This will greatly reduce the potential to decarbonize the global power generation sector by mid-century. Going forward, it is important that national DFIs include Sustainable Development Goals and Paris Agreement in their policy agenda and redirect finance away from coal power towards renewable technologies.

Chapter 3 expands the analyses of power sector bilateral financing and examines financing both through national DFIs and through greenfield FDI from the three largest economies in the world. In contrast to extensive domestic and multilateral mitigation efforts, I find that bilateral financing of fossil fuel power infrastructure from China, Japan and the U.S. has continued with little restriction. Chinese, Japanese, and U.S. overseas finance committed between 2000 and 2018 has mostly facilitated fossil fuel infrastructure development such as coal and gas power plants. Over 60% of Chinese finance and U.S. finance facilitated capacity additions and over 80% of those facilitated by Japanese finance are coal or gas plants. Less than 10% of Chinese and Japanese finance facilitated capacity additions are non-hydro renewable technologies such as solar, wind and geothermal. 13% of U.S. financed capacity additions are wind and solar power. Fossil fuel power plants financed by China, Japan and the U.S., which commissioned operation in or after 2005 and were operating or under construction as of 2019, will lock in 24 Gt CO_2 emissions by 2060. This is more than the total energy-related CO_2 emissions from the developing world in 2019. The technology choices of bilateral financing from China, Japan, and the U.S. follow portfolios of power sector development in the top recipient countries which have mainly prioritized fossil fuel power development, instead of leading a low-carbon transition there.

Moreover, the technology portfolios of bilateral finance from these three countries are not aligned with their domestic power sector development (except for Chinese greenfield FDI), which have gradually reduced fossil fuel infrastructure expansion and increased wind and solar capacity.

Chapter 4 finds that Southeast Asia's fossil fuel power infrastructure including coal and natural gas plants are expanding rapidly, while most other countries have either reduced or slowed their expansion of coal power fleet. In early 2020, 84 GW coal and 77 GW gas power generation capacity were in operation in Southeast Asian countries. Power plants that were under construction and being planned as of mid-2020 will further add 100 GW coal and 60 GW gas power plants. In contrast, non-hydro renewables remained a tiny portion of Southeast Asia's power capacity mix and contributed a marginal share of total electricity generation in 2019. It is critical that Southeast Asian countries take into account short-term and long-term risks of fossil fuel infrastructure in their power sector development. First, fossil fuel power infrastructure results in large committed CO_2 emissions over their lifetimes. Fossil fuel power plant that were under construction and planned in 2020 will double Southeast Asia's total committed CO_2 emissions from the power sector. Second, coal fired power plants take a longer time than non-hydro renewable projects to plan and construct. Therefore, relying on coal power to meet future electricity demand may cause financial losses as renewable technologies become cheaper in the future. Continued reliance on fossil fuel power generation may also hinder non-hydro renewable energy deployment. Third, fossil fuel power infrastructure may cause local air pollution and are vulnerable to climate change induced water scarcity and water temperature change.

Based on the analyses and findings in **Chapter 2-4**, I conclude that it is critical that both the financing countries and the recipient countries consider renewable alternatives to fossil fuel power infrastructure in bilateral finance. Bilateral finance of fossil fuel power plants lock in long-term CO_2 emissions and may deteriorate local air quality. Newly built and planned fossil fuel plants may be underutilized in the future and become stranded assets, which will cause financial losses for both the financiers and the recipients. Therefore, continued research is needed to understand how we may steer bilateral financing and align it with decarbonization goals. Based on the findings in this dissertation, I consider the following aspects to be important in future actions and research:

- Throughout my research, I find that bilateral financing was not tracked in a continuous and systematic manner, which hindered a comprehensive understanding of it in the past. Going forward, **continuous tracking of bilateral financing of the power sector is needed.** In particular, **a more transparent and consistent disclosure of overseas financing by national DFIs is crucial** as the first step for evaluating national DFIs' wider environmental impacts and their alignment with Paris Agreement.

- This dissertation shows that bilateral financing of the power generation sector supports overseas expansion of the financing countries' domestic fossil fuel power industry. However, bilateral financing of overseas renewable power projects has been limited compared with the financing countries' domestic renewable energy development. **Future research that examine the distinction between bilateral financing of different technologies will be valuable.** Important aspects include the political economy of how

national DFIs and commercial investors make financing decisions on various technology options, what barriers they may face financing non-hydro renewable technologies, and what approaches they may take to increase renewable financing.

- **Case studies will be valuable to understand how to steer the developing countries' power sector to a low carbon pathway and how bilateral financing may facilitate the transition.** While bilateral financing is typically aligned with the recipient countries' energy resources and domestic capacity portfolios, cases about bilateral financing of renewable power technologies in countries with abundant fossil fuel resources are especially valuable. Motives behind such atypical cases can provide valuable insights to the prospects of renewable power development in developing countries. Additionally, **a better understanding of the interactions between stakeholders is needed**. For example, dynamics between foreign financiers and stakeholders in the recipient countries may reveal opportunities or obstacles of financing a renewable energy transition.

Appendix for Chapter 2

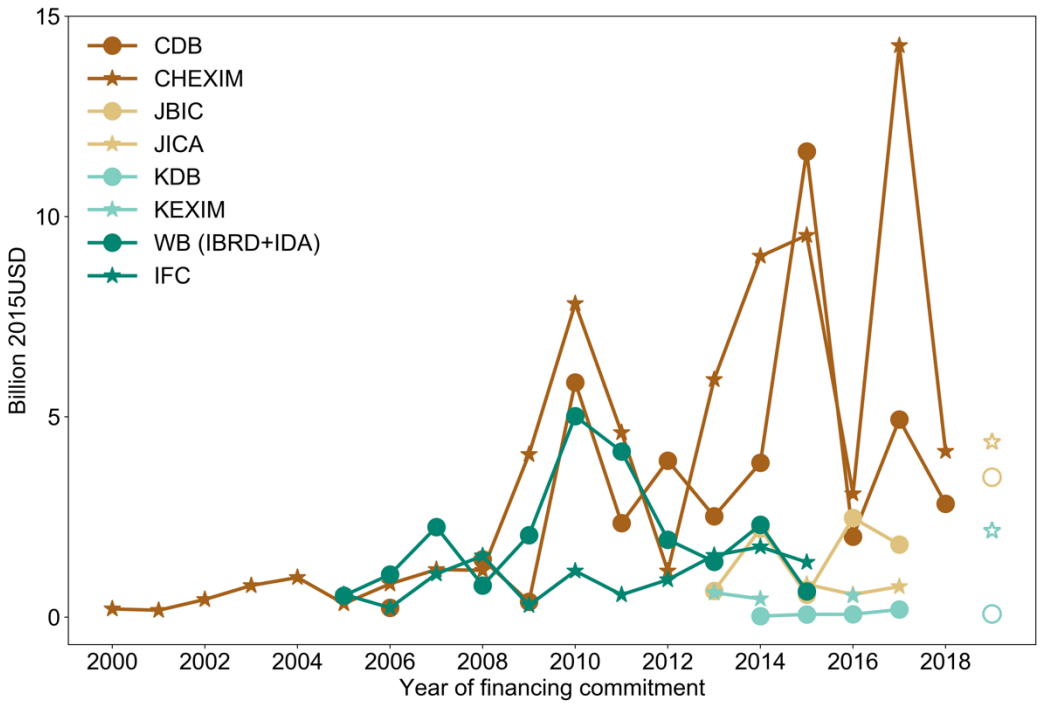


Figure S1. Major DFIs' financing in the global power generation system. National DFIs data is limited to their overseas financing. Data source: China's policy banks (CDB and CHEXIM) financing data[a] (2005-2018) from China Global Energy Finance Database (CGEF) from Boston University (Gallagher, 2019); WB and IFC financing data (2005-2015) from Steffen & Schmidt (2018); Japanese and South Korean policy banks (JBIC, JICA, KDB, and KEXIM) financing data (January 2013-August 2017) from the Consolidated Coal and Renewable Energy Database from Natural Resource Defense Council (NRDC)[b] (Chen et al., 2016). Numbers after 2018 (open marks) indicate financial commitments that were pending as of August 2017).

