Multilevel actor networks in China's growing fossil-fuel based role in the global electricity sector

Sauer, Jürgen Michael Thomas; Kirchherr, Julian; Plummer Braeckman, Judith; Díaz Anadón, Laura

Published in:
Environmental Research Letters

DOI:
10.1088/1748-9326/ad7bcf

Publication date:
2024

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Sauer, J. M. T., Kirchherr, J., Plummer Braeckman, J., & Díaz Anadón, L. (2024). Multilevel actor networks in China's growing fossil-fuel based role in the global electricity sector. *Environmental Research Letters*, *19*(11), Article 114037. https://doi.org/10.1088/1748-9326/ad7bcf

LETTER • **OPEN ACCESS**

Multilevel actor networks in China's growing fossil-fuel based role in the global electricity sector

ENVIRONMENTAL RESEARCH
LETTERS

LETTER

Multilevel actor networks in China's growing fossil-fuel based role in the global electricity sector

Jürgen Michael Thomas Sauer[1,*], **Julian Kirchherr**[2], **Judith Plummer-Braeckman**[3] and **Laura Díaz Anadón**[1,4]

[1] Department of Land Economy, Centre for Environment, Energy and Natural Resource Governance (C-EENRG), University of Cambridge, Cambridge CB2 3QZ, United Kingdom
[2] Copernicus Institute of Sustainable Development, Utrecht University, 3584 CB Utrecht, The Netherlands
[3] University of Cambridge Institute for Sustainability Leadership, Entopia Building 1 RegentStreet, Cambridge CB2 1GG, United Kingdom
[4] Belfer Center for Science and International Affairs, Havard University, Cambridge, MA 02138, United States of America
[*] Author to whom any correspondence should be addressed.

E-mail: jmts5@cam.ac.uk

Keywords: china, belt and road initiative, development, electricity sector, networks

Supplementary material for this article is available online

OPEN ACCESS

RECEIVED
3 October 2023

REVISED
30 August 2024

ACCEPTED FOR PUBLICATION
17 September 2024

PUBLISHED
3 October 2024

Abstract

Chinese investments into fossil fuel-based electricity generation capacity under its belt and road initiative will create lock-in for decades. Despite China's recent rise as major public finance provider for the electricity sector of the developing world and the related environmental impacts, there is limited knowledge of the extent and characteristics of non-Chinese participation in Chinese-funded projects. We apply complexity theory approaches and network modeling on a new dataset that links funding activities of developmental institutions (Chinese developmental institutions (CDIs), Western-backed multilateral development banks (MDBs)) and the involvement of companies in different roles (i.e., as direct investors, contractors, equipment suppliers, and other service providers) to power plants around the world at the unit-level (1999–2020). Previous literature suggests that CDI funded projects show preference to Chinese commercial partners, but we find more than 70% include non-Chinese participants. This also applies for fossil-fuel based technologies where we observe increasing shares of international actors that together account for nearly every third commercial linkage. However, involvement levels and interaction patterns not only differ by technologies (fossils, hydro, non-hydro renewable, nuclear) but also by the time period and types of commercial partners and we observe overall convergence between the CDI- and MDB-supported power plant networks over time. The decreasing involvement of Chinese companies in CDI-funded projects, across technologies, in favor of increasing Western involvement, has important implications for development and climate policy on which we elaborate. However, the failure of both MDB and CDI funding to promote domestic company involvement in the recipient countries may be the largest failing of both sets of agencies in the pursuit of development outcomes.

1. Introduction

Western policymakers and scholars often state that Chinese development finance is more 'self-interested' than its Western complements [1–4]. A central claim is that China is using its development program supported by Chinese development institutions (CDIs) to secure unfair commercial advantage for the international expansion of Chinese companies (e.g. 5, 6) related to construction, equipment manufacturing, and trading [6]. Given the immense scale and related potential environmental impacts of China's belt and road initiative (BRI)—for which infrastructure investment estimates range in the trillions [7, 8]—suggestions regarding the possible unfair advantage enjoyed by Chinese companies in BRI projects have become more frequent (e.g. 9–15). Given that this Chinese Government backed infrastructure

investment programme spans over 70 countries, the commercial opportunities it could offer are significant. However, despite increasing attention to the involvement of different types of commercial entities (e.g. owner, contractor, equipment supplier) in implementing Chinese-funded infrastructure projects, the various claims of a Chinese bias lack empirical evidence (see Supplemental Text S1 for a more detailed literature review and more background on Chinas BRI and its underlying motivations). This lack of clear data is largely a result of difficulties tracking project funding activities of CDIs [16, 17] their project procurement processes [18] and the companies involved. In the words of a recent World Bank paper: 'comprehensive and comparable cross-country data permitting analysis do not exist' (18, p 133).

The present study addresses this gap for commercial entities involved in CDI-funded power plant projects in the global electricity sector in comparison to those funded by multilateral development banks (MDBs) and non-CDI/MDB-supported projects. MDBs, have long been considered the key development finance providers in the power sector [19–21]. For the purposes of this paper, we consider Western-backed MDBs to be traditional MDBs with at least one country from the global north amongst their main contributors, in line with Steffen and Schmidt (2019).

The recent rapid emergence of CDIs now rivals their dominating role [16, 22, 23]. The electricity sector is an important sector to understand because there is evidence that it has received the majority of China's investments under its BRI so far [24, 25] and research indicates that the majority of CDI-funded electricity capacity is coal fired with immense environmental implications [16, 26]. Coal-fired capacity increases supported by CDI were calculated as 46.5 MW in 2020 [16], the largest area of CDI-backed electricity investment, causing concern as to climate impacts.

We apply complexity theory approaches [27, 28] and simple network modeling to a new dataset that not only links funding activities of financial institutions (CDIs, MDBs), but also the involvement of companies in different roles, to power plant investments around the world between 1999 and 2020. The database breaks power plants down to unit (turbine) level, reflecting that some plants are built in unit-based stages rather than all at once, and thus that the companies involved in construction may differ between units. Thee corporate roles can be as diverse as direct investors, contractors, equipment suppliers, and other service providers, and together with the financiers, are described generically, in this paper, as 'actors' in the field of power plant development. This allows us to analyse: the evolution of the prevalence of non-Chinese commercial involvement in CDI-funded power plants. Hence expanding consideration of the ways in which companies interact along the CDI-funded power plant value chain relative to MDB- and non-CDI/MDB-supported projects and across different technologies (fossils, hydro, non-hydro-renewables, nuclear). Our research contrasts with previous global quantitative academic research on the Chinese expansion in the global power sector, which has tended to focus on separate actors such as developmental institutions: [16, 22]; direct investors: [26,29]; and contractors: [29] (see text S1 for a more detailed literature review).

By following this comparative approach and including the broad range of actors involved in power projects, this study maps the evolution of networks of actors in both CDI- and MDB-funded projects globally. Building on studies that understand energy systems as complex adaptive systems (CASs) [28, 30, 31], we expand beyond a reductionistic 'single-species' research approach [28] by creating a granular power plant unit-level network perspective that includes all main commercial entity types involved in CDI- and MDB-funded power plants globally. This is particularly valuable in the Chinese context as it has been suggested that CDIs and Chinese companies constitute a highly interlinked system in their internationalization with a considerably higher degree of state coordination in comparison to the approach from the West ([6, 18, 32–34]; supplemental text S1 for literature review).

