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Financing carbon lock-in in developing countries: Bilateral financing for power generation technologies from China, Japan, and the United States

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HIGHLIGHTS

- We find China, Japan, and the U.S. to be major financiers of overseas power plants.
- Most of their financed power capacity additions are from coal and gas plants.
- Bilateral financing of fossil fuel plants locks in carbon emissions for decades.
- It is urgent to align bilateral power sector financing with the Paris commitments.

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ABSTRACT

Power sector decarbonization requires a fundamental redirection of global finance from fossil fuel infrastructure towards low carbon technologies. Bilateral finance plays an important role in the global energy transition to non-fossil energy, but an understanding of its impact is limited. Here, for the first time, we compare the influence of overseas finance from the three largest economies – United States, China, and Japan – on power generation development beyond their borders and evaluate the associated long-term CO_2 emissions. We construct a new dataset of Japanese and U.S. overseas power generation finance between 2000 and 2018 by analyzing their national development finance institutions' press releases and annual reports and tracking their foreign direct investment at the power plant level. Synthesizing this new data with previously developed datasets for China, we find that the three countries' overseas financing concentrated in fossil fuel power technologies over the studied period. Financing commitments from China, Japan, and the United States facilitated 101 GW, 95 GW, and 47 GW overseas power capacity additions, respectively. The majority of facilitated capacity additions are fossil fuel plants (64% for China, 87% for Japan, and 66% for the United States). Each of the countries' contributions to non-hydro renewable generation was less than 15% of their facilitated capacity additions. Together, we estimate that overseas fossil fuel power financing through 2018 from these three countries will lock in 24 Gt CO_2 emissions by 2060. If climate targets are to be met, replacing bilateral fossil fuel financing with financing of renewable technologies is crucial.

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 [1–4]. Decarbonizing the power generation sector is particularly crucial, as electrification is a key strategy for decarbonizing other end-use sectors like transport and buildings [1,3,5–7]. This energy transformation requires vast investment in low carbon technologies and a rapid and fundamental redirection of global finance away from fossil fuel infrastructure.

International investment through bilateral and multilateral financing has been facilitating power infrastructure development in developing countries [8,9] and can play a pivotal role in the clean energy transition [10]. Among international financiers, most of the largest multilateral

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Nomenclature

BRI	Belt and Road Initiative
CDB	China Development Bank
CHEXIM	The Export-Import Bank of China
DFC	U.S. International Development Finance Corporation
DFI	Development Finance Institution
ECA	Export Credit Agency
FDI	Foreign Direct Investment
GHG	Greenhouse Gas
GREEN Operations	"Global action for Reconciling Economic growth and ENvironmental preservation" Operations
IDFC	International Development Finance Club
JBIC	Japan Bank for International Cooperation
JFC	Japan Finance Corporation
JICA	Japan International Cooperation Agency
M&A	Mergers and Acquisitions
MDB	Multilateral Development Bank
ODA	Official Development Assistance
OPIC	Overseas Private Investment Corporation
UAE	The United Arab Emirates
US-EXIM	The Export-Import Bank of the United States
USAID	U.S. Agency for International Development
WEPP	World Electric Power Plant (Database)

development banks (MDBs) have gradually shifted their financing portfolios away from fossil fuel power projects towards renewable projects since the 2010s [8]. In 2017, the major MDBs declared jointly with members of the International Development Finance Club (IDFC) that they would align their financing activities with the Paris Agreement and in 2018 further reinforced this commitment [11,12]. After 2017, none of the major MDBs have provided new financing for coal-fired power plants and will not in the future.

While most research and policy arrangements on power sector decarbonization have focused on multilateral finance, bilateral finance plays an increasingly important role. However, structured analyses of bilateral financing of the power generation sector are limited and its influence is much less understood. Advanced economies such as Japan have long provided both technologies and financing in the power sector of developing countries [9]. Beginning in the late 2000s, China emerged as a prominent source of international finance for global power generation [13–15]. Existing studies on coal power financing indicate that national development finance institutions (DFIs) and commercial investors from China, the United States, Japan, Germany, and South Korea have provided significant finance for overseas coal-fired power plants since 2000 [16–19]. Yet comprehensive analyses that cover all types of power technologies, especially non-coal technologies, are missing. Therefore, the impact of bilateral financing on global fossil fuel and renewable power adoption remains unclear. Bilateral financing of renewable technologies is critical to facilitate the low carbon energy transition in developing countries and financing of fossil fuels amplifies carbon lock-in [20]. Thus, understanding the role of bilateral financing and its implications for global power sector decarbonization is important.