Notes:

[a] When CDB and CHEXIM co-financed the same power generation project but no information of their respective financing share is available, we divide the financing equally between CDB and CHEXIM.

[b] The Consolidated Coal and Renewable Energy Database from NRDC includes only financing to coal, solar, wind and geothermal power. Data for Japanese and South Korean DFIs' financing of gas, oil, hydro, nuclear, or biomass plants is not available.

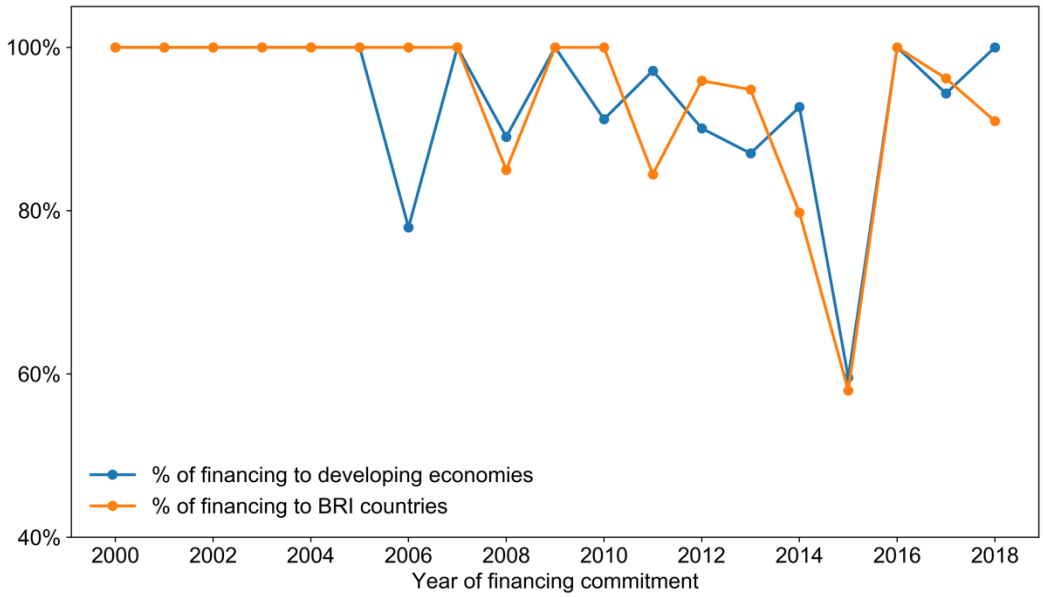


Figure S2. CDB and CHEXIM financing to developing economies and to BRI participating countries. Blue: Percentage of CDB and CHEXIM financing to developing economies[a]. **Orange**: Percentage of CDB and CHEXIM financing to countries that participate in the BRI[b]. The dips in 2015 in both trends are due to CDB's financing commitment to build a nuclear plant in the United Kingdom that year.

Notes:

[a] Countries' economic development status is based on United Nations country classification in 2019 (United Nations, 2019).

[b] BRI country membership status in April 2019 is used. When BRI was first announced in 2013, the fraction of CDB's and CHEXIM's financing to BRI countries was negligible. In 2017, when 70 countries had joined the BRI, the fraction of CDB's and CHEXIM's financing to BRI countries increased tremendously. At present, 87% of CDB's and CHEXIM's cumulative financing between 2000-2018 is devoted to 42 BRI countries (among a total of 126 BRI countries as of April 2019). With more countries joining China's BRI, the fraction of CDB's and

CHEXIM's financing to BRI countries is likely to increase further. As of April 2019, CDB's and CHEXIM's cumulative financing commitments have facilitated 83 GW power generation capacity additions that are in operation, under construction or planned in Belt and Road countries, and 7 GW in non-BRI countries. CDB's and CHEXIM's contributions in non-BRI countries is located in Latin America (e.g. coal fired power plants in Brazil and hydroelectric dams in Argentina), Africa (e.g. hydroelectric dams in Mali and Malawi), and Europe (e.g. a nuclear power plant in United Kingdom).

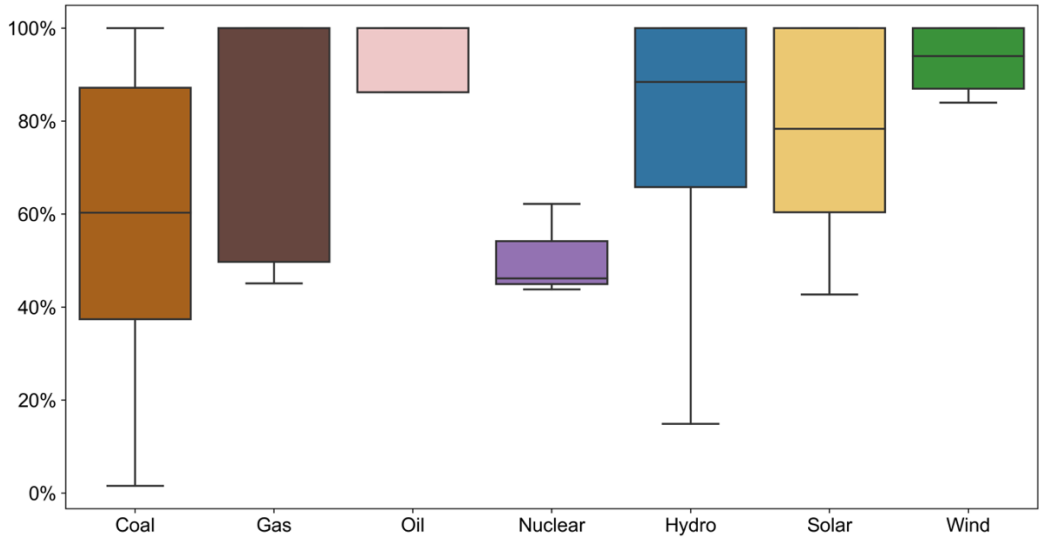


Figure S3. Box plot of percentages of overseas power plant's capital costs financed by CDB and CHEXIM across technologies[a,b]. The box limits indicate first quartile (Q_1) and third quartile (Q_3). The band inside each box denotes the median percentage. Whiskers of each box extend to the largest datum below $Q_3 + 1.5 \times IQR$ and the smallest datum above $Q_1 - 1.5 \times IQR$, where $IQR = Q_3 - Q_1$.

Note:

[a] To estimate the percentage of each power plant's capital cost financed by CDB and CHEXIM, we assume the capital cost per kW for each power generation technology following Li et al. (2020). The percentage of CDB's and CHEXIM's financial contribution to each power plant (pp) is calculated as:

$$F_{pp} = \frac{CDB\ or\ CHEXIM's\ financing\ commitments\ to\ pp}{Nameplate\ generation\ capacity\ of\ power\ plant\ pp \times average\ capital\ cost\ per\ kW\ of\ pp's\ fuel\ type} \quad (1)$$

In cases where the calculated financial contribution by CDB and CHEXIM to a power plant, $F_{power\ plant\ pp}$, is larger than 100%, we assume CDB's and CHEXIM's financial contribution is 100%.