2. Methods

2.1. Covered actors

Following Sauer *et al* [16] this work not only covers China's two largest bilateral developmental institutions (the Export-Import Bank of China (ExIm) and the China Development Bank (CDB)), but also China-backed development funds which are restricted to specific areas or purposes (such as the Silk Road Fund) and two newly established China-backed MDBs: the Asian infrastructure investment bank (AIIB) and New Development Bank (NDB)). Table S1 provides a full list of the developmental institutions and Western-backed MDBs included in the study. The involvement of Chinese companies is contrasted with the evolution of the involvement of domestic (headquartered in the country where the power plant project is located) and other international companies including companies from the top five major Western shareholder countries of traditional MDBs, namely, of the United States, Japan, France, United Kingdom and Germany. The commercial entities are categorized across the power plant value chain covering funding, development, construction, equipment and operation (see Supplemental Methods M2 and table S6 for more details).

2.2. Network analysis

Complexity theory 'provides an integrative and dynamic framework to understand the interaction

patterns in networks of interdependent agents' (35, p 356). Within this flexible framework, we consider the interaction of project funders and commercial entities involved in the planning, implementation and operation of power plant infrastructure as CASs defined as 'highly connected networks of semi-independent agents from which system wide patterns emerge' (36, p 334). More specifically, we use social network analysis techniques to investigate the interaction patterns of actors (see Bale *et al* [28] for a review). In line with Wang, Bar, and Hong [37], we develop and analyse two simple types of networks: first, an agency-power plant network that captures ties between different types of actors involved in power plant; and second, an agency-agency collaboration network that connects actors with a tie when their commercial activities appear in the same power plant units. Collaboration patterns in these networks are analyzed and visualized with force-directed spatialization algorithms, which model the network graphically (e.g.ForceAtlas2 [38]). A network community detection analysis is applied to the agency-agency collaboration networks using the Louvain algorithm [39] which helps to identify the groups of actors with the strongest connections to each other (see Supplemental Methods M1 for more details). This approach not only allows us see the global interaction patterns in CDI-supported plants, but also to explore comparative trends with the MDB-supported power plant network over time (using 1364 power plants, and 3024 distinct actors, between 2000 and2020).

Furthermore, we expand the analysis to several supporting comparison groups to contrast patterns with projects that are not supported by developmental institutions. As pointed out by Ghossein *et al* [18], this is important, as high observed shares in other projects might reflect that Chinese companies have simply become highly competitive and are equally prevalent in all types of infrastructure projects.

2.3. Dataset construction

The data on power plant funding activities from CDIs and MDBs for power plants globally in the period 1999–2020 was compiled by the authors of this work as described in more detail in Sauer *et al* (2022). This dataset draws on commercial data tracking, publicly available datasets, and more than 1000 supporting documents to match financial transactions by the main CDIs and MDBs in power plant projects worldwide. Here, we extend this dataset to involve commercial actors along the power plant value chain of those publicly supported power plants (and beyond) by using the commercial power plant dataset GlobalData (2020) and publicly available sources. This commercial data provider tracks the involvement of commercial companies along the power plant value chain of more than 130 000 power plants globally (according to the provider nearly all power plants in the world) and maintains a (separate) database with more than 40 000 energy companies. We use publicly available sources to track the headquarters of those companies, to classify them as state-owned or private and to support the matching and linking process needed for the analysis (using unique power plant identifiers as described in more detail in the supplemental method sections M2 and M3. This section also describes several robustness checks that have been conducted such as to verify indirect Chinese origins by, for example, checking for the headquarters of parent companies).

3. Results and discussion

3.1. Non-chinese participation in CDI-funded projects

We identify 350 CDI-funded power plants globally between 1999–2020 in our power plant network (i.e. directed network that captures ties from commercial entities to publicly supported power plants). Within this network of CDI-funded plants and companies involved in each project, we identify a link (tie) for at least one Chinese company for almost three-quarters (260/350) of all CDI-funded plants. For those plants where at least one Chinese actor is present, the share of Chinese actors in the total number of involved actors varies broadly from plants with minimal Chinese involvement (e.g. one-time supply of uncritical equipment) to a few plants where only Chinese actors could be identified (see supplemental figure S1 for the distribution of the shares). The mean share of Chinese commercial actors involved in CDI funded power plant implementation is 32.4%, with a standard deviation of 28.5%. This means that, on average across our data set, one in three commercial actors involved in CDI funded power plants are Chinese-based companies.

Figure 1 shows that across different actor types, the prevalence of Chinese actors in CDI-funded plants differs markedly. We observe the highest share being for Chinese equipment suppliers (43.9%), followed by Chinese contractors (38.9%) and considerably lower shares for Chinese power plant owners (19.6%). These differences may reflect the global competitiveness of different types of Chinese actors and institutional barriers to foreign plant ownership in CDI-funded recipient countries. As expected, and in line with their mandate to support the internationalization of Chinese companies [32], projects supported by the ExIm and CDB have the largest share of Chinese company participation across all actor types: 36.1% and 30%, respectively. These projects have considerably higher shares of Chinese commercial ties when compared to the newly established China-backed MDBs (AIIB = 7.2%, NDB = 2.8%) and China-backed development funds (19.7%), which might be explained by the lower degree of influence of the Chinese state that goes along with the multilateral nature of those

institutions. Supplemental table S2 provides more details on the number of actors involved and of plants per funding vehicle. Supplemental figure S2 demonstrates how involvement levels are relatively stable across technologies. The results are robust to several robustness checks, including checking for potentially missed indirect Chinese involvement via parent companies of subsidiaries and excluding the hypothesis that non-Chinese ties are limited to niche transactions[5] (see Methods for more details).

An important finding is that nearly 70% of the actors involved in CDI-funded projects are non-Chinese actors. CDI-supported projects are therefore considerably more open to non-Chinese involvement than recently suggested by the existing empirical estimates and various case-study based analysis (e.g. [10, 11, 13–15, 40]), according to which non-Chinese participation in Chinese-funded projects is restricted to 'niche roles' [9, p 6]. To contrast, Hillman [12] estimates that nearly 90% of the contractors in Chinese-funded projects covered are Chinese (see Supplemental Text S1 for more details). In addition, the heterogeneity of results across different CDIs implies the need for a more differentiated approach that goes beyond a generic BRI project classification—often any presence of Chinese actors that involves some form of funding or even only contracting in a foreign project is used to define a 'BRI project' (e.g. [9,24]), despite very different degrees to which the Chinese state is involved (see table S1). Two potential explanations for the observed discrepancy between our results and the existing literature might be data limitations from previous empirical studies (see supplemental text S1) and our focus on the more complex and knowledge-intensive electricity sector compared to other types of infrastructure, such as roads. The latter argument is supported by the fact that non-Chinese participation (in particular in the form of Western companies) is particularly prevalent for goods and services related to knowledge-intensive turbines and generators, as we elaborate later on in the results section.