Here, for the first time, we elucidate the role of bilateral finance from the United States, China, and Japan, the three largest economies in the world, in facilitating power generation technology deployment beyond their borders. Chen et al. [13] and Li et al. [15] have compiled Chinese overseas power finance data but similar research for U.S. and Japanese overseas finance across power generation technologies has not been conducted due to data limitations. To fill this gap, we construct new datasets for Japanese and U.S. overseas finance across all power generation technologies. Synthesizing this new data with previously developed datasets for China, we provide the first characterization of bilateral power finance from China, Japan, and the U.S. between 2000 and 2018 and a systematic comparison of their contributions to power generation deployment around the world. We analyze two channels of financing from these three countries: public financing from their national DFIs and commercial financing in the form of greenfield foreign direct investment (FDI). The new Japanese and U.S. power finance datasets are compiled by analyzing Japanese and U.S. DFIs' press releases and annual reports and tracking Japanese and U.S. greenfield FDI in overseas power plants using the World Electric Power Plant Database (WEPP) from S&P Global Market Intelligence. Utilizing the newly constructed datasets, 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 across different regions for each type of bilateral finance. We also estimate the long-term CO_2 emissions resulting from these countries' financial commitments to overseas fossil fuel power plants.

The paper is structured as follows: in Section 2 we review and discuss bilateral financing in the power generation sector and relevant policy arrangements; in Section 3 we introduce data sources and methodology; in Section 4 we discuss results and findings from multiple perspectives; in Section 5 we discuss policy implications for global power sector decarbonization; lastly, we conclude in Section 6.

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

Bilateral financing is overtaking the role of multilateral lending in global power generation development [13,14]. Bilateral financing occurs in the commercial sector through FDI and increasingly through national DFIs, in addition to traditional official development assistance (ODA). Through FDI, electric power companies invest in overseas power plants and hold 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 the development of key sectors as mandated by the governments, such as electricity generation, infrastructure and power technology export, and the promotion of national firms. 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 has 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.

2.1. U.S. overseas power finance

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 [21]. Since then, its contribution to the overseas electric power sector (including generation, transmission, and distribution) has been around US$10–20 billion annually [21]. 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 supported off-grid and utility-scale power projects around the world. Prominently, through partnership in the U.S. Power Africa Initiative, OPIC supported more than 30 power projects since 2013 [22]. 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.

2.2. Japanese overseas power finance

Japanese finance has 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$258 billion in 2019 [23]. Japanese electric power companies, which hold large domestic power generation assets, such as Mitsubishi Corporation, have successfully expanded to the 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 the 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 the 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 uses loans to support Japanese power equipment export or Japanese FDI. Specifically, under its "Global action for Reconciling Economic growth and ENvironmental preservation" (GREEN) operations, JBIC supports overseas renewable energy and energy efficiency projects as well as 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 the early 2000s [9].

2.3. Chinese overseas power finance

China's overseas financing of power plants has been rapidly expanding for over a decade. Before 2000, China was a major destination of FDI with around US$40 billion FDI inflows and less than US$5 billion outflows [24]. 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$137 billion in 2019 [24]. Chinese power companies have also increasingly integrated with the global economy, leading to a rapid increase of FDI in overseas power generation. As a result, by 2017 Chinese companies held around US$115 billion foreign power generation assets [15]. 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 [14]. 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 [13]. 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 in 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. CHEXIM offers export credit for trade and loans for China's overseas investment and contracting. Additionally, it also facilitates international economic cooperation by granting loans to eligible projects that may not involve Chinese companies.

2.4. Policy arrangements on bilateral power finance

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. 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 lacks completeness. Overall, 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, however, are currently limited. The OECD Arrangement on Officially Supported Export Credits (the "Arrangement") places environmental regulation on export credit; however, emerging market 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 [25]. The IDFC, of which JICA and CDB are members, is committed to implementing the Sustainable Development Goals and the Paris Agreement, but has not committed to specific targets and timelines in which to do so. 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 [26]. 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. After the U.S.-led Climate Summit in April 2021 where South Korea announced an end to its public financing for overseas coal plants, China and Japan are left as the only major public financiers for overseas coal plants. Nevertheless, none of China, Japan, the U.S., or other major economies has put in place policies to restrict private financing for overseas coal plants or public financing for other types of fossil fuel plants such as gas power plants.

