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Revisiting carbon lock-in in energy systems: Explaining the perpetuation of coal power in Japan

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ABSTRACT

Carbon lock-in hampers the realisation of sustainable energy systems. It occurs when carbon-intensive technologies, markets and institutions co-evolve and become wedded to historical trajectories despite environmentally superior technologies being available. Multiple material and non-material causes are discussed in literature on socio-technical or energy transitions and carbon lock-in. However, these are yet to be synthesised into a comprehensive framework to guide the empirical identification of lock-in factors. Also, empirical understanding into how various causes of lock-in can interact is limited. To deepen understanding into the various types of socio-technical lock-in affecting energy transitions, we develop an encompassing analytical framework accounting for material, human, non-material and exogenous factors. In addition to carbon lock-in and path dependency, we synthesise diverse literature encompassing sustainability transitions, energy policy, innovation and firm management, economics and political economy. The resultant framework provides a finer-grained and more comprehensive understanding of lock-in than previous studies. Using Japan as a case study, we then apply this framework with two questions in mind: (i) What factors are contributing to the perpetuation of coal power in Japan? and ii) What opportunities emerge to overcome these? The empirical analysis is informed by triangulated data involving 46 semi-structured interviews and diverse documents. Our findings reveal a wide array of interacting factors that contribute to the perpetuation of coal-power in Japan and several emerging opportunities to tackle these. They also demonstrate our framework's utility as a heuristic that scholars could apply to other cases to increase empirical understanding into the multiple causes of socio-technical lock-in.

1. Introduction

Amidst mounting recognition of the incompatibility between unabated coal combustion and climate change mitigation [1,2], numerous studies have documented the difficulty of phasing-out coal-fired power plants (CFPPs) globally [3–8] and in specific countries [9–12]. Several studies have grappled with the issue of why some countries are able to more easily phase-out CFPPs and increase renewables while others remain locked-in to coal dependence [13–15].

Literature offers several explanations regarding this. Coal extraction industries can pose a significant political barrier to ambitions to reduce coal-fired electricity generation since the employment of mine workers and company profits depend on sales to power stations [3,15,16]. Meanwhile, scholars highlight other factors such as varying transaction costs when transitioning to alternative energies, the desirability of reputational benefits from becoming a climate leader, the role of institutions and firms in national political economies, and additionally, differing degrees of transparency and autonomy in government decision-making [13–15]. Thus, a multitude of factors influence the extent to which a country's energy system remains wedded to coal utilisation. Additionally, these factors can be material or non-material and located inside or outside the energy system.

These insights from coal literature are entirely compatible with work on carbon or socio-technical 'lock-in' and 'path dependency'. These states arise due to tendencies in socio-technical systems for carbon-intensive technologies, industries, policy and institutional environments to co-evolve in a mutually beneficial and dependent manner [17,18]. Interactions amongst the material, human and non-material dimensions comprising a socio-technical system then create stability and self-perpetuation. Path dependency occurs when interlinkages or self-reinforcing feedbacks between differing components wed a socio-technical system to developing along its current trajectory [19,20]. This can lock-in carbon-intensive technologies and prevent uptake of environmentally superior alternatives [21,22]. While such understanding lies at the roots of sustainability transitions theory [23], studies on coal phase-outs have only recently integrated these concepts [14,24].

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Table 1
Sources of socio-technical lock-in.

Source	Description	Key literature
1. Material *Technologies, assets and infrastructure*	The technological state and financial value embedded in material assets and infrastructure that influence the ability of regime actors to adopt alternative technologies or dispose assets.	• Seto, Davis et al. [17] • Unruh [18] • David [49] • Janipour, de Nooij et al. [21] • Chignell and Gross [50] • Erickson, Kartha et al. [51]
2. Human actors *Actors and agency*	The composition, relationships, power structures and vested interests (with either financial or non-financial roots) of the internal actors involved in maintaining and changing the system.	• Sandén and Hillman [41] • Geels [23] Geels [52] • Smith, Stirling et al. [53] • Fischer and Newig [54] • Newell and Johnstone [55]
3. Non-material *Formal institutions (policies, rules and commitments)*	Formalised (i.e. codified and explicit) rules and principles that guide behaviour such as policies, standards, formal contracts, roadmaps, commitments and formalised governance mechanisms.	• Sandén and Hillman [41] • Geels [23,25] • Walker [56] • Unruh [18] • Seto, Davis et al. [17]
Informal institutions (cognitive frames, norms, narratives and expectations)	Informal (and often non-codified and implicit) rules, cognitive schemes, routines, values and norms affecting the way actors view and respond to sustainability issues (e.g. problem awareness/framing, narratives, missions, mindsets, worldviews, expectations).	• Geels [23,25] • Scott [57] • Metze [29] • Dosi [28] • Sandén and Hillman [41]
Knowledge and competences	Intellectual capital such as accumulated knowledge and skills/competences in human resources, R&D programmes and business models.	• Geels [23,25] • Turnheim and Geels [31] • Sandén and Hillman [41] • Hill and Rothaermel [58] • Bohnsack, Pinkse et al. [20]
Micro-economic factors	Economic conditions and incentives affecting the ability of actors to adopt alternative technologies or practices that do not necessarily stem from material assets and infrastructure (e.g. increasing returns, a firm's position relative to competitors, the cost of producing or adopting current or alternative technologies etc.).	• Pierson [19] • Maréchal Maréchal [59] • Hill and Rothaermel [58] • Klitkou, Bolwig et al. [30]
4. Exogenous context *Societal, geographical, technological and environmental conditions*	Macro-level conditions outside the socio-technical regime that influence or constrain the socio-technological preferences and behaviour of regime actors.	• Jakob, Flachsland et al. [48] • Geels [33,34] • Van Driel and Schot [60] • Unruh [18] • Seto, Davis et al. [17] • Valentine and Sovacool [32] • Sovacool and Griffiths [61]

There are several knowledge gaps in existent literature. First, although theoretical studies emphasise how interlinkages, interdependencies and feedbacks can occur across sources of lock-in [17,18,25–27], empirical studies [21,22] are limited. Second, given the multiplicity of factors causing socio-technical lock-in, explanations are scattered across diverse academic fields. Although Seto et al. [17] integrate diverse knowledge on carbon lock-in, multiple causes described in other literature are unaccounted for. These include discourse [24], cultural or cognitive frames and institutions [25,28,29], economic conditions and intellectual capacities that guide, incentivise or restrain the behaviour of regime actors [30,31]. Third, carbon lock-in literature typically affords little attention to the broader contextual conditions surrounding socio-technical systems. This is problematic if considering that much literature on energy and sustainability transitions [32–34] and coal phase-outs [13–15,35] has underscored how exogenous factors (e.g. political, environmental, societal) outside the energy system itself can both trigger and *impede* change.

To address these limitations in literature, this study first develops an encompassing analytical framework accounting for material, human, non-material and exogenous causes of lock-in. This framework synthesises a broad body of literature covering not only carbon lock-in and path dependency, but also sustainability transitions more broadly, energy policy, innovation and firm management, economics and political economy. The resultant framework provides a finer-grained and more comprehensive understanding of lock-in than previous studies. Using Japan as a case study, we then apply this framework with two questions in mind: (i) What factors are contributing to the perpetuation of coal power in Japan? and ii) What opportunities emerge to overcome these? The empirical analysis is based on triangulated data involving 46 semi-structured interviews and diverse documents. Application of this framework demonstrates its utility as a heuristic that scholars could apply to other cases to increase empirical understanding of socio-technical lock-in.

The lens of socio-technical lock-in is highly relevant to Japan. As many industrialised nations are actively reducing reliance on coal, Japan has attracted much attention in scholarship and international media following the extensive upgrading and expansion of its CFPP fleet after the Fukushima nuclear disaster [11,36–40]. In parallel, private and public actors continue to finance and export coal power technologies abroad. Being one of few studies to examine socio-technical lock-in empirically, our findings uncover multiple and interlinked factors exasperating the persistence of coal power in Japan. These bear significant implications for global efforts to reduce fossil fuels in line with the Paris Agreement's climate targets.

This paper's remainder proceeds as follows. Section 2 identifies various sources of carbon or socio-technical lock-in from literature and synthesises these into a framework. Section 3 then briefly introduces the context of climate and energy policy in Japan. Our methods are presented in Section 4. Next, Section 5 applies our framework to empirically identify factors contributing to the perpetuation of coal power in Japan. Section 6 then examines several clusters of interacting lock-in factors and emerging trends with potential to weaken these. Finally, conclusions are summarised in Section 7.

2. Analytical framework: Causes of path dependency and socio-technical lock-in

This section develops an analytical framework for identifying, understanding and, ultimately, targeting differing sources of lock-in. Diverse literature is examined from fields including sustainability transitions, climate and energy policy, innovation and firm management, economics and political economy. Relevant studies were identified with a two-step approach: (i) searching on Web of Science with various combinations of 'path dependency', 'lock-in', 'resistance', 'inertia' or 'stability', 'socio-technical', 'energy' and 'carbon'; and (ii) examining the resulting hits to identify additional references. This procedure thus covered studies dealing explicitly with carbon or socio-technical lock-in and path dependency as well as those focused on energy or socio-technical transitions, but also discussing such factors.

The framework shown in Table 1 is rooted in the pertinent literature [23,33,41,42] that conceptualises socio-technical systems as comprising three distinct but interlinked dimensions: (i) *material* (e.g. technology, assets and infrastructure), (ii) *human actors* (e.g. market, societal and government actors) and (iii) *non-material* factors influencing actor behaviour (e.g. formal and informal institutions, cognitive frameworks, knowledge and competences, economic incentives etc.). Thus, socio-technical systems may be conceived as a constellation of material, human and non-material factors that co-evolve in a mutually reinforcing way [27,31,43,44]. Socio-technical lock-in occurs when interlinkages or feedbacks between these differing components collectively create system stability and resist—by design or consequence—the integration of environmentally or otherwise superior technologies and configurations [17,18,22]. By re-producing or maintaining the material and non-material properties of the system, socio-technical 'regimes' (consisting of incumbent actors and entrenched institutions) are a crucial determinant of lock-in [23,45]. Hence, this understanding is also integrated into the conceptual foundations of the framework.

In addition, our framework integrates a fourth dimension; (iv) *exogenous context.* This reflects the broader cultural, political, geographical and economic factors lying outside the socio-technical system in society at large. Most transitions scholars portray the landscape as a driver of change, since it creates pressures on the socio-technical regime and opens windows of opportunity for alternative socio-technical configurations [23,46,47]. However, these same exogenous factors may also *inhibit* change. This is particularly visible in recent studies examining the varying capacities of countries to transition beyond coal [13–15,48].

This analytical framework is novel and useful in several regards. Theoretically speaking, it synthesises conceptually congruent knowledge that was, until now, scattered across diverse scholarly fields. The resultant framework also provides a finer-grained picture of lock-in sources in energy systems and the multiple forces that obstruct or drive socio-technical change than previous studies [e.g. 17,18]. It also responds to a call for more cross-fertilisation between transitions theory and other fields [34]. Empirically speaking, this framework provides a heuristic that can aid the identification and evaluation of different sources of lock-in and potential leverage points to overcome these. Thus, this tool can facilitate the production of improved empirical knowledge into the various and interlinked dynamics that perpetuate or destabilise incumbent socio-technical regimes—particularly in the context of transitioning beyond fossil fuels.

In the the following sections, we synthesise insights from diverse literature to explain various sources of socio-technical lock-in shown in Table 1. Although we describe lock-in sources separately, empirically speaking, these dimensions will interact and may create self-reinforcing feedbacks [17,22]. This nuanced aspect is dealt with in the findings.

2.1. Technologies, assets and infrastructure

Existing fossil fuel technologies, material assets and infrastructure can create lock-in by preventing or hampering efforts to adopt cleaner alternatives [17,18,41]. The first issue concerns technological interrelatedness or compatibility [49]. New technologies such as renewables and electric vehicles are disruptive due to their incompatibility with existing technologies and infrastructures (e.g. power grids and fuelling stations) [30,44]. Existing technologies and infrastructure can thereby pose a physical barrier to the adoption of environmentally superior alternatives. The second issue is financial and concerns the ownership lifecycle and value of material assets (e.g. power/steel/cement plants) and associated infrastructure and supply chains (e.g. fossil fuel extraction projects and distribution networks like pipelines or ships) [21]. Since these require significant upfront investments, investors have a financial imperative to operate these installations at least until sunk capital is recovered [50,51]. Their technological specificity and singular purpose can exasperate this need by limiting their utility for other buyers or objectives [17].

2.2. Actors and agency

The incumbent human actors involved in controlling or changing the system (e.g. firms, industry organisations, government agencies, politicians and research institutes etc.) can contribute to socio-technical lock-in [23,41,53,54]. Three facets are particularly relevant: (i) actor composition and power balances, (ii) actor networks, and (iii) vested interests.

First, the inclusion or exclusion of certain actors (e.g. those championing or opposing alternative technologies and practices) into decision-making bodies can hamper change when the technological preferences of incumbents are rigid [53,62]. Even when diverse actors are involved, change can be suppressed by skewed power balances if the voices and actions of some are more powerful than others [52]. Second, actors interact via networks [41] by sharing resources (e.g. knowledge, funds, and personnel) and cognitive information such as ideas, beliefs, expectations etc. [23]. As reflected in the economic concept of 'embeddedness' [63], the technological preferences of one set of actors can be affected by relationships with other actors through informal institutions (see Section 2.4) that diffuse across networks. Thus, social networks can drive or restrict socio-technical change through factors differing distinctly from economic logic. Third, vested interests can also impede change when the preferences of regulators and the regulated coalesce around the goal of maintaining the current system [22,45,64]. Interests may be financial in nature due to the economic value of assets or business models. However, they can also be non-financial, arising from co-dependant relationships and loyalty among government or industry actors or ideological attachment to established technologies and practices [19,32,65,66]. Furthermore, the vested interests of industry can influence formal institutions (discussed next) via lobbying or personnel exchanges between government and regulated entities [55,67].

