Foreign actors, faster transitions? Co-evolution of complementarities, perspectives and sociotechnical systems in the case of Indonesia's electricity supply system

Abstract:

Some low- and middle-income countries go through a transition to a coal-based electricity system as a way of overcoming the trilemma between energy security, equity, and sustainability. Foreign actors have played a role in addressing bottlenecks in energy transitions and can affect the speed and direction of transition. However, the literature on both the geography and temporality of transitions provides a limited understanding of how different dimensions and layers, as well as domestic and foreign actors, interact and complement each other in the course of transition toward a coal-based electricity supply system. To fill this research gap, this paper provides rigorous supporting evidences to the concept of complementarities in the electricity supply system, making it operationalize for empirical analysis. The case study of Indonesia finds that transition is hastened by interplay between foreign investors and domestic actors that addresses multiple complementarity bottlenecks in a package. China plays a distinct role among large foreign coal power investors in the transition to a coal-based system by providing both tangible and intangible resources to address complementarity bottlenecks in the crisis period, and in more acceptable terms of conditions to domestic actors who exert power to influence decisions and political goals in their favor.

Keywords

Complementarity; bottleneck; electricity system; foreign actor; Indonesia; China; crisis

1. Introduction

Sustainability transitions must overcome conflicting priorities and interests among multiple stakeholders, represented as the trilemma between energy security, equity, and sustainability [1]. On the one hand, the "four A's of energy security" (availability, accessibility, affordability, and acceptability) have been prioritized [2] to meet the needs of multiple stakeholders at multiple levels of governance, including economic growth, poverty alleviation, and social welfare. To satisfy this objective, energy systems are constructed in association with their dominant energy interests. On the other hand, sustainability transitions call for long-term, multidimensional transformation processes that shift established sociotechnical systems into more sustainable modes of production and consumption [3]. These transitions might include prohibitively high transaction costs because large sociotechnical systems encompass the technological, industrial, social, political, regulatory, and cultural aspects of supply and use [4-6], and well-entrenched and developed systems create path dependencies or lock-ins [7]. In addition, sustainability transitions are not always consistent with the dominant paradigm of incumbent regime actors and may contradict pressing needs to address poverty and racial inequalities in a society. As a result, sustainability transitions may fail to gain social acceptance and political feasibility, leading to comparative rejection [8].

To overcome the trilemma, many countries frame climate change in the context of entrenched energy interests where appropriate [9] and prioritize the use of indigenous energy sources [1]. Countries where the neoliberal development regime dominates frame climate change as ecological modernization, green economy or green growth, fostering domestic clean energy industries [10-12]. Countries that place a higher priority on energy for development and have high path dependency on fossil fuel, on the other hand, promote renewable energy as a means of maintaining the dominant paradigm of incumbent regime actors [1,13]. Their choice at a time of crisis can generate feedback effects [14] and create entrenched systems from which there is no turning back in a post-crisis period.

Foreign actors such as bilateral donors and multilateral development banks can play a key role in addressing energy transition bottlenecks. They can facilitate the flow of knowledge, technological and financial resources, and organizational capabilities in energy efficiency [15], wind [16], and geothermal power projects [17]. They can also address policy, institutional, and regulatory barriers [18,19], and create industrial networks [16] on different theoretical grounds [20]. These interventions can generate a series of changes in the prevailing system [21], giving the promise of more sustainable development pathways where local actors initiate emerging sustainability experiments to satisfy local demand [22]. However, these supports can be dwarfed by domestic and foreign financial institutions that provide financing for fossil fuel development and power generation projects [23]. They even entrench fossil fuel lock-in and the inertia of its incumbency [24,25].

This raises the question of the influence of foreign actors on the speed and direction of energy transitions. Specifically, how and when can they effectively address bottlenecks to accelerate energy transitions, and in which direction?

The literature on the geography of transitions explores the role of foreign actors in sustainability experiments and upscaling through the lens of transnational linkages [26-29] and the global sociotechnical regime [30]. The literature on the temporality of transitions classifies dimensions and layers in energy systems to show the differing speed of transitions among them [31], arguing that faster transitions in some dimensions and layers can accelerate incremental innovation in others through learning [32]. However, they provide limited understanding of how different dimensions and layers interact and complement each other in the course of transition, and why the transition to coal-based electricity supply systems is taking place in some low- and middle-income countries [33].

Against this backdrop, this paper aims to explore the role of foreign actors in the transition to a coal-based electricity system. We employ sociotechnical complementarities as an analytical framework and take Indonesia as a case study.

The paper's main contributions are twofold. First, it provides rigorous supporting evidences to the concept of complementarities in in the electricity supply system, making it operationalize for empirical analysis. Second, it adds some empirical novelty and interpretive value on the role of foreign actors to literature on the geography and temporality of transitions.

The remainder of the paper proceeds as follows. The next section develops the concept of sociotechnical complementarities to build it on rigorous supporting evidences for empirical analysis. The section 3 presents a methodology of the cases study, including the logic behind case selection. In section 4, we presents a brief history of the electricity supply system in Indonesia, and results in the form of an analysis of changes in complementarities, and Section 5 discusses the role of foreign actors on the direction and speed of the change. Finally, Section 6 concludes the paper with this study's contribution to this body of research and provides suggestions for future research.

2. Co-evolution of complementarities and sociotechnical system in developing countries

2.1 Methodology

We begin with Markard and Hoffmann [34], who provide a conceptual framework for complementarities in sociotechnical systems in transition. They classify elements of complementarity into technological, organizational, institutional, and infrastructure, and identify unilateral or bilateral complementarities among elements based on criticality for performance. They argue that technological limitations and asynchronous development of complemental elements can create bottlenecks that slow down or impede a transition under strong complementarity. Each technology has its own dynamics, different time horizons, and speed of development, and a transition leads to diverging logic between them considering the goals pursued, decision-making style, and scale of operations [35]. Intangible institutions tend to show faster transitions than technologies, markets, consumption patterns, infrastructures, production facilities, and supply and distribution chains [32].

To enhance the rigor of the framework and broaden its scope to include the role of foreign actors, we conducted a systematic literature review [36]. On 3 April 2020, we collected journal articles and book chapters published between 2015 and 2020 from Scopus and Web of Science. We searched only English materials using the keywords “energy transitions” AND “complementarities”, “energy transitions” AND “bottleneck”, and “energy transitions” AND “developing countries”, and selected the subject areas of energy, development, environmental and regional studies, economics, finance, management, and political science. In total, about 343 papers (78 from Scopus and 265 from Web of Science) were retrieved at this stage (Table A1; A2). We then manually excluded duplicates and entries that were too broad to be considered within the scope of energy transitions. This resulted in 34 papers. Several journal articles that were published in earlier years were added to complement the explanations in these papers.

2.2 Complementarities in electricity supply system

Thermal power generation is located along the supply chain of electricity. This chain begins with resource exploitation, moves to transport and conversion, then to power generation, transmission, and distribution, ultimately reaching end users. This structure creates a co-existence of competition and complementarities within and across the sector.

As the infrastructure element, coal, diesel, natural gas, nuclear and intermittent energy are complementary in ensuring the four A’s of energy security [34] at the sector level, while they are competing technologies for power generation due to technological characteristics. Diesel, natural gas, and hydroelectric are complementary to nuclear, intermittent energy and to a less extent coal power since they can adjust the amount of power generation more flexibly in response to demand [37].

As the organizational element, complementarities are created to minimize commercial risks and avoid sunk cost investments. They include a long-term fuel supply and a transportation contract to ensure a stable fuel supply for power plants for the life of the plant, and a long-term take-or-pay clause with transmission and distribution companies to ensure stable sales of their products at a pre-determined price. In India, coal linkage system is established to force linkages and complementary capital investments between domestic fuel mining and thermal power plants [38].

As the engineering and manufacturing elements, development activities such as site-specific engineering design, permitting procedures, and the use of local supply chains and labor markets are called for to ensure compatibility between the technologies employed in large-scale power plants and local conditions [39]. Non-leader countries that lack a home market are disadvantaged in fostering the ability of domestic industries, particularly complex and capital-intensive ones that require testing and qualifying technology. They are also disadvantaged in technology product architecture, which describes the number of technologies and linkages between subsystems [40]. These disadvantages can be mitigated if these countries gain cross-country spillovers from strong market formation in other subsystems [41]. Closely related industries can also provide important sources of tangible and intangible resources if they have similarities in resources and if beneficial resource flows are actually exploited [42].

As the institutional element, financial capital plays a key role in the direction and speed of transitions in the electricity sector. Capital intensity in terms of capital cost divided by expected kilowatts is lowest for traditional biomass, higher for modern energy solutions such as natural gas and coal, higher still for hydro and geothermal, and substantially higher for wind and solar. However, formal financial institutions in developing countries are generally less willing to make loans for new capital-intensive power generation plants due to longer supply chains and longer pay-back periods. In particular, they are unwilling to do so to small and medium-sized energy enterprises due to the high default risk, insufficient competition, poor guarantees, and a lack of information about their ability to repay loans [43]. Deepening domestic capital markets can overcome this bottleneck, since it enables capital intensive energy projects to access private financial capital and increase their viability on a commercial basis [44]. However, large electricity generators may capitalize on their structural power to lobby the government through the capital market policy process [45], preventing them from emerging.