3. Methods and data

To examine the impact of bilateral financing from China, Japan, and the U.S. on power generation technology deployment around the world, we compile a new database for Japanese and U.S. overseas finance and combine it with the existing Chinese data from Chen et al. [13] and Li et al. [15]. 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. 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 investments. 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. 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.

3.1. Constructing datasets for DFI overseas power financing

Each of the examined national DFIs from China, Japan, and the U.S. lacks full transparency when disclosing their overseas financing activities. Except for 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 examined 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. We construct plant-level data of JBIC's and US-EXIM's financing of overseas power plants between 2000 and 2018 utilizing the press release archives, annual reports, the WEPP database, together with web searches. We construct JICA's plant-level financing data using JICA's ODA Loan Project Data [27], JICA's press release archive, JICA's project evaluation reports, and the WEPP database. OPIC's project-level financing data is constructed using three data sources: OPIC's annual reports from 2000 to 2019, OPIC's Portfolio by Project as of 9/30/2018 [28], and DFC's Active Projects database as of 6/30/2020 [29] (see Supplementary Method for more detailed steps of constructing each DFI's financing data).

3.2. Constructing datasets for FDI in power plants

Companies' FDI is considered commercial information and thus project-level data is generally not publicly disclosed in a systematic way. Therefore, we track Japanese and U.S. greenfield FDI in overseas power plants following the methodology in Li et al. [15]. We search through the WEPP database using a list of keywords of Japanese and U.S. electric power companies to 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. 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 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 over the same period of 2000–2018, we examine financed power plants with a commissioning year of 2005 or later so that the impact of FDI occurring before 2000 is excluded. This allows for a 5-year lag between financing commitments and power plant commissioning, which is the average lag 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.

3.3. Impacts on generation capacity growth

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. [13], we label this impact of bilateral financing on power capacity growth as "facilitated capacity additions".

3.4. Committed CO_2 emissions from financed power plants

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. [13]. 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 database [30].

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. committed significant finance to global power generation development between 2000 and 2018. Chinese DFIs specifically, despite being latecomers to international development financing, 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 (Fig. 1). Japanese and U.S. DFIs were 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 (Fig. S1). In contrast, overseas finance from Chinese DFIs increased substantially from the late 2000s to the late 2010s – from less than US$5 billion per year before 2010 to a peak of US$21 billion in 2015 (Fig. S1). More recently, Chinese DFIs have scaled back their 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 (Fig. S2–S4). The most Chinese DFI financing was committed to coal (US$47 billion; 42%), with lesser 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 of U.S. DFI financing was to gas (US$4 billion; 18%), solar (US$3 billion; 15%) and wind power (US$3 billion; 12%). Meanwhile, OPIC contributed to the vast majority of these solar and wind projects.

Chinese, Japanese, and U.S. DFIs' different financing portfolios reflect their distinct policy priorities. Two Chinese DFIs, CDB and CHEXIM, 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 moved away from coal power financing. U.S. DFIs are significantly different. OPIC followed its vision to support small and medium enterprises and catalyze private sector investment, and was mostly engaged in financing wind and solar plants. US-EXIM's contributions to overseas gas, solar, and wind plants were closely linked with its policy agenda to support U.S. export. JBIC supported Japanese businesses through its financing of overseas gas and coal plants which utilize Japanese FDI or equipment. Its financing of renewable projects was mainly through the GREEN Operations and export credit lines. JICA's ODA, in contrast, was mostly untied loan commitment.

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 (Fig. S1). All three countries' commitments to non-hydro renewables increased after 2010 when the 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 for expanding electricity access in developing countries. Two U.S. DFIs had distinct financing portfolios. While the technology mix of US-EXIM didn't change significantly (mostly to fossil fuel and nuclear 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.