2.3. Formal institutions: policies, rules and commitments

By influencing the behaviour and decisions of regime actors, formalised (i.e. codified and explicit) institutions and governance mechanisms can also create socio-technical lock-in [18,23,25,41]. This can include highly explicit rules including public policies, regulations and standards [27,31,44,47] as well as legally-binding contracts that commit firms to purchasing specific types of fuel, energy or materials [56]. Formal institutions can also include industry targets, voluntary commitments and technology roadmaps or visions since these can oblige or encourage actors to follow particular trajectories with regard to investments, decisions and technological development [41]. The lock-in effect of formal institutions is such that once formulated, they can be difficult to change, and can persist for long durations [18,68]. This can result in favourable outcomes for actors championing a particular technology. Thus, the lock-in effect of formal institutions is often anticipated and consciously orchestrated by particular actors [17].

2.4. Informal institutions: cognitive frames, norms, narratives and expectations

The informal institutions influencing actor behaviour can also contribute to lock-in. Being slow to form, informal institutions can resist change and lag behind technological developments. Cognitive frames are particularly emphasised in literature [23,25,41,69]. These include diverse factors such as worldviews (i.e. fundamental cognitive orientations), beliefs and guiding principles [70]. These set boundaries around desirable or acceptable codes-of-conduct and influence how problems are interpreted and which solutions are pursued [27,31,57]. Lock-in occurs when such frames produce a 'blinding effect', whereby alternative technologies or ways of viewing problems are excluded from consideration [28]. Similarly, collective identities and expectations about the societal mission or purpose of firms or organisations can wed actors to particular behaviours [25]. Also emphasised are routines, norms and unwritten 'rules of the game' [27,55,66]. These behavioural templates can affect business world practices as much as government policymaking. Like cognitive frames, these are learned and shared across communities or generations of actors (i.e. from senior to junior) [42]. Finally, cognitive frames and expectations often emerge in shared discourse about sustainability issues and the desirability of particular responses. By transmitting established logic and practices to other actors, discursive patterns and narratives can also contribute to socio-technological lock-in [11,24,29].

2.5. Knowledge and competences

By enabling or restraining actions, intellectual capital such as the knowledge, skills and competences accumulated in human resources, R&D programmes, technologies and business models can also generate lock-in [18,25,31,41]. Knowledge and competencies are the cumulative result of historical decisions, investments and actions. Thus, while disruptive inventions often stem from newcomer firms, incumbent counterparts with historical expertise in a particular technology often face difficulties in developing or adopting new technologies and business models [27,58]. Since new technologies and practices require new competences, organisations can be reluctant to pursue these for fear of rendering obsolete existent skills, knowledge and business practices [71]. Alternatively, they may be unable to because of insufficient knowledge, competences or aptly skilled human resources [72].

2.6. Micro-economic factors

Micro-economic conditions can also influence behaviour and hamper the ability of market actors to adopt alternative technologies and business models. As discussed in Section 2.1, sunk investments in specific material assets or infrastructure (e.g. power plants, mines and fuel supply chains) can exert a shackling effect on business or policy decisions to abandon fossil fuels. Yet economic incentives and restraints can also stem from a combination of market conditions and the characteristics of a firm (e.g. business models, production methods, intellectual resources and market position relative to competitors). In particular, three economic factors are emphasised.

First, the higher cost of producing or purchasing new low-carbon technologies or energy can prolong the preference for incumbent technologies in business decisions [15]. Second, economic incentives may also arise from one firm's position relative to another [73]. For example, when a technology producer enjoys a niche market with few competitors, increased opportunities for profit can reduce the desirability of embracing alternative technologies or business models. Third, numerous scholars describe 'increasing returns' where financial (and non-financial) benefits increase with time and scale [18,21,74]. Learning curves and economies of scale are a major cause of increasing returns as the costs of technology production or utilisation fall over time while quality, reliability and expertise all increase [20,30,58]. In this situation, each 'step' (i.e. each investment, output or business strategy) in a particular direction decreases the costs associated with continuing [19] while, conversely, increasing the costs of retreating or adopting alternatives [21]. These increasing benefits can lock-in actors to business models that continually produce, purchase or invest in incumbent technologies [30,59,66].

2.7. Societal, geographical, technological and environmental conditions

The broader and exogenous conditions surrounding the socio-technical regime in question can drive change by creating momentary pressures, instability or crises [33,34,47,48]. Conversely however, by virtue of their *stability,* these slow-developing forces can hamper the emergence of novel practices and technologies—and thereby exasperate lock-in [17,18]. Our conceptualisation of this category is rooted in observations that the societal, geographical, technological and environmental conditions that can inhibit change are often found outside the affected socio-technical regime [60,75]. As an example of environmental conditions, severe air pollution in one country can drive societal demand for non-emitting technologies [32,76]. In another country, the social acceptance of particular technologies (e.g. nuclear or coal) may be more influenced by the shared normative values embedded in culture and institutions (e.g. educational and political) at large [61]. Circulating on a wider scale outside the control of regime actors, these cultural norms differ to those discussed above in informal institutions (Section 2.4) such as professional norms and routines in business and policymaking. Furthermore, these wider norms might be shaped by international developments. The global diffusion of fossil fuel divestment norms is one example [77]. Geographical conditions are also relevant. For example, abundant fossil fuel resources can foster societal resistance to renewable energy due to the symbiotic socio-economic and political systems that prosper from their extraction [3]. Meanwhile, the varying availability of energy resources and land availability across countries can generate differing cost burdens when expanding renewables [78]. Finally, literature also highlights the driving and hampering force of differing political institutions and styles of governing markets when explaining the ability or motivation for certain countries to phase-out fossil fuel technologies like CFPPs [13–15] or internal combustion engines [79].

3. Case study background: climate, energy and coal policy in Japan

Portrayed by literature as firmly locked into coal-fired power generation [3,11,38,80], Japan is a major player in the global coal market. Being the world's fourth largest consumer of coal [81], the domestic CFPP fleet contains around 43 GW (comprising 110 plants) of currently operating capacity [82]. In parallel, industry and government agencies have actively assisted developing countries to construct CFPPs over the past decade. As measured by government financing (e.g. loans, grants and insurance), Japan is the second largest contributor to overseas CFPPs development after China [83,84]. Key private actors that have supported the domestic and international coal market include plant equipment manufacturers, general trading companies (which invest in coal mines and CFPPs), electric utilities, banks, industry lobby groups and power sector research institutes [see 11,38].

While more and more countries commit to phasing-out coal-fired power generation by the 2030's [13–15,85], the Japanese government is reluctant to fix an explicit long-term policy signal for phasing-out coal power. The *Long-Term Outlook for Energy Supply and Demand* and the *Fifth Strategic Energy Plan* (formulated in 2015 and 2018 respectively) posit coal as an important, low-cost baseload power and plan an electricity mix for 2030 containing a 26% share of coal [86,87]. Natural gas and coal originally provided a short-term substitute for idled nuclear reactors after the Fukushima disaster. However, dependence on coal has grown after a spate of CFPP construction activity occurred in response to the above and other policy signals [see 11]. Concretely, 15 plants totalling 5 GW of capacity have come online since 2011. A further 8.7 GW (comprising 15 plants) are under construction while 4.6 GW (7 plants) are under planning [88]. In the absence of legally binding carbon emission restrictions for power producers, coal's share of annual electricity generation rose from 27% in 2010 to 31% in 2018 [89]. In July 2020, the national government reacted to this increasing coal power capacity and generation by announcing ambitions to gradually retire over the next decade some 100 inefficient CFPP units built before 1990 [90]. Yet a significant share of newer coal capacity (and possibly future additions) will remain after these retirements. Consequently, this policy development still maintains the above-mentioned commitment to maintaining coal in Japan's power mix. Moreover, even if 100 older units were retired, coal's share of electricity generation in 2030 could still hover around 24–27% [91].[1]

Energy and climate policies are crafted and implemented by bureaucrats in the Ministry of Economy, Trade and Industry (METI) and the inhouse Agency for Natural Resources and Energy. With close ties to the business world and much autonomy from the political apparatus [65,92], both bodies support industry self-regulation and voluntary frameworks for climate and energy affairs while resisting command-and-control approaches like carbon pricing. Although the Ministry of Environment is vocally opposed to coal power constructions domestically and abroad [93], it lacks legal and political authority to halt new projects. The strong emphasis on technical and economic feasibility for industry in the incumbent bureaucracy [94] has consistently hampered climate ambitions. With an unambitious pledge of reducing greenhouse gas emissions 26% by 2030 from 2013 levels (and 80% by 2050), the Nationally Determined Contribution submitted to the Paris Agreement has attracted widespread criticism from researchers and investors [95,96]. Incidentally, although consistently supporting coal, METI and the dominating conservative political party are by no means opposed to renewable energy [97]. Notable measures to promote renewables include liberalisation of the retail electricity market in 2016 to break up the historical domination of regional power utilities [98,99], introduction of a generous feed-in-tariff scheme [100] and, more recently, a zoning policy to kick-start Japan's nascent offshore wind industry [101].

Nevertheless, with growing international scrutiny around the absence of ambitious measures to reduce coal dependence [39,102,103], the underlying causes behind the persistence and resilience of Japan's coal power industry merit a deeper investigation. This persistence is even more remarkable given that Japan has negligible coal reserves and mining communities that would be affected by a coal phase-out. As we will demonstrate, the persistence of coal can be largely explained by multiple, interacting lock-in factors. These occur both inside and outside the various material, non-material and human dimensions comprising the socio-technical regime of Japan's coal power industry.

[1] It is unclear at this stage what share of electricity generation from coal would result in 2030 from this newly announced measure to retire inefficient, older plants. This estimate of 24–27% assumes that the remaining fleet, although decreasing in size by around 20%, would operate at a capacity factor of between 70-80% for 2030 in line with government and industry estimates.

4. Methods

4.1. Data sources and scope

Our empirical analysis draws on a dataset assembled over three years, from April 2017 to July 2020. Secondary sources include government policy documents, research institute or industry reports, websites, symposium presentation materials and academic literature. Primary sources were obtained from 46 semi-structured interviews with 84 respondents (see Appendix). Data collection occurred over three rounds in accord with evolving but interconnected research interests. The first, conducted from April 2017 to June 2019, focused on understanding the basic political economy drivers of new CFPP construction in Japan and the narratives underpinning this [11]. The second, finishing in December 2019, examined the drivers and barriers to coal divestment amongst the various private actors comprising Japan's coal market [38]. The third and final round occurred between January and July 2020. This involved 12 semi-structured interviews that specifically focused on deepening understanding of lock-in factors and interrelations. By integrating interviews and documents collected over a three-year period, this dataset enables the identification of temporally persistent lock-in factors.

The 46 interviews targeted diverse actors in coal-related organisations such as government agencies, electric utilities, plant equipment manufacturers, coal mining and CFPP developers, financial institutions, industry groups and research institutes. Experts in NGOs, thinktanks and universities were also interviewed to secure critical perspectives. Interviews mostly took place on-site and in Japanese by the first author and lasted between 60 and 90 min. Interview questions were sent to respondents in advance, and conversations were recorded to produce transcripts (except two for which recording was not permitted). When referred to in the text, all interviews use codes known only to the first author (e.g. int. 1,3).

The temporal focus is on the period after the Fukushima nuclear accident in March 2011, after which new CFPP construction increased significantly. The analysis mostly covers CFPP development (i.e. R&D, construction and plant operation) on Japanese soil but also considers exports abroad. We do not explicitly focus on coal mining. This is addressed in earlier work [38] and was not observed to be a significant lock-in factor (see Section 5.1).

4.2. Lock-in identification and data analysis

Lock-in sources were identified by two processes. In the first, hypotheses about causes of lock-in and interactions were formulated based on an early version of our framework and after analysing documents and interview transcripts from early rounds. These were assessed across multiple interviews by asking questions such as: 'To what extent does Factor A influence the perpetuation of coal power in Japan?' Or; 'Does Factor B interact with other factors to influence system reliance on coal power?'. In the second process, interview respondents provided new information during spontaneous discussion or in response to questions like: 'What are the most important factors making it difficult for Japan to reduce reliance on coal power?'. New and previously unknown lock-in factors emerging in this way were examined in light of other interview data and documents. In cases where no corresponding evidence was found in other data sources, further consideration of such lock-in factors was abandoned.

Data was coded manually. Relevant excerpts from interviews and documents were inputted into an Excel spreadsheet in the original language (i.e. either Japanese or English). This listed the seven categories in the analytical framework as primary codes along with each data source. Secondary codes were then added as needed. This approach enabled a systematic and rapid comparison of differing data sources in each framework category. It also divided the data into the three periods of data collection.

Table 2
Illustrative quotations from interviews.