3.2. Comparison with non-CDI-supported projects

Nevertheless, and as is also evident from figure 1, the share of Chinese actors in CDI-supported plants (32.4%) is nearly eight times greater than the share of Chinese actors in all non-CDI financed power plants (4.2%) in the same recipient countries excluding India[6]. This difference in the share of Chinese actors in CDI financed and non-CDI-financed power plants, which we refer to as the 'elevation effect' is significant at the 0.01 significance level. A disaggregation of the elevation effects by actor type (see figure 1) indicates that the relative elevation effect is by far the highest for plant owners (×17), followed by contractors (×7) and equipment suppliers (×5). The total CDI-supported plant capacity with full or partial ownership of Chinese companies equals to 38.4 GW (1999–2020), which represents 47% of the total global power plant capacity (81 GW) with Chinese foreign direct investments, as recently estimated by Li, Gallagher and Mauzerall [26] for the period 2000–2017. The elevation effect related to foreign plant ownership is particularly high for the CDB where 31% of all plant ownership ties are Chinese. Hence, we see a strong association between CDI financial support and the participation of Chinese companies in the ownership of foreign power plants.

We observe a considerably smaller 'elevation effect' for companies with a headquarters in major Western donor countries (USA, GER, FRA, GBR, JPN) when comparing Western-backed MDB-supported power plants (21.5%) and remaining power plants in recipient countries (20.5%). The observed difference is not statistically significant at the 0.05 significance level in this aggregated view. However, a disaggregated view by country and financial institutions indicates a few positive elevation effects for major Western shareholders of MDBs. For example, we see more companies from Japan in plants supported by the Asian development bank (see figure S3).

In line with claims that Chinese-supported projects are marked by low domestic involvement (e.g. [12,13]), by which we mean a low involvement of commercial actors from recipient countries, the share of domestic actors in CDI-supported plants (40%) is significantly (at the 0.01 significance level) lower when compared to all remaining non-CDI-supported plants in CDI recipient countries (57%). We also observe significantly lower domestic involvement for plants supported by Western-backed MDBs (see figure 1). However, for MDB-supported power plants, the 'crowding-out' effect (defined as reduced domestic actor shares compared to all remaining plants in MDB-recipient countries) is approximately three times smaller compared to the CDI-supported power plants when measured in absolute percentage difference (see figure 1). To some

[5] The data available does not provide evidence that domestic and other non-Chinese involvement was restricted to 'niche roles' [9, p.6] (see table S5 and S6 for full analysis that supports this conclusion). In only 37 cases (0.1%) it was possible to detect a Chinese parent company for the involved companies with a headquarters outside China (check 2). Out of the 3,507 ties between actors and power plants, only 29 (0.8%) had a headquarters in Hong Kong, and another 21 had Chinese origins (0.6%) (check 3).

[6] India has been excluded from the main comparison group due to its skewing effect linked to its relatively large size. Several robustness checks with synthetic counterfactuals (with and without India) support the view that the observed elevation effect in the main analysis is not artificially created by other unobserved variables (see supplemental note S4).

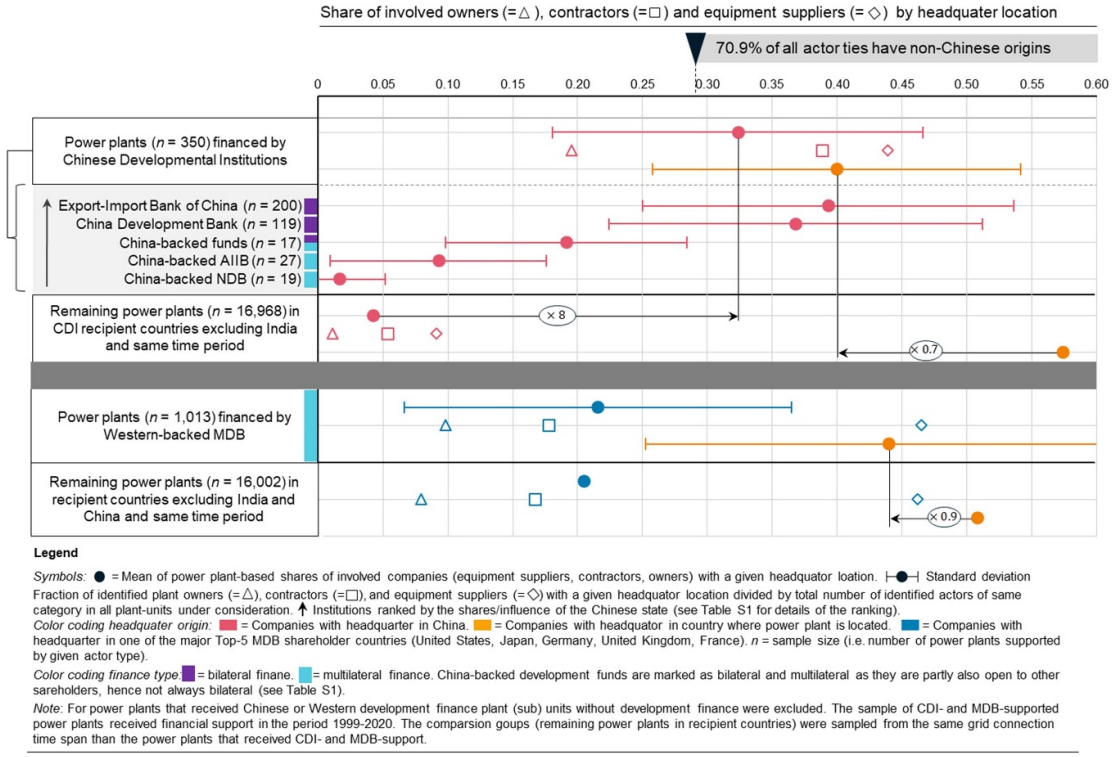

Figure 1. Share of Chinese and non-Chinese actors in ownership, contracting, and equipment supply engaged in power plants funded by Chinese developmental Institutions and Western-backed MDBs. The number in the ovals refers to the 'elevation effect' i.e. the ratio between the actor shares in publicly-supported power plants (CDIs top half, MDBs bottom half) divided by the observed shares of the same actor category in all remaining power plants in the recipient countries of the considered public finance types.

extent, the observed lower domestic involvement in CDI- and MDB-supported plants when compared to remaining power plants in recipient countries might be explained by the fact that the presence of MDBs and CDIs signals risk mitigation for private actors [41] which may make the investments and engagement more attractive for international players. Another possible explanation is that domestic actors may not have sufficient expertise to compete with the international bidders in such internationally funded projects. Future research could consider the extent to which one or both of these explanations play the dominant role.

3.3. Evolution of participation levels over time and technologies

Figure 2 displays how involvement levels for Chinese actors change over time. The three-year rolling average for companies with a headquarters in China in CDI-supported power plants shows a clear decreasing trend for plants connected to the grid in the period 2000–2020 (see figure 2(A)). This is in marked contrast to that which can be observed, in the same countries, for the share of Chinese companies in non-CDI-supported power plants, and for Western companies in MDB-supported plants.