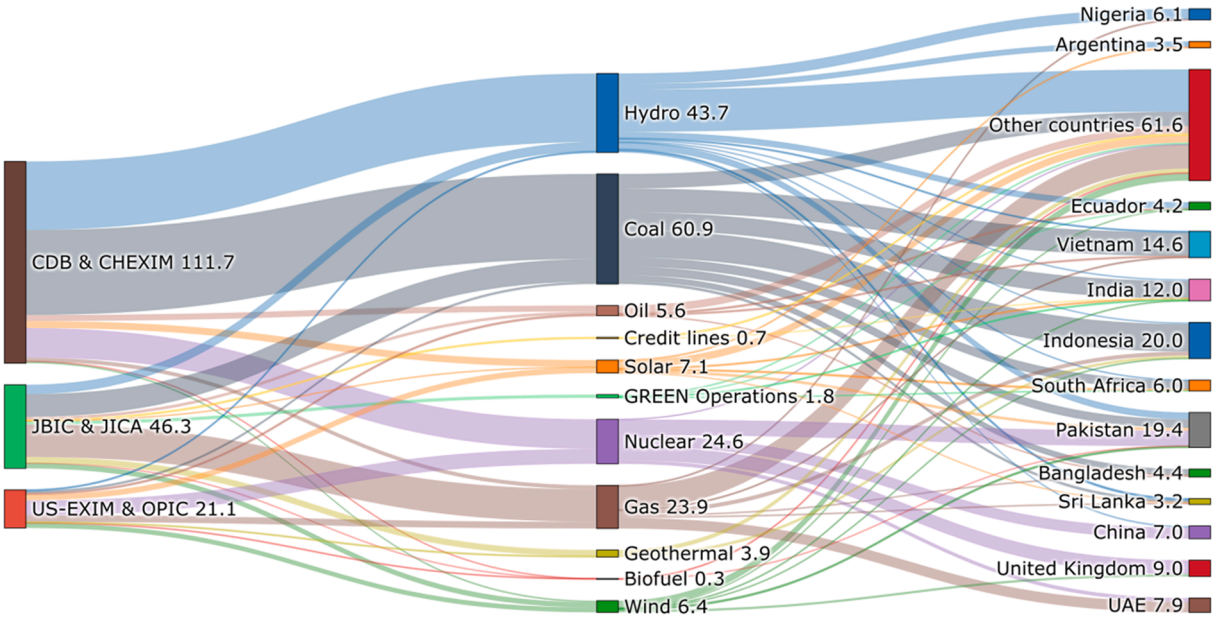

Fig. 1. Total financing commitments from Chinese, Japanese, and U.S. DFIs to recipient countries between 2000 and 2018, by technology type (unit: billion 2015USD). Colors of financing flow indicate different technology types. Numbers indicate financing commitments. Also see Figs. S2-S4 for financial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

Geographically, Chinese and Japanese DFIs 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 (Fig. S2-S4). Chinese and Japanese DFIs both financed hotspot recipient countries like Indonesia, Vietnam, and India, where electricity demand grows rapidly, mostly in support of their coal plants. Other recipient countries, likely strategic or close partners of the financing countries, received preferential finance from DFIs of one country. For example, Chinese DFIs 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. supported power sector development in all developing regions of the world. Their development finance to overseas power plants combined surpassed the major MDBs' total commitments as estimated in Steffen and Schmidt [8], doubling the available global development finance.

4.2. Contribution of Chinese, Japanese, and 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 Fig. 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 approximately 70 GW of new generation capacity were commissioned annually in non-OECD countries except China [31]. Thus, about one-fifth of capacity growth in non-OECD countries except China was facilitated by bilateral finance from China, Japan, or the U.S.

Respectively, Chinese, Japanese, and U.S. overseas finance facilitated 101 GW, 95 GW, and 47 GW generation capacity additions

