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RESEARCH ARTICLE

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Policy entry points for facilitating a transition towards a low-carbon electricity future

Abstract This study extends the ambit of the debate on electricity transition by specifically identifying possible policy entry points through which transformative and enduring changes can be made in the electricity and socio–economic systems to facilitate the transition process. Guided by the "essence" of the multi-level perspective — a prominent framework for the study of energy transition, four such entry points have been identified: 1) destabilising the dominant, fossil fuel-based electricity regime to create room for renewable technologies to break through; 2) reconfiguring the electricity regime, which encompasses technology, short-term operational practices and long-term planning processes, to improve flexibility for accommodating large outputs from variable renewable sources whilst maintaining supply security; 3) addressing the impact of coal power phase-out on coal mining regions in terms of economic development and jobs; and 4) facilitating a shift in transition governance towards a learning-based, reflexive process. Specific areas for policy interventions within each of these entry points have also been discussed in the paper.

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1 Introduction

Fossil fuels are the mainstay of global electricity landscapes, and they contribute to nearly two-thirds of electricity supply worldwide (IEA, 2019). The urgency of addressing the climate change challenge has emphasised the need for a rapid and deep decarbonisation of the electricity sector (referred to as electricity transition in modern day parlance). However, achieving electricity transition is likely to be an extremely challenging task. It would require an aggressive shift in generation-mix, away from fossil fuels, towards renewable energy, in the next two or three decades (IEA, 2021a).

A large number of studies have been undertaken in the recent years to understand the dynamics of energy transition and recommended ways to expedite the transition process. While these studies cover a wide range of perspectives, overwhelmingly however they consider electricity transition as a technological challenge and accordingly offer technological solutions to redress the challenge, including innovations to improve the "performance" of renewable technologies, such as wind and solar photovoltaic (PV) (Seba, 2014; LaBelle and Horwitch, 2013); effective business models and strategies to take renewable innovation to the market (Loorbach et al., 2010; Boons and Lüdeke-Freund, 2013); market and regulatory changes required to facilitate a successful renewable innovation (Bakker, 2014; Bohnsack et al., 2016; Gong et al., 2021; Zhou et al., 2021); overcoming incumbency effects on obstructing renewable innovations (Smink et al., 2015; Dijk et al., 2016; Lauber and Jacobsson, 2016); and optimal combination of options (e.g., fast-responsive capacity, energy storage and grid connectivity) for changing the technical layout of the electricity system to accommodate large outputs from variable renewable sources (Pleßmann et al., 2014; Child et al., 2019; Baldinelli et al., 2020; Lu et al., 2021).

These studies provide useful insights into and bases for progressing the debate on technological aspects of electricity transition. The rapidly increasing maturity of some renewable technologies (i.e., solar PV and wind), as well as rapid diffusion of renewables in some countries (i.e., China, India, Germany and the United Kingdom), has somewhat shifted the focus of the debate on electricity transition, away from exclusively technological, to system–socio–economic–institutional realms. In fact, some argue that the ongoing diffusion of renewable energy could slow down or even stall if 1) it is not accompanied by wider changes in the electricity system to facilitate renewable integration given that this situation could cause system dysfunction and thus affect the sociopolitical acceptance of electricity transition; and 2) the socio–economic consequences (e.g., laid-off workers and economic slowdown in coal-dependent regions) of reduced generation from fossil fuels are left unattended (Markard, 2018). Consequently, a new genre of studies has emerged that focuses on broader "system-level" aspects of electricity transition, such as on necessary changes in electricity and socio–economic systems required to facilitate the transition process (Markard and Hoffmann, 2016; Geels, 2018; McMeekin et al., 2019; Wang et al., 2021).

Against the above-mentioned backdrop, the main purpose of this study is to extend the ambit of the debate on electricity transition by identifying possible policy entry points through which transformative and enduring changes can be made in the electricity and socio–economic systems to facilitate the transition process. Kanger et al. (2020) defined such points as "particular areas in the socio–technical system or its environment where the application of appropriate policy instruments would likely facilitate transformative change in the system's directionality". They represented an essential mid-step between goals (electricity transition in our instance) and mixes of policy instruments for achieving the goals.

The rest of the paper is structured as follows. Section 2 