Stable institutions, including those with consistent long-term demand-side policies, legitimacy, and alignment with practices in other sectors and regional/local institutions, are key systemic factors for rapid development and diffusion [46]. Manufacturing push policies aimed at improving and scaling domestic manufacturing technologies and processes enable the global diffusion through economies of capacity and scale [47]. However, pressure to ensure energy supply is likely to direct the government to adopt fossil fuels as long as they have cost advantage [48]. Institutions are also affected by incumbent regime actors who exert power to influence decisions and political goals in their favor [49]. The "nature" of the country and the close ties between political and economic elites create high entry barriers, thereby narrowing opportunities for change [50] and restricting the development of bottom-up solutions to sustainability problems [23].

2.3 Foreign actors in the change of complementarities

Foreign actors can address these complementarity bottlenecks in developing countries in several ways. They have lowered the cost of new technology globally, and as donors of public financial capital, they can play a decisive role in (re)configuring the electricity system through support for sector reform programs, certain pathways [51], and investments in particular infrastructure [43,52]. They can mediate interactions between actors and institutions situated across different levels of spatial scale [53], enhancing alignment between government policies, existing infrastructure, and the practices and capabilities of actors that may support the new technology [54]. They can also enhance transnational linkages so that domestic actors and institutions can gain access to resources and markets in various forms such as relationships with foreign technical experts and inter-firm partnerships with foreign suppliers of technology [55].

These foreign actors can also support weak or missing system functions in the early stages of transitions. These measures include not only knowledge development and diffusion, search guidance, and legitimacy creation, but also market-stimulating interventions, the fostering of new entrants, and support for continued experimentation with new technology [54].

However, classical technological transfer mechanisms tend to focus largely on knowledge diffusion and development functions rather than on the configuration of learning and innovative capabilities to acquire, operate, modify and assimilate technologies [28]. Although more design-intensive technologies require a higher share of locally adapted or sourced components [39], foreign actors often lack meaningful engagement with place-specific cultures, power relations, and infrastructures [16,26,27]. Accordingly, they are more likely to initiate projects with technology requiring hard-to-acquire capabilities and no major local tacit knowledge, and fail to achieve widespread diffusion of technology requiring important local tacit knowledge even if these technologies are low-cost and proven, such as improved cook stoves [54].

Foreign private investors are playing a greater role in the global diffusion of environmental technology in host countries with demand-side policies, political stability, and international public finance [56]. Both technological push and demand-side policies can stimulate innovation in foreign countries when markets become mature and the corresponding technologies are considered commodities. At the same time, shareholder activists and divestment campaigners may direct their investment pathway, affecting the fossil fuel-based energy regime in host countries [57].

2.4 Sociotechnical complementarities in energy transitions with foreign actors

Figure 1 illustrates the four types of complementarities and complementary bottlenecks in the oil-based electricity supply system. It goes beyond an indication of barriers to transitions in a power supply system [43,58] to provide timing and bottlenecks so that interventions can effectively (re)configure the incumbent system. The larger asynchronous development becomes among subsystems with complementarities and the larger interventions regime actors are required to reinforce the incumbent system. Meanwhile, more wide-ranging opportunities are created for outsiders and foreign actors, not limiting them to niche innovators to (re)configure the system, thereby accelerating transition.

Figure 1 also indicates the points of intervention by foreign actors in a change in complementarities. They can address these complementary bottlenecks by providing engineers, manufacturers, and financial capital for power plants and transmission and distribution networks, and supporting more stable policies and institutions that are compatible with thermal power supply. Their interventions can be more effective when they address the complementarity bottleneck by providing technologies that do not require in situ activities [39], and when they bring benefits to political and economic elites who influence planning and decision-making in domestic policy processes [52].

3. Methodology and case selection

3.1. Case selection and research design

We use the framework described above to analyze the co-evolution of complementarities and the sociotechnical system of the Indonesian electricity system. The logic of this selection is that Indonesia is representative of middle-income countries that could have chosen a renewable energy-based system at the time of power crisis but instead transitioned to a coal-based one, and is a country where a variety of foreign actors have provided support for both systems. We adopt a case study strategy because case studies are rich in context and can track complex developments over time [59]. Given that the seeds for the transition are sown early on, the paper uses a longitudinal case study design, starting in 1998 when the Asian economic crisis substantially destabilized the previous oil-based system.

3.2. Data sources

Data collection is guided by the analytical framework, which focuses on the asynchronous development of complemental elements and the interplay between foreign and domestic actors. For the electricity system transition, we mainly use data from secondary sources (academic books and articles). For the roles of foreign and domestic actors, we draw on a combination of secondary and primary sources such as annual reports, company press reports, consultant reports, reports from business journals and a daily English newspaper. Documents are collected from online archives by searching for company names. These data are complemented by information from two interviews with international non-governmental research institutes, conducted in November 2019 in Jakarta.

4. Case study

4.1 Electricity system transition during 1990-2017

Indonesia capitalized on domestically produced, plentiful, and cheap oil to develop an oil-based electricity supply system to satisfy a growing demand and expanded access. PLN, the state electricity company obtained foreign loans to develop the system. PLN also took advantage of exclusive powers over the transmission and sale of electricity to develop the centralized and monopolized supply system [60]. The government implemented electricity tariff adjustment measures that allowed PLN to gain an 8 percent rate of return [61]. PLN could then gain sufficient revenue to cover operational costs, as well as to expand new investments.

In the early 2000s, Indonesian electricity sector suffered from the three interrelated challenges: insufficient generation, peaked oil production, and increased energy subsidy. Insufficient generation capacities caused frequent blackout. Peaked oil production increased oil import and brought about fuel price hike. Increased energy subsidy squeezed fiscal resources for infrastructure development. However, political elites hesitated to fuel subsidy reform. They were well aware that the populace demanded the government to see energy subsidies not as a financial burden, but as a social obligation

[62]. They worried that the subsidy cuts could trigger widespread civil unrest that resulted in step-downs of the president [63]. Nonetheless, global oil price hike in 2005 prompted the government to reduce price subsidies, which triggered political repercussions [64].

In response, the Yudoyono administration legislated the National Security Act, calling for a diversification of the national energy supply in order to curb the country's strong reliance on oil. Coupled with the National Energy Policy (NEP), the administration released the Fast Track Program (FTP-I) that charged PLN with increasing power generation capacity of 10,000 MW. Perceiving coal power as readily available, accessible, affordable, and less vulnerable alternative to address the above challenges [65], the FTP-I assumed increasing capacity by coal power plants.

Then the administration released the Electricity Development Plan 2012-21 with target electrification ratio of 92 percent [66], and unveiled the second phase of the FTP (FTP-II) aiming to increase generation capacity of 17,918 MW additionally. To achieve the greenhouse gas emissions target described in the Nationally Appropriate Mitigation Actions, the administration shifted focus from coal to geothermal and hydropower[1]. A feed-in tariff for geothermal, biomass, and city waste was implemented to support the shift. The administration also shifted the regional focus from the Java-Bali system to Sumatra, and lifted the ban on develop renewable energy projects in forests, natural reserves, and conservation areas [67]. In the 2014 NEP, the administration shifted the focus on rebalancing the energy mix towards indigenous energy supplies to fulfill electricity supply-demand gap at least costs [66].

The Jokowi administration initially succeeded the spirit of the 2014 NEP. It expanded the scope of a feed-in tariff to mini and micro hydropower and solar power, along with the security of a 20-year power purchase agreement. However, the administration shifted the focus from renewable energy to efficiency and fuel subsidy removal. It implemented the Regulation 12/2017 on the Use of Renewable Energy for the Provision of Electricity (Regulation 12) to cap all renewable energy tariffs at 85 percent of PLN local production costs (BPP) if local production cost is higher than the national average. This regulation expected PLN to purchase electricity from renewable energy sources as long as it decreased PLN's financial burden. It also swung the focus back to coal in the Program 35,000 MW, the five-year power generation capacity development program that rolled over the revised FTP-II [68].

As a result, coal accounts for a greater portion in power generation, growing from 27 percent in 2001 to 60 percent in 2017 while oil declines from 33 to 7 percent and new and renewable remained the same (Figure 2).

4.2 Changes in complementarities

Elements of complementarities were largely segregated in the Indonesian electricity system. While electricity network was available, financial capital and engineering expertise were lacking due to the loss of investor confidence to electricity sector during the 1997/98 Asian Economic Crisis [61]. The confusion over the Law 20/2002 on Electricity further discouraged private investments [66].

In addition, coal industry was developed without regard to domestic power development, and fragmented with a few large producers and many small players. In the 1980s, eight foreign coal mining companies and Bukit Asam, a state-owned coal mining company, started operation through a Coal Contract of Work (CCoW) system. Except for Bukit Asam, they developed coal mining in East and South Kalimantan mainly for exports [69]. They developed transportation infrastructure for exports rather than sales in the domestic market. Their export-oriented development was unchanged after Indonesian oligarchs took over the majority ownership or managerial control of the four largest foreign coal producers of KPC, Arutmin, Adaro, and Kideco [70]. A number of small local coalminers, which emerged by gaining concession from local governments under the Regional Autonomy and by taking advantage of legal loopholes[2], also exported more than 80 percent of the products [69].