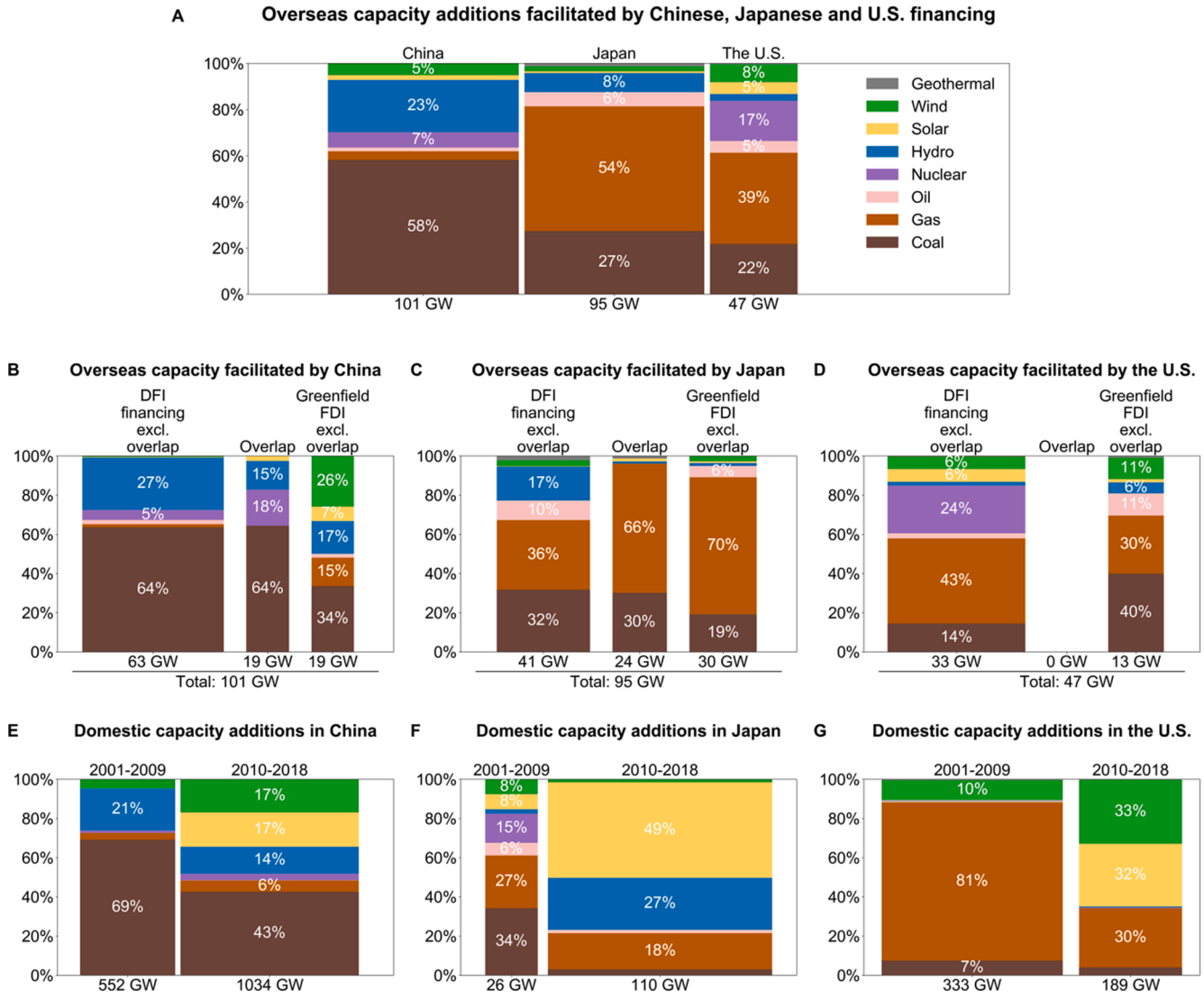

Fig. 2. Total power generation capacity additions facilitated by Chinese, Japanese, and U.S. overseas financing between 2000 and 2018, by technology type (**A**). The facilitated capacity additions include power plants that were in operation or under construction as of 2019 which have a commissioning year of 2005 or after. Colors indicate different fuel/technology types. Widths of bars represent facilitated capacity additions. The 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 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 and 2009 and between 2010 and 2018, by technology (retired and decommissioned capacity not included).