As shown in panel B of figure 2, the share of Chinese actors decreased from 35% in the period before the initiation of the BRI (1999–2013) to 26% in the following period of the BRI (2013–2020) in favor of higher involvement of international actors including companies from the major Western MDB shareholder countries. From 2013–2020, these international actors show a strong increase in their presence in CDI-supported plants from 13% to 20%. The observed increase in Western and other international involvement levels is particularly prominent in the hydropower sector, where companies from the top 5 major MDB shareholders from OECD countries nearly triple their involvement (see figure 2(B1)). Fossil-fuel based technologies (of which the majority is coal-fired) also show a slight reduction of Chinese involvement in favor of more commercial linkages from Western and other international actors. The share of Western and other international linkages in fossil-fuel plants raises from 28% (1999–2012) to 33% in the period 2013–2020.

In contrast, domestic involvement (by companies headquartered in the recipient country) is not increasing with the decreasing Chinese presence as domestic involvement levels stay constant or decrease across technologies. Domestic involvement levels decrease from 38% in the period of the Going Out policy to 34% in the period of the BRI. However, averaged across all technologies we likewise do not find increasing domestic involvement

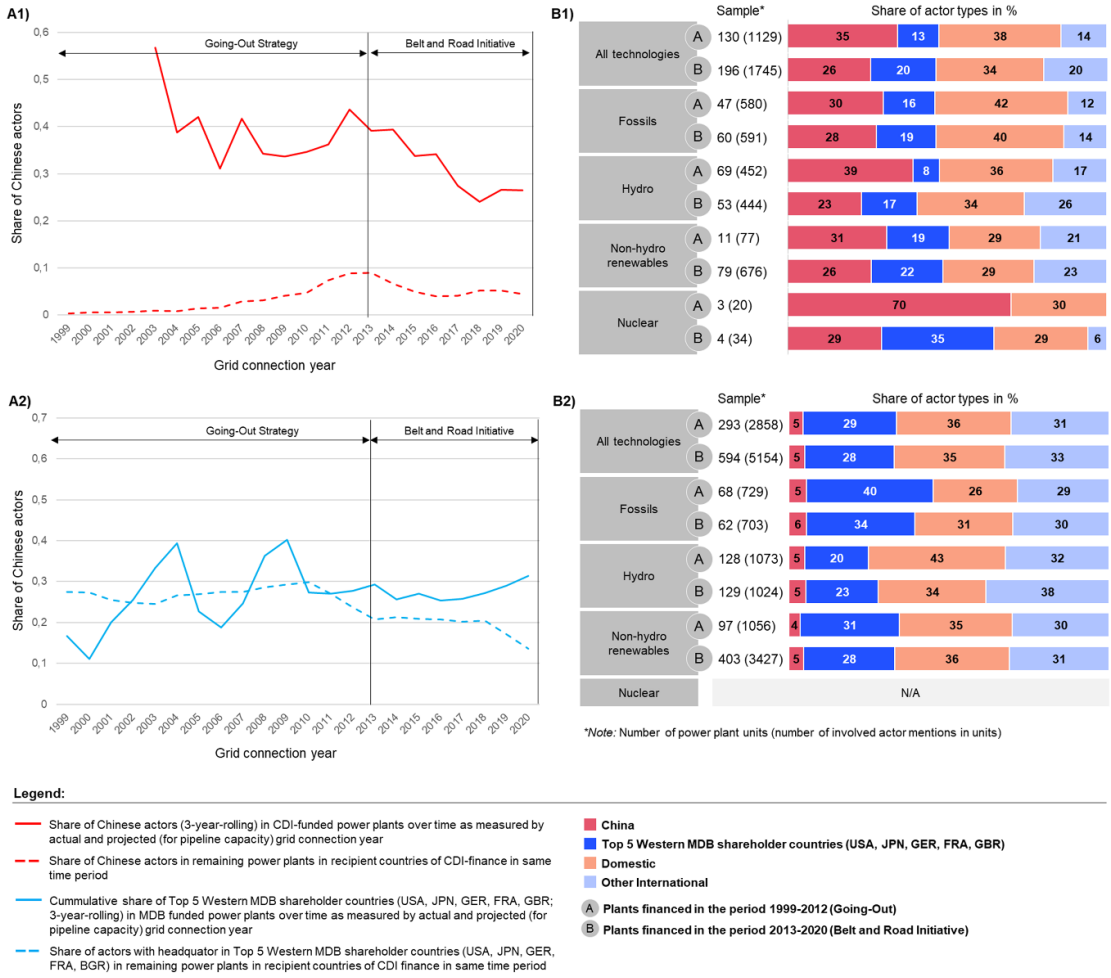

Figure 2. Chinese actor shares over time and by technology for CDI-supported power plants in comparative perspective to MDB-supported power plants. Panel (A1) displays the 3-year-rolling average of the share of Chinese actors in CDI-supported plants over time (1999–2020) in comparison to the shares of Chinese actors in all remaining power plants in countries where those CDI-supported plants are built. Panel (A2) provides a comparison for MDB-supported plants and the cumulative share from its major top-5 shareholders (United States, Japan, Germany, France, and United Kingdom) by replicating the analysis from Panel 1 for those actors. Panels (B1) and (B2) disaggregate the actor structure in CDI (Panel (B1)) and MDB (Panel (B2)) supported power plants further by technologies (fossils, hydro, non-hydro renewable, nuclear) and time-periods (1999–2012, 2013–2020). The sample is the number of power plant units and the number in parenthesis is the number of actors mentioned for that plant.

levels for power plants supported by Western-backed MDBs when the period of the Going Out Policy (36%) is compared with the following period of the BRI (35%).

Hence, we observe a decreasing share of Chinese involvement over time in favor of international and, in particular, Western actors from major MDB donor countries. The increasing shares of Western and other international actors in CDI-supported power plants might be a combined effect of the materialization of the announcements [42] of the Chinese state to make procurement processes within BRI projects more transparent and open. Similarly, it may reflect an increasing willingness of international actors to invest in CDI-supported projects as the CDI investments are increasingly converging towards less risky and thereby commercially more viable environments. As illustrated by Sauer *et al* [23], CDI investments cumulated in particularly risky environments during the period of the Going-Out policy, which raises the question of whether those projects would have been initiated and completed without the willingness of Chinese companies to invest in those high-risk areas. In addition, the steady or declining shares of domestic actors (local to the recipient country) over time for CDI- and MDB-funded projects alike raise the question of whether developmental institutions could do more to support the involvement of domestic actors, and consequent local development.

3.4. Comparison of network characteristics

We now present results on the collaboration patterns in CDI-supported power plants relative to what can be observed for MDB-supported power plants. The combined agency power plant network for the entire time period 1999–2020 contains 1364 power plants (350 CDI supported, 1050 MDB supported) and 3024 distinct actors (acting as funders, owners,

contractors, equipment suppliers, and other service providers) with a total of 12 354 ties. On average, a CDI-supported power plant had 10.3 reported ties to other actors, whereas MDB-supported plants had 9.5 ties. Likewise, we find that the average number of distinct actors involved in CDI-supported power plants (2.8) is comparable and slightly higher compared to MDB-supported plants (2.4). Table S7 provides additional network statistics (i.e., modularity, graph density), including the distribution of ties across different actor types, indicating that there are no evident major structural differences between the networks of actors involved in CDI- and MDB-supported power plants.