When the Yudoyono administration decided to define coal as the alternative energy for power generation, it implemented a number of policies and developed institutions required to address the complementary bottlenecks in the oil-based electricity supply system. To address complementarity bottleneck in financial capital, the administration enacted the new public-private partnership act in 2005 and allowed direct tender to invite foreign actors to FTP-I. The 2009 Electricity Law allowed foreign shareholding of independent power producers (IPPs) with electricity business licenses for public use at a rate of as high as 95 percent. This law also allowed IPPs to sell directly to the public without connecting to PLN's transmission line, while imposing local content requirements for different sources of power generation.

Then the government implemented Law 4/2009 on Mineral and Coal Mining and a domestic market obligation (DMO) regulation. The 2009 Mining Law required CCOWs holders to abide by new foreign investor divestiture requirements[3] and direct their investments towards domestic processing and refining[4] to prevent coal export manipulation for price, which brought slower growth to royalty revenue [69]. The DMO regulation mandated coal miners to supply no more than 35 percent of the produced coal to the domestic market. In response, domestic coal mining companies began to diversify sales destination to include domestic coal power generation, which led to stable coal supply at a cheaper price. As a result, an organizational complementarity was crated between coal power generation and coal mining[5].

4.3 The role of foreign actors

China has addressed all the four complementarity bottlenecks in Indonesian electricity supply system. To complement a lack of financial capital and engineering expertise, Chinese consortium provided coal power plants in the form of engineering expertise in the form of engineering, procurement, and construction (EPC). Chinese government banks, such as Bank of China, Chinese Development Banks, and China Export-Import Bank provided loans that were required to develop at least 17 out of 31 new coal power projects in the FTP-I, with a combined capacity of 8,000 MW [71].

However, China did not provide these resources without cost. The Indonesian government gave in the Chinese banks by accepting their demand for higher interest payments [72], and full guarantee to PLN credit risk from Indonesian government [73,74].

Learning from these terms, Yudoyono administration shifted focus from EPC contracts with PLN to a build-operation-transfer (BOT) scheme with IPPs in the FTP-II and Program 35,000 MW. It also imposed restrictive regulations on foreign investors in the mining sector, Nonetheless, Chinese actors adjusted the strategies to continue involvement in three ways. First, they set up joint IPPs with a subsidiary of PLN and obtained credit from Chinese state banks. This strategy was quite similar to the one in the FTP-I in that Chinese consortiums provided services in conformity with the incumbent transmission and distribution network under EPC or service supply contracts [75,76]. Second, they set up joint IPPs with Indonesian coal oligarchs, such as Bukit Asam, Sinar Mas/ DSS Power, Intraco Penta (INTRA), or Sumberenergi Sakti Prima to do the same. By providing managerial and technological expertise, they helped domestic coal oligarchs transform into power generation businesses, which secure stable and long-term coal supply for power plants. Finally, the Chinese and Indonesian governments made an agreement on the construction of power plants, as well as in the planning, construction, operation, and maintenance of electrical grids [77]. This not only enhanced institutional complementarity in the electricity supply system, but also placed pressure on Indonesian PLN and IPPs to ensure stable supporting policies that were favorable to Chinese coal power investors.

As a result of the changes in the four elements of complementarities, coal power capacity and generation by PLN saw a rapid increase in 2011, and all but one of the commissioned projects were complete in 2014, almost ten years after FTP-I was unveiled. Under the FTP-II and the Program 35,000 MW, many IPPs were established as joint ventures between Chinese investors and Indonesian coal oligarchs, winning bids to develop a number of coal power plants. Coal power now accounts for more than two thirds of IPP generation capacity, and more than one-third of total power generation in Indonesia (Figure 3).

5. Discussion

5.1 Direction and speed of an energy transition

Figure 4 summarizes the above results, showing how Chinese actors have addressed each element of complementary bottleneck, inducing co-evolution of complementarities and electricity supply system toward a coal-based one and reinforced lock-in into a coal-based system.

As for the infrastructure element, coal power does not claim a higher reconfiguration capacity than intermittent energy, which requires supporting infrastructure such as sufficient network capacity, system-balancing facilities, stronger transmission grids such as a region-wide super-grid, and batteries to store energy cost-effectively for proper grid operation [78]. In addition, Chinese consortium provided coal power plants that did not demand so much changes in the operation of electricity grid [79]. This favorable infrastructure complementarity enables massive investments in coal power plants, which causes excess supply in the Java-Bali system that have suffered from a power shortage since the Asian economic crisis. On the other hand, excess supply reduces the capacity for grids to accept additional renewable energy-based power [80]. Coupled with limited grid connectivity and weak capacity at the local level, foreign investors in intermittent energy suffer from heavy distress [79,81].

As for the engineering and manufacturing elements, coal power generation is a proven, standardized technology that requires less testing and qualifying processes [40] and site-specific activities [39]. Few low- and middle-income countries have manufacturers or closely related industries with sufficient engineering and manufacturing expertise to engineer, procure, and construct power plants. Thus, host country governments prefer EPC contracts to promote power development even though they have no effect in fostering domestic expertise.

As for the organizational element, the take-or-pay clauses in power purchase contracts with foreign power generators and joint IPPs may ultimately harm grid access for wind and solar power. The clauses will force transmission companies to pay for unnecessary electricity and worsen their financial status once the system has excess generation capacity. The clauses usually remain unchanged for 10-20 years, so the amount of such payments becomes significant when renewable energy becomes cheaper than coal power. This poses a risk of making transmission companies incapable of investing in grid management [68].

As for the institutional element, coal miners and power generators who are backed by foreign investors may make institutions work in their favor once they become dominant in the market and gain political power in the regime. In Indonesia, coal oligarchs convinced the government to designate low quality coal as the design coal for coal power plants. This allowed them to expand their coalmining in the deep forests of Kalimantan for use in new mine-mouth coal power plants [61], which narrowed the space for wind and solar power to develop outside the Java-Bali system. PLN claimed that feed-in tariffs for renewable energy exceeded average cost of generation and created a financial deficit and excess supply. In response, the Jokowi administration capped a tariff that paid to private renewable energy developers and implemented reverse auctions as capacity quota packages to solar and wind projects. The House of Representatives rejected a renewable energy subsidy to PLN in 2017.

5.2 The unique role of China in changing complementarities

Figure 4 also indicates that how China has enhanced interplay with domestic actors in the process of co-evolution.

China’s Common Fate and Destination Model of Infrastructure Finance strategy enables wide-ranging intervention. It underscores common interests between both China and the host country. The key actor in this model is the joint venture established between a Chinese state company and a host company. These companies take advantage of cost competitiveness, moving early in response to policy changes while encouraging other governments to host favorable biddings. When winning a bid, the companies mobilize financing from Chinese institutions by combining export buyer credits and non-concessional loans. These syndicated loans are often tied to the services provided by the company that won the bid [82]. At the same time, they require host country counterparts to invest in developers to ensure full ownership by host country governments. PLN does so for all Chinese-engaged projects under the FTP-I.

Such ability to provide a package of financial capital, technologies, engineering, and construction expertise ensures stable domestic coal supply and institution, thereby enabling PLN to reduce transaction costs for changing elements of complementarities. Its ability to supply several types of coal power plants with different levels of efficiency and costs also allows PLN to balance between cost and environmental concerns[6]. These costs are further reduced by collectively implementing projects, even if each individual project is small in scale. As PLN and political elites become accustomed to this system, they shift their perspectives in favor of the new complementarities. Moreover, local investors defend their own wealth via institutional lobbying of local agents to minimize the political and market risks of Chinese investors.

In addition, China's proposal at the time of crisis helped change the perspectives of key domestic actors in changing the elements of complementarities. When the Yudoyono administration released the Fast Track Program (FTP-I), few foreign and domestic actors offered proposals that satisfied the administration and overcome the crisis. China offered proposals that were more acceptable to the domestic coal oligarchs that had political influence to the administration, and the administration in terms of investment costs.

China's engagement is distinct from other large foreign coal power investors such as South Korea and Japan in reducing transition costs associated with changes in complementarities. South Korea employs the same model in IPP projects. It organizes international consortiums with Indonesian oligarchs such as Indika Energy to help them diversify business, as well as to comply with the foreign investment regulations [83,84]. Indika Energy and Korean Samtan, both of which are Kideco subsidiaries, or Adaro are invited to the consortiums and EPC contracts are made with Korean companies so as to provide a package comprising capital, technology, engineering, and fuel to create coal complementarities. However, South Korea has implemented only four projects with a total capacity of 4,000 MW, and three of them are joint ventures with Japanese companies. In addition, they did not take sufficient considerations to prevent harmful emissions. This brought about local protests against the construction of the Cirebon 1 and 2 coal power projects, which, coupled with revelations of bribery, delayed commercial operation [84].