Category	Theme	Quote*	Respondent category (code)**
Technologies, assets and infrastructure	*Sunk capital in assets*	Right now, coal-fired power plants are being built one after the other. And when built, this means that an investment has been made. If electric utilities are unable to recuperate their capital on an asset, they will suffer a loss. And then management will be held responsible by shareholders. So they can't abandon coal. If the government does not make a roadmap for phasing-out coal, they can't be expected to take the initiative.	Research organisations (31)
	Grid hampering renewables integration	Another area creating problems for Japan is that the grid hertz is different between the eastern and western regions. This is a big bottleneck. Because there are large power consumption areas in the east and west (Tokyo and Osaka), if we linked these, we could overcome moderate fluctuations (in power supply if integrating more renewables). Yet the idea of operating the grid as a whole beyond the jurisdiction of each regional utility has only just emerged after the retail power market was liberalised (in 2018). So Japan is lagging here.	Research organisations (44)
Actors and agency	*Industry lobbying*	Industry is pressuring the government with regards to both domestic and international policy. Especially, plant equipment makers are lobbying the government to sell coal-fired power plants domestically and overseas.	Research organisations (7)
	Actor composition	(…) to explain how bureaucrats make policy, they first form an advisory committee where matters are deliberated. A report is written by that committee and policy is made around this. Members are selected as experts and include many (industry) advocacy groups. Since there are lots of advocacy groups, committees are full of people that don't want to change current policy. And when you let committees like this formulate policy, naturally, the resulting policies will be the same as before.	Research organisations (31)
	Actor composition	We feel that only the opinions of certain actors are reflected in policymaking. For instance, until now, there was virtually no representation of the demand side in policymaking for the electricity sector.	Industry groups and consultants (48)
Formal institutions	*National policy influence on market behaviour*	Until national policy forbids all types of coal power plant construction, we financial institutions have a duty to fully support the needs of our customers (Japanese corporations with coal businesses).	Financial institutions (9)
	National policy influence on market behaviour	We are strongly cognisant of the government's idea of a diverse energy mix and build our (electricity generation) portfolio around this.	Power industry (incumbent utility) (2)
	Formal rules of electricity market protecting coal assets	When we finance power generation projects domestically or overseas, electric utilities will pay capacity payments to the independent power producer. So even if the operating capacity were to drop (e.g. due to carbon regulations or competition from renewables), there should not be much effect on the feasibility of the project.	Financial institutions (16)
	Formal rules of electricity market delaying asset disposal	Our new coal policy is not something that will drastically change our business strategy. The reason why is that most of the investments we make in coal-fired power plants are based on a power purchase agreement and we have a duty to operate the plant for that entire period. The average operating lifetime of a coal plant is around 30-years when short and 40–50 years when long. And the period of the power purchase agreement is close to this.	General trading houses (3)
Informal institutions	*Bureaucratic norms in policymaking*	Basically, policy can only be formulated or modified by building on or strengthening past commitments. Once policy has been set—for example if the government says "coal power is important" or "coal is necessary for energy security"—then the current system cannot change this. Policies are made without discarding historical ones. In English I guess you would say policymaking is 'incremental' or 'path dependant'.	Research organisations (43)
	Cleanliness of Japanese coal	Asides CO_2, there is no coal-fired power plant that inflicts health damage on the public. Furthermore, new technological progress is being made and so, for example, there is no risk of health damage like in China where people develop respiratory illnesses.	Government institutions (23)
	Cleanliness of Japanese coal	There are people that believe you can save CO_2 emissions by building a high-efficiency coal plant. This is then used a lot in marketing the technology (…) On the other hand, I don't think there are people that don't believe this and just push this narrative for marketing purposes.	Research organisations (40)
	Energy security and need for diversity	The key word is that Japan is an island nation and we don't have any (energy) resources. This can be said for nuclear, for LNG and for oil as well, but the most important thing for us is that we must avoid relying on any single power source. This is important not just for cost management; it also concerns the stability of (energy) supply.	Power industry (incumbent utility) (25)
Knowledge and competencies	*Lack of renewables knowhow*	Japanese (incumbent) utilities have lots of regular engineers (for coal, gas, nuclear, hydro) but they have very few renewables engineers. (…) Also, they have virtually no domestic experience (with renewable power generation projects).	Financial institutions (9)
	Lack of renewables knowhow	Compared to wind and solar PVs, coal remained as the one area we could exhibit our strength (…) I don't know if this is the right expression, but we threw our renewables business away (around two decades ago).	Plant equipment manufacturers (14)
	Lack of renewables knowhow	Because there are frontrunners making the core components for wind turbines and solar PV panels, and because they are too big and too strong, if we tried to enter the market now after all this time, I doubt we could catch up.	Plant equipment manufacturers (21)
Micro-economic factors	*Worker redundancy problem if reducing coal businesses*	The issue is not so much the factory itself; it's what to do with the people working there (if we stop making coal-fired power plants).	Plant equipment manufacturers (42)
	Low economic incentive to enter renewables market	If coal power was to disappear, company profits (for Japanese plant equipment makers) would drastically decrease. So naturally, they want to avoid that and are looking for new construction opportunities.	Financial institutions (30)
	Low economic incentive to enter renewables market	The problem (for Japanese plant equipment manufacturers) with taking over another company with renewables expertise is the concern and risk around profitability. In the wind turbine making business there is only around 5% profitability compared to say 10–15% (for coal). And since there are lots of equipment makers and prices are dropping, competition is fierce. So if Japanese plant makers were to enter this market, would there be prospects for profit?	Financial institutions (9)

(*continued on next page*)

Table 2 (*continued*)

Category	Theme	Quote*	Respondent category (code)**
Societal, geographical, technological and environmental conditions	*Public apathy around coal and climate issues*	In Japanese society, interest in the problem of coal power is extremely low. And with regard to the deeper and related issue of climate change, again, interest is low. So this is creating a situation where the government can easily ignore these issues.	Research organisations (43)
	Low public demand for renewables	When talking to utilities, they often say that consumers are not that worried about how their electricity is generated and that the most important thing is cost. (…) And they also say how customers tend to avoid those companies with higher prices (which can result from increasing the share of power generation from renewables and decreasing coal).	Research organisations (31)
	Public apathy around coal and climate issues	Japanese people are not that cognisant of energy issues (…) There is a certain resistance towards nuclear but when it comes to having to choose between coal and renewables, not many people think about this issue.	Research organisations (18)

* Information inside brackets added by author to explain contextual details.

** These interview codes match those used in the main text. The identity of each is known only to the first author to protect the anonymity of respondents.

5. Findings: factors perpetuating coal power in Japan

The analytical framework will now be applied to the case of Japan. Illustrative quotations from interviews are compiled into Table 2 in accord with each of the lock-in categories discussed below.

5.1. Technologies, assets and infrastructure

Two sources of material lock-in are significantly hampering efforts to reduce reliance on coal: (i) the young age of the CFPP fleet, and (ii) the electricity grid. Incidentally, there is little evidence suggesting that coal mining assets are locking-in the operation of CFPP assets. Japanese electric utilities do not typically invest in upstream extraction (except *J-Power*) and instead purchase coal from suppliers via short-term contracts (around a year).

First, Japan's currently operating CFPP fleet (comprising 124 plants and around 46 GW of capacity) is the youngest in the world [88]. The average plant age is 25-years against a possible technical lifetime of 40 years or more [36]. Significant future operation is thus required to recuperate sunk investments. Furthermore, as already noted, 22 new plants totalling 13.3 GW are under construction or planning [88]. The overnight capital cost of this is estimated at $US 29 billion [88]. Roughly 15–20 years of operation will be required to recover this sunk capital [39]. Even if assuming conservatively that new plants operate a mere 5-years beyond this period, recently added coal capacity could still be operating and emitting carbon well after 2040 [36,104]. Furthermore, researchers estimate that if Japan was to hypothetically phase-out all coal power by 2030, this would generate some $71 billion in stranded assets (including operating and planned plants) [88]. Given the capital value sunk into this young fleet, operators and investors have a financial motivation to run plants as much as possible (int. 36 and see Table 2). Indeed, the power industry's desire to prioritise the operation of CFFPs over other electricity sources is visible in asset management plans submitted to the national grid regulator [105]. According to these, over the next decade (2019–29) utilities intend to maintain high capacity factors for coal (currently 66% in 2019) while reducing the operation of gas-fired plants.[2] The same plans reveal few intentions to retire old CFPPs.[3]

Next, the physical nature of the electricity grid also creates conditions that favour the operation of centralised thermal powerplants while hampering the integration of renewables (int. 31,40,44). Two issues merit emphasis. The first concerns the absence of any international grid connecting Japan with neighbouring countries. Government, utility and industry actors are therefore reluctant to significantly increase reliance on intermittent renewable sources out of concern that no option exists for importing power during production shortfalls (int. 12,23). The second concerns the fragmented nature of the national grid. This poses several infrastructural barriers to electricity trading at the national level and exploiting rich wind and solar reserves in the north and south. This is exasperated by different hertz frequencies used in Western Japan (i.e. 60 Hz in the region west of Tokyo) and in Eastern Japan (i.e. 50 Hz) (see Table 2). In addition, trading renewable electricity over long distances is also restrained by: (i) a lack of large-scale transmission capacity between Honshu/Hokkaido in the north and Kyushu/Honshu in the south, and (ii) division of the national grid into 10 blocks, where each incumbent utility manages its own power supply.

5.2. Actors and agency

Three sets of issues related to human actors and agency are contributing to the perpetuation of formal and informal institutions (discussed further below) that support coal power: i) the composition of decision-making bodies, (ii) skewed degrees of agency amongst actors, and (iii) vested interests between government and industry. Interview evidence suggests the first two are particularly significant lock-in factors.

The first issue concerns actors with authority to formulate or influence energy policy. Beginning with government, METI and the aforementioned in-house Agency for Natural Resources and Energy enjoy exclusive authority and autonomy in formulating national energy policy. They experience little interference from the Prime Minister and Cabinet, with the latter's role usually limited to 'rubber stamping' proposals from METI (int. 33). When formulating environmental policy, METI is known to prioritise economic interests and cost feasibility over ambition [65,107]. As mentioned, they also oppose stringent climate regulation such as carbon pricing. While competing powers like the Ministry of Environment and Ministry of Foreign Affairs both oppose coal and support carbon pricing, their influence on energy policy is decidedly inferior to METI. Beyond government actors, advisory committees (*shingikai*) are periodically hosted by METI, the Cabinet and other ministries to guide policy formulation. Multiple NGO, thinktank, academic and industry respondents (int. 27,31,40,43,45,48) problematised the composition of these committees. They claimed that the interests of energy producers and heavy industry are overrepresented and that government actors intentionally populate committees with industry groups or academic experts in favour of the status quo (see Table 2). Conversely, actors in favour of change (e.g. NGOs, thinktanks and pro-renewable corporations like retail, communications and electronics manufacturers) are underrepresented (see also [108,109]).

[2] Concretely, average planned capacity factors for coal increase slightly from 66% in 2019 to 68% in 2029. Capacity factors for gas-fired plants decline significantly from 49% in 2018 to 33% in 2028. Source: OCCTO[105].

[3] Total installed capacity for coal is forecast to grow from roughly 46 GW in 2019 to 53 GW in 2029. Source: OCCTO [105].For example, power purchase agreements concluded in Indonesia and Vietnam for Japanese-built CFPPs often last between 25 and 30 years.

Problematising a lock-in situation, one member of several government committees argued (int. 31): 'Since the government consciously selects members who don't want to change policy, the resultant policies never change.'

Second, actors enjoy varying degrees of agency and power. Respondents (int. 31,43) argued that even if government committees were assembled to better represent diverse perspectives and positions, this would not necessarily lead to radical policy change. This is because the scope of issues for deliberation is often defined narrowly in advance by government bureaucrats. 'Debates about energy policy, in the true sense of the term, thus rarely occur', one respondent argued (int. 43). The differing power of actors was also underscored. Some (int. 33,44) argued that many policy decisions are made before committees are assembled due to intensive industry lobbying and interaction with bureaucrats from pro-coal groups like the Federation of Electric Power Companies (FEPCO) and the Japan Business Federation (Keidanren). With the latter being present in many government committees, respondents from pro-renewable industry and a thinktank (int. 33,48) argued that Keidanren's influence on energy policy lay in their exclusive claim of 'representing the entire Japanese economy'. Meanwhile, the lobbying influence of the power industry was underscored by several respondents (int. 30,31,43,44,48). Since government policy (rather than technological innovation) is the primary driver of change, electric utilities allegedly possess specialised regulatory affair divisions that enable frequent interactions with government regulators. The above thinktank respondent (int. 33) argued that this results in 'regulatory capture' and 'expertise in lobbying that goes over and above other companies'.

Third, vested interests might also be contributing to the perpetuation of pro-coal institutions. These allegedly form via frequent and amicable interactions between regulators and energy-intensive industry (int. 31,33). Some (int. 31,45) claimed the early retirement system (*amakudari)* is also responsible for nurturing consideration for the interests of incumbent electric utilities and heavy industry [65]. With top-ranking government bureaucrats retiring at the age of 55, many assume managerial positions in industrial sectors they once regulated. These claims, however, are nuanced. Most respondents agreed that the power sector's interests are consistently reflected in formal institutions that favour coal over renewables (int. 9,30,31,33,43,44). Yet there were conflicting views on the claims of some (int. 7,30,44 and Table 2) that the interests of plant equipment manufacturers are reflected in pro-coal policies. This said, it is worth noting that the influence of vested interests from energy-intensive industry on Japan's energy policy are widely documented in scholarship [64,65,109–111].

5.3. *Formal institutions: Policies, rules and commitments*

Numerous formal institutions are perpetuating Japan's dependence on coal power. In particular, three sources of lock-in appear significant: (i) self-reinforcing government policies and commitments, (ii) operation rules for the electricity grid, and (iii) institutional arrangements protecting CFPPs from market risks.

First, national policies promoting coal power create self-reinforcement effects, whereby each builds on the legacy of former policies and then influences other formal institutions. One example is the *Long-Term Supply and Demand Outlook*, published by METI [87]. Forecasting an electricity mix for 2030 with a 26% share of coal (against 27% of gas, 20–22% of nuclear and 13–14% of non-hydro renewables), this outlook promotes coal as a cheap and reliable baseload. Several high-level policies inherit this legacy. Notably, the *Nationally Determined Contribution (NDC)* submitted to the Paris Agreement in 2015 [112] —and reaffirmed in 2020 [113]—derives Japan's GHG emissions reduction goal for 2030 (i.e. −26% from 2013 levels) from the above electricity mix. Meanwhile, the *Fifth Strategic Energy Plan* (arguably the most influential national energy policy) inherits the same legacy. It pledges a commitment for Japan to focus 'all its efforts on the steady realisation of the 2030 energy mix' [86: 4]. In turn, this *Fifth Strategic Energy Plan* influences other institutions and market activities. As well as promoting new CFPP construction, it pledges support for the continued development and deployment of high-efficiency coal technologies (see Section 5.5). This in turn shapes the mandates of government agencies. Interviewed export credit agencies (int. 5,15) explained that their mandate to support overseas construction of CFPPs is shaped by the *Strategic Energy Plan* [114]. Meanwhile, the New Energy and Industrial Technology Development Organization also cites the *Fifth Strategic Energy Plan*'s objective to export high-efficiency power. One example is a funding call in late-2019 to support market research into strategies to increase CFPP export opportunities for Japanese firms [115]. Furthermore, interviews with industry also revealed how government policies drove their involvement in coal power businesses (see Table 2).