The fraction of CDB's and CHEXIM's financial contribution to each fuel type (f) is calculated as:

$$F_f = \frac{CDB\ and\ CHEXIM's\ total\ financing\ commitments\ to\ power\ plants\ of\ fuel\ type\ f}{Total\ facilitated\ capacity\ additions\ of\ fuel\ type\ f \times average\ capital\ cost\ per\ kW\ of\ fuel\ type\ f} \quad (2)$$

[b] The box plot generated based on calculations following Equation (1) is only indicative of the degree of CDB's and CHEXIM's financial involvement across power plants and fuel types on average, but not definitive, because a power plant's actual capital cost per kW is determined by many technological and non-technological factors. For example, the cost varies by specific technology configuration: ultra-supercritical and supercritical coal plants have higher capital costs per kW than subcritical coal plants; the cost of a coal plant's boiler depends on its temperature and pressure configurations; installation of advanced pollution control devices increases the cost of coal plants; etc. Furthermore, a power plant's total capital cost depends on its location (e.g. construction and labor costs vary with the location of the power plants), varies by its equipment manufacturer and construction contractor (e.g. Chinese coal power manufacturers and contractors are reported to have lower costs (Hervé-Mignucci & Wang, 2015; Zhao & Alexandroff, 2019)), and changes with construction time (costs of renewable technologies have decreased rapidly). Moreover, the political and economic environment may also influence the plant's capital costs. To illustrate the uncertainty of capital costs, minimum and maximum estimates of power plants' capital costs of each fuel type from other studies are listed in Table S11, against the average capital costs used in this study.

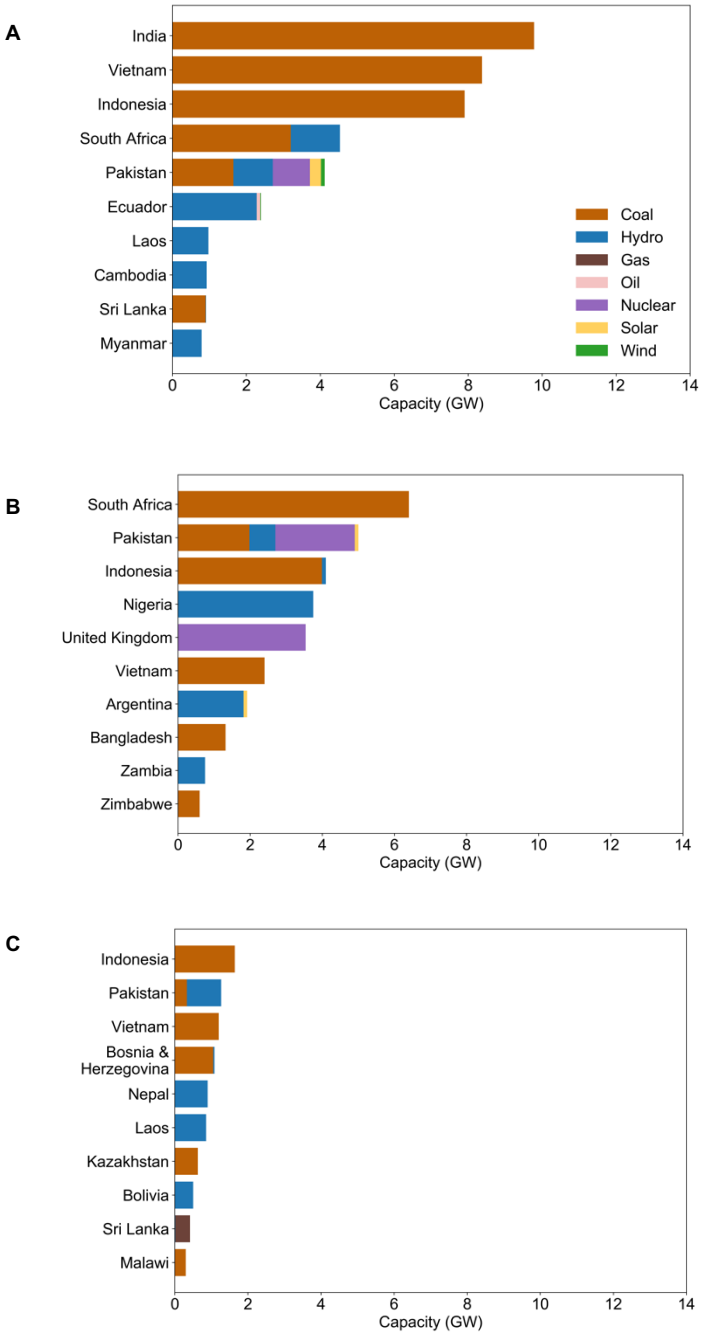


Figure S4. Ten countries with most power generation capacity additions that are (A) in operation, (B) under construction, and (C) planned facilitated by CDB and CHEXIM, related to Figure 3.

Financing committed by CDB and CHEXIM between 2000-2018. Colors indicate different technologies.

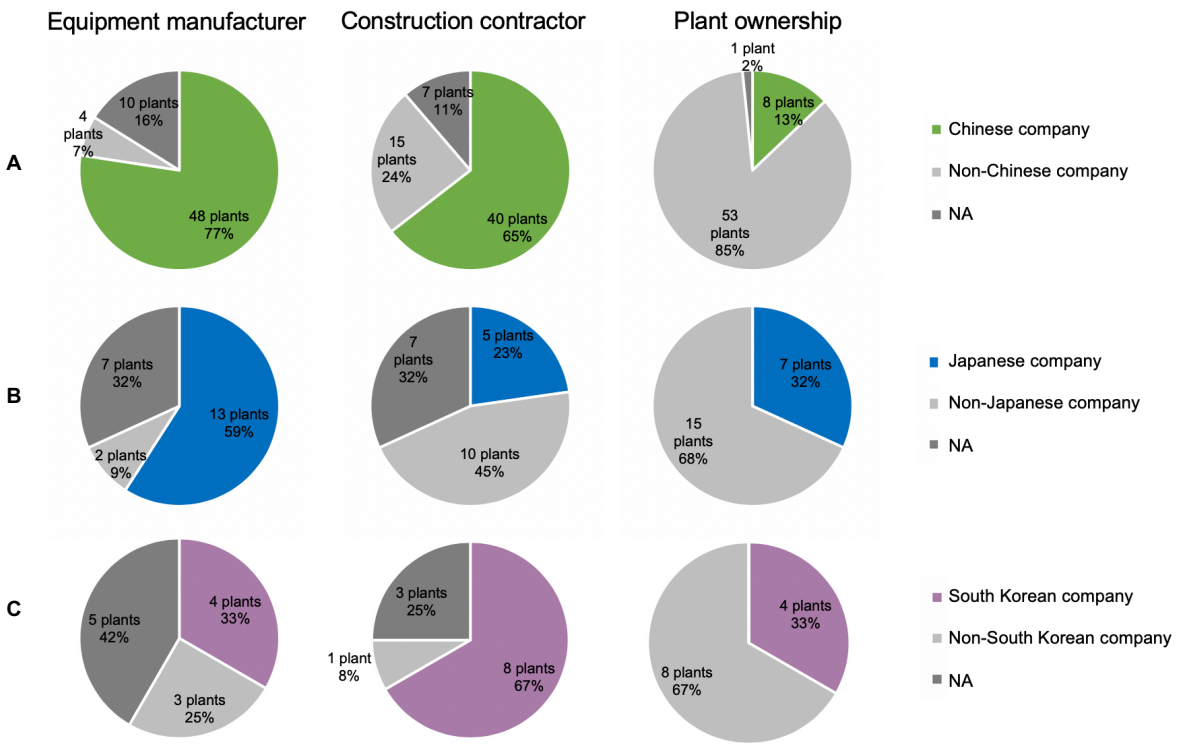


Figure S5. Summary of Chinese and Japanese DFIs' overseas coal power finance to support their domestic industry to go abroad. Equipment manufacturer, construction company and plant ownership[a] of coal fired power plants (**A**) that received financing commitments from CDB or CHEXIM between 2000-2018[b], (**B**) that were financed or under consideration for financing by JICA or JBIC[c] between 2013-2017, and (**C**) that were financed or under consideration for financing by KDB or KEXIM[d] between 2013-2017.