Figure 3 visualizes the combined agency-power plant (panels (A1) & (A2)) and agency-agency (panel (B)) network for CDI- and MDB-supported power plants. We separate the network of funding transactions before (1999–2012) and after the initiation of China's BRI (2013–2020). For CDIs, which are colored in dark red, the ExIm and CDB (denoted by the numbers 1 and 2, respectively, in figure 3) are the largest institutions measured by the number of ties to power plants, as represented by the size of the bubbles. The newly established AIIB (# 3 in figure 3), NDB (# 4) and development funds (# 5) still play a smaller role. The ties can be weighted by the capacity of the power plants supported (total plant capacity divided by number ties, i.e. where there are few actors on a very large power plant each actor maybe considered more significant than one of many actors on a small power plant). As shown in panel (A2), this weighting further decreases the relative relevance of the newly established developmental institutions and strongly increases the relevance of the ExIm and CDB in comparison to the unweighted network in panel (A1). This shows that those two institutions are increasingly investing in larger (mostly fossil fuel based) power plants. On the side of MDBs, which are colored in dark blue, the World Bank (#5), Asian development bank (#6) and African Development Bank (#7) are the largest institutions in the capacity-weighted network (see figure 3(A2)).

Contrary to our expectations, we do not find that the Chinese actors involved in CDI-supported projects (marked in light red in figure 3) are highly concentrated in a few large state-owned companies. Instead, we find that there is a wide range of Chinese companies involved in the 350 CDI-supported projects: we find 172 distinct Chinese commercial actors in CDI-supported plants, most of which (>80%) are headquartered in the more developed coastal regions of China's East. Ranking companies by absolute and cumulative involvement as measured by their number of ties to power plants, we find that the network characteristics of Chinese firms in CDI-funded projects are comparable to those of companies from major Western shareholder countries in MDB-funded projects (see figure S4 for the comparison of these Pareto plots). The top 3 Chinese companies (see table S13 for more details), for example, have comparable involvement levels when measured by the sum of ties to power plants (Sinohydro = 95, Dongfang Electric = 47, China Gezhouba Group = 39) to the top 3 Western companies in CDI-supported power plants (GE Power = 70, GE Renewable Energy = 47, and Siemens AG = 28).

From the total number of observed ties between companies with a headquarters in China and CDI-supported power plants, considering the entire time period (CDI-transactions 1999–2020) 42% originate from state-owned companies (as defined in the Methods section) with a decreasing trend from the period before (1999–2012: 46%) to the period after the BRI (2013–2020: 38%).

In contrast, the share of state-owned companies for companies with a Chinese headquarters in MDB-supported power plants is only slightly lower, with 39% over the full time-period (1999–2020). Hence, although the significant involvement of state-owned companies is a main distinguishing feature compared to Western companies, their observed prevalence is still surprisingly low given the notion of dominating state-owned companies in existing (mostly qualitative) research (e.g.[32]). This might be explained by the fact that a lot of the smaller transactions are not reflected in case studies or analyses with highly aggregated data.

3.5. Convergence of collaboration patterns

An analysis of the interaction patterns between the actors involved supports a convergence trend between the CDI and MDB-supported networks over time in three ways:

First, although the ExIm and CDB have comparable collaboration clusters that are different from those of the Western-backed MDBs, the newly established institutions (AIIB, NDB, Development Funds) show collaboration patterns that are closer and partly comparable to those of Western-backed MDBs. This is supported by their position in the combined agency-power plant as well as agency-agency network. The network position of the AIIB (#3) in the agency-power plant network (figure 3(A1)), for example, lies in between Western-backed MDBs. This is also supported by a comparison of their respective collaboration communities. Figure 4 displays the detected collaboration communities for the major CDIs. While the communities of the ExIm (figure 4(A)) and CDB (figure 4(B)) form hub and spoke-like clusters with limited involvement of Western actors, the clusters for the newly established CDIs (in particular the one of the AIIB) are less centralized and marked by high levels of collaboration with Western-backed MDBs as well as higher collaboration with Western companies (i.e. companies with a headquarters in one of the top-5 Western shareholder countries marked in light blue in figure 4). This contradicts to some extent non-empirical claims