(including co-financed plants; Fig. 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. One reason is that 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 leveraged other financial resources more than China, whereas Chinese DFI financing was more concentrated and funded a larger portion of the power plant's total costs. On the other hand, Japanese enterprises 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 Chinese, Japanese, and U.S. finance facilitated capacity additions in fossil fuel power were as high as 64%, 87%, and 66%, respectively. China's overseas finance contributed the most to coal-fired power generation, followed by hydroelectric power. Together coal and hydroelectric power account for over 80% of China's facilitated capacity additions. In comparison, China's involvement in overseas natural gas plants was 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' contributions to non-hydro renewable technology deployment were limited, with the U.S. being the only one that devoted 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. In the case of China, the 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 extended 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 made a larger contribution to overseas coal plants and hydroelectric dams. The technology portfolio of Japanese FDI, on the other hand, was 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 "greenness" of the technology portfolios of Chinese, Japanese, and U.S. 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 (Fig. 2). Between 2010 and 2018, 34%, 50%, and 65% of new capacity additions (retirement and decommissioning of old generation capacity excluded) were wind or solar power in China, Japan, and the U.S., respectively. Yet, overseas capacity additions facilitated by their DFIs were much more concentrated on fossil fuels, resembling the three financing countries' domestic capacity development between 2001 and 2009. While the portfolio of Chinese greenfield FDI is similar to China's domestic development between 2010 and 2018, portfolios of Japanese and U.S. FDI are much less "green" 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. all used bilateral financing to support their equipment and service export (Fig. 3). Among China, Japan, and the U.S. financed power plants, 42–53% deployed major equipment manufactured within the financing country. Not surprisingly, DFI financing supported 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, 35% of Japanese financed plants and 22% of the U.S. financed plants hired a Japanese or U.S. contractor.

Moving from the financing countries to the recipient countries, in Fig. 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 these recipient countries, the technology mixes of facilitated capacity additions receiving bilateral finance align with these recipient countries' domestic power sector 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 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 fuels.

4.3. Committed CO_2 emissions associated with Chinese, Japanese, and U.S. overseas power finance

Bilateral finance has significantly facilitated global power generation development, both through direct financing and its 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 were mostly concentrated on 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 operates for decades. Continued financing of fossil fuel infrastructure 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. (Fig. 5). The financed fossil fuel plants 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 would 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 fuel plants.