Notes:

[a] Power plant ownership includes both majority ownership and joint ownership. The ownership data from WEPP (S&P Global Market Intelligence, 2020) has been added since 2011 and is not definitive. The ownership data may change over time with the transfer of plant ownership.

[b] Between 2000 and 2018, CDB and CHEXIM each committed finance to 33 and 34 overseas coal plants, respectively (among these plants, CDB and CHEXIM co-financed 5 of them). The

patterns of their support for Chinese and non-Chinese equipment manufacturers, construction contractors, and plant ownership are similar with each other. Thus we only present their aggregate figure here.

[c] From January 2013 to August 2017, JICA and JBIC committed financing to 12 coal fired power plants. As of August 2017, another 10 plants were under consideration by JICA or JBIC for financing. A total of 22 coal plants involving or potentially involving JICA or JBIC finance are examined here.

[d] From January 2013 to August 2017, KDB and KEXIM committed financing to 4 coal fired power plants. Another 8 plants were under consideration for their financing as of August 2017. A total of 12 coal plants involving or potentially involving KDB or KEXIM's finance are examined here.

Table S1. Power generation financing by CDB and CHEXIM (2000-2018) and by ten major MDBs combined (2005-2015), related to Figure 1: their financing commitments (billion 2015USD), facilitated generation capacity additions (unit: GW), and fraction of facilitated coal power capacity additions. The largest number in each column is in bold.

Year	Financing commitments (billion 2015USD)		Facilitated capacity additions (GW)[a]		Fraction of facilitated coal power capacity additions	
	CDB and CHEXIM	10 MDBs	CDB and CHEXIM	10 MDBs	CDB and CHEXIM	10 MDBs
2000	0.2					
2001	0.2					
2002	0.4					
2003	0.8		0.2		0%	
2004	1.0		0.0		0%	
2005	0.3	5.4	0.0		-	
2006	1.1	4.2	0.1		100%	
2007	1.2	7.8	0.6	9.5	0%	15%
2008	2.6	7.2	0.0	12.1	-	**37%**
2009	4.4	12.6	0.1	10.5	0%	16%
2010	13.7	**14.1**	0.7	16.5	43%	24%
2011	7.0	12.1	5.2	11.1	85%	26%
2012	5.1	9.6	3.8	**23.0**	74%	21%
2013	8.4	11.1	5.3	11.9	82%	0%
2014	12.9	11.9	8.9	12.9	86%	0%
2015	**21.2**	9.1	4.9	9.7	**90%**	0%
2016	5.1		5.4	20.0	20%	10%
2017	19.2		6.3	11.7	79%	0%
2018	7.0		5.3		61%	
2019			**10.5**		66%	
2020			6.5		63%	
After 2020[b]			28.5		47%	
Total	**111.7**	**105.2**	**92.1**	**149.0**	**63%**	**14%**

Notes:

[a] Year of facilitated capacity additions corresponds to the commissioning year of power plants. For CDB- and CHEXIM-facilitated capacity additions, data of power plant commissioning year comes from the WEPP database. For MDB facilitated capacity additions, data of actual power plant commissioning year is not available. Following Steffen & Schmidt (2018), an assumption

of a two-year lag between MDBs' financing commitment and power plants' commissioning is made.

[b] 31 power plants to which CDB and CHEXIM committed financing are expected to commence operation after 2020. Among these power plants, 22.5 GW will come online between 2021 and 2029; another 6 GW do not yet have an estimated commissioning year including 2 plants currently delayed.

Table S2. Power generation capacity additions contributed by major DFIs' financing commitments presented over various available time intervals of financing (unit: MW).

Technology Type	CDB & CHEXIM (2000-2018)	JICA & JBIC (2013-August 2017)	KDB & KEXIM (2013-2017)	10 MDBs[a] (2005-2015)	IFC (2005-2015)	AsDB (2006-2015)	WB (2005-2015)
Coal	56,446	14,681	3,800	21,269	4,660	11,360	4,800
Gas	1,572	NA	NA	40,406	7,421	8,210	5,129
Oil	926	NA	NA	1,595	670	6	152
Nuclear	6,745	NA	NA	0	0	0	0
Hydro	23,345	NA	NA	36,611	10,360	4,561	7,102
Solar	908	74	1,088	11,487	8,083	845	1,317
Wind	440	609	447	9,727	3,450	1,289	768
Biomass	20	NA	NA	346	176	6	30
Geothermal	0	1,248	0	1,979	72	560	665
Waste	0	NA	NA	557	57	460	0
Unspecified	0	NA	NA	25,024	13,586	2,774	3,485
Total	**90,401**	**16,612[b]**	**5,335[c]**	**149,000**	**48,534**	**30,070**	**23,447**

Notes:

[a] Ten MDBs' collective contributions are listed, as well as three MDBs with the largest total contributions – IFC, AsDB, and the WB.

[b] Includes only power plants that reached 'financial close' status by August 2017. As of 2017, another 10,471 MW coal fired power plants were pending for financing consideration by JICA or JBIC.

[c] Same as data of Japan, capacity additions include only power plants that reached "financial close" status by August 2017. As of 2017, another 7,639 MW power plants were pending for financing consideration by KDB or KEXIM, including 7,340 MW coal power.

Table S3. Summary of CDB and CHEXIM overseas finance between 2000 and 2018 in the power sector by technology type: their financing commitments (billion 2015USD), number of financed power plants, and facilitated generation capacity additions that are operating, under construction, and planned (unit: GW).

Technology type	Financing commitments (billion 2015USD)	Number of financed power plants	Facilitated capacity additions (GW)
Coal	47.05 (42%)	62 (38%)	56.45 (62%)
Gas	2.15 (2%)	6 (4%)	1.57 (2%)
Oil	3.33 (3%)	5 (3%)	0.93 (1%)
Nuclear	16.37 (15%)	3 (2%)	6.75 (7%)
Hydro	37.92 (34%)	73 (45%)	23.35 (26%)
Solar	3.86 (3%)	9 (6%)	0.91 (1%)
Wind	0.94 (1%)	4 (2%)	0.44 (0%)
Biomass	0.06 (0%)	1 (1%)	0.02 (0%)
Total	**111.67 (100%)**	**163 (100%)**	**90.40 (100%)**

Table S4. Recipient countries of CDB and CHEXIM oversea power generation financing: CDB's and CHEXIM's financial commitments between 2000-2018 (million 2015USD), facilitated capacity additions that are operating, under construction and planned (unit: MW), and recipient country's BRI membership.