Second, operation rules for the electricity grid are exasperating lock-in to coal by favouring the operation of CFPPs and limiting the integration of renewables (int. 31,35,40,44). Grid operation is based on a logic presuming a baseload power. Instead of abiding by a 'merit order' rationale that affords priority to renewable sources with no fuel costs, incumbent utilities—which own and operate the grid—utilise a formalised system of 'first-come, first-served' (*senchakuyusen*). This system grants grid access in accord with the chronological order by which connection contracts are negotiated. Since utilities prioritise the operation of their own assets, renewable power generation projects coming online afterwards are frequently denied grid access (int. 35,48) [116].

Third, formal institutions in the wider electricity market also perpetuate the long-term operation of CFPPs. In particular, long-term power purchase agreements between utilities and power producers were emphasised by industry and thinktank respondents (int. 9,16,30,31,40,42,43 and Table 2). These shield new and existing CFPP assets from market risks by assuring a guaranteed revenue in return for supplying an agreed amount of electricity. Such contracts typically last 15–20 years at home and often longer for overseas.[4] These institutions provide confidence to investors planning new plant development (int. 9,40). For this reason, numerous banking, industry and government experts denied the possibility that recently built plants might become 'stranded assets' (int. 2,6,16,18,30,42). Interestingly, as renewable energy increases to the detriment of newly added thermal power generation, policymakers have reacted by formulating new institutional arrangements to protect domestic assets. A capacity market is currently under development and scheduled for launch in April 2021. Collecting revenue from consumers, this will distribute payments to large thermal powerplants in accord with generation capacity. By shielding assets from economic risks posed by reduced plant operation, this governance arrangement is expected to perpetuate the long-term business viability of CFPPs (int. 31) [39].

5.4. *Informal institutions: cognitive frames, norms, narratives and expectations*

Empirical evidence points overwhelmingly to the strong influence of informal institutions on other lock-in categories. Three salient issues concern: (i) bureaucratic norms influencing policymaking, (ii) shared cognitive frames and narratives in regime actors, and (iii) acceptance of these by society at large.

First, the persistence of the aforementioned formal institutions that support coal power can be largely explained by the influence of informal institutions on policymaking norms. Numerous respondents from thinktanks, NGOs and pro-renewable corporations (int. 31,40,43,45,48 and Table 2) described an institutional culture of path dependence, where policymakers prefer incremental rather than

[4] For example, power purchase agreements concluded in Indonesia and Vietnam for Japanese-built CFPPs often last between 25 and 30 years.

fundamental change. Radically overhauling policy objectives is allegedly difficult as this requires bureaucrats to admit errors in past logic and younger policymakers, trying to achieve change, to counter the practices of seniors. One thinktank (int. 40) argued: 'Instead of trying to abandon coal, they (policymakers) are running with the exact opposite intention. Since there has only ever been policies that support coal, they can't breakout of this paradigm'. The Abe Administration's long-term decarbonisation vision for Japan's energy system in 2050 [117] supports this claim. Although emphasising disruptive and low-carbon innovation, this omits any explicit mention of phasing-out coal.[5] Meanwhile, an industry representative (int. 48) explained that policymaking culture around climate and energy issues is averse to back-casting approaches (e.g. aiming for zero emissions in year 2050). This is due to the widely entrenched norm of planning future carbon emissions cuts by tallying current policies and technological capabilities.

Next, cognitive frames also contribute to the perpetuation of coal power. Interviews with industry, government and researchers (int. 2,12,23,25,27,30,31,36,45 and Table 2), policy documents [86] and industry literature [118,119] all point to an unwavering belief that maintaining coal in Japan's electricity mix is essential for energy security. This cognition has roots in several historical experiences. These include successive oil crises during the 1970′s and the Fukushima nuclear disaster in 2011. With these events triggering massive disturbances to baseload electricity supplies and fuel prices, coal played a key role in substituting oil and nuclear. The historically proven need to minimise energy supply risks through diversification thus provides an entrenched cognitive frame that influences both formal institutions and market decisions. For policymakers, it rationalises the continued support for a balanced energy mix containing coal at the national level (int. 23). For individual utilities, it justifies decisions to invest in CFPP construction to avoid overreliance on natural gas or nuclear (int. 2,25,36).

The cognitive perception that Japanese coal technology is the cleanest in the world (in terms of carbon and air pollutant emissions) also influences behaviour in government and industry. This encompasses two dimensions. First, numerous regime actors share a belief that coal power is compatible with climate change mitigation since technological progress is rapidly decreasing emissions and raising efficiency. This logic drives multiple behaviours. These include the construction of new CFPP assets, the development of next-generation coal technologies in industry (i.e. knowledge and competences), and the support for these activities via policy and R&D funding (i.e. formal institutions). Pride in the superiority of Japanese coal technology also underpins exports to developing countries. Interviews (int. 5,6,15,23,27,30,36,44 and Table 2) and documents from government and industry [118,120–122] convey a belief that exporting CFPPs overseas can contribute to global climate mitigation due to the lower emissions of Japanese technology. Second, industry and government actors spread this narrative as propaganda or marketing [e.g. 123,124] to garnish support for coal-power. While separating these two dimensions (i.e. entrenched beliefs and manufactured narratives) is difficult, interviews (int. 23,24,27,16,30,36) revealed that support for coal power in government and industry is heavily influenced by firmly engrained beliefs in the cleanliness of Japanese technology.

Perceptions about the cleanliness of Japanese coal technology extend beyond regime actors. Interviews (int. 12,23,24,27,32,41,45) conveyed that society at large regards air pollution as a thing of the past due to technological progress. Indeed, for many Japanese, the idea of domestic air pollution conjures up historical images of the highly polluted period of rapid economic growth during the 1970's. Since faith in modern air-pollution control also extends to CFPPs, the clean coal narrative driving the regime is widely accepted by the public as well as industry and government at large. This spares regime actors from having to contend with significant levels of public or media opposition when constructing new plants (int. 27,41,43,45). Thus, there is a notable interaction between cognitive frames in the informal institutions inside the regime, exogenous socio-political conditions, and the construction and operation of CFPPs.

5.5. Knowledge and competences

Coal power is also perpetuated by the intellectual capital accumulated in firms and research institutes through: (i) public–private R&D programmes for advanced coal technologies, and (ii) business models focused on coal power. By creating a need to continue constructing new CFPPs, both factors are contributing to the lock-in of technology, assets and infrastructure. This said, the second factor was heavily stressed in several interviews.

First, government agencies, research institutes, electric utilities and plant equipment manufacturers have collaboratively developed and commercialised next-generation technologies over the past few decades. Recently, efforts are focused on coal gasification and carbon capture (with carbon storage or recycling). Significant intellectual and human capital has amassed in this community through R&D, information exchanges and demonstration projects. A variety of formal institutions drive this activity [104]. National policy (e.g. the *Fourth and Fifth Strategic Energy Plan)* consistently articulates support for the development and commercialisation of advanced coal and carbon capture technologies [86,125]. Interactions with industry shape this policy. Specifically, a utility representative (int. 36) explained how discussions with government bureaucrats influence the choice of technological targets for budgetary support. Meanwhile, a roadmap [120] fixing a multi-decade commitment to develop common base materials and commercialise new technologies such as Integrated Gas Combined Cycle and Integrated Gas and Fuel Cell was jointly formulated by government and industry. The Japanese government is operationalising this commitment by providing R&D funds and demonstration subsidies to the power industry and plant equipment makers. These funds sustain private sector R&D activities by minimising investment risks associated with technology development in the liberalised electricity market (int. 36). Moreover, ongoing R&D activities for next-generation coal technologies trigger a need for new plant construction to showcase results. Two coal gasification plants are under construction in Fukushima (i.e. Nakoso and Hirono) while another in Hiroshima (Osaki) has operated since 2017 [104]. Further construction may occur, as plant equipment manufacturers and utilities (int. 2,10,14,36,42) expressed intentions to continue efforts to commercialise new coal technologies at home and abroad.[6] Meanwhile, the aforementioned decarbonisation vision for 2050 from the Abe Administration [117] also voices a commitment to supporting the long-term development and deployment of carbon capture and storage/recycling (which includes coal). Underscoring this nexus of policy signals, public–private investments and intellectual capital, an NGO researcher (int. 43) asserted: 'By sending a policy signal that sustains technological development on the same visible trajectory as now, the government is making it harder for change to occur. The further we continue on this trajectory the more difficult it will be to retreat and achieve an energy transition.'

[5] This document, *The Long-term Strategy under the Paris Agreement,* mentions ambitions to 'reduce reliance' on coal power generation and 'fade out' inefficient plants while continuing efforts to develop and commercialise high-efficiency thermal power and carbon capture technologies.

[6] This said, utilities and plant equipment manufacturers are aware that future market prospects for deploying next-generation coal technology are increasingly limited (int. 36,14). This is due to increasing coal divestment trends across Japan and elsewhere (see Section 6.4) and the increasing share of renewable electricity generation. Therefore, efforts to deploy next-generation coal gasification plants are envisioned more so as replacing older, larger plants with smaller, high-efficiency plants (e.g. 400–500 MW) with more flexibility to respond to demand fluctuations (int. 36).

Second, the shackling effect of historical business models and intellectual capacities surfaced across multiple interviews. With most engineers and marketing teams specialised in thermal power, nuclear and hydro, both electric utilities and plant equipment makers share a deficit of intellectual capital for renewables like offshore wind (int. 2,9,36 and Table 2). This issue is most pronounced for plant equipment manufacturers (e.g. Mitsubishi Hitachi Power Systems, Toshiba, IHI etc.). While these firms have profited from Japan's recent CFPP construction boom, their business models are largely dependent on coal. Conversely, a lack of expertise and international competitiveness in manufacturing renewables equipment is inhibiting expansion into this market. This is mainly due to past decisions to abandon R&D and manufacturing efforts for wind and solar (due to poor profitability and market immaturity) to focus on thermal power (int. 14,21,42 and see Table 2). Building high-efficiency CFPPs requires materials and assemblies that can withstand high temperature and pressures. Such technological barriers protect incumbent manufacturers from competitors (int. 42). Marketing knowhow was also problematised. An industry expert (int. 28) explained that since the distributed nature of the renewables market involves a diversified mix of customers, plant equipment manufacturers are faced with a fundamental marketing problem of not knowing which player to target. In sum, this ensemble of intellectual paucity is hampering the emergence of stronger ambitions to expand businesses with renewables. Additionally, historical expertise in thermal power is motivating Japan's plant equipment makers to continue playing to their strengths by pursuing new construction and retrofitting opportunities for CFPPs at home and abroad.

5.6. Micro-economic factors

Three factors were stressed in interviews as creating an economic imperative for industry actors to maintain coal power businesses: (i) redundancy risks for human resources, (ii) increasing returns, and (iii) the cost of alternatives. The first two affect plant equipment manufactures while the last concerns utilities.

First, industry representatives (int. 9,14,21,28,30,42 and Table 2) emphasised that the human resources of plant equipment manufacturers are creating an economic imperative to continue seeking CFPP construction projects at home and abroad. Manufacturing and installing boilers and turbines is labour intensive. It requires vast teams of specialised workers both in factories and on-site. Reducing the scale of CFPP manufacturing—whether by market forces or business decisions—would thus generate a surplus of workers. Two strategies can tackle this. The first is to retrain and shift workers to other growth areas. This strategy is restrained by the limited scale of alternative operations to absorb workers. Specifically, demand for new construction of nuclear power plants is in decline globally while little growth is expected for natural gas-fired plants [126]. Meanwhile, the current scale of domestic equipment manufacturing for renewables is limited too. Not only does this require less human labour relative to the equipment used in CFPPs (int. 28), uncertainty around market growth is hampering ambitions to increase manufacturing efforts. The second strategy involves reducing worker numbers by freezing new hires, offering early retirement packages and retrenching. The last approach, however, is restrained by industry norms (i.e. informal institutions) (int. 9,21,30,42). Concretely, while Japanese firms are expected to provide lifetime employment, mass retrenchment is rare and usually avoided. Consequently, plant equipment manufacturers must seek new construction opportunities to win revenue to support worker salaries.

Second, as specialised competitors (i.e. Siemens) retreat from the overseas CFPP market, plant equipment manufacturers enjoy an economic incentive to maintain R&D programmes and pursue new construction opportunities. This was termed 'survivor profits' in interviews (int. 28,42,44). Although equipment manufacturers are aware the international market for CFPP construction is shrinking [126], less competition from fewer players has created increased opportunities for the remaining firms to win construction bids and generate profit. Conversely, there is a low financial incentive for plant equipment manufacturers and electric utilities to expand their renewables businesses. The market is flooded with highly specialised and competitive players, and profits are generally lower than for coal (int. 9 and see Table 2).

Third, the higher cost of alternatives also prolongs dependence on coal power. Not only is the cost of renewable electricity generation[7] roughly double the global average [127], industry respondents and thinktanks underscored natural gas prices as another barrier (int. 12,13,25,31,36). High prices are largely due to the absence of an international pipeline (e.g. to neighbouring Russia). This necessitates the import of gas via ship in liquid form. Formal institutions compound this situation. Energy companies and utilities typically forge long-term contracts (e.g. 20-years or more) with upstream producers. Since these are linked to highly volatile crude oil prices, Japanese utilities often lack an economic rationale to shift thermal power generation from coal to gas (int. 31,36).