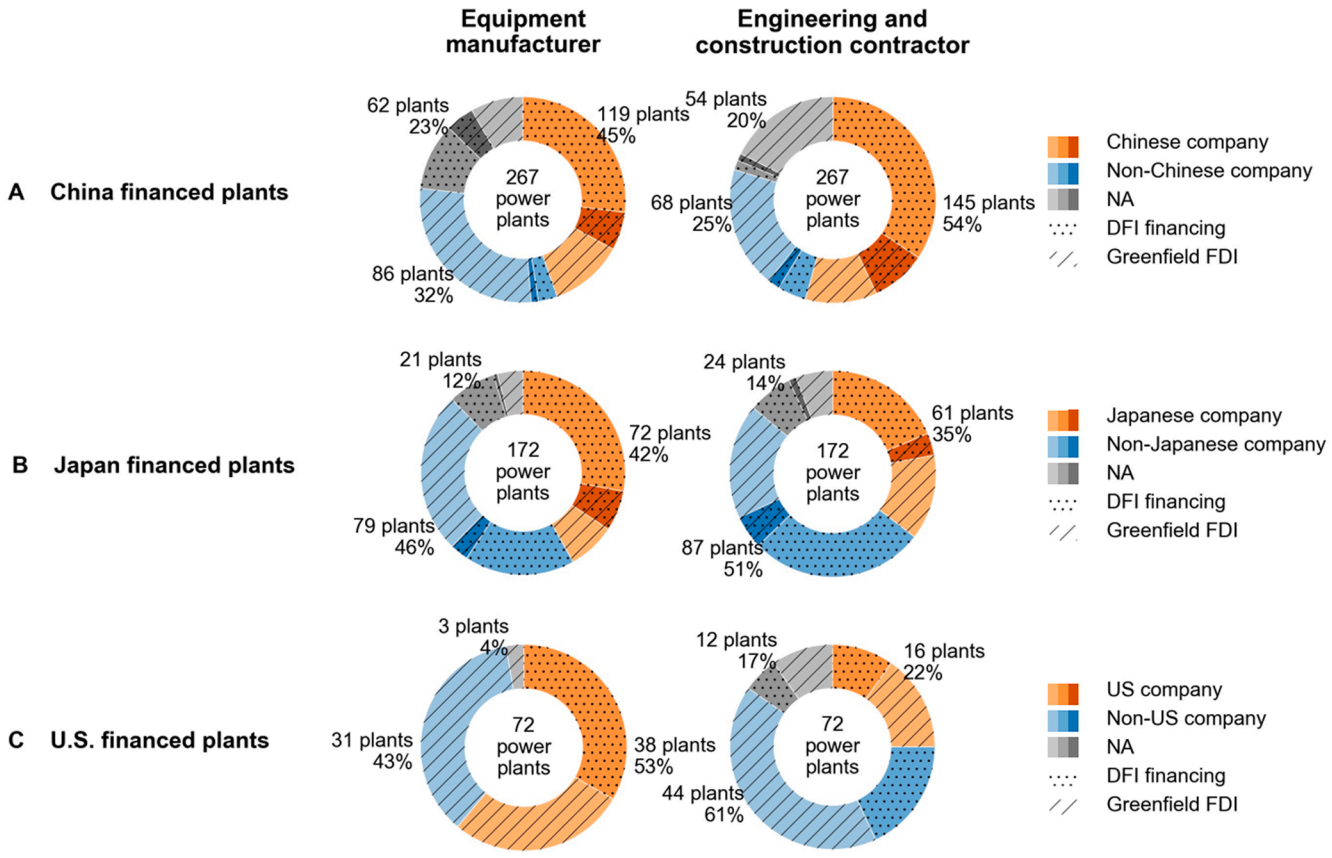

Fig. 3. Nationality of manufacturers and contractors of power plants that received bilateral finance from China, Japan, and the U.S. The hollow circles and the numbers at the center of these circles represent numbers of power plants with overseas financing from (**A**) China, (**B**) Japan, and (**C**) the U.S. U.S. DFI financing only includes US-EXIM. The financed 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.

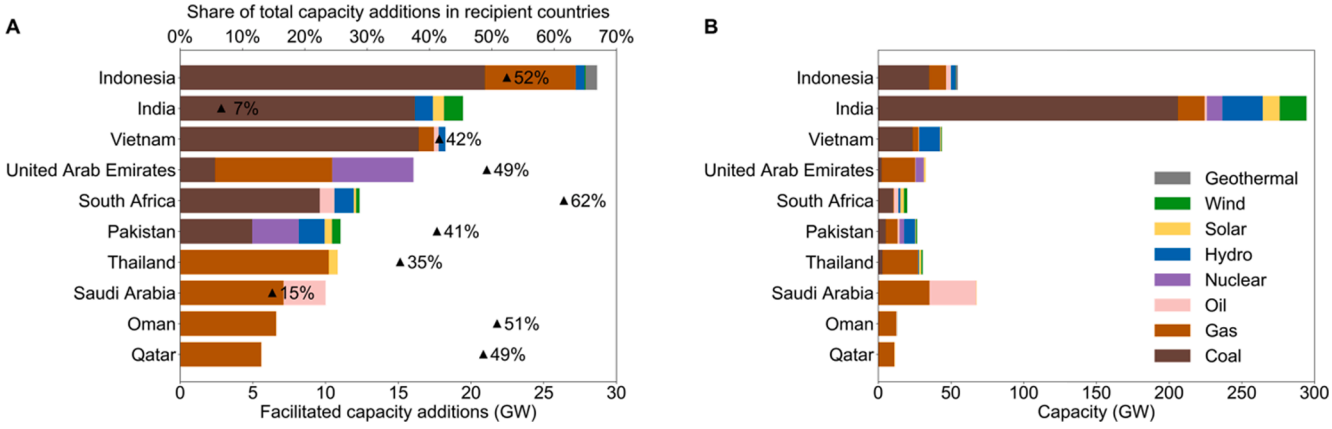

Fig. 4. Ten recipient countries with the most power capacity additions facilitated by overseas finance from China, Japan, and the U.S. **A:** Capacity additions facilitated by Chinese, Japanese, and U.S. finance committed between 2000 and 2018 and their shares in the total capacity added in the recipient countries in or after 2005. 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 includes plants that were in operation or under construction as of 2019. Colors indicate different technology types.