Recipient country	Financing commitments (million 2015USD)	Facilitated capacity additions (MW)	BRI membership (as of April 2019)
Argentina	3,540	2,117	0
Bangladesh	2,094	1,476	1
Belarus	896	383	1
Benin, Togo	550	147	0
Bolivia	988	500	1
Bosnia & Herzegovina	2,136	1,385	1
Brazil	392	350	0
Bulgaria	128	85	1
Cambodia	1,961	927	1
Cameroon	743	225	1
Chile	929	18	1
Cote d'Ivoire	953	387	1
Cuba	118	70	0
DRC	1,082	390	0
Ecuador	4,209	2,402	1
Equatorial Guinea	302	120	1
Ethiopia	1,110	675	1
Fiji	77	40	1
Gabon	330	160	1
Ghana	334	403	1
Guinea	1,462	690	1
India	8,363	9,780	1
Indonesia	10,150	13,642	1
Italy	794	0	1
Jordan	1,530	470	1
Kazakhstan	642	930	1
Kenya	131	55	1
Kyrgyzstan	393	300	1
Laos	2,212	1,997	1
Malawi	630	300	0
Mali	537	165	0

Morocco	300	350	1
Myanmar	258	790	1
Nepal	2,794	1,047	1
Nigeria	6,062	4,387	1
Pakistan	18,899	10,386	1
Papua New Guinea	251	51	1
Peru	353	206	0
Philippines	536	600	1
Republic of Congo	307	120	1
Serbia	609	350	1
South Africa	4,304	10,932	1
Sri Lanka	2,818	1,340	1
Sudan	1,182	390	1
Tajikistan	332	400	1
Uganda	1,943	783	1
United Kingdom	7,772	3,540	0
Uzbekistan	401	150	1
Vietnam	9,528	11,974	1
Zambia	2,042	1,110	1
Zimbabwe	1,268	908	1
Total	**111,672**	**90,401**	**-**

Table S5. Summary of technology (ultra-supercritical, supercritical, or subcritical) and pollution controls (SO_2 control, NO_x control, and PM control) of coal power plants financed by national DFIs (unit: GW). For comparison among national DFIs, we choose coal plants with financing commitments made between 2013-2017.

	Year of financing commitments: 2013-2017					
Financing DFIs	**China (CDB & CHEXIM)**		**Japan (JBIC & JICA)**		**Korea (KDB & KEXIM)**	
Total coal power capacity (GW)	34.0	(100%)	14.7	(100%)	3.8	(100%)
Ultra-supercritical	1.3	(4%)	6.9	(47%)	1.2	(32%)
Supercritical	20.5	(60%)	6.6	(45%)	2.4	(63%)
Subcritical	7.1	(21%)	1.2	(8%)	0.2	(5%)
SO_2 control[a]	19.9	(58%)	8.4	(57%)	2.6	(68%)
SO_2 control excl. CF[b]	11.1	(33%)	4.4	(30%)	2.6	(68%)
NO_x control	10.0	(29%)	1.9	(13%)	1.2	(32%)
PM control	19.6	(58%)	11.0	(75%)	2.4	(63%)

Notes:

[a] We aim to compare DFIs' financing to coal power plants and these coal plants' installation of pollution control devices. However the change in installation rates of SO_2 control devices in coal plants financed by CDB and CHEXIM between two periods (2013-2017 vs. 2005-2014) indicates data inconsistencies. Generally, a higher fraction of coal fired power plants have pollution control devices installed in recent years due to increasingly stringent emission and air quality standards and due to concerns about air pollution and its adverse health impacts in recipient countries. Therefore air pollutant emission control data from WEPP is likely underestimating the installation rates, because according to WEPP data, CDB- and CHEXIM-financed coal plants between 2013-2017 have lower installation rates than coal plants financed between 2005-2014. We note that numbers listed here are likely the lower bound of actual installation rates as lack of data coverage in WEPP may indicate lack of installation of pollution control devices, incomplete reporting of control devices installed, or lack of data access.

Therefore it is difficult to draw definitive conclusions. The imperfect data coverage highlights the need for a more transparent and complete reporting system for coal fired power plants.

[b] Compliance fuel (CF) is a SO_2 control strategy that requires that coal burned in the power plants meet certain standards (e.g. sulfur content level of coal). CF is listed as SO_2 control in WEPP when it is the only known control strategy for a coal plant and there is no other physical equipment of end-of-pipe control. We exclude CF in order to examine the installation of end-of-pipe control devices.

Table S6. Summary of steam conditions and pollution control technologies of coal power plants financed by Chinese DFIs vs. by the MDBs (including MDBs collectively, and AsDB and AfDB separately) (unit: GW). For comparison between Chinese DFIs and the MDBs, we choose coal plants with financing commitments made between 2005-2014.

	Year of financing commitments: 2005-2014							
Financing DFIs	China (CDB & CHEXIM)		MDBs[a]		AsDB		AfDB	
Total coal power capacity (GW)	31.5	(100%)	20.3	(100%)	10.4	(100%)	5.5	(100%)
Ultra-supercritical	0.0	(0%)	1.4	(7%)	0.0	(0%)	0.0	(0%)
Supercritical	13.4	(42%)	12.2	(60%)	6.6	(64%)	4.8	(87%)
Subcritical	17.8	(57%)	6.7	(33%)	3.8	(36%)	0.7	(13%)
SO2 control	27.5	(87%)	20.0	(99%)	10.4	(100%)	5.5	(100%)
SO2 control excl. CF	11.1	(35%)	6.0	(30%)	1.9	(18%)	0.6	(11%)
NOx control	5.7	(18%)	10.2	(50%)	4.0	(39%)	4.8	(87%)
PM control	27.3	(87%)	19.1	(94%)	9.3	(90%)	5.5	(100%)

Notes:

[a] MDBs examined here include the WB, IFC, AsDB, AfDB, EBRD, IsDB, IADB and MIGA. CAF and EIB did not finance any coal plants during 2005-2014.

Table S7. CO_2 emissions from power plants with partial or full financing from Chinese DFIs (CDB and CHEXIM) (unit: Gt CO_2), related to Table 2. Total committed emissions are separated into realized emissions before the end of 2018 and remaining committed emissions afterwards. Emissions are summarized by fuel and by recipient country. The power plants are facilitated by CDB's and CHEXIM's financing commitments between 2000-2018.

	Committed emissions (Gt CO_2)	Realized emissions	Remaining committed emissions
By fuel type			
Coal	11.81	0.88	10.93
Oil	0.14	0.00	0.14
Gas	0.08	0.01	0.06
By country			
India	3.50	0.47	3.03
Indonesia	3.01	0.21	2.80
Vietnam	1.99	0.12	1.87
South Africa	1.82	0.04	1.78
Rest of world	1.72	0.06	1.65
Total	**12.03**	**0.89**	**11.14**

Table S8. CO_2 emissions from power plants with partial or full financing from Japanese DFIs (JBIC and JICA) (unit: Gt CO_2), related to Table 2. The power plants are facilitated by JBIC and JICA's financing commitments between 2013-2017[a]. Data for JBIC and JICA's financing of gas and oil plants is unavailable, therefore we only include emissions from financed coal plants. Emissions summarized by recipient country.

	Committed emissions (Gt CO_2)	Realized emissions	Remaining committed emissions
By fuel type			
Coal	3.25	0.06	3.19
By country			
Indonesia	1.09	0.00	1.09
India	1.04	0.03	1.00
Vietnam	0.69	0.01	0.68
Morocco	0.32	0.01	0.31
Rest of world	0.12	0.01	0.11

Note:

[a] Power plants that were pending for financing are not included in the table. Coal fired power plants that JBIC or JICA were considering financing as of August 2017 will emit another 1.99 Gt CO_2 after 2018.

Table S9. CO_2 emissions from power plants with partial or full financing from South Korean DFIs (KDB and KEXIM) (unit: Gt CO_2), related to Table 2. The power plants are facilitated by KDB and KEXIM's financing commitments between 2013-2017[a]. Data for KDB and KEXIM's financing of gas and oil plants is unavailable, therefore we only include emissions from financed coal plants. Emissions summarized by recipient country.

	Committed emissions (Gt CO_2)	Realized emissions	Remaining committed emissions
By fuel type			
Coal	1.20	0.01	1.19
By country			
Vietnam	0.76	0.01	0.76
Kazakhstan	0.38	0.00	0.38
Indonesia	0.06	0.00	0.06

Note:

[a] Power plants that were pending for financing are not included in the table. Coal fired power plants that KDB or KEXIM were considering financing as of August 2017 will emit another 1.47 Gt CO_2 after 2018.