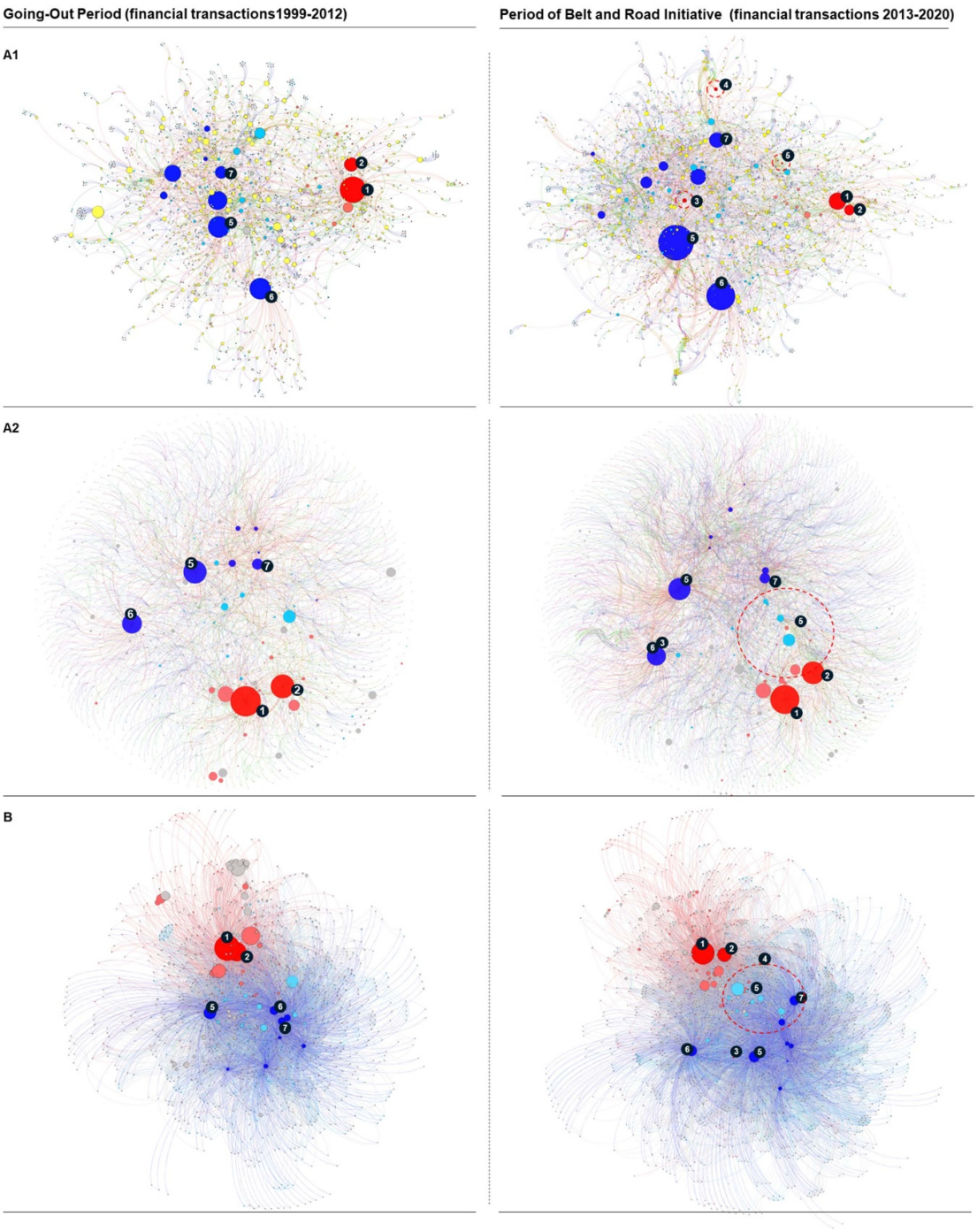

Figure 3. Combined CDI- and MDB-supported agency-power plant (**A**) and agency-agency (**B**) network for the period before (left) and after (right) the initiation of China's BRI. The blue and red bubbles represent the actors funding the projects. Note that red dotted circles are simply to highlight the presence of small red bubbles where those bubbles might otherwise be overlooked. In network A2 the ties are weighted by the supported capacity (total plant capacity divided by number ties) whereas the network A1 is based on unweighted ties. Note: *color coding nodes*: red = CDI, blue = MDB, light red = actor with Chinese headquarters, light blue = actor with headquarters in top five major Western shareholder countries (US, JPN, FRA, GER, GBR), yellow = power plant (A1). *Numbering*: 1 = ExIm, 2 = CDB, 3 = AIIB, 4 = NDB, 5 = WB, 6 = AsDB, 7 = AfDB.

(e.g. 43) that the AIIB has been established by China as a vehicle to fulfill its bilateral policy interests.

Second, we find that major companies with a headquarters in Western MDB shareholder countries (marked in light blue) cluster around MDBs in the combined network in the period 1999–2012, but they seem to have moved closer towards the ExIm and CDI in the period 2013–2020 as shown in figure 3. This effect is particularly prominent for a few large companies including GE Power, Siemens and Mitsubishi that mostly act as providers of knowledge and cost-intensive generator and turbines technologies (figure S5 provides a more detailed overview of the shares of respective major equipment categories provided by involved Western companies in the network). Alternative potential explanations for parts of

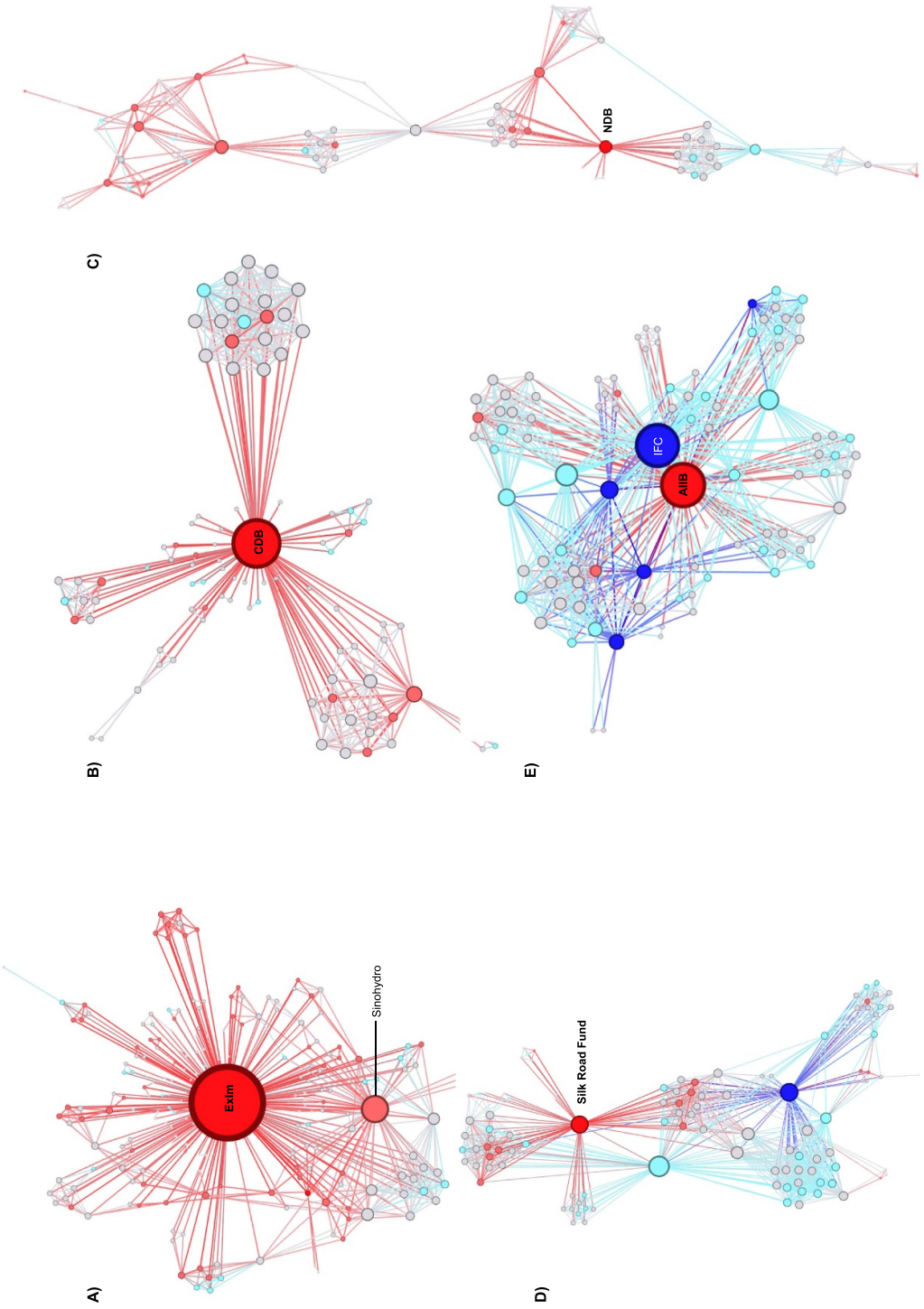

Figure 4. Collaboration clusters resulting from the community detection analysis. A = ExIm, B = CDB, C = Silk Road Fund, D = NDB, E = AIIB (in total representing 15% of agency-agency collaboration). Color coding: red = CDI, blue = MDB, light red = actor with Chinese headquarters, light blue = actor with headquarters in top five major Western shareholder countries (US, JPN, FRA, GER, GBR). Supplemental figure B2 displays frequency of nodes across all communities.

these shifts might also include possible misconduct in the context of increasingly strict and monitored public procurement rules in MDB-supported projects. Examples of this latter possible explanation include the fact that subsidiaries of GE Power, Siemens, and Mitsubishi have been temporarily banned from participation in bids for projects supported by several major MDBs (covered in our sample) over allegations of violations of public procurement rules (see supplemental text S2). Similar bans on many large Chinese companies [44], such as Sinohydro (see figure 4(A)), might explain why we only see considerably smaller convergence from the largest Chinese companies towards the MDBs from the period before to the period after the initiation of the BRI (see figure 4).