5. Policy implications

The financing commitments from China, Japan, and the U.S. to overseas fossil fuel power infrastructure are misaligned with the Paris Agreement Article 2.1(c) to "[make] finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development" and will pose long-term climate and financial risks. The goal of the Paris Agreement to limit global average temperature increases to less than 2 °C or preferably 1.5 °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. were still under construction as of 2019 and

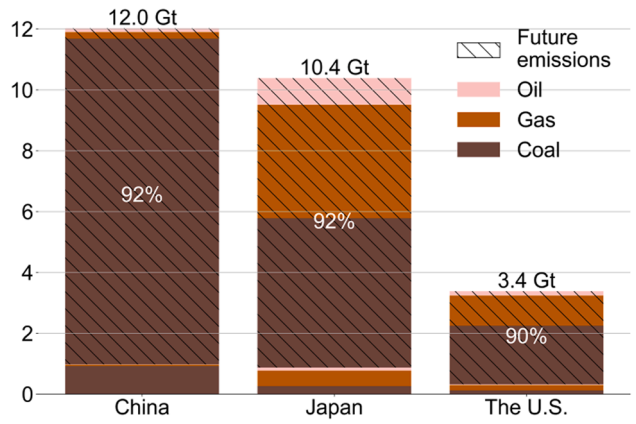

Fig. 5. Committed lifetime CO_2 emissions from power plants with Chinese, Japanese, and U.S. overseas financing between 2000 and 2018. Emissions from power plants with a commissioning year of 2005 or after, which were in operation or under construction as of 2019, are shown. Numbers above each country 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 co-financed a few plants. Percentages over shaded areas indicate the fractions of future CO_2 emissions (emissions occurring after 2019) out of total lifetime emissions. Colors indicate different fossil fuel types.

the vast majority of the projected CO_2 emissions would 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 [3]. On the other hand, with the 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 [32], 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. 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 their overseas finance are not as "green" as each 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. At present, national climate policies only account for greenhouse gas (GHG) emissions produced domestically. Neither national nor international climate policies consider the impacts of international financing on global GHG emissions. To characterize the impacts of bilateral financing commitments on the climate, more transparency is needed. While all major MDBs 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. Japanese and U.S. financing, specifically, is misaligned with the Paris Agreement which in Article 9.7 requires developed country parties to "provide transparent and consistent information on support for developing countries" [33]. Importantly, 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 imperative that national DFIs divest away from financing overseas fossil fuel infrastructure and move towards financing a low-carbon power system.

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 in the process of its domestic renewable power development. China's renewable power development has also contributed to the manufacturing cost reduction of solar panels and wind turbines globally and has facilitated global renewable power deployment. Through the BRI, China has signed a Memorandum of Understanding with 138 countries as of March 2020. Although overseas finance from CDB and CHEXIM decreased in 2019 [34], BRI still stands as an umbrella of bilateral cooperation, through which CDB and CHEXIM may support overseas renewable and sustainable businesses 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 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 in January 2021, 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 power infrastructure, U.S. policies would have larger climate benefits.

6. Conclusions

Through tracking overseas finance from China, Japan, and the U.S. to the global power generation sector between 2000 and 2018, our analyses illuminate 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 additions since 2005 around the globe. This accounted for one-fifth of generation capacity growth in non-OECD countries except China. However, while multilateral financing has shown signs of moving towards supporting renewable technologies in line with the Sustainable Development Goals and the Paris Agreement, bilateral finance has lagged in this transition. We find that Chinese, Japanese, and U.S. overseas finance between 2000 and 2018, through their DFI financing and greenfield FDI, 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 plants. Among their total facilitated capacity additions, less than 10% are non-hydro renewable technologies. To decarbonize the power generation sector and meet the

Paris climate targets, steering bilateral financing from fossil fuel technologies towards renewables is crucial.

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. 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 of natural gas infrastructure. 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 on power sector technology choices is needed. National governments must make DFIs transparent in their fossil fuel lending practices to allow understanding of the alignment of their balance sheets with climate goals and to facilitate decarbonization.

7. Data availability

Chinese, Japanese and U.S. overseas power generation finance data can be found at https://doi.org/10.34770/dgqm-rk88. Part of our database utilizes proprietary data through subscription to the World Electric Power Plant Database from S&P Global Market Intelligence. We provide WEPP unit IDs for this data and additional information from WEPP can be obtained using the power units' IDs via subscription to the WEPP database.

CRediT authorship contribution statement

Xu Chen: Conceptualization, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing - original draft, Writing - review & editing. **Zhongshu Li:** Investigation. **Kevin P. Gallagher:** Conceptualization, Writing - review & editing, Supervision, Funding acquisition. **Denise L. Mauzerall:** Conceptualization, Writing - original draft, Writing - review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apenergy.2021.117318.

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