5.7. Societal, geographical, technological and environmental conditions

Finally, numerous exogenous circumstances are contributing to coal lock-in. Interviews were particularly vocal about the influence of: (i) stable political conditions, and (ii) societal apathy towards coal and climate change. Incidentally, some interviews stressed geographical conditions such as Japan's limited land surface area and a lack of shallow seas (for offshore wind) as hampering the large-scale penetration of renewables (int. 12,40). However, as a principle cause of coal lock-in, the frequency by which this explanation emerged across interviews was secondary to social conditions.

First, Japan has experienced few changes of national political leadership that trigger the overhaul of actors and institutions relevant to energy policy. Losing only two elections since their establishment in 1955, the currently reigning conservative party, the Liberal Democratic Party (LDP), enjoys remarkable societal support [92]. Contributing to this supremacy, although both changes of leadership in the past were accompanied by expectations for positive changes, to the contrary, changed leadership prompted many frictions with ministries and internal party divisions (int. 45). Consequently, inclusive of the current Abe Administration (in power since 2012), the majority of Japanese voters have historically supported the conservative political status quo (i.e. the LDP) for over 60-years [65]. Furthermore, Japanese are generally averse to public demonstrations against government policy (int. 44). Multiple respondents (int. 33,43,44,45,48 and Table 2) problematised these stable socio-political conditions and a lack of external pressures on actor configurations and institutions as a major factor facilitating the continuation of pro-coal policy and investments.

Second, multiple interviews underscored low public interest in climate policy as another reason behind pro-coal policy and new CFPP construction. Respondents from academia, industry and thinktanks/NGOs (int. 18,31,45 and Table 2) characterised the majority of the Japanese public (including households and businesses) as being sensitive to cost but apathetic to how electricity is sourced. Consequently, societal demand for renewable energy (in the sense of actual purchase decisions) is low (int. 18,45,48). Multiple lines of evidence support these claims. In a global comparison of environmental attitudes presented at the *2020 World Economic Forum*, public support in Japan for prioritising the environment over the economy ranked the lowest

[7] For example, the cited report from the International Renewable Energy Agency estimates installed costs for utility-scale solar PV in Japan in 2018 at $US 2,101/kW against the global weighted-average of $US 1,210/kW. For offshore wind, generation costs (levelized cost of electricity) are US$ 0.20/kWh against the global weighted average of US$ 0.127/kWh. Reasons for high costs include a lack of scale, limited land availability (for solar) and high construction costs due to a lack of experience.

amongst 30 countries surveyed[8] [128]. Meanwhile, following the liberalisation of the retail electricity market, most customers switching electric utility are motivated by cost rather than environmental concerns [129]. Additionally, a survey by *Reuters* in January 2020 on attitudes toward coal power shows that only 20% of Japanese corporations support a complete phase-out of coal, with only 4% seeing benefit from a coal-free power mix [130]. This contrasts to an extremely high degree of public opposition towards nuclear power (int. 9,31,33). As one thinktank respondent (int. 31) explained: 'The biggest difference with nuclear and coal is that while it's not possible to build a new nuclear plant (due to public opposition), it is for coal.'

6. Reinforcing dynamics and emerging counter developments

Findings revealed multiple and diverse factors contributing to the perpetuation of coal power in Japan. Furthermore, we identified sources of lock-in corresponding with all categories in the analytical framework (see Section 2). Thus, the theoretical discussions underpinning this framework—which are synthesised from a wide body of literature—stand up to the empirical litmus test of our case study. Moreover, findings revealed that lock-in to coal power is exasperated by a complex array of interactions, interdependencies and self-reinforcing feedbacks across the various sources.

Although we did not aim to explicitly determine which factors were more important than others, Fig. 1 (using numbered labels and colours) summarises four clusters of relationships that were found to be particularly significant. After briefly describing each below, we consider emerging developments with promise to rupture or weaken these sources of lock-in.

6.1. Actors and agency, formal institutions and exogenous conditions

Label 1 depicts a lock-in situation created by a low diversity of decision-making actors and a skewed distribution of power. Concretely, those with exclusive control over energy policy formulation (i.e. pro-coal government bureaucrats in METI) are exposed to lobbying from the power industry and pro-coal business groups. Additionally, conservative or pro-coal business actors dominate government advisory committees. Meanwhile, anti-coal actors like the Ministry of Environment, thinktanks/NGOs and pro-renewable industry have less agency in policymaking or political discussions. With stable socio-political (i.e. exogenous) conditions leaving these actor configurations and power relations unchallenged, energy policies are consistently shaped by the same actors with the same *status quo* supporting preferences. New pressures, however, have emerged to confront these structures.

Firstly, industry coalitions in favour of ambitious climate action and renewables have formed since 2018. The *Japan Climate Initiative* represents 159 large companies, 25 municipalities and 64 organisations while the *Japan Climate Leaders' Partnership* represents 141 large companies. These coalitions fill an important gap in the actor landscape. Japan is home to many companies in favour of expanding renewable electricity beyond current government targets[9] [108,109]. Although many feel their interests are not represented in policy advocacy from Keidanren (int. 33,37,48), most have been reluctant to publicly state areas of dissent. Industry coalitions erase this hesitancy. Both the *Japan Climate Initiative* and *Japan Climate Leaders' Partnership* have released multiple statements on policy preferences [131] targeting various government ministries and advisory committee members. These critique the regressive nature of national climate policy while calling for more ambitious targets for emissions reductions under the Paris Agreement[10] and renewables. Multiple concerns underpin these coalitions. These include the high cost and low volume of renewable electricity (which is hampering efforts to procure 100% of electricity from renewables), reputation risks from international investors, and reduced opportunities for upscaling low-carbon businesses (int. 48).

Expectations were expressed that these industry coalitions might influence the formal and informal institutions supporting coal (int. 40,43,48). However, this influence is so far limited. One respondent (int. 43) underscored that the industry-government relations around energy policy still privilege Keidanren and the power industry. An industry informant (int. 48) explained that the relatively weaker political influence of pro-climate coalitions is largely due to their weak membership from heavy industries (e.g. steel, automotive and power). Meanwhile, being focused on renewables, neither coalition has voiced a standalone message about coal power.

6.2. Formal institutions and technology, assets and infrastructure

Label 2 shows how coal lock-in is exasperated by: (i) new construction encouraged by government policy (and market forces), and (ii) formal institutions protecting the bankability of these assets (e.g. power purchase agreements and capacity payments). In parallel, grid operation rules allow utilities to prioritise operation of their own powerplants over renewable electricity generated by market newcomers.

Yet formal rules around grid operation are changing. Concretely, as of April 2020, regulation initiated by METI requires the 10 incumbent utilities to legally separate their grid and powerplant operations into separate companies. Also, government and industry are currently planning a new 'connect and manage' regime to replace the 'first-come, first-served' rules, which facilitate the denial of grid access to renewables project developers. Interviewed thinktanks expressed expectations these institutional reforms will create important financial incentives for incumbent utilities to more actively prioritise the despatch of renewable electricity (int. 38,40).

Despite these institutional changes, new rules do not completely remove grid control from the incumbent utilities as each utility will still manage its own jurisdiction (although under a separate legal entity). Furthermore, the degree to which utilities are actually adhering to connect and manage rules is also reported to be inconsistent [116]. Consequently, new project proposals for renewable power generation continue to encounter difficulties in securing grid access (int. 38,39) [132].

6.3. Formal institutions, micro-economic factors, and knowledge and competences

Label 3 shows a complex web of factors contributing to the construction of CFPPs at home and abroad. These include supportive government policies, economic and knowledge-based incentives for plant makers to secure new construction opportunities, and the need to demonstrate progress in developing next-generation coal technologies from R&D programmes. Until now, industry actors such as general trading companies[11], electric utilities, and plant manufacturers have

[8] Concretely, the percentage of respondents supporting the idea that: 'Protection of the environment should be given priority even if it slows down economic growth' was 22% in Japan (the lowest, n = 314) against 58% in India (the highest, n = 838).

[9] Current national policy (i.e. the Long-term Energy Supply and Demand Outlook published in 2015) projects a 13.4–14.4% share of non-hydro renewables in the electricity mix for 2030. Industry and government actors widely interpret this projection as a target.

[10] As stated earlier, Japan's current Nationally Determined Contribution (resubmitted to the United Nations Framework Convention on Climate Change in early 2020), leaves unchanged the original target (first submitted in 2015) of reducing GHG emissions by 26% from 2013 levels by 2030 (first submitted in 2015).

[11] General trading companies have historically played an important role in importing resources from abroad to fuel economic growth in Japan. They invest in all areas of the value chain, from the extraction of raw materials to the production and sale of finished materials. In the coal market, they have played in important role in both importing coal from abroad and developing independent power producer projects abroad (including CFPPs). See Trencher et al. [38].

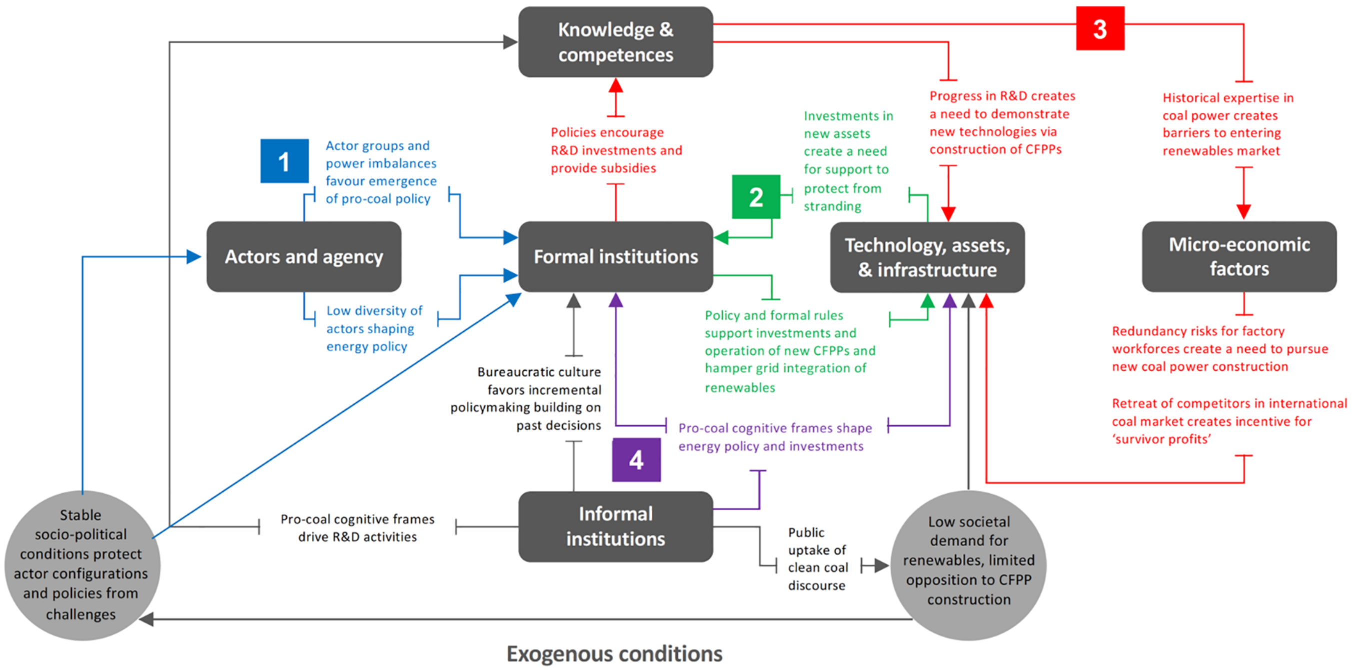

Fig. 1. Key interlinkages and feedbacks across lock-in sources. *Note:* Arrows show the direction of influence. Key sets of interactions (discussed in Section 6.1–6.4) shown with colours and numbers.

driven new CFPP development. But important changes are occurring.

First, four of Japan's major general trading companies have disclosed policies to reduce shares of coal in electricity portfolios (which are mostly held overseas) [38]. Since trading companies are the core investor partners for electric utilities, an industry analyst (int. 30) predicted that utilities would follow suite and no longer build new CFPPs overseas (except those currently under planning). This leaves plant manufacturers. Although their economic and intellectual imperative to secure equipment orders is still strong, there is increasing acceptance that demand for new CFPP construction has permanently decreased (int. 14,21,28,30,42). Second, some efforts are being made to reduce business model dependence on coal. *Mitsubishi Hitachi Power Systems* has notably repurposed a domestic factory in Nagasaki to produce hydrogen fuel-cells while all plant manufacturers are seeking to move boiler technologies towards alternatives like hydrogen, ammonia and biomass.

This said, these trends point to a decline and not a *cessation* of coal-related businesses. Plant manufactures still have an economic incentive to focus efforts on maintenance or retrofitting aged plants and pursuing new projects abroad. Furthermore, the R&D momentum for carbon capture and storage/recycling may also trigger CFPP construction or retrofitting.

6.4. Informal and formal institutions

Label 4 shows how multiple informal institutions provide the intellectual justification for policies supporting coal, the continuation of R &D activities, and investments into new CFPPs. These notably concern cognitive framings around clean coal and energy security. While thinktanks and NGOs have long challenged the clean coal discourse [133,134], these counterclaims typically suffer from low coverage in mainstream Japanese language media (int. 48). However, new formal institutions have recently emerged from industry with potential to disrupt the legitimacy of dominating cognitive frames.

Influenced by global changes in investment norms (i.e. exogenous factors), Japanese market actors are adopting new decision-making protocols and disclosure rules around carbon-intensive investments. These principally concern ESG criteria (i.e. Environmental, Social and Governance) and guidelines from the United Nation's Task Force on Climate-related Financial Disclosures. Japan's major banks and general trading companies are integrating such institutions as a basis for formulating coal divestment policies or tightened investment rules [38]. These set formal commitments to increasing investments in renewables while refraining, in principle, from building new CFPPs and gradually disposing existing assets. Meanwhile, in February 2020, an international investor platform (comprising half the world's managed wealth) issued a letter to the Japanese Prime Minister urging greater climate leadership and renewables ambition [96]. With international finance norms (i.e. exogenous factors) already infiltrating the formal institutions of major industries supporting Japan's coal market, international investors are now targeting Japanese government policy.