Japan has provided financial capital and engineering expertise but has hesitated to provide them in a package. This is due to past criticism over Japan's integrative assistance model that closely linked official development assistance, foreign direct investments, and exports [18]. In addition, Japanese public financial institutions follow the OECD Sector Understanding on Export Credits for Coal-Fired Electricity Generation Projects that limits support to coal plants utilizing ultra-supercritical technology and provides support to supercritical or subcritical plants only in the poorest countries [85]. Since ultra-supercritical technology requires higher upfront costs, Japanese developers have lost bidding in the face of Chinese developers. It is not until Indonesian government employed a BOT scheme in the FTP-II that Japanese companies were awarded to invest in coal power projects. In addition, these projects are construction of additional units for existing plants, such as Paiton, Tanjung Janti B, and Lontar, all of which are located in the Java-Bali system that has excessive capacity. Their provision of financial capital and engineering expertise may not even reinforce lock-in, let alone change the complementarities.

6. Conclusions

Sustainability transitions must overcome the trilemma between energy security, equity, and sustainability. To overcome this problem, many countries use and frame climate change in the context of entrenched energy interests where compatible, resulting in a transition to a coal-based electricity system in some low- and middle-income countries. While foreign actors can affect the speed and direction of transition, the literature on both the geography and temporality of transitions provides limited understanding.

To fill the research gap, this paper explores the concept of sociotechnical complementarities to analyze why a transition from oil-based to coal-based electricity system is taking place, and identify the roles of foreign actors, taking Indonesia as a case study. Our contributions are summarized as follows.

First, this paper develops the concept of sociotechnical complementarities to make it operationalize in empirical analysis of transitions. It provides rigorous supporting evidence on complementarity bottlenecks that are caused by asynchronous development of complementary elements in an electricity supply system, and shows how the methods used to address these bottlenecks affect the direction and speed of transition.

Second, it adds empirical novelty to the literature on the geography and temporality of transitions by finding that the interplay between foreign and domestic actors in addressing multiple complementarity bottlenecks in a package hastens transition. The foreign investors and domestic actors can reinforce complementarities in coal-based electricity system, in particular at organizational and institutional levels. This increases the transaction cost of a transition to alternative electricity supply system, especially renewable energy-based one.

Finally, the paper finds that China plays a distinct role among large foreign coal power investors in the transition toward a coal-based system. It provides both tangible and intangible resources for host countries to address complementarity bottlenecks not only in the institutional element but also in other elements. It offers the terms of conditions that are attractive to domestic influential actors, who work on the government to change perspectives on the new complementarities. China’s packaged resource provision generates policy feedback effects, fastening a transition toward a coal-based electricity system.

These findings indicate the need for further research on this topic. Coal power is not the only competitive yet environmentally unsustainable technology that foreign actors work to scale and create complementarities for in low- and middle-income countries. Large-scale hydropower is also a key technology in this regard. Globally, China plays the same role in the same manner[7]. Further research should further investigate how foreign actors may facilitate complementarities that promotes sustainable electricity system.

References

[1] La Viña, AGM, JM Tan, TIM Guanzon, MJ Caleda, L. Ang, Navigating a trilemma: Energy security, equity, and sustainability in the Philippines' low-carbon transition, *Energy Res. Soc. Sci*. 35 (2018) 37-47, http://dx.doi.org/10.1016/j.erss.2017.10.039.

[2] Asia Pacific Energy Research Centre (APERC), *A Quest for Energy Security in the 21st Century: Resources and Constraints*, Tokyo: Institute of Energy Economics Japan https://aperc.or.jp/file/2010/9/26/APERC_2007_A_Quest_for_Energy_Security.pdf/, 2007 [accessed 16 April 2020].

[3] van den Bergh, JCJM B. Truffer, and G. Kallis, Environmental innovation and societal transitions: introduction and overview. *Environ. Innov. Soc. Transit*. 1(1) (2011) 1-23, https://doi.org/10.1016/j.eist.2011.04.010.

[4] Geels, FW, Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study, *Res. Policy* 31 (2002) 1257-74, https://doi.org/10.1016/S0048-7333(02)00062-8.

[5] Geels, FW, From sectoral systems of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory. *Res. Policy* 33 (2004) 897-920, https://doi.org/10.1016/j.respol.2004.01.015.

[6] Markard, J. Transformation of infrastructures: sector characteristics and implications for fundamental change. *J. Infrastruct. Syst.* (ASCE) 17 (2011) 107-17.

[7] Schmidt, TS, T. Matuo, and A. Michaelowa, Renewable energy policy as an enabler of fossil fuel subsidy reform? Applying a socio-technical perspective to the cases of South Africa and Tunisia, *Global Environ. Change* 45 (2017) 99-110, https://doi.org/10.1016/j.gloenvcha.2017.05.004.

[8] Sovacool, BK, Rejecting renewables: The socio-technical impediments to renewable electricity in the United States, *Energy Policy* 37 (2009) 4500-13, https://doi.org/10.1016/j.enpol.2009.05.073.

[9] Toke, D., SE Vezirgiannidou, The relationship between climate change and energy security: key issues and conclusions, *Environ. Polit.* 22(4) (2013) 537-52, https://doi.org/10.1080/09644016.2013.806631.

[10] Hillebrand, R., Climate protection, energy security, and Germany's policy of ecological

modernization, *Environ. Polit.* 22(4) (2013) 664-82, https://doi.org/10.1080/09644016.2013.806627.

[11] Mori, A., Sociotechnical and political economy perspectives in the Chinese energy transition, *Energy Res. Soc. Sci*. 35 (2018) 29-36, https://doi.org/10.1016/j.erss.2017.10.043.

[12] Byrne, R., K. Mbeva, D. Ockwell, A political economy of niche-building: Neoliberal-developmental encounters in photovoltaic electrification in Kenya, *Energy Res. Soc. Sci*. 44 (2018) 6-16, https://doi.org/10.1016/j.erss.2018.03.028.

[13] Mohan, A. K. Topp, India's energy future: Contested narratives of change, *Energy Res. Soc. Sci*. 44 (2018) 75-82, https://doi.org/10.1016/j.erss.2018.04.040.

[14] Pierson, P. When effect becomes cause: Policy feedback and political change, *World Polit.* 45(4) (1993) 595-628, https://doi.org/10.2307/2950710.

[15] Yang, M. *Closing the Gap: GEF Experiences in Global Energy Efficiency*, Springer, New York, 2013.

[16] Mori, A., Overcoming barriers to effective environmental aid: A comparison between Japan, Germany, Denmark, and the World Bank, *J. Environ. Dev.* 20(1) (2011) 3-26, https://doi.org/10.1177/1070496510394316.

[17] Dong, L. and A. Mori, Multi-Level analysis of sustainable energy transition in Kenya: Role of exogenous actors, *International J. Energy Econ. Policy* 7(5) (2017) 111-22, https://www.econjournals.com/index.php/ijeep/article/view/5449/3330.

[18] Mori, A., *Environmental Aid: Logic, Strategy and Evaluation of Environmental Aid for Sustainable Development*, Yuhikaku, Tokyo, 2009 (in Japanese).

[19] Saculsan, PG, A. Mori, Why developing countries go through an unsustainable energy transition pathway? The case of the Philippines from a political economic perspective. *J. Sustain. Res.* 2(2) (2020) 1-24, https://doi.org/10.20900/jsr20200012.

[20] Mossberg, J., P. Söderholm, H. Hellsmark, and S. Nordqvist, Crossing the biorefinery valley of death? Actor roles and networks in overcoming barriers to a sustainability transition, *Environ. Innov. Soc. Trans.* 27 (2018) 83-101, https://doi.org/10.1016/j.eist.2017.10.008.

[21] Berkhout, F., G. Verbong, A. Wieczorek, R. Raven, L. Lebel, and X. Bai, Sustainability experiments in Asia: Innovations shaping alternative development pathways? *Environ. Sci. Policy* 13 (2010) 261-71, https://doi.org/10.1016/j.envsci.2010.03.010.

[22] Marquardt, J., How transition management can inform development aid, *Environ. Innov. Soc. Trans.* 14 (2015) 182-85, https://doi.org/10.1016/j.eist.2014.11.003.

[23] Baker, L., P Newell and J. Phillips, The political economy of energy transitions: The case of South Africa, *New Polit. Econ.* 19(6) (2014) 791-818, https://doi.org/10.1080/13563467.2013.849674.

[24] Jia, L., B. Baratz, J. Fritz, Environmental Performance of Bank-Financed Coal-Fired Power Plants in China, Washington DC: World Bank,

http://documents.worldbank.org/curated/en/199551468746703644/Environmental-performance-of-Bank-financed-coal-fired-power-plants-in-China/, 2000 [accessed 2 April 2020].

[25] Li Z., K. Gallagher, DL Mauzerall, China's global power: Estimating Chinese foreign direct investment in the electric power sector, *Energy Policy* 136 (2020) 111056, https://doi.org/10.1016/j.enpol.2019.111056.

[26] Hansen, UE and I. Nygaard, Transnational linkages and sustainable transitions in emerging countries: Exploring the role of donor interventions in niche development, *Environ. Innov. Soc. Trans.* 8 (2013) 1-19, https://doi.org/10.1016/j.eist.2013.07.001.