Table S10. CO_2 emissions from power plants with partial or full financing from the MDBs (unit: Gt CO_2), related to Table 2. Emissions are summarized by fuel and by recipient country. The power plants are facilitated by MDBs' financing commitments between 2005-2014. "Coal" plants include plants that use hard coal or lignite as fuel.

	Committed emissions (Gt CO_2)	Realized emissions	Remaining committed emissions
By fuel type			
Coal	5.00	1.11	3.89
Oil	0.15	0.02	0.12
Gas	3.41	0.54	2.87
By country			
India	2.60	0.65	1.95
South Africa	1.10	0.19	0.91
Egypt	0.77	0.12	0.66
Vietnam	0.45	0.10	0.35
Rest of world	3.63	0.61	3.02
Total	**8.56**	**1.67**	**6.89**

Table S11. Capital costs of power plants across fuel types (unit: US$/kW), related to Figure S3. To illustrate the uncertainty of capital costs of power plants, minimum and maximum estimates from IEA and IRENA reports are presented[a].

Fuel type	Capital costs used in this study[a] (US$/kW)	Estimates of average capital costs from alternative sources (US$/kW)			
		IEA (2015)		IRENA (2020)[b]	
		min	max	min	max
Coal	1,500	813	3,067	-	-
Gas	1,000	500	1,289	-	-
Oil	1,000	-	-	-	-
Nuclear	4,756	1,807	6,215	-	-
Hydro	2,186	598	9,400	800	>5,500
Solar	2,500	728	2,563	772	>5,500
Wind	2,354	1,200	2,999	1,120	3,060
Biomass	4,200	587	8,667	500	>10,000

Note:

[a] Average capital costs of power plants used in this study are estimated by Li et al. (2020) based on the same IEA report listed here and an older version of the IRENA report listed here.

[b] Maximum estimates of the average capital costs of hydro, solar, and biomass power plants are not directly available from the IRENA report, thus rough ranges are listed instead. They are still indicative of the large range between minimum and maximum estimates of capital costs.

Table S12. Estimated capacity factor and emission intensity. Capacity factor and emission intensity estimated in this study represent the average capacity factor and emission intensity of power plants covered in this study, weighted by nameplate generation capacity.

	Capacity factor		Emission intensity (kg CO_2/MWh)	
Fuel type	**This study**	**Other studies[a]**	**This study**	**Other studies[b]**
Coal	57%	44% - 61%	1,072	889 - 1,668
Gas	42%	35% - 39%	610	453 - 713
Oil	39%	28%	778	657 - 869

Note:

[a] Davis & Socolow (2014); Pfeiffer et al. (2018).

[b] Davis & Socolow (2014); IEA (2018); Tong et al. (2018).

Supplemental Methods

Committed CO_2 emissions: estimating the capacity factor and emission intensity of DFI financed power plants using CARMA

CARMA contains information of 68,931 power plants worldwide (Center for Global Development, 2012). It estimates these power plants' annual power generation (MWh) and annual CO_2 emission (Mt CO_2) in 2004, in 2009 or for a future year. CARMA includes the power plants' names but not their fuel type or generation capacity. To obtain information about the fuel type and generation capacity of power plants documented in CARMA, we first merged CARMA with WEPP (2012 version). Through this process we also divided the power plants in CARMA into individual power generators (each power plant documented in WEPP can have one or more generators). We used WEPP 2012 version because it has the highest degree of overlap with CARMA (89% of the power plants in CARMA were found in WEPP 2012).

Second, we searched for the power plants financed by East Asian national DFIs in CARMA. If the power plant was found in CARMA and has a non-zero value for annual CO_2 emissions in 2009 or estimated for a future year, we used CARMA's estimation of its annual CO_2 emissions if the power plant's documented nameplate capacity stays the same between WEPP 2012 and WEPP 2019 databases. For power plants whose capacity changed from WEPP 2012 version to WEPP 2019 version we scaled the emissions based on the capacity change. Scaling is necessary because CARMA was developed in 2012 and new generator(s) may have been added to the same

plant after that. We did not use CARMA's annual emission data in 2004 because the majority of DFI financed plants commenced or will commence operation after 2004.

Third, if the East Asian national DFI financed power plant was not found in CARMA, we estimated the capacity factor and emission intensity of this plant's individual generators according to the average capacity factor and emission intensity of power generators in CARMA (i) that are located in the same country, (ii) that use the same fuel type (e.g. coal, gas, or oil) and the same fuel (e.g. anthracite coal, bituminous coal, lignite, or sub-bituminous coal; conventional gas, liquefied natural gas, or liquefied petroleum gas), and (iii) whose nameplate capacity is within ± one standard deviation range of the DFI financed generators (standard deviation is calculated based on power generators in CARMA that meet requirements (i) and (ii)). If no eligible power generator was found in CARMA that met these three requirements, we relaxed the second requirement to include power generators that use the same fuel type but not necessarily exactly the same fuel. If there was still no eligible power generator, we further relaxed the third requirement and included power generators of all sizes that are in the same country and use the same fuel type. If still no generator was eligible, we estimated the emissions based on the average capacity factor and emission intensity of power generators burning the same type of fuel around the world. In this step, uncertainty is introduced with the relaxation of screening constraints in order to construct a sample for our estimation.

Fourth, we estimated the capacity factor and emission intensity of MDB financed plants. The MDB database from Steffen and Schmidt (2018) documents power generation projects' total capacity and fuel type (coal, lignite, gas, or oil) but not the capacity of each generator or specific

fuel used (e.g. different types of gas or oil). To estimate the CO_2 emissions from MDB financed power plants, we therefore applied a similar procedure to the third step described above but largely relaxed the conditions when screening eligible power generators in CARMA. For each MDB financed fossil fuel plant, we estimated its capacity factor and emission intensity based on the average capacity factor and emission intensity of power plants (rather than generators) in CARMA (i) that are in the same country, (ii) that use the same fuel type (with the exception of MDB financed plants that use lignite as fuel, for which we chose plants in CARMA that also use lignite as fuel as our sample), and (iii) with similar nameplate generation capacity (defined as nameplate capacity within ± one standard deviation). Similar to the third step, when no eligible plant was found in CARMA, we relaxed the screening constraints step by step in the analysis.