So far, however, the effect of the above described developments on government policy is limited. As a notable indication of the resilience of Japan's pro-coal institutions, METI has recently responded to domestic and international pressures (especially from the Ministry of Environment) to cease support for overseas CFPP exports. Concretely, a report [135] issued by METI in May 2020 summarises the conclusions of a government advisory committee for infrastructure system exports. This re-affirms historical arguments that coal power can 'co-exist with decarbonisation efforts without contradiction' if using high efficiency technologies.[12] Meanwhile, media report that the aforementioned national plan to retire 100 older, inefficient plants by 2030 (see Section 4) was influenced by international pressure [136]. However, by allowing younger and new plants to operate, this plan is not expected to result in a significant decrease of coal power generation [91]. Thus, despite the above developments, the multiple causes of lock-in analysed until here continue to prevail.

7. Discussion and conclusion

Using the lens of socio-technical lock-in, this study developed an analytical framework for identifying, understanding and targeting

[12] The specific technologies mentioned are coal gasification (Integrated Gasification Combined Cycle) in the short-term, ammonia co-firing in the mid-term and carbon recycling in the long-term (see p. 7 of the cited report).

differing factors that may hamper the transition from fossil fuels to sustainable energy systems. Based on empirical data collected over three years, it then identified the interacting and self-reinforcing factors contributing to the perpetuation of coal power in Japan. Findings showed that important causes of lock-in include the young age of CFFP assets, formal institutions that support their operation while hampering the growth of renewables, power imbalances in a decisive group of actors controlling energy policy formulation, and historically established R&D programmes for next-generation coal technologies. These components are exasperated by informal institutions such as deeply engrained cognitive frames around clean coal and its need for energy security, economic incentives for market actors to pursue new plant development, and the shackling effect of intellectual capital and business models historically built around coal power. Finally, stable socio-political conditions reinforce these dynamics.

As general implications, our analysis shows that carbon lock-in can arise from a complex interplay of factors. This complexity underscores the difficulty of overcoming carbon lock-in, as it may not suffice to alter one or a limited set of factors. However, turning this argument upside down, the relevance of multiplex factors points to several opportunities for intervention measures to rupture lock-in. As identified, changes in Japan are emerging with potential to weaken the nature of actor dynamics influencing energy policy as well as the formal and informal institutions that drive CFPP investments and prioritise their operation. Thus, the challenge for practitioners aiming to dislodge carbon lock-in is to identify and target not only the relevant system components, but especially those with high leverage effects on others.

Despite the importance of this task, our chosen method of explorative interviews and document analysis did not allow us to rank the relative importance of individual sources of coal lock-on. Nonetheless, the powerful leverage effect of high-level national policies (e.g. the *Long-Term Outlook for Energy Supply and Demand* and the *Strategic Energy Plan*) surfaced in multiple areas. Such policies exert various cascading effects on other government policies, missions of government agencies, funding for R&D programmes, and the behaviour of market actors. While this observation points to the strategic importance of reforming the coal-related policy signals influencing regime actors, findings also revealed several factors hampering change in government decision-making. These include actor configurations and interests, the need to protect newly constructed CFPP assets from business risks and temporally persistent informal institutions and exogenous conditions. Given this complex array of constant, interacting and self-perpetuating forces, numerous obstacles stand in the way of phasing-out coal power in Japan—even despite the emerging trends and pressures examined.

Our study makes several contributions to literature. Conceptually, it systematically marries knowledge on carbon lock-in, sustainability transitions, coal policy and diverse innovation management related fields. By synthesising an array of material, non-material, human and exogenous factors that were previously scattered across differing academic fields, this framework provides a more comprehensive picture of carbon lock-in than previous scholarship. This framework also provides an analytical tool that scholars elsewhere could use to identify lock-in factors in other types of energy or socio-technical systems. Additionally, by empirically demonstrating how a complex web of technological, institutional, human and contextual elements can interact and self-perpetuate, we further understanding into the complex and intertwined dynamics that underpin the stability of socio-technical regimes [23,42,47]. Our framework and findings can thus inform further work on carbon and socio-technical lock-in, particularly in the context of transitioning from fossil fuels. Moreover, our case study adds knowledge to growing literature on the challenges entailed in phasing out coal-power [3,7,13]. Specifically, our contribution is to have demonstrated the complex factors that can hamper efforts to reduce dependence on coal power even in nations with no significant domestic coal resources.

To continue advancing understanding into lock-in, further studies might adopt formalised techniques such as cross-impact analysis [137,138]. This could rank the importance of various factors and interactions and determine the most important leverage points for overcoming lock-in. Such studies could employ survey-based approaches where respondents could objectively assign a numerical score to a predefined source of lock-in. Further research might also elucidate what role agency plays in exasperating various sources of lock-in. This could examine more closely the influence of strategies deliberately employed by regime actors to lock-in particular energy systems [67] as well as opportunities or strategies taken to counter these.

Declaration of Competing Interest

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

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Appendix

Details of interviews (n = 46)

Organisation*	No. of respondents	Date
Financial institutions (banks/insurance firms)		
Meiji Yasuda Life Insurance	1	13/12/2018
Mizuho	1	16/01/2019
Mitsubishi UFJ	4	05/02/2019
Mizuho	1	25/02/2020
General trading companies		
Mitsui	5	19/11/2018
Marubeni	4	20/11/2018
Mitsubishi	2	10/12/2018
Government institutions		
Ministry of the Environment	1	12/01/2018
Ministry of Trade, Economy and Industry (METI)	1	05/02/2018
Japan, Oil, Gas and Metals National Corporation (JOGMEC)	4	08/03/2018
Japan Bank for International Development (JBIC)	2	05/06/2018

Japan International Cooperation Agency (JICA)	2	27/11/2018
Nippon Export and Investment Insurance (NEXI)	3	15/01/2019
Industry organisations and consulting firms		
Keidanren (Japan Business Federation)	2	18/12/2017
Japan Coal Energy Centre (JCOAL)	7	06/02/2018
E's Incorporated	1	31/05/2018
Future Sessions	1	30/01/2020
Japan Climate Leaders' Partnership	1	09/04/2020
Power industry (incumbent utilities)		
Tohoku Electric Power Corporation	1	15/01/2018
Federation of Electric Power Companies of Japan (FEPCO)	5	16/01/2018
JERA	1	18/01/2018
Tohoku Electric Power Corporation	2	23/01/2018
J-Power	1	12/11/2018
Tokyo Electric Power Company (TEPCO)	3	26/11/2018
Central Research Institute of Electric Power Industry	1	03/04/2020
Power industry (renewables utilities)		
SB Energy (Softbank Group)	1	06/02/2018
Shizen Denryoku	1	11/07/2018
Plant equipment manufacturers		
Toshiba Energy Systems	3	14/05/2018
Mitsubishi Hitachi Power Systems (MHPS)	1	19/12/2018
IHI	1	16/01/2019
Mitsubishi Hitachi Power Systems (MHPS)	3	28/01/2020
Research institutions (NGO/university/thinktanks)		
Japan Centre for a Sustainable Environment and Society (JACSES)	1	25/12/2017
Renewable Energy Institute	1	25/01/2018
Influence Map	1	26/01/2018
National Resources Defense Council (NRDC)	1	30/01/2018
Institute for Sustainable Energy Policies (ISEP)	1	16/04/2018
Kiko Network (Kyoto)	1	22/05/2018
Japan Research Institute (Nihon Soken)	1	11/12/2018
Greenpeace Japan	2	22/03/2019
Chiba University (Faculty of Law, Politics and Economics)	1	17/01/2020
Influence Map	1	22/01/2020
Kiko Network (Tokyo)	1	06/02/2020
Renewable Energy Institute	1	07/02/2020
Citizens' Nuclear Information Center	1	10/02/2020
Tohoku University (Graduate School of Arts and Letters)	1	20/02/2020
Institute for Sustainable Energy Policies (ISEP)	1	07/04/2020
Total	84	

* *Note:* To protect the anonymity of respondents, interview codes used throughout the findings do not correspond with the order of this list.

References

[1] A. Pfeiffer, C. Hepburn, A. Vogt-Schilb, B. Caldecott, Committed emissions from existing and planned power plants and asset stranding required to meet the Paris Agreement, Environ. Res. Lett. 1315 (2018), https://doi.org/10.1088/1748-9326/aabc5f.

[2] O. Edenhofer, J.C. Steckel, M. Jakob, C. Bertram, Reports of coal's terminal decline may be exaggerated, Environ. Res. Lett. 13 (2) (2018) 024019.

[3] S. Zhao, A. Alexandroff, Current and future struggles to eliminate coal, Energy Policy 129 (2019) 511–520, https://doi.org/10.1016/j.enpol.2019.02.031.

[4] M. Blondeel, T. Van de Graaf, Toward a global coal mining moratorium? A comparative analysis of coal mining policies in the USA, China, India and Australia, Clim. Change (2018), https://doi.org/10.1007/s10584-017-2135-5.

[5] B. Brown, S. Spiegel, Coal, climate justice, and the cultural politics of energy transition, Glob. Environ. Politics 19 (2) (2019) 149–168, https://doi.org/10.1162/glep_a_00501.

[6] M. Kalkuhl, J.C. Steckel, L. Montrone, M. Jakob, J. Peters, O. Edenhofer, Successful coal phase-out requires new models of development, Nat. Energy 4 (11) (2019) 897–900, https://doi.org/10.1038/s41560-019-0500-5.

[7] P.K. Gellert, P.S. Ciccantell, Coal's persistence in the capitalist world-economy: against teleology in energy "transition" narratives, Sociology of Development 6 (2) (2020) 194–221, https://doi.org/10.1525/sod.2020.6.2.194.

[8] M. Jakob, J.C. Steckel, F. Jotzo, B.K. Sovacool, L. Cornelsen, R. Chandra, O. Edenhofer, C. Holden, A. Löschel, T. Nace, N. Robins, J. Suedekum, J. Urpelainen, The future of coal in a carbon-constrained climate, Nat. Clim. Change 10 (8) (2020) 704–707, https://doi.org/10.1038/s41558-020-0866-1.

[9] C. Strambo, A.C. González Espinosa, A.J. Puertas Velasco, L.M. Mateus Molano, Contention strikes back? The discursive, instrumental and institutional tactics implemented by coal sector incumbents in Colombia, Energy Res. Soc. Sci. 59 (2020) 101280, , https://doi.org/10.1016/j.erss.2019.101280.

[10] M. Boulle, The hazy rise of coal in Kenya: the actors, interests, and discursive contradictions shaping Kenya's electricity future, Energy Res. Social Sci. 56 (2019) 101205, , https://doi.org/10.1016/j.erss.2019.05.015.

[11] G. Trencher, N. Healy, K. Hasegawa, J. Asuka, Discursive resistance to phasing out coal-fired electricity: narratives in Japan's coal regime, Energy Policy 132 (2019) 782–796, https://doi.org/10.1016/j.enpol.2019.06.020.

[12] M. Kuchler, G. Bridge, Down the black hole: sustaining national socio-technical imaginaries of coal in Poland, Energy Res. Social Sci. 41 (2018) 136–147, https://doi.org/10.1016/j.erss.2018.04.014.

[13] J. Jewell, V. Vinichenko, L. Nacke, A. Cherp, Prospects for powering past coal, Nat. Clim. Change 9 (8) (2019) 592–597, https://doi.org/10.1038/s41558-019-0509-6.

[14] G. Rentier, H. Lelieveldt, G.J. Kramer, Varieties of coal-fired power phase-out across Europe, Energy Policy 132 (2019) 620–632, https://doi.org/10.1016/j.enpol.2019.05.042.

[15] M. Blondeel, T. Van de Graaf, T. Haesebrouck, Moving beyond coal: exploring and explaining the powering past coal alliance, Energy Res. Soc. Sci. 59 (2020) 101304, , https://doi.org/10.1016/j.erss.2019.101304.

[16] S. Pai, H. Zerriffi, J. Jewell, J. Pathak, Solar has greater techno-economic resource suitability than wind for replacing coal mining jobs, Environ. Res. Lett. 15 (3) (2020) 034065, , https://doi.org/10.1088/1748-9326/ab6c6d.

[17] K.C. Seto, S.J. Davis, R.B. Mitchell, E.C. Stokes, G. Unruh, D. Ürge-Vorsatz, Carbon Lock-in: types, causes, and policy implications, Annu. Rev. Environ. Resour. 41 (1) (2016) 425–452, https://doi.org/10.1146/annurev-environ-110615-085934.

[18] G.C. Unruh, Understanding carbon lock-in, Energy Policy 28 (12) (2000) 817–830, https://doi.org/10.1016/S0301-4215(00)00070-7.

[19] P. Pierson, Increasing returns, path dependence, and the study of politics, Am. Polit. Sci. Rev. 94 (2) (2000) 251–267, https://doi.org/10.2307/2586011.

[20] R. Bohnsack, J. Pinkse, A. Kolk, Business models for sustainable technologies: exploring business model evolution in the case of electric vehicles, Res. Policy 43 (2) (2014) 284–300, https://doi.org/10.1016/j.respol.2013.10.014.

[21] Z. Janipour, R. de Nooij, P. Scholten, M.A.J. Huijbregts, H. de Coninck, What are sources of carbon lock-in in energy-intensive industry? A case study into Dutch chemicals production, Energy Res. Social Sci. 60 (2020) 101320, , https://doi.org/10.1016/j.erss.2019.101320.

[22] J.H. Wesseling, A. Van der Vooren, Lock-in of mature innovation systems: the transformation toward clean concrete in the Netherlands, J. Cleaner Prod. 155 (2017) 114–124, https://doi.org/10.1016/j.jclepro.2016.08.115.