[27] Marquardt, J., K. Steinbacher, and M. Schreurs, Driving force or forced transition? The role of development cooperation in promoting energy transitions in the Philippines and Morocco, *J. Clean. Prod.* 128 (2016) 22-33, https://doi.org/10.1016/j.jclepro.2015.06.080.

[28] Sengers, F., and R. Raven, Toward a spatial perspective on niche development: the case of Bus Rapid Transit. *Environ. Innov. Soc. Transit.* 17 (2015) 166–82, https://doi.org/10.1016/j.eist.2014.12.003.

[29] Wieczoreka, AJ, R. Raven, and F. Berkhout, Transnational linkages in sustainability experiments: A typology and the case of solar photovoltaic energy in India, *Environ. Innov. Soc. Transit.* 17 (2015) 149–65, http://dx.doi.org/10.1016/j.eist.2015.01.001.

[30] Fuenfschilling, L., C. Binz, Global socio-technical regimes, *Res. Policy* 47 (2018) 735-49, https://doi.org/10.1016/j.respol.2018.02.003.

[31] Grubler, A., C. Wilson, G. Nemet, Apples, oranges, and consistent comparisons of the temporal dynamics of energy transitions, *Energy Res. Soc. Sci.* 22 (2016) 18–25, https://doi.org/10.1016/j.erss.2016.08.015.

[32] Sovacool, BK, FW Geels, Further reflections on the temporality of energy transitions: A response to critics, *Energy Res. Soc. Sci.* 22 (2016) 232-37, http://dx.doi.org/10.1016/j.erss.2016.08.013.

[33] Verbong, GPJ and D. Loorbach, Introduction, In: Verbong, GPJ and D. Loorbach (eds.) *Governing the Energy Transition: Reality, Illusion or Necessity?* Routledge, Abington (2012) 1-23.

[34] Markard, J. and VH Hoffmann, Analysis of complementarities: Framework and examples from the energy transition, *Technol. Forecast. Soc. Change* 111 (2016) 63-75, http://dx.doi.org/10.1016/j.techfore.2016.06.008.

[35] Markard, J., S. Wirth, and B. Truffer, Institutional dynamics and technology legitimacy – A framework and a case study on biogas technology, *Res. Policy* 45 (2016) 330-44, https://doi.org/10.1016/j.respol.2015.10.009.

[36] Xiao, Y., M. Watson, Guidance on conducting a systematic literature review, *J. Plan. Educ. Res.* 39(1) (2017) 93-112, https://doi.org/10.1177/0739456X17723971.

[37] Schwarz, PM, *Energy Economics*, Routledge, Abington (2018).

[38] Carl, J., The Causes and implications of India's coal production shortfall, In: Thurber, MC and RK Morse (eds.) *The Global Coal Market: Supplying the Major Fuel for Emerging Economies*, Cambridge University Press, Cambridge (2015) 294-373.

[39] Steffen, B., T. Matsuo, D. Steinemann, TS Schmidt, Opening new markets for clean energy: The role of project developers in the global diffusion of renewable energy technologies, *Bus. Polit.* 20(4) (2018) 553-87, https://doi.org/10.1017/bap.2018.17.

[40] Tushman, ML, L. Rosenkopf, Organizational determinants of technological change: Toward a sociology of technological evolution, *Res. Organ. Behav.* 14 (1992) 311-47.

[41] Norman, HE, J. Hanson, The role of domestic markets in international technological innovation systems, *Ind. Innov*. 25(5) (2018) 482-504, https://doi.org/10.1080/13662716.2017.1310651.

[42] Leitch, A., B. Haley, S. Hastings-Simon, Can the oil and gas sector enable geothermal technologies? Socio-technical opportunities and complementarity failures in Alberta, Canada, *Energy Policy* 125 (2019) 384-95, https://doi.org/10.1016/j.enpol.2018.10.046.

[43] Haselip J., D. Desgain, G. Mackenzie, Financing energy SMEs in Ghana and Senegal: Outcomes, barriers and prospects, *Energy Policy* 65 (2013) 369-76, https://doi.org/10.1016/j.enpol.2013.10.013.

[44] Best, R., Switching towards coal or renewable energy? The effects of financial capital on energy transitions, *Energy Econ.* 63 (2017) 75-83, http://dx.doi.org/10.1016/j.eneco.2017.01.019.

[45] Lockwood, M., C. Mitchell, R. Hoggett, Unpacking 'regime resistance' in low-carbon transitions: The case of the British Capacity Market, *Energy Res. Soc. Sci.* 58 (2019) 101278, https://doi.org/10.1016/j.erss.2019.101278.

[46] Negro, SO, F. Alkemade, MP Hekkert, Why does renewable energy diffuse so slowly? A review of innovation system problems, *Renew. Sust. Energ. Rev.* 16(6) (2012) 3836-46, https://doi.org/10.1016/j.rser.2012.03.043

[47] Hansen, EG, F. Lüdeke-Freund, XI Quan, J. West, Cross-national complementarity of technology push, demand pull, and manufacturing push policies: The case of photovoltaics, *IEEE T Eng. Manage.* 66(3) (2019) 381-97, https://doi.org/ 10.1109/TEM.2018.2833878.

[48] Aguirre, M., G. Ibikunle, Determinants of renewable energy growth: A global sample analysis, *Energy Policy* 69 (2014) 374-84, https://doi.org/10.1016/j.enpol.2014.02.036.

[49] Meadowcroft, J., Engaging with the politics of sustainability transitions, *Environ. Innov. Soc. Trans* 1(1) (2011) 70-5, https://doi.org/10.1016/j.eist.2011.02.003.

[50] Stirling, A., Transforming power: social science and the politics of energy choices, *Energy Res. Soc. Sci.* 1 (2014) 83–95, https://doi.org/10.1016/j.erss.2014.02.001.

[51] Newell, P., J. Phillips, Neoliberal energy transitions in the South: Kenyan experiences, *Geoforum* 74 (2016) 39-48, https://doi.org/10.1016/j.geoforum.2016.05.009.

[52] Boulle, M., The hazy rise of coal in Kenya: The actors, interests, and discursive contradictions shaping Kenya's electricity future, *Energy Res. Soc. Sci*. 56 (2019) 101205,

https://doi.org/10.1016/j.erss.2019.05.015.
[53] Ramos-Mejía, M., M-L Franco-Garcia, and JM Jauregui-Becker, Sustainability transitions in the developing world: Challenges of sociotechnical transformations unfolding in contexts of poverty, *Environ. Sci. Policy* 84 (2018) 217–23, http://dx.doi.org/10.1016/j.envsci.2017.03.010.
[54] Tigabua, A., F. Berkhout, P. van Beukering, Development aid and the diffusion of technology: Improved cookstoves in Kenya and Rwanda, *Energy Policy* 102 (2017) 593–601, http://dx.doi.org/10.1016/j.enpol.2016.12.039.
[55] Raven, R., J. Schot, and F. Berkhout, 2012. Space and scale in socio-technical transitions. *Environ. Innov. Soc. Transit*. 4, 63-78, https://doi.org/10.1016/j.eist.2012.08.001.
[56] Ragosa, G., P. Warren, Unpacking the determinants of cross-border private investment in renewable energy in developing countries, *J. Clean. Prod.* 235 (2019) 854-65, https://doi.org/10.1016/j.jclepro.2019.06.166.
[57] Johnstone, P., P. Newell, Sustainability transitions and the state, *Environ. Innov. Soc. Transit*. 27 (2018) 72-82, http://dx.doi.org/10.1016/j.eist.2017.10.006.
[58] Haselip, J., D. Desgain, G. Mackenzie, Non-financial constraints to scaling-up small and medium-sized energy enterprises: Findings from field research in Ghana, Senegal, Tanzania and Zambia, *Energy Res. Soc. Sci.* 5 (2015) 78–89, http://dx.doi.org/10.1016/j.erss.2014.12.016.
[59] George, AL, A. Bennett, *Case Studies and Theory Development in the Social Sciences*, MIT Press, Cambridge (2004).
[60] Gunningham, N., Managing the energy trilemma: The case of Indonesia, *Energy Policy* 54 (2013) 184-93, https://doi.org/10.1016/j.enpol.2012.11.018.
[61] Sambodo, MT, *From Darkness to Light: Energy Security Assessment in Indonesia's Power Sector*, ISEAS Publishing, Singapore (2016).
[62] McBeth, J., Fuel prices drive Indonesia's election debate 2019, *Asia Times*, 20 February 2019, https://www.asiatimes.com/2019/02/article/fuel-prices-drive-indonesias-election-debate/, 2019 [accessed 8 April 2019].
[63] Marquardt, J., Indonesia: A long way to low-carbon development, in Roehrkasten, S., S. Thielges and R. Quitzow (eds.) *Sustainable Energy in the G20*, IASS Potsdam (2016) 64-9.
[64] Dillon, HS, T. Laan, HS Dillon, HSBiofuels-at what cost? Government support for ethanol and biodiesel in Indonesia, The Global Subsidies Initiative of the International Institute for Sustainable Development, https://www.iisd.org/pdf/2008/indonesia_biofuels.pdf/, 2008 [accessed 21 March 2020].
[65] Reshetova, E., Indonesia's energy transition: From oil to coal, *Georgetown J. Asian Affairs* Winter 2019 (2019) 18-24, http://hdl.handle.net/10822/1053160.
[66] PwC. *Power in Indonesia: Investment and Taxation Guide, November 2018, 6th edition*, https://www.pwc.com/id/en/publications/assets/eumpublications/utilities/power-guide-2018.pdf/, 2018 [accessed 6 April 2019].