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Appendix for Chapter 3

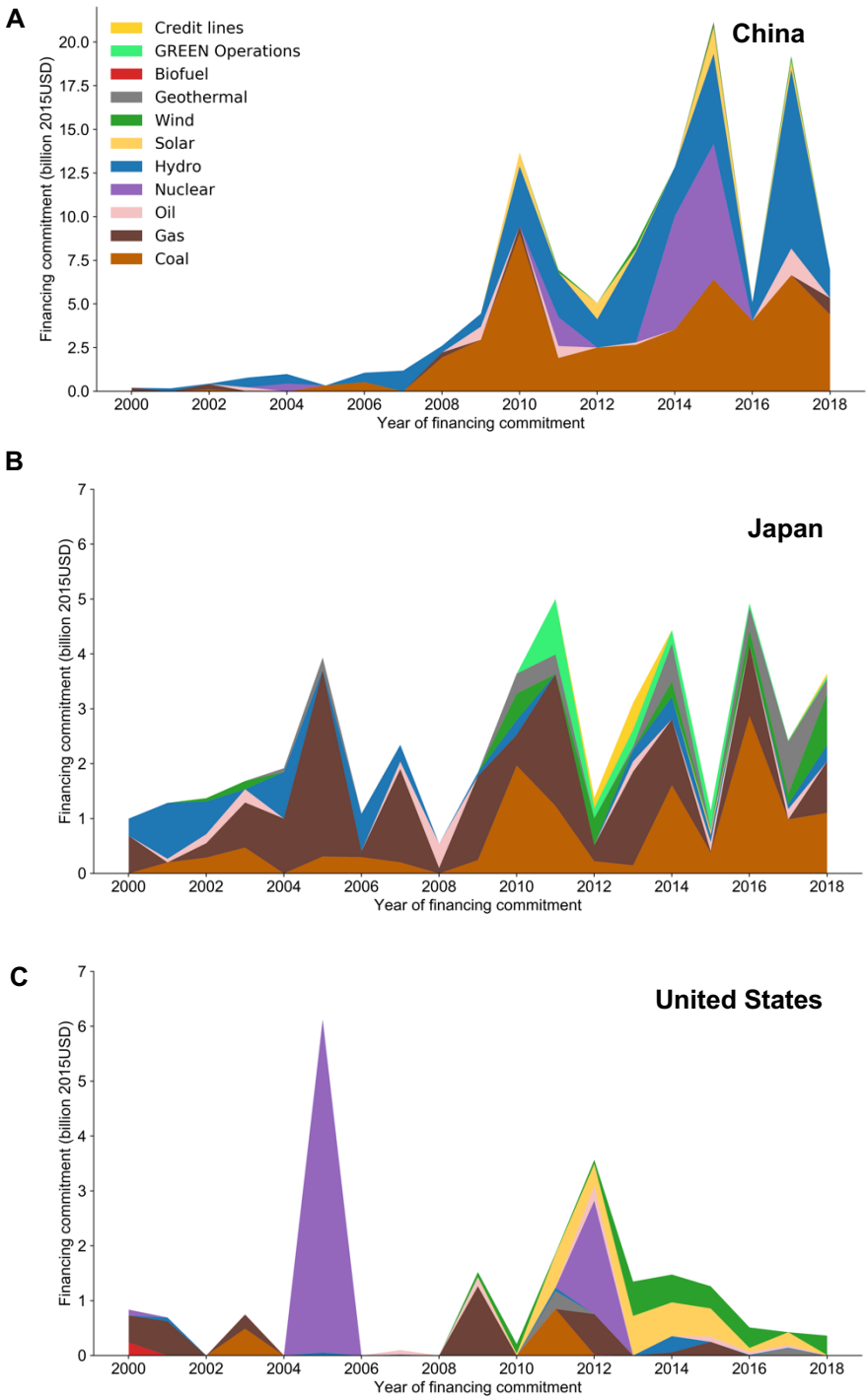


Figure S1. Annual development financing committed by (A) Chinese, (B) Japanese, and (C) U.S. DFIs between 2000 and 2018, by technology type (unit: billion 2015USD). Overseas development

financing is counted in the year in which a financing commitment is made. “Credit line” represents JBIC’s overseas finance to renewable projects provided via lines of credit. “GREEN operations” represent JBIC’s overseas finance to renewable projects provided under its “Global Action for Reconciling Economic Growth and ENvironmental Preservation” framework.

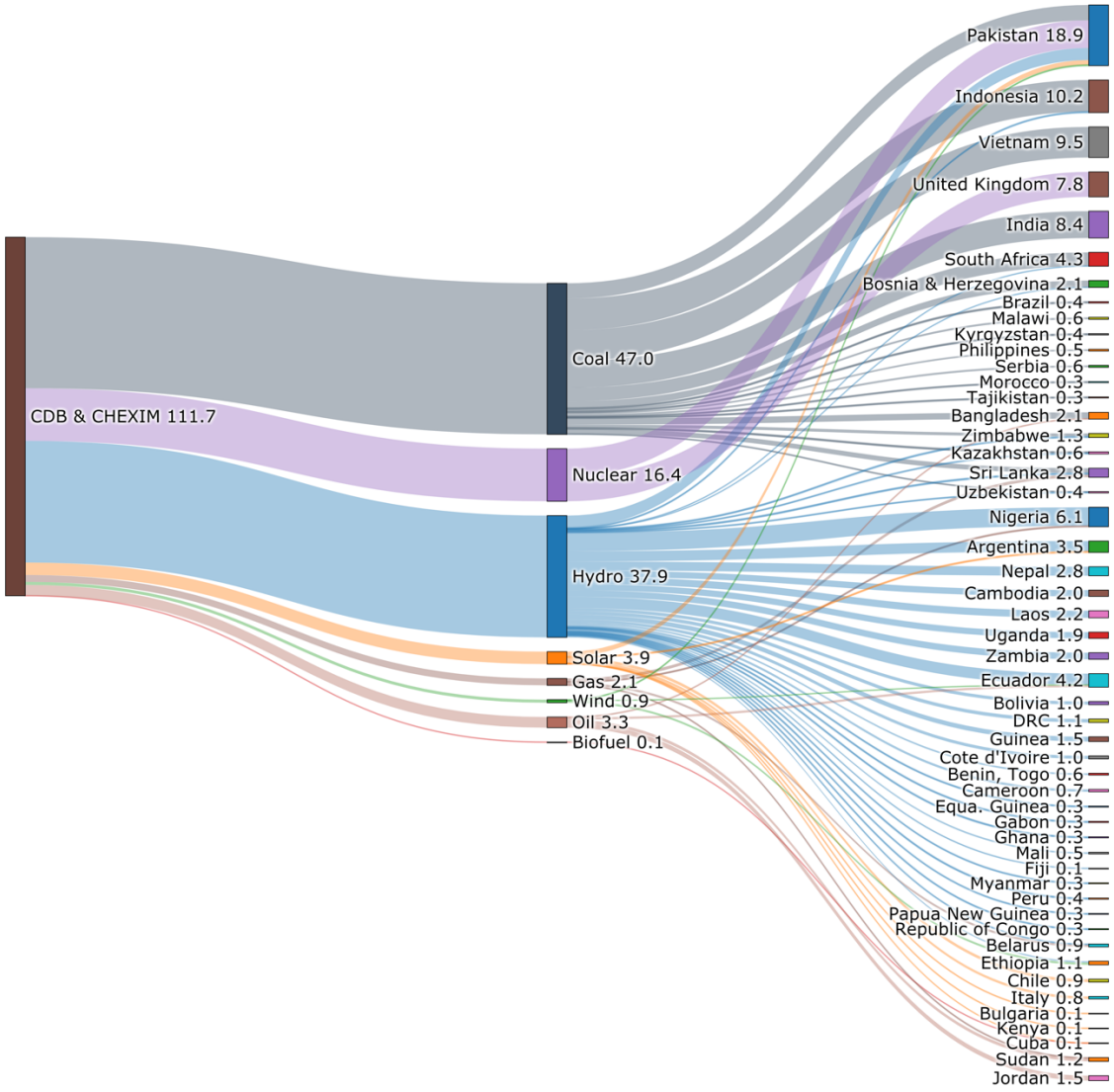


Figure S2. Financing commitments from Chinese DFIs to recipient countries between 2000 and 2018, colored by technology type (unit: billion 2015USD).