Third, beyond selective convergence trends related to newly-established CDIs and major actors from Western shareholder countries, the overall CDI- and MDB-supported networks are increasingly interconnected over time. The CDI and MDB-supported networks stay isolated only for the first 5 years after the initiation of China's Going Out policy in 1999, with the networks becoming strongly interconnected over time. This not only includes more actors that are present in both networks but also more joint investments between China's traditional bilateral financing institutions (ExIm, CDB) and the MDBs.

Thus, we do not find a dominating role of large state-owned Chinese companies whose expansion is 'orchestrated' [32, p 27] by the Chinese state in an (isolated) Chinese 'sphere of influence' [45, p 10, 15, p 2]. Instead, a more accurate characterization of the emerging network over time is that of a highly interconnected, emergent, dynamic and self-organizational nature of a heterogenous set of involved Chinese and Western actors. This supports the value of understanding the complex and 'messy' realities on the ground from the Chinese and Western foreign expansion as co-evolving CASs. Further research into the long-term impact of the observed convergence could be of use to future global energy financiers.

4. Implications for public policy

There is a pressing necessity to redirect the CDI portfolio of support for power plant infrastructure outside of China, which is presently significantly invested in coal-fired capacity, towards paths with lower carbon intensity. Power plants are long lived assets and investment in coal-fired plants now will create lock-in to this fuel for decades to come [23]. However, we observe that more than 70% of all involved actors in Chinese fossil-fuel-based (mostly coal-fired) power plants have non-Chinese origins with a growing prevalence of companies from five major Western economies (Germany, USA, Japan, UK, France) and other international actors accounting for nearly every third commercial transaction. Hence, while Chinese engagement into foreign coal plants is strongly criticized it is also important to acknowledge that Western companies—in particular providers of advanced technologies such as plant turbines—play an important role in this expansion that has been steering the pathways of the electricity sector of the developing world into a fossil-fuel based . Governments and climate-policy makers from the five major Western economies analyzed in detail in this work might consider providing more oversight over outgoing commercial transnational technology coal linkages. They might, for example, consider extending the OECD deal to ban export credits for coal plants from October 2021 to the provision of equipment and contracting services; and potentially even question whether the neo-institutional market logic would require more substantial adjustments to induce the radical socio-technical change that is needed in the global electricity sector to meet climate goals.

In addition, the finding that more than 70% of involved actors in CDI-funded power plants have non-Chinese origins across all technologies and that this fraction is increasing over time might inform Western policymakers tasked with developing policies to assess potential market distortions linked to China's BRI, as well as various critics claiming that there is a severe lack of openness in Chinese-supported projects. Nevertheless, the small observed sub-sample of power plants with high levels of integration of Chinese actors (see figure S1) might have (geo) political implications for recipient countries. We also find that over 20 years the role of domestic companies has remained stable (around 1/3), not growing, in spite of many pledges and requests to support domestic capacity development [20]. Given the criticality of power plant infrastructure—something that is increasingly prominent in the ongoing Ukraine war—countries might negotiate more ambitious local content requirements and upper limits to foreign involvement levels in domestic power plants, in particular with respect to plant ownership and operation. Such requirements would also address the significantly lower domestic involvement levels for CDI- as well as Western-backed MDB-funded power plants in our sample when compared to remaining power plants in recipient countries. Likewise, international developmental institutions should wrestle with these findings because they question the extent to which the reduced domestic involvement levels in their supported plants reflects their mandates to foster local development.

Finally, the global network perspective developed in this work emphasizes the highly interconnected and dynamic nature of interactions among a heterogenous set of Chinese and Western actors. Our results highlight the importance of leaving behind, or at least questioning, the, often prevalent, narrative in qualitative research and in the international discourse

of a bipolar world with China and the West as two opposed monolithic blocks, as this does not reflect the 'messy' and complex reality on the ground. Given the heterogeneity of involved actors, a more differentiated micro-data-driven approach that goes beyond a generic BRI project classification is needed. This work has also demonstrated how complexity theory and, in particular, the concept of CASs in combination with social network modeling techniques (i.e. community detection algorithms, spatial network visualization) is a promising approach to improve our understanding of complex multi-actor relationships and their evolution to inform policy and research alike.

Data availability statement

The data on power plant funding activities from CDIs and MDBs for power plants globally in the period 1999-2020 has been compiled by the authors of this work as described in more detail (incl. a specification of used publicly available sources) in Sauer *et al* (2022, https://doi.org/10.1016/j.gloenvcha.2022.102553). We extend this dataset to involve commercial actors along the power plant value chain of those publicly supported power plants by using the commercial power plant dataset GlobalData (2020) and other publicly available sources (see method section). While we provide sufficient detail for replication of the dataset (see section 'dataset description' and corresponding Supplemental information sections) we are unable to provide access to the underlying unit-level power plant data from GlobalData (2020) as this part of the data is proprietary and subject to a fee-based data access license (i.e. our data use agreement does not allow for making the unit-level data accessible). Non unit-level views on the data are provided in the article and the SI.

The data cannot be made publicly available upon publication because they contain commercially sensitive information. The data that support the findings of this study are available upon reasonable request from the authors.

Acknowledgment

The authors would like to thank Sergey Kolesnikov, Deyu Li, Thea Jung, and Daniel Navia from the Cambridge Centre for Environment, Energy and Natural Resource Governance (C-EENRG) for their valuable comments.

ORCID iDs

Jürgen Michael Thomas Sauer https://orcid.org/0000-0001-5677-7191
Judith Plummer-Braeckman https://orcid.org/0000-0002-9121-8798
Laura Díaz Anadón https://orcid.org/0000-0002-2688-118X