[23] F.W. Geels, From sectoral systems of innovation to socio-technical systems:

Insights about dynamics and change from sociology and institutional theory, Res. Policy 33 (6) (2004) 897–920, https://doi.org/10.1016/j.respol.2004.01.015.
[24] P. Buschmann, A. Oels, The overlooked role of discourse in breaking carbon lock-in: the case of the German energy transition, Wiley Interdiscip. Rev. Clim. Change 10 (3) (2019) e574, , https://doi.org/10.1002/wcc.574.
[25] F.W. Geels, Reconceptualising the co-evolution of firms-in-industries and their environments: developing an inter-disciplinary Triple Embeddedness Framework, Res. Policy 43 (2) (2014) 261–277, https://doi.org/10.1016/j.respol.2013.10.006.
[26] F.W. Geels, Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective, Res. Policy 39 (4) (2010) 495–510, https://doi.org/10.1016/j.respol.2010.01.022.
[27] T.J. Foxon, A coevolutionary framework for analysing a transition to a sustainable low carbon economy, Ecol. Econ. 70 (12) (2011) 2258–2267, https://doi.org/10.1016/j.ecolecon.2011.07.014.
[28] G. Dosi, Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change, Res. Policy 11 (3) (1982) 147–162, https://doi.org/10.1016/0048-7333(82)90016-6.
[29] T. Metze, Framing the future of fracking: discursive lock-in or energy degrowth in the Netherlands? J. Cleaner Prod. 197 (2018) 1737–1745, https://doi.org/10.1016/j.jclepro.2017.04.158.
[30] A. Klitkou, S. Bolwig, T. Hansen, N. Wessberg, The role of lock-in mechanisms in transition processes: the case of energy for road transport, Environ. Innovation and Societal Transitions 16 (2015) 22–37, https://doi.org/10.1016/j.eist.2015.07.005.
[31] B. Turnheim, F.W. Geels, The destabilisation of existing regimes: confronting a multi-dimensional framework with a case study of the British coal industry (1913–1967), Res. Policy 42 (10) (2013) 1749–1767, https://doi.org/10.1016/j.respol.2013.04.009.
[32] S.V. Valentine, B.K. Sovacool, Energy transitions and mass publics: manipulating public perception and ideological entrenchment in Japanese nuclear power policy, Renewable Sustainable Energy Rev. 101 (2019) 295–304, https://doi.org/10.1016/j.rser.2018.11.008.
[33] F.W. Geels, Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study, Res. Policy 31 (8) (2002) 1257–1274, https://doi.org/10.1016/S0048-7333(02)00062-8.
[34] F.W. Geels, Disruption and low-carbon system transformation: progress and new challenges in socio-technical transitions research and the Multi-Level Perspective, Energy Res. Social Sci. 37 (2018) 224–231, https://doi.org/10.1016/j.erss.2017.10.010.
[35] D. Rosenbloom, Framing low-carbon pathways: a discursive analysis of contending storylines surrounding the phase-out of coal-fired power in Ontario, Environ. Innovation Societal Transitions 27 (2018) 129–145, https://doi.org/10.1016/j.eist.2017.11.003.
[36] P.Y. Parra, N. Okubo, U. Roming, M. Fuentes, M. Schaeffer, B. Hare. Science Based Coal Phase-Out for Japan: Implications for Policymakers and investors, available from: < http://climateanalytics.org/publications/2018/science-based-coal-phase-out-timeline-for-japan.html > , 2018 (cited 2019 15 December).
[37] M. Webb, P. Parra. Japan at an International Crossroads - Seeking a Sunset for Coal, available from: < http://climateanalytics.org/briefings/japan-at-an-international-crossroads-seeking-a-sunset-for-coal.html > , 2018 (cited 2018 15 September).
[38] G. Trencher, C. Downie, K. Hasegawa, J. Asuka, Divestment trends in Japan's international coal businesses, Renewable Sustainable Energy Rev. 124 (2020), https://doi.org/10.1016/j.rser.2020.109779.
[39] Gray, M., Y. Takamura, and M. Morisawa. Land of the Rising Sun and Offshore Wind 2019 [cited 2019 15 December]; Available from: https://www.carbontracker.org/reports/land-of-the-rising-sun/.
[40] D. Normile, Bucking global trends, Japan again embraces coal power, Science 360 (6388) (2018) 476–477, https://doi.org/10.1126/science.aau0562.
[41] B.A. Sandén, K.M. Hillman, A framework for analysis of multi-mode interaction among technologies with examples from the history of alternative transport fuels in Sweden, Res. Policy 40 (3) (2011) 403–414, https://doi.org/10.1016/j.respol.2010.12.005.
[42] L. Fuenfschilling, B. Truffer, The interplay of institutions, actors and technologies in socio-technical systems — an analysis of transformations in the Australian urban water sector, Technol. Forecast. Soc. Chang. 103 (2016) 298–312, https://doi.org/10.1016/j.techfore.2015.11.023.
[43] E. Schmid, Beyond resistance: toward a multilevel perspective on sociotechnical inertia in digital transformation, in: 27th European Conference on Information Systems (ECIS). 2019, ECIS 2019: Stockholm & Uppsala, Sweden. pp. 1–18.
[44] P. Johnstone, K.S. Rogge, P. Kivimaa, C.F. Fratini, E. Primmer, A. Stirling, Waves of disruption in clean energy transitions: sociotechnical dimensions of system disruption in Germany and the United Kingdom, Energy Res. Social Sci. 59 (2020) 101287, , https://doi.org/10.1016/j.erss.2019.101287.
[45] M. Lockwood, C. Mitchell, R. Hoggett, Unpacking 'regime resistance' in low-carbon transitions: the case of the British Capacity Market, Energy Res. Social Sci. 58 (2019) 101278, , https://doi.org/10.1016/j.erss.2019.101278.
[46] F.W. Geels, J. Schot, Typology of sociotechnical transition pathways, Res. Policy 36 (3) (2007) 399–417, https://doi.org/10.1016/j.respol.2007.01.003.
[47] D.L. Edmondson, F. Kern, K.S. Rogge, The co-evolution of policy mixes and socio-technical systems: towards a conceptual framework of policy mix feedback in sustainability transitions, Res. Policy 48 (10) (2019) 103555, , https://doi.org/10.1016/j.respol.2018.03.010.
[48] Jakob, M., C. Flachsland, J. Steckel, and J. Urpelainen, Actors, objectives, context: A political economy framework of energy and climate policy applied to India, Indonesia, and Vietnam, Energy Res. Social Sci. (in press).
[49] P.A. David, Clio and the economics of QWERTY, Am. Econ. Rev. 75 (2) (1985) 332–337.
[50] S. Chignell, R.J.K. Gross, Not locked-in? The overlooked impact of new gas-fired generation investment on long-term decarbonisation in the UK, Energy Policy 52 (2013) 699–705, https://doi.org/10.1016/j.enpol.2012.10.033.
[51] P. Erickson, S. Kartha, M. Lazarus, K. Tempest, Assessing carbon lock-in, Environ. Res. Lett. 10 (8) (2015) 084023, , https://doi.org/10.1088/1748-9326/10/8/084023.
[52] F.W. Geels, Regime resistance against low-carbon transitions: introducing politics and power into the multi-level perspective, Theory, Culture & Society 31 (5) (2014) 21–40, https://doi.org/10.1177/0263276414531627.
[53] A. Smith, A. Stirling, F. Berkhout, The governance of sustainable socio-technical transitions, Res. Policy 34 (10) (2005) 1491–1510, https://doi.org/10.1016/j.respol.2005.07.005.
[54] L.B. Fischer, J. Newig, Importance of actors and agency in sustainability transitions: a systematic exploration of the literature, Sustainability 8 (5) (2016) 476, https://doi.org/10.3390/su8050476.
[55] Newell, P. and P. Johnstone, The Political Economy of Incumbency, in The Politics of Fossil Fuel Subsidies and their Reform, V.A. H. and J. Skovgaard, Editors. 2018, Cambridge University Press: Cambridge. p. 66-80.
[56] W. Walker, Entrapment in large technology systems: institutional commitment and power relations, Res. Policy 29 (7) (2000) 833–846, https://doi.org/10.1016/S0048-7333(00)00108-6.
[57] R. Scott, Institutions and Organizations: Ideas, Interests and Identities, Sage, USA, 1995.
[58] C.W.L. Hill, F.T. Rothaermel, The performance of incumbent firms in the face of radical technological innovation, Acad. Manage. Rev. 28 (2) (2003) 257–274, https://doi.org/10.2307/30040712.
[59] K. Maréchal, The economics of climate change and the change of climate in economics, Energy Policy 35 (10) (2007) 5181–5194, https://doi.org/10.1016/j.enpol.2007.05.009.
[60] H. Van Driel, J. Schot, Radical innovation as a multilevel process: introducing floating grain elevators in the port of Rotterdam, Technology and Culture 46 (1) (2005) 51–76.
[61] B.K. Sovacool, S. Griffiths, Culture and low-carbon energy transitions, Nat. Sustainability (2020), https://doi.org/10.1038/s41893-020-0519-4.
[62] B.K. Sovacool, M.-C. Brisbois, Elite power in low-carbon transitions: a critical and interdisciplinary review, Energy Res. Social Sci. 57 (2019) 101242, , https://doi.org/10.1016/j.erss.2019.101242.
[63] B. Uzzi, Social structure and competition in interfirm networks: the paradox of embeddedness, Adm. Sci. Q. 42 (1) (1997) 35–67, https://doi.org/10.2307/2393808.
[64] S. Valentine, Modifying recipes: insights on japanese electricity sector reform and lessons for China, in: T. Carroll, D.S.L. Jarvis (Eds.), Asia after the Developmental State: Disembedding Autonomy, Cambridge University Press, United Kingdom, 2017, pp. 429–456.
[65] E. Moe, Vested interests, energy efficiency and renewables in Japan, Energy Policy 40 (2012) 260–273, https://doi.org/10.1016/j.enpol.2011.09.070.
[66] K.D. Arbuthnott, B. Dolter, Escalation of commitment to fossil fuels, Ecol. Econ. 89 (2013) 7–13, https://doi.org/10.1016/j.ecolecon.2013.02.004.
[67] M.M. Smink, M.P. Hekkert, S.O. Negro, Keeping sustainable innovation on a leash? Exploring incumbents' institutional strategies, Business Strategy and the Environment 24 (2) (2015) 86–101, https://doi.org/10.1002/bse.1808.
[68] P. Pierson, Dismantling the Welfare State? Reagan, Thatcher, and the Politics of Retrenchment, Cambridge University Press, New York, 1994.
[69] G. Gavetti, D.A. Levinthal, 50th Anniversary article: the strategy field from the perspective of management science: divergent strands and possible integration, Manage. Sci. 50 (10) (2004) 1309–1318, https://doi.org/10.1287/mnsc.1040.0282.
[70] E.U. Weber, Breaking cognitive barriers to a sustainable future, Nat. Hum. Behav. 1 (1) (2017) 0013, https://doi.org/10.1038/s41562-016-0013.
[71] M.L. Tushman, P. Anderson, Technological discontinuities and organizational environments, Adm. Sci. Q. 31 (3) (1986) 439–465, https://doi.org/10.2307/2392832.
[72] K.M. Weber, H. Rohracher, Legitimizing research, technology and innovation policies for transformative change: combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework, Res. Policy 41 (6) (2012) 1037–1047, https://doi.org/10.1016/j.respol.2011.10.015.
[73] C. Downie, Fighting for King Coal's Crown: business actors in the US coal and utility industries, Glob. Environ. Politics 17 (1) (2017) 21–39, https://doi.org/10.1162/GLEP_a_00388.
[74] W.B. Arthur, Competing technologies, increasing returns, and lock-in by historical events, Econ. J. 99 (394) (1989) 116–131, https://doi.org/10.2307/2234208.
[75] F.W. Geels, The multi-level perspective on sustainability transitions: responses to seven criticisms, Environ. Innovation Societal Transitions 1 (1) (2011) 24–40, https://doi.org/10.1016/j.eist.2011.02.002.
[76] G.C. Chen, C. Lees, The New, green, urbanization in china: between authoritarian environmentalism and decentralization, Chin. Polit. Sci. Rev. 3 (2) (2018) 212–231, https://doi.org/10.1007/s41111-018-0095-1.
[77] F. Green, Anti-fossil fuel norms, Clim. Change 150 (1) (2018) 103–116, https://doi.org/10.1007/s10584-017-2134-6.
[78] S.V. Valentine, A STEP toward understanding wind power development policy barriers in advanced economies, Renewable Sustainable Energy Rev. 14 (9) (2010) 2796–2807, https://doi.org/10.1016/j.rser.2010.07.043.
[79] J. Meckling, J. Nahm, The politics of technology bans: industrial policy