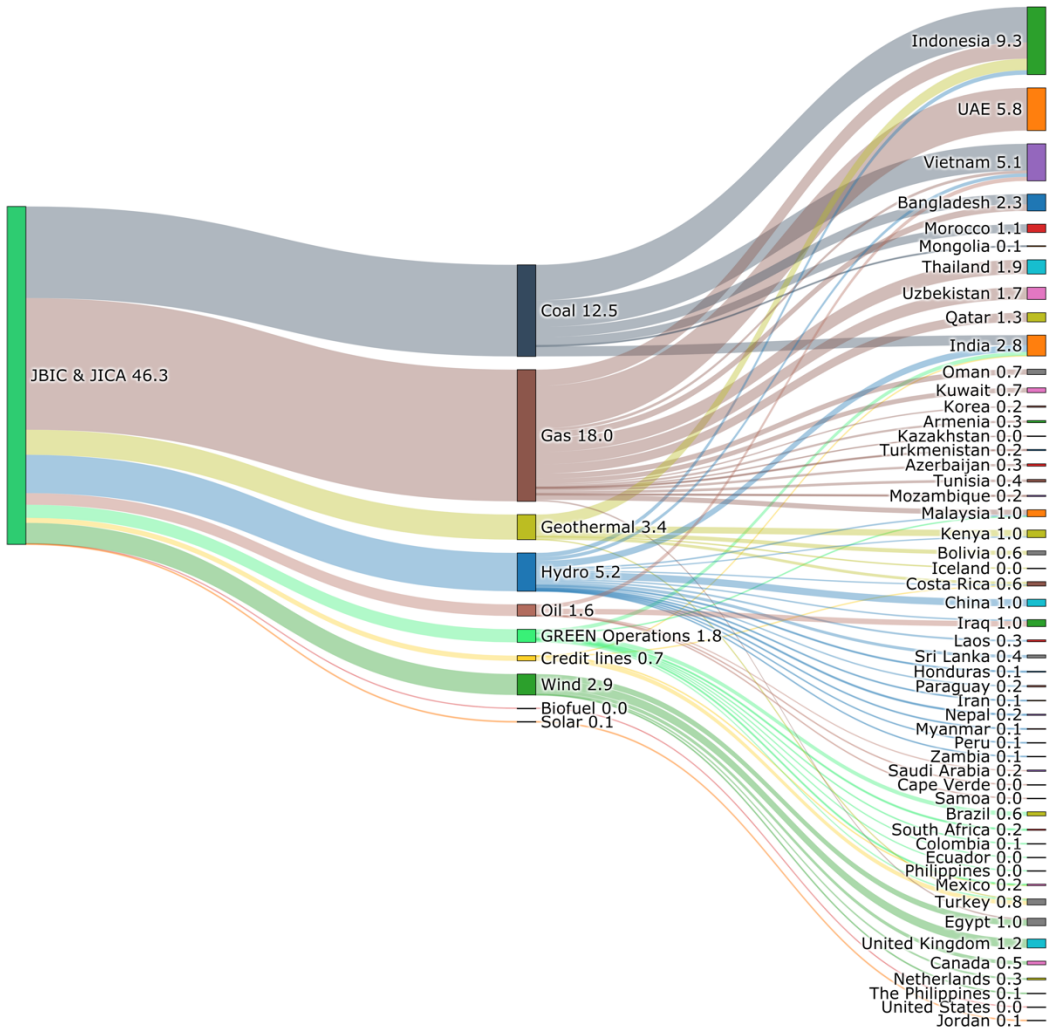


Figure S3. Financing commitments from Japanese DFIs to recipient countries between 2000 and 2018, colored by technology type (unit: billion 2015USD).

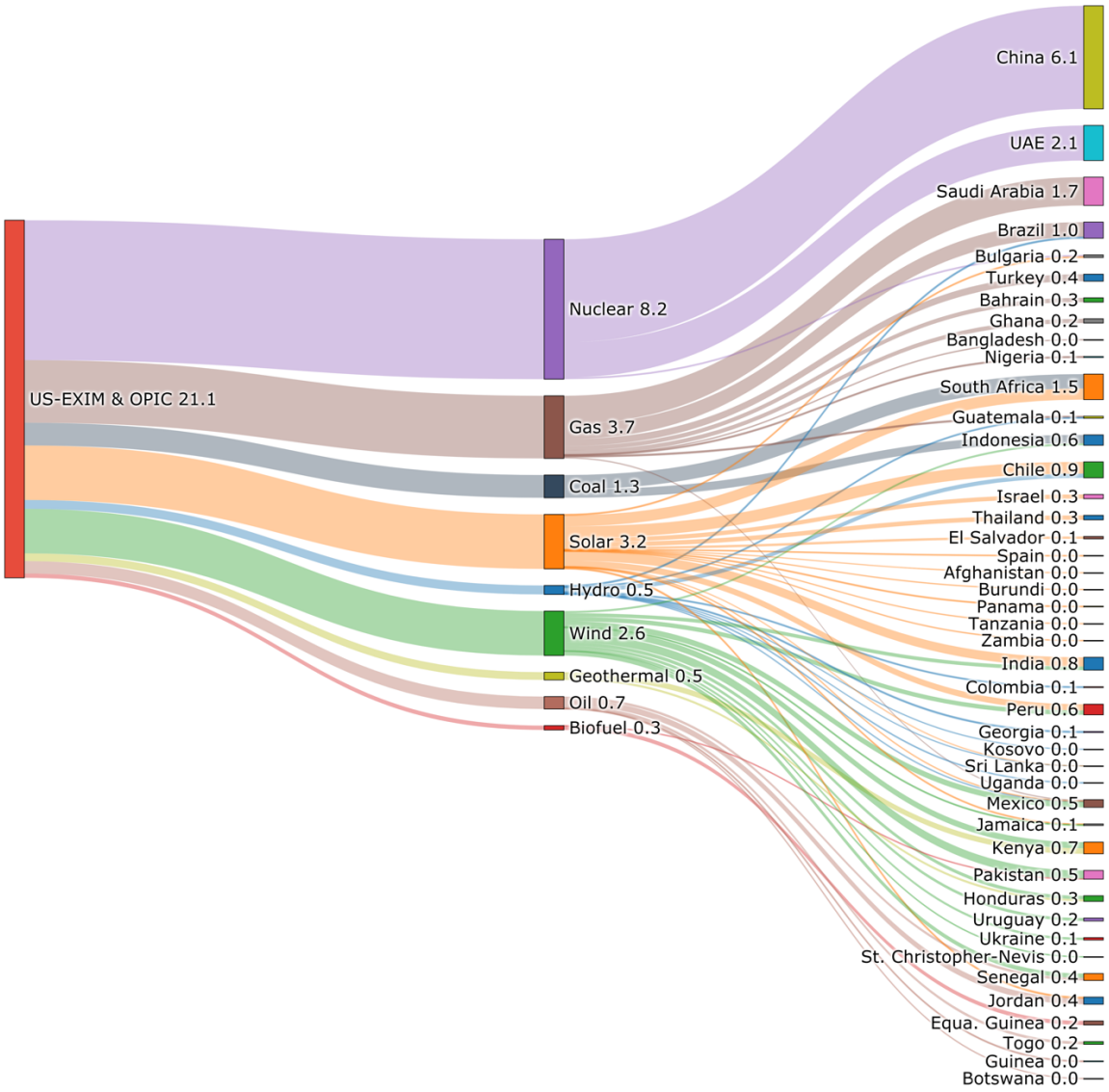


Figure S4. Financing commitments from U.S. DFIs to recipient countries between 2000 and 2018, colored by technology type (unit: billion 2015USD).

Appendix for Chapter 4

Table S1. Expected lifetimes of power plants by technology.

Power plant technology	Lifetime (years)
Coal	40
Gas	40
Oil	40
Nuclear	40
Hydro	65
Solar	25
Wind	20
Geothermal	30
Biomass & waste	20

Table S2. Heat rates and efficiencies of various power plant technologies.

	Technology	Heat rate (Btu/kWh)	Efficiency (%)
Coal	Subcritical	9,478	36%
	Supercritical	8,530	40%
	Ultra-supercritical	7,582	45%
Gas	Gas turbine	11,373	30%
	Steam turbine	10,339	33%
	Internal combustion	8,979	38%
	Combined cycle	7,582	45%
Oil		8,979	38%