[67] PT PLN (PERSERO) *Rencana Usaha Penyediaan Tenaga Listrik (Electricity Business Plan) 2015-2024*, https://www.pln.co.id/statics/uploads/2017/05/BUKU_1_RUPTL_2015_2024.pdf/, 2015 [accessed 30 November 2019].

[68] Burke, PJ, J. Widnyana, Z. Anjum, E. Aisbett, B. Resosudarmo, and KGH Baldwin, Overcoming barriers to solar and wind energy adoption in two Asian giants: India and Indonesia, *Energy Policy* 132 (2019) 1216-28, DOI: 10.1016/j.enpol.2019.05.055.

[69] Lucarelli, B., Government as creator and destroyer: Indonesia's rapid rise and possible decline as steam coal supplier in Asia, In: Thurber, MC and RK Morse (eds.) *The Global Coal Market: Supplying the Major Fuel for Emerging Economies*, Cambridge University Press, Cambridge (2015) 294-373.

[70] Hadiz, VR and R. Robinson, The political economy of oligarchy and the reorganization of power in Indonesia, In: Ford, M. and TB Pepinsky (eds.) *Beyond Oligarchy: Wealth, Power, and Contemporary Indonesian Politics*, Cornell Southeast Asian Program Publications, Ithaca (2014) 35-56.

[71] Hervé-Mignucci, M. and X. Wang, *Slowing the growth of coal power outside China: The role of Chinese Finance*, A CPI Report, Climate Policy Initiative, 2015.

[72] LGS Online, PLN May Possibly Miss Target For Second 'Fast-Track' Scheme, 26 February 2009, http://www.lgsonline.com/pages/g/lgsimp997/node/lgs4a1d77eb99e7a/, 2009 [accessed 14 April 2019].

[73] Ali, M., Indonesia power firm signs loan agreements for over $1 bln, *Reuters*, 14 October 2009, https://www.reuters.com/article/indonesia-power-loan/indonesia-power-firm-signs-loan-agreements-for-over-1-bln-idUSJAK54822220091014/, 2009 [accessed 14 April 2019].

[74] Castle, JW and A. Manuwoto, *Indonesian Business: The Year in Review 2010*, Equinox Publishing (Asia), Jakarta, 2011.

[75] Dongfang Electric Co. Ltd, DEC signs Indonesia Kelteng 2*100MW coal-fired power plant EPC contract, 20 June 2016, http://www.dec-ltd.cn/en/index.php/asnews/detail/?subCategory=News&nid=331/, 2016 [accessed 27 April 2019].

[76] Investor Daily, Sinar Mas' energy holding pushes ahead with coal-fired power plants, *Jakarta Globe*, 25 June 2015, https://jakartaglobe.id/context/sinar-mas-energy-holding-pushes-ahead-coal-fired-power-plants/, 2016 [accessed 27 April 2019].

[77] People's Republic of China and the Republic of Indonesia, People's Republic of China and the Republic of Indonesia, Joint Statement on Strengthening Comprehensive Strategic Partnership between the People's Republic of China and the Republic of Indonesia, 27 March 2015, http://id.china-embassy.org/eng/zgyyn/zywx/t1249223.htm/, 2015 [accessed 14 June 2019].

[78] Gulagi, A., D. Bogdanov, C. Breyer, The role of storage technologies in energy transition pathways towards achieving a fully sustainable energy system for India, *J. Energy Storage* 17

(2018) 525-39, https://doi.org/10.1016/j.est.2017.11.012.
[79] Ardiansyah, F., The energy challenge, *Inside Indonesia*, July 2011, www.insideindonesia.org/the-energy-challenge-3/, 2011 [accessed 30 March 2019].
[80] Kennedy, SF, Indonesia's energy transition and its contradictions: Emerging geographies of energy and finance, *Energy Res. Soc. Sci.* 41 (2018) 230-37, https://doi.org/ 10.1016/j.erss.2018.04.023.
[81] Marquardt, J. A struggle of multi-level governance: Promoting renewable energy in Indonesia, *Energy Procedia* 58 (2014) 87-94, https://doi.org/10.1016/j.egypro.2014.10.413.
[82] Lin, JY and Y. Wang, *Going beyond Aid: Development Cooperation for Structural Transformation*, World Bank, Washington DC (2017).
[83] Ock, H-J., Korea should stop funding coal power in Indonesia, The Korea Herald (7 October 2019), http://www.koreaherald.com/view.php?ud=20191007000792/, 2019 [accessed 30 November 2019].
[84] Farrow, A., A. Anhäuser, L. Myllyvirta, and M. Son, *A Deadly Double Standard: South Korea's Financing of Highly Polluting Overseas Coal Plants Endangers Public Health*, Greenpeace East Asia Seoul office, Seoul, https://storage.googleapis.com/planet4-international-stateless/2019/11/ea2d3c1d-double_standard_report-high-resolution.pdf/, 2019 [accessed 30 November 2019].
[85] Son, M., A. Anhäuser, N. Sivalingam, A. Farrow, L. Myllyvirta, A deadly double standard: How Japan's financing of highly polluting overseas coal plants endangers public health, Greenpeace Southeast Asia and Greenpeace Japan, https://storage.googleapis.com/planet4-southeastasia-stateless/2020/03/e06c0c3f-double_standard_report.pdf/, 2019 [accessed 16 April 2020].
[86] Springer, CH, Energy entanglement: New directions for the China-Indonesia coal relationship, In: Morris-Jung, J. (ed.) *In China's Backyard: Policies and Politics of Chinese Resource Investments in Southeast Asia*, ISEAS Publishing, Singapore, 2018, 79-103.
[87] Supardi, A., Lawsuit against Indonesian coal plant reveals permit irregularities, Mongabay, November 1, 2019, https://news.mongabay.com/2019/11/indonesia-coal-plant-sumatra-permit-sepang-bay-lawsuit/, 2019 [accessed 2 December 2019].
[88] Jakarta Post, Bengkulu woos investors with 200 MW coal-fired power plant, 21 November 2019, https://www.thejakartapost.com/adv/2019/11/21/bengkulu-woos-investors-with-200-mw-coal-fired-power-plant.html/, 2019 [accessed 30 November 2019].
[89] Rainforest Action Network. Kluet Hydropower Dam Threatens Upper Kluet Region of the Leuser Ecosystem, 28 September 2017, https://www.ran.org/leuser-watch/leuser_watch_kluet_dam/, 2017 [accessed 13 April 2019].
[90] Singgih, VP, PowerChina to build hydropower plants for $17.8 billion, *Jakarta Post*, 19 April 2018, https://www.thejakartapost.com/news/2018/04/19/powerchina-to-build-hydropower-plants-for-17-8-billion.html, 2018 [accessed 13 April 2019].

[91] News desk of Jakarta Post, Bank of China to evaluate Batang Toru hydropower plant project, *Jakarta Post*, 14 March 2019, https://www.thejakartapost.com/news/2019/03/14/bank-of-china-to-evaluate-batang-toru-hydropower-plant-project.html, 2019 [accessed on 13 April 2019].

[92] Kementerian Energi dan Sumber Daya Mineral, Statistik Ketenagalistrikan Dan Energi, Tahun 2005, 2009, 2012, 2013, 2014 2015, 2016, 2017, 2018, 2019, Jakarta, http://gatrik.esdm.go.id/frontend/download_index/?kode_category=statistik/ [accessed 3 December 2019].

[93] PT PLN (PERSERO) *Rencana Usaha Penyediaan Tenaga Listrik (Electricity Business Plan) 2018-2027*, https://www.pln.co.id/statics/uploads/2018/04/RUPTL-PLN-2018-2027.pdf/, 2018 [accessed 30 November 2019].

[Note]

[1] They planned to build 4,945 MW of geothermal power plant and 1,753 MW of hydroelectric power plants (MEMR Decree 1/2012).

[2] These include a duplicated licensing system, inconsistent and contradictory rules between the Mining Law and the Forest Law, and corruption at the local level [86].

[3] They initially must divest a minimum of 20 percent of capital to Indonesian nationals, and then 51 percent by the tenth year of commercial operation.

[4] Including, but not limited to, a divestment requirement to compensate for untaxed resource rent (GR 23/2010, amended by GR 24/2012), an export ban on raw minerals (GR 7/2012), and (after the ban was canceled by a Supreme Court decision) progressive rates of export duty.

[5] This complementary might have limited to major coal mining, because domestic sales and exports by small local coalminers and unreported ones were expanded since 2009 [69].

[6] Despite local protests over alleged irregularities in the process of environmental permit, which was brought into a court case [87], Jakarta Post published an inforial that highlighted no pollution at the Bengkulu coal power plant, for the reason that China applies stricter air pollution standards and more advanced technology in building power plants than Indonesia [88].

[7] Despite protests by scientists and non-government organizations for the huge environmental impact of these projects, the Indonesian government ultimately approved the transition to coal [89-91].

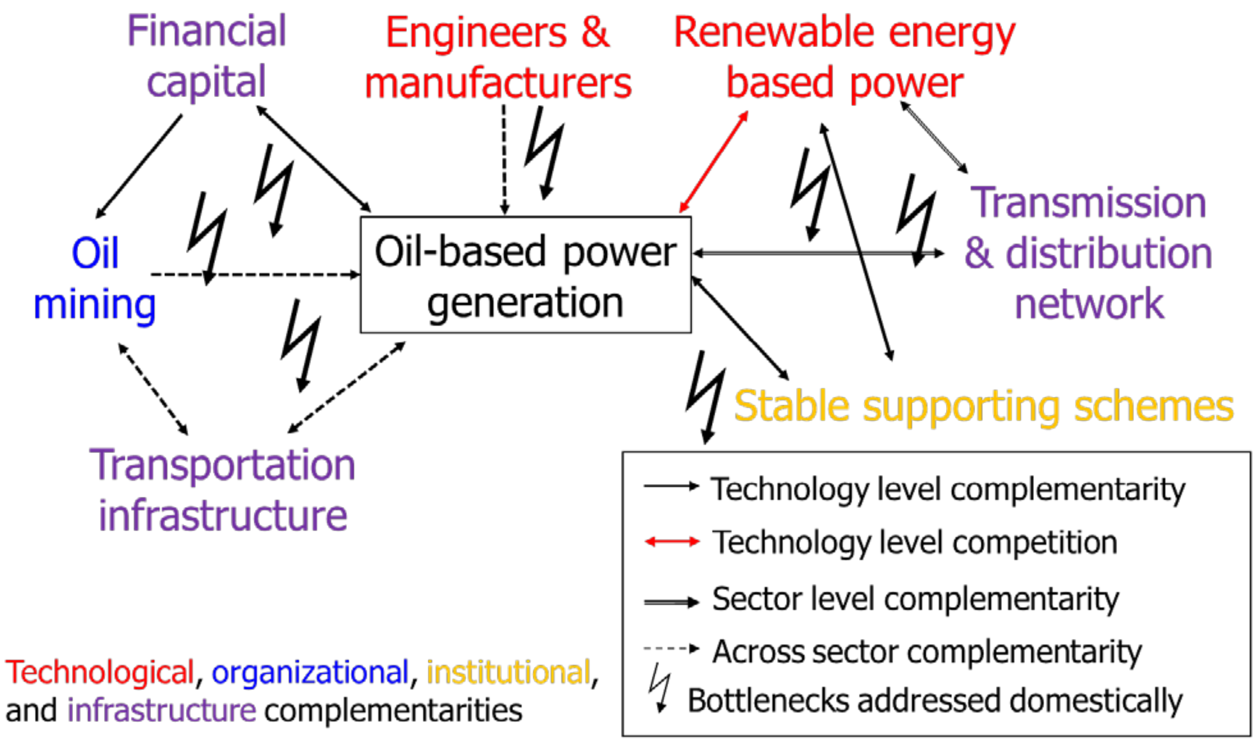

Figure 1 Complementarities and their bottlenecks in the oil-based electricity supply system

Source: Author.

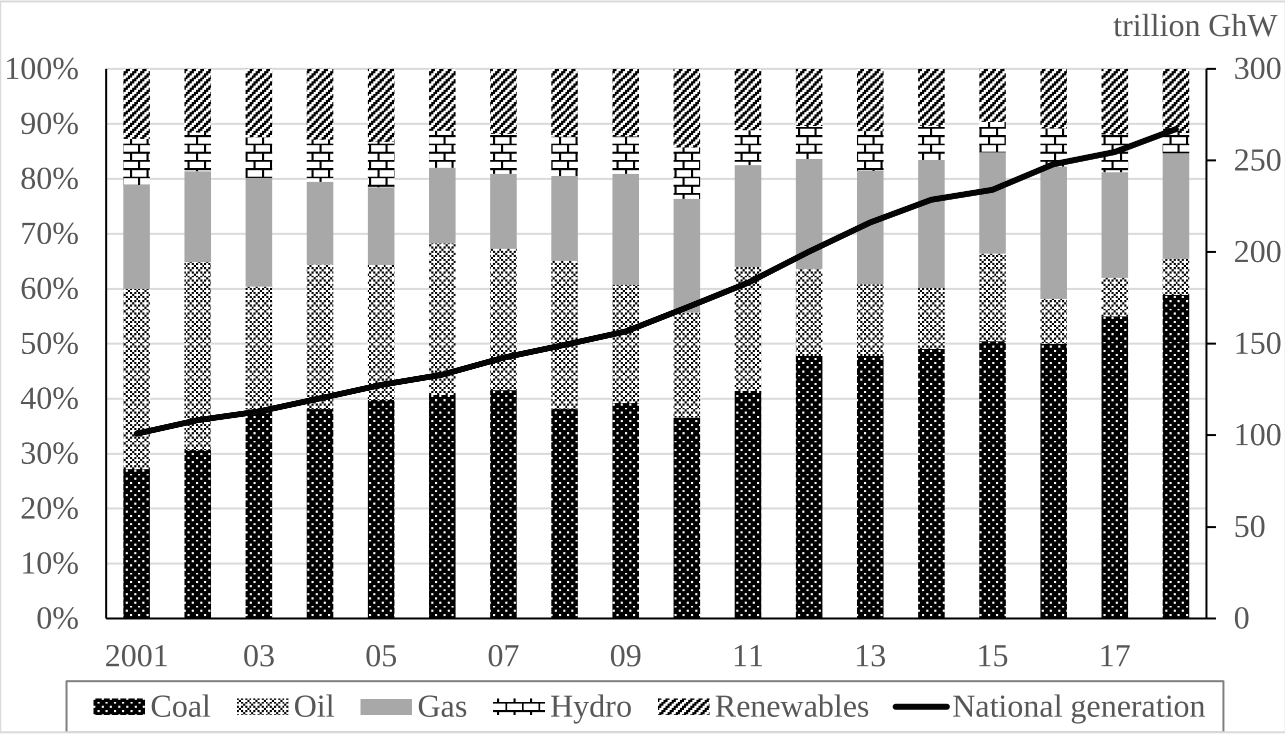

Figure 2 Energy mix in power generation in Indonesia, 2001-18

Note 1: Renewable includes large, mini and micro hydropower, geothermal, wind, solar PV and biomass power.

Note 2: In Indonesia, PLN and Ministry of Energy and Mineral Resources publish statistical yearbook of electricity. However, there are slight discrepancy between them, and both update a series of data in later years, which makes it difficult to analyze with consistent data. In addition, PLN annual reports are accessible only in 2014-18, which is narrower than the scope of this paper. For these reasons, this paper takes the data from the Ministry of Energy and Mineral Resources because it provides disaggregated data for many years, which enables to trace source of energy.

Source: Author compilation based on [92].

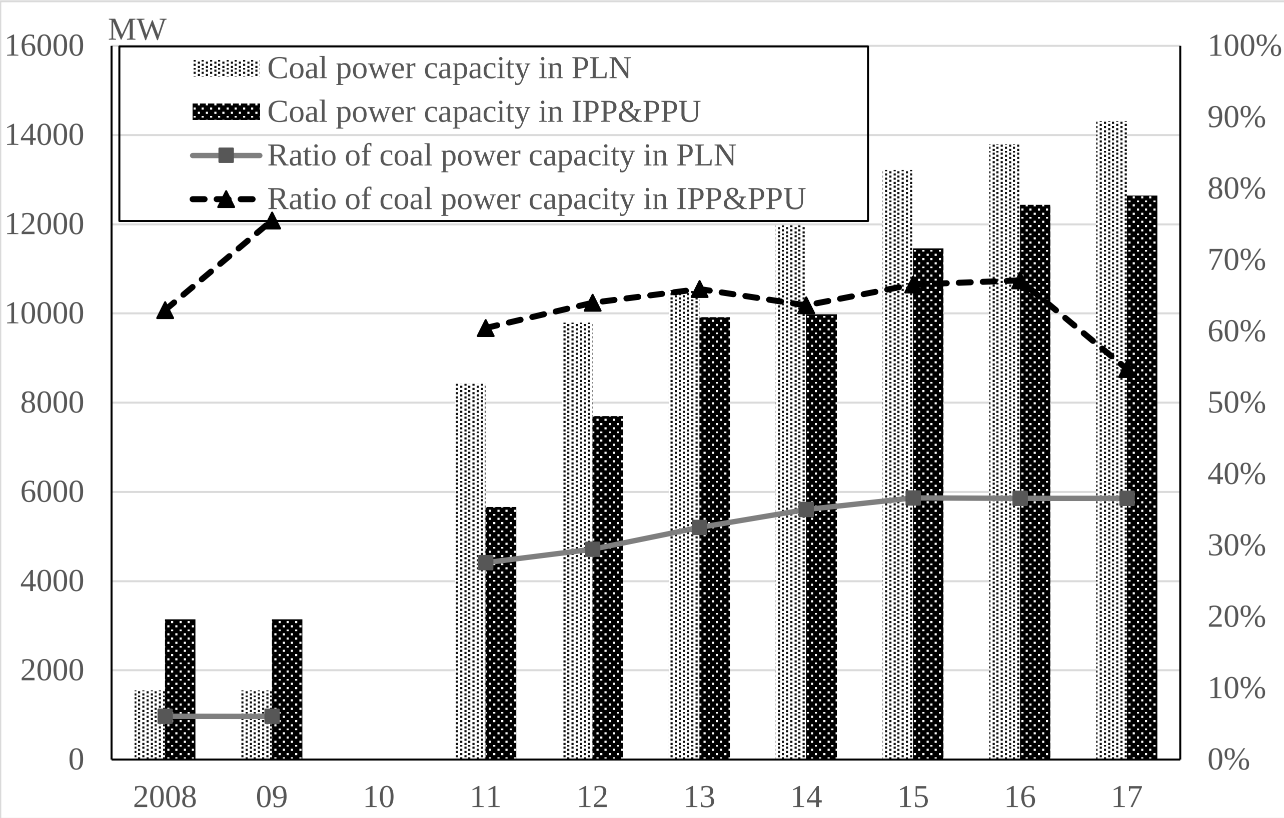

Figure 3 Coal power generation capacity and share in total capacity in 2008-17

Note 1: No reliable data are available for power generation capacity by source of energy in 2010.

Note 2: PLN also reports significant hike in the ration of coal but with different figure; 60 percent in 2018 from 42 percent in 2011 [93].

Source: Same as Figure 2.

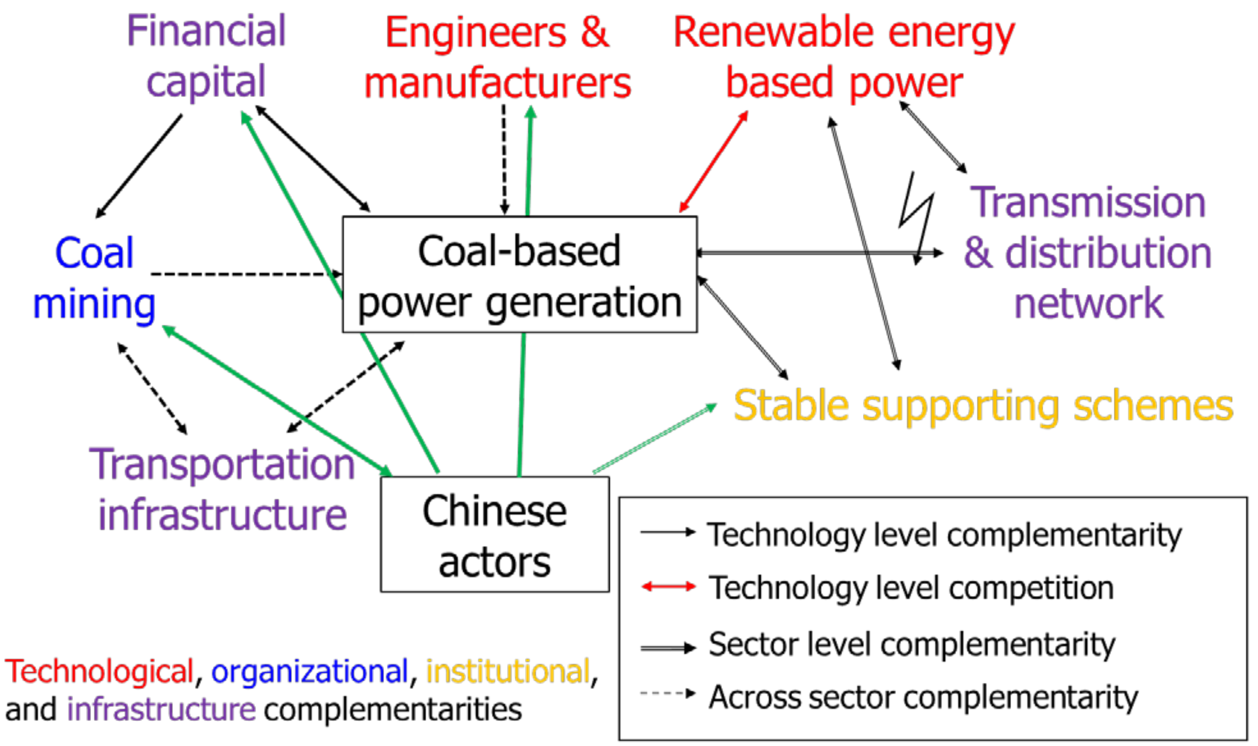

Figure 4 Interplay between foreign and domestic actors in complementarities in coal-based electricity supply system

Source: Author.

Table A1 Process for the document search in Web of Science

	Inclusion/Exclusion	Web of Science
1	Inclusion: Insert "energy transition" AND "complementarity" Exclusion: Limit the time scope between 2015 and 2020 Exclusion: Limit to journal articles	(TS=(energy transition AND complementarity)) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) Refined by: WEB OF SCIENCE CATEGORIES: (BUSINESS OR ENVIRONMENTAL STUDIES OR MANAGEMENT OR ECONOMICS OR REGIONAL URBAN PLANNING OR DEVELOPMENT STUDIES) Timespan: Last 5 years. Indexes: SSCI, BKCI-SSH, ESCI.
2	Inclusion: Insert "energy transition" AND "bottleneck" Exclusion: Limit the time scope between 2015 and 2020 Exclusion: Limit to journal articles	(TS=(energy transition AND complementarity)) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) Refined by: WEB OF SCIENCE CATEGORIES: (ENVIRONMENTAL STUDIES OR BUSINESS OR MANAGEMENT OR DEVELOPMENT STUDIES OR ECONOMICS OR REGIONAL URBAN PLANNING) Timespan: Last 5 years. Indexes: SSCI, BKCI-SSH, ESCI.
3	Inclusion: Insert "energy transition" AND "complementarity" Exclusion: Limit the time scope between 2015 and 2020 Exclusion: Limit to journal articles, book chapter, and book	(TS=(energy transition AND complementarity)) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) Refined by: WEB OF SCIENCE CATEGORIES: (ENVIRONMENTAL STUDIES OR ECONOMICS OR DEVELOPMENT STUDIES OR PUBLIC ADMINISTRATION OR REGIONAL URBAN PLANNING OR GEOGRAPHY OR BUSINESS OR POLITICAL SCIENCE OR MANAGEMENT OR URBAN STUDIES OR BUSINESS FINANCE OR AREA STUDIES OR INTERNATIONAL RELATIONS) Timespan: Last 5 years. Indexes: SSCI, BKCI-SSH, ESCI.

Table A2 Process for the document search in Scopus

	Inclusion/Exclusion	Scopus
1	Inclusion: Insert “energy transition” AND “complementarity” Exclusion: Limit the time scope between 2015 and 2020 Exclusion: Limit to journal articles	TITLE-ABS-KEY ("energy transition" AND "complementarity") AND DOCTYPE (ar OR re) AND PUBYEAR > 2014 AND (LIMIT-TO (SUBJAREA , "ENER") OR LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-TO (SUBJAREA, "BUSI") OR LIMIT-TO (SUBJAREA, "ECON") OR LIMIT-TO (SUBJAREA , "PSYC"))
2	Inclusion: Insert “energy transition” AND “complementarity” Exclusion: Limit the time scope between 2015 and 2020 Exclusion: Limit to book chapters and book	TITLE-ABS-KEY ("energy transition" AND "complementarity") AND DOCTYPE (bk OR ch) AND PUBYEAR > 2014
3	Inclusion: Insert “energy transition” AND “bottleneck” Exclusion: Limit the time scope between 2015 and 2020 Exclusion: Limit to journal articles	TITLE-ABS-KEY ("energy transition" AND "bottleneck") AND DOCTYPE (ar OR re) AND PUBYEAR > 2014 AND (LIMIT-TO (SUBJAREA , "ENER") OR LIMIT-TO (SUBJAREA, "SOCI") OR LIMIT-TO (SUBJAREA, "BUSI") OR LIMIT-TO (SUBJAREA , "PSYC"))
4	Inclusion: Insert “energy transition” AND “bottleneck” Exclusion: Limit the time scope between 2015 and 2020 Exclusion: Limit to book chapters and book	TITLE-ABS-KEY ("energy transition" AND " bottleneck") AND DOCTYPE (bk OR ch) AND PUBYEAR > 2014
5	Inclusion: Insert “energy transition” AND “developing countries” Exclusion: Limit the time scope between 2015 and 2020 Exclusion: Limit to journal articles	TITLE-ABS-KEY ("energy transition" AND "developing countries") AND DOCTYPE (ar OR re) AND PUBYEAR > 2014 AND (LIMIT-TO (SUBJAREA , "ENER") OR LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-TO (SUBJAREA , "ECON") OR LIMIT-TO (SUBJAREA , "BUSI") OR LIMIT-TO (SUBJAREA , "PSYC"))
6	Inclusion: Insert “energy transition” AND “developing countries” Exclusion: Limit the time scope between 2015 and 2020	TITLE-ABS-KEY ("energy transition" AND "developing countries") AND DOCTYPE (bk OR ch) AND PUBYEAR > 2014

	Exclusion: Limit to book chapters and book	