competition and green goals for the auto industry, Energy Policy 126 (2019) 470–479, https://doi.org/10.1016/j.enpol.2018.11.031.
[80] T. Kuramochi, Review of energy and climate policy developments in Japan before and after Fukushima, Renewable Sustainable Energy Rev. 43 (2015) 1320–1332, https://doi.org/10.1016/j.rser.2014.12.001.
[81] BP. BP Statistical Review of World Energy, available from: < https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html > , 2019 (cited 2020 25 March).
[82] Japan Coal Plant Tracker. List of Existing Plants, available from: < http://sekitan.jp/plant-map/en/v2/table_en > , 2020 (cited 2020 June 10).
[83] H. Chen, J. Schmidt. Power Shift: Shifting G20 International Public Finance From Coal to Renewables, available from: < https://www.nrdc.org/resources/power-shift-g20-international-public-finance-from-coal-to-renewables > , 2017 (cited 2018 July 4).
[84] I. Gencsu, S. Whitley, L. Roberts, C. Beaton, H. Chen, A. Doukas, A. Geddes, I. Gerasimchuk, L. Sanchez, Suharsono. G20 Coal Subsidies: Tracking Government Support to a Fading Industry, available from: < https://www.odi.org/sites/odi.org.uk/files/resource-documents/12744.pdf > 2019 (cited 2020 25 March).
[85] A. Rinscheid, R. Wüstenhagen, Germany's decision to phase out coal by 2038 lags behind citizens' timing preferences, Nat. Energy 4 (10) (2019) 856–863, https://doi.org/10.1038/s41560-019-0460-9.
[86] Agency for Natural Resources and Energy (ANRE). Fifth Basic Energy Strategy, Available from: < https://www.enecho.meti.go.jp/en/category/others/basic_plan/5th/pdf/strategic_energy_plan.pdf > , 2018 (cited 2019 March 1).
[87] Ministry of Economy, Trade and Industry (METI). Long-term outlook for energy supply and demand, available from: < https://www.meti.go.jp/english/press/2015/pdf/0716_01a.pdf > , 2015 (cited 2019 15 July).
[88] Japan Coal Plant Tracker. List of Proposed Plants, available from: < http://sekitan.jp/plant-map/en/v2/table_en > , 2020 (cited 2020 April 10).
[89] International Energy Agency (IEA). Japan - Countries & Regions, available from: < https://www.iea.org/countries/japan > , 2020 (cited 2020 June 30).
[90] A. Sheldrick, Japan to shut or mothball 100 ageing coal-fired power plants, available from: < https://uk.reuters.com/article/uk-japan-powerstation-coal-idUKKBN24306U > , 2020 (cited 2020 July 2).
[91] Kiko Network. Analysis of Japan's Government Policy to Shut Down or Mothball 100 "inefficient" Coal Power Units: Government's Proposed Policy Would Extend the Life of Coal, not Phase it out, Available from: < https://www.kikonet.org/wp/wp-content/uploads/2020/07/Japans-100-shutdown-analysis_20200706_ENG.pdf > , 2020 (cited 2020 August 20).
[92] T. Incerti, P.Y. Lipscy, The energy politics of Japan, in: K. Hancock, J.E. Allison (Eds.), The Oxford Handbook of Energy Politics, Oxford Handbooks Online, 2020.
[93] M. Toda, A. Kanda, H. Nogami, T. Ishii, Japan's Exports of Coal-fired Thermal Plants at a Crossroads, available from: < http://www.asahi.com/ajw/articles/13312270 > , 2020 (cited 2020 1 July).
[94] K. Sofer, Climate Politics in Japan: The Impacts of Public Opinion, Bureaucratic Rivalries, and Interest Groups on Japan's Environmental Agenda, USA, 2016.
[95] Climate Action Tracker. Country Summary: Japan, available from: < https://climateactiontracker.org/countries/japan/ > , 2020 (cited 2020 July 1).
[96] Institutional Investors Group on Climate Change (IIGCC). International investor group letter on Japan's NDC, available from: < https://www.iigcc.org/resource/international-investor-group-letter-on-japans-ndc/ > , 2020 (cited 2020 March 25).
[97] T. Fraser, D.P. Aldrich, The Fukushima effect at home: the changing role of domestic actors in Japanese energy policy. WIREs, Clim. Change (2020) e655, , https://doi.org/10.1002/wcc.655.
[98] J.B. Kucharski, H. Unesaki, An institutional analysis of the Japanese energy transition, Environ. Innovation Societal Transitions 29 (2018) 126–143, https://doi.org/10.1016/j.eist.2018.07.004.
[99] Japan Electric Power Information Center (JEPIC). The Electric Power Industry in Japan, Available from: < https://www.jepic.or.jp/pub/pdf/epijJepic2019.pdf > .
[100] J.S. Duffield, Japanese energy policy after fukushima daiichi: nuclear ambivalence, Polit. Sci. Q. 131 (1) (2016) 133–162, https://doi.org/10.1002/polq.12431.
[101] Ministry of Economy, Trade and Industry (METI). Cabinet Orders concerning the Act of Promoting Utilization of Sea Areas in Development of Power Generation Facilities Using Maritime Renewable Energy Resources Approved, available from: < https://www.meti.go.jp/english/press/2019/0315_003.html > , 2019 (cited 2019 April 20).
[102] United Nations Environment Programme (UNEP). Emissions Gap Report 2019, available from: < https://www.unenvironment.org/resources/emissions-gap-report-2019 > , 2019 (cited 2020 15 March).
[103] I. Matsuo, K. Katori, T. Ishii, Koizumi gives up Pledge to curb coal 'addiction' due to opposition, available from: < http://www.asahi.com/ajw/articles/AJ201912120059.html > , 2019 (cited 2020 20 March).
[104] I. Barnes, HELE Technologies and Outreach in Japan and South Korea, available from: < https://www.iea-coal.org/hele-technologies-in-japan-and-south-korea-2/ > , 2019 (cited 2019 10 December).
[105] Organization for Cross-regional Coordination of Transmission Operators (OCCTO). 2020 Nendo Kyokyu Keikaku no Torimatome (Aggregation of Electricity Supply Plans Fiscal Year 2020), in Japanese, available from: < https://www.occto.or.jp/kyoukei/torimatome/files/200331_kyokei_torimatome.pdf > , 2020 (cited 2020 25 March).
[107] J. Huenteler, T.S. Schmidt, N. Kanie, Japan's post-Fukushima challenge – implications from the German experience on renewable energy policy, Energy Policy 45 (2012) 6–11, https://doi.org/10.1016/j.enpol.2012.02.041.
[108] Influence Map. Japanese Industry Groups and Climate Policy, Available from: < https://influencemap.org/presentation/Japanese-Industry-Groups-and-Climate-Policy-899704d005cb96359cc5b5e2a9b18a84 > , 2020 (cited 2020 August 21).
[109] Tanner, D. Japan's Energy Choices Towards 2020: How its shift to coal is misaligned with the strategic interests of Japan, available from: < https://influencemap.org/site/data/000/302/Japan_Report_October_2017.pdf > , 2018 (cited 2018 22 March).
[110] M. Hartwig, Y. Kobashi, S. Okura, L. Tkach-Kawasaki, Energy policy participation through networks transcending cleavage: an analysis of Japanese and German renewable energy promotion policies, Qual. Quant. 49 (4) (2015) 1485–1512, https://doi.org/10.1007/s11135-014-0093-9.
[111] V. Vivoda, Japan's energy security predicament post-Fukushima, Energy Policy 46 (2012) 135–143, https://doi.org/10.1016/j.enpol.2012.03.044.
[112] Government of Japan. Submission of Japan's Intended Nationally Determined Contribution (INDC), available from: < https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Japan%20First/20150717_Japan%27s%20INDC.pdf > , 2015 (cited 2020 1 July).
[113] Ministry of Environment (MOE). Submission of Japan's Intended Nationally Determined Contribution (INDC), available from: < https://www.env.go.jp/press/files/en/827.pdf > , 2020 (cited 2020 15 June).
[114] Kantei (Prime Minister of Japan and His Cabinet). Infurashisutemu yusyutsu senryaku (Infrastructure export strategy for FY2018), in: Japanese, available from: < https://www.kantei.go.jp/jp/singi/keikyou/dai37/siryou2.pdf > 2018 (cited 2019 23 March).
[115] New Energy and Industrial Technology Development Organization (NEDO). Senshintekina karyokuhatsuden gijutsu nado no kaigaitenkai suishin jigyo (Project for promoting the overseas export of advanced thermal power technologies), in: Japanese, available from: < https://www.nedo.go.jp/koubo/EV2_100193.html > , 2020 (cited 2020 10 April).
[116] K. Takase, M. Ishida, S. Telang. Renewable Energy Market Briefing Japan, available from: < http://media.virbcdn.com/files/28/dcf62df1869a1abd-RE100JapanMarketBriefingJanuary2020-use.pdf > , 2020 (cited 2020 26 March).
[117] Kantei (Prime Minister of Japan and His Cabinet). The Long-term Strategy under the Paris Agreement, available from: < https://www.env.go.jp/earth/earth/ondanka/mat3.pdf > , 2019 (cited 2020 20 March).
[118] JCOAL. Recommendations for coal policy in Japan: JCOAL Journal, available from: < http://www.jcoal.or.jp/eng/publications/upload/recommendations%20towards%20clean%20coal%20technology.pdf > , 2019 [cited 2019 5 April].
[119] Federation of, Electric Power Companies (FEPCO). Wagakuni no energi jijo (The energy situation of Japan), in Japanese, Keidanren Monthly (2017. July) 66–69.
[120] Ministry of Economy, Trade and Industry (METI). Jisedai Karyoku Hatsuden ni Kakawaru Gijutsu Rodomappu (Next Generation Thermal Power Generation Technological Roadmap), in: Japanese. available from: < http://www.meti.go.jp/press/2016/06/20160630003/20160630003-1.pdf > , 2016 (cited 2018 5 July).
[121] Keidanren, Jizokukanona seicho wo sasaeru energi ondankataisaku (Climate policy to support sustainable economic growth), in: Japanese, Keidanren Monthly (2018. July) 6–22.
[122] Agency for Natural Resources and Energy (ANRE). Kuni ni yotte kotonaru sekitankaryokuhatsuden no riyoukatsuyo (Ways of exploiting coal-fired power in differing countries), in: Japanese, available from: < http://www.enecho.meti.go.jp/about/special/johoteikyo/sekainosekitankaryoku.html > , 2018 (cited 2018 20 July).
[123] Agency for Natural Resources and Energy (ANRE). Naze Nihon ha sekitankaryokuhatsuden no katsuyo wo tsuzuketeiru no ka? 2030 nendo no energi-mikusu to CO2 sakugen wo tassei suru tame no torikumi (Why is Japan continuing to use coal-fired electricity? Measures for acheiving the 2030 energy mix), in Japanese, available from: < http://www.enecho.meti.go.jp/about/special/johoteikyo/qa_sekitankaryoku.html > , 2018.
[124] Agency for Natural Resources and Energy (ANRE). Intabyu: Senshin Gijutsu de Sekitan no Zero Emissyonka wo Mezashi, Jisedai no Energi ni (Interview: Aiming for Zero-Emissions with Advanced Technology, Towards Next-Generation Energy), in Japanese, available from: < https://www.enecho.meti.go.jp/about/special/johoteikyo/interview17kitamura02.html > , 2020 (cited 2020 March 20).
[125] Agency for Natural Resources and Energy (ANRE). Fourth Basic Energy Strategy. Available from: < https://www.enecho.meti.go.jp/en/category/others/basic_plan/pdf/4th_strategic_energy_plan.pdf > , 2014 (cited 2020 March 17).
[126] Mitsubishi Heavy Industries (MHI). Power Systems Business Plan: Presentation material (July 12, 2019), available from: < https://www.mhi.com/finance/library/business/ > , 2019.
[127] International Renewable Energy Agency (IRENA). Renewable Power Generation Costs in 2018. Available from: < https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf > , 2019 (cited 2020 15 April).
[128] SAP + Qualtrics. Towards a more sustainable world: A global study of public opinion. Available from: < http://www3.weforum.org/docs/WEF_More_Sustainable_World.pdf > , 2020 (cited 2020 10 April).
[129] A. Chapman, K. Itaoka, Curiosity, economic and environmental reasoning: public perceptions of liberalization and renewable energy transition in Japan, Energy Res. Social Sci. 37 (2018) 102–110, https://doi.org/10.1016/j.erss.2017.09.026.
[130] Reuters. Ichigatsu Roita Kigyo Chyosa: Kozui heno Sonae Hansu Ika, Sekitan Karyoku Hantai ha, 2 Wari Domari (Reuter Company Survey in January: Flood Readiness Below Half, Coal-power Opposition Only 20%), in Japanese. Available from: < https://jp.reuters.com/article/japan-corpsurvey-january-env-idJPKBN1ZG051 > , 2020 (cited 2020 March 15).
[131] Influence Map. Japanese Industry Groups and Climate Policy. Available from < https://influencemap.org/presentation/Japanese-Industry-Groups-and-Climate-Policy-899704d005cb96359cc5b5e2a9b18a84 > , 2020 (Accessed August 21 2020).

[132] Shizen Enerugi Kyogikai (Council on Renewable Energy). Shizen Enerugi no Saidai Donyu ni Mukete: Shizen Enerugi Donyukasoku ni yoru Jizenbosai no Suishin (Towards Large-scale Penetration of Renewable Energy: Accelerating the Adoption of Renewable Energy by Promoting Countermeasures). In Japanese. Available from: < http://www.enekyo.jp/wp-content/uploads/2019/11/20191118.pdf > , 2019 (cited 2020 2 July).

[133] H. Takizawa, 5 Fallacies of Japan's Coal-fired Power Export Policy. Available from: < https://www.renewable-ei.org/en/activities/reports/20200316.php > , 2020 (cited 2020 25 March).

[134] H. Hakko, M. Lou, Uncertain and Harmful: Japanese Coal Investments in Indonesia. Available from: < https://www.greenpeace.org/japan/sustainable/publication/2018/12/06/6544/ > , 2018 (cited 2019 23 March).

[135] Ministry of Economy, Trade and Industry (METI). Keizaisangyosho Infura Kaigai Tenkai Kondankai Chukantorimatome (Denryoku Enerugi). (METI Committee for Overseas Infrasystems Exports Mid-term Report (Power and Energy)), in: Japanese. Available from: < https://www.meti.go.jp/press/2020/05/20200521001/20200521001-1.pdf > , 2020 (cited 2020 July 1).

[136] Nikkei Asian Review, Japan Seeks Stoppage of 100 Inefficient Coal Plants in a Decade. Available from: < https://asia.nikkei.com/Business/Energy/Japan-seeks-stoppage-of-100-inefficient-coal-plants-in-a-decade > , 2020 (cited 2020 July 2).

[137] M. Godet, Introduction to la prospective: Seven key ideas and one scenario method, Futures 18 (2) (1986) 134–157, https://doi.org/10.1016/0016-3287(86)90094-7.

[138] M. Godet, The art of scenarios and strategic planning: tools and pitfalls, Technol. Forecast. Soc. Change 65 (1) (2000) 3–22, https://doi.org/10.1016/S0040-1625(99)00120-1.