References

[1] Alden C 2005 Red star, black gold *Rev. Afr. Political Economy* **32** 415–9
[2] Tull D M 2006 China's engagement in Africa: scope, significance and consequences *J. Mod. Afr. Stud.* **44** 459–79
[3] Lum T, Fischer H, Gomez-Granger J and Leland A 2009 China's foreign aid activities in Africa, Latin America, and Southeast Asia *Russia China and Eurasia-Social Historical and Cultural Issues* vol 25 p 175
[4] Halper S 2010 Beijing's coalition of the willing *Foreign Policy* **180** 100
[5] Naim M 2007 Rogue aid *Foreign Policy* **159** 96
[6] Gill B and Reilly J 2007 The tenuous hold of China Inc. in Africa *Wash. Q.* **30** 37–52
[7] Balding C 2017 Can China afford its belt and road? Bloomberg (available at: www.bloomberg.com/opinion/articles/2017-05-17/can-china-afford-its-belt-and-road) (Accessed 10 October 2019)
[8] Hillman J 2018 How big is China's belt and road? Center for strategic and international studies 3 (available at: www.csis.org/analysis/how-big-chinas-belt-and-road) (Accessed 6 April 2024)
[9] EUCCC 2020 The road less travelled: european involvement in China's belt and road initiative *European Chamber of Commerce in China* (available at: https://static.europeanchamber.com.cn/upload/documents/documents/The_Road_Less_Travelled[762].pdf) (Accessed 6 April 2024)
[10] Smith J 2018 China's belt and road initiative: strategic implications and international opposition *Backgrounder* **3331** 2018–08
[11] Hillman J, Sacks D, Lew J J and Roughead G 2021 *China's Belt and Road: Implications for the United States* (Council on Foreign Relations)
[12] Hillman J 2018 *China's Belt and Road Initiative: Five Years Later* (Center for Strategic & International Studies) vol 25
[13] Russel D R and Berger B H 2020 Weaponizing the belt and road initiative *Asia Policy Society Institute* (available at: https://asiasociety.org/sites/default/files/2020-09/Weaponizing%20the%20Belt%20and%20Road%20Initiative_0.pdf) (Accessed 6 April 2024)
[14] Saalman L and Dethlefsen K 2017 Following the forum: China's belt and road initiative and the EU. friedrich ebert stiftung (available at: http://library.fes.de/pdf-files/bueros/singapur/13565.pdf) (Accessed 6 April 2024)
[15] Massa I 2011 Export finance activities by the Chinese government. european parliament directorate-general for external policies of the Union (available at: www.europarl.europa.eu/RegData/etudes/note/join/2011/433862/EXPO-INTA_NT(2011)433862_EN.pdf) (accessed 6 April 2024)
[16] Sauer J M T, Anadón L D, Kirchherr J, Plummer Braeckman J and Schulhof V 2022 Chinese and multilateral development finance in the power sector *Global Environ. Change* **75** 102553
[17] Dreher A, Fuchs A, Parks B, Strange A M and Tierney M J 2018 Apples and dragon fruits: the determinants of aid and other forms of state financing from China to Africa *Int. Stud. Q.* **62** 182–94
[18] Ghossein T, Hoekman B and Shingal A 2021 Public procurement, regional integration and the belt and road initiative *World Bank Res. Obs.* **36** 131–63
[19] Steffen B and Schmidt T S 2019 A quantitative analysis of 10 multilateral development banks' investment in conventional and renewable power-generation technologies from 2006 to 2015 *Nat. Energy* **4** 75–82
[20] Tirpak D and Adams H 2008 Bilateral and multilateral financial assistance for the energy sector of developing countries *Clim. Policy* **8** 135–51

[21] Delina L L 2011 Asian development bank's support for clean energy *Clim. Policy* **11** 1350–66
[22] Chen X, Gallagher K P and Mauzerall D L 2020 Chinese overseas development financing of electric power generation: a comparative analysis *One Earth* **3** 491–503
[23] Sauer J M, Anadón L D, Kirchherr J, Plummer Braeckman J and Schulhof V 2022 Determinants of Chinese and Western-backed development finance in the global electricity sector *Joule* **6** 1230–52
[24] Eder T S and Mardell J 2019 Powering the belt and road. Mercator Institute for China Studies (MERICS) (available at: www.merics.org/de/bri-tracker/powering-the-beltand-road) (Accessed 25 May 2020)
[25] Gallagher K P, Kamal R, Jin J, Chen Y and Ma X 2018 Energizing development finance? The benefits and risks of China's development finance in the global energy sector *Energy Policy* **122** 313–21
[26] Li Z, Gallagher K P and Mauzerall D L 2020 China's global power: estimating Chinese foreign direct investment in the electric power sector *Energy Policy* **136** 111056
[27] Turner J R and Baker R M 2019 Complexity theory: an overview with potential applications for the social sciences *Systems* **7** 4
[28] Bale C S, Varga L and Foxon T J 2015 Energy and complexity: new ways forward *Appl. Energy* **138** 150–9
[29] Gopal S, Pitts J, Li Z, Gallagher K and Kring W 2018 Fueling global energy finance: the emergence of China in global energy investment *Energies* **11** 2804
Hannam P M, Liao Z, Davis S J and Oppenheimer M 2015 Developing country finance in a post-2020 global climate agreement Nat. Clim. Change **5** 983–7
[30] Diaz-Maurin F and Kovacic Z 2015 The unresolved controversy over nuclear power: a new approach from complexity theory *Global Environ. Change* **31** 207–16
[31] Surana K, Doblinger C, Anadon L D and Hultman N 2020 Effects of technology complexity on the emergence and evolution of wind industry manufacturing locations along global value chains *Nat. Energy* **5** 811–21
[32] Kong B and Gallagher K P 2016 The globalization of Chinese energy companies: the role of state finance *Global Economic Governance Initiative Working Paper*
[33] Kong B and Gallagher K P 2017 Globalizing Chinese energy finance: the role of policy banks *J. Contemp. China* **26** 834–51
[34] Bräutigam D and Gallagher K P 2014 Bartering globalization: china's commodity-backed finance in Africa and Latin America *Global Policy* **5** 346–52
[35] Borzillo S and Kaminska-Labbé R 2011 Unravelling the dynamics of knowledge creation in communities of practice though complexity theory lenses *Knowl. Manag. Res. Pract.* **9** 353–66
[36] Davis A P, Dent E B and Wharff D M 2015 A conceptual model of systems thinking leadership in community colleges *Syst. Pract. Action Res.* **28** 333–53
[37] Wang R, Bar F and Hong Y 2020 ICT aid flows from China to African countries: a communication network perspective *Int. J. Commun.* **14** 1498
[38] Jacomy M, Venturini T, Heymann S and Bastian M 2014 ForceAtlas2, a continuous graph layout algorithm for handy network visualization designed for the Gephi software *PLoS One* **9** e98679
[39] Blondel V D, Guillaume J-L, Lambiotte R and Lefebvre E 2008 Fast unfolding of communities in large networks *J. Stat. Mech.: Theory Exp.* **2008** 10008
[40] Wolf S O 2020 *The China-Pakistan Economic Corridor of the Belt and Road Initiative Concept, Context and Assessment* (Springer)
[41] Hainz C and Kleimeier S 2012 Political risk, project finance, and the participation of development banks in syndicated lending *J. Financ. Intermediation* **21** 287–314
[42] Chen J and Wang Z J 2020 BRI 2.0: cosmetic repairs or a change of course? *J. World Trade* **54** 791–812
[43] Heilmann S, Rudolf M, Huotari M and Buckow J 2014 China's shadow foreign policy: parallel structures challenge the established international order *China Monit.* **18** 1–9
[44] Hillman J E 2019 Corruption flows along China's belt and road. Commentary (Center for Strategic and International Studies) (available at: www.csis.org/analysis/corruption-flows-along-chinas-belt-and-road). (Accessed 6 April 2024)
[45] Hervé-Mignucci M and Wang X 2015 Slowing the growth of coal power outside China: the role of Chinese Finance *A CPI Report* (available at: www.climatepolicyinitiative.org/wp-content/uploads/2015/11/Slowing-the-Growth-of-Coal-Power-Outside-China.pdf) (Accessed 6 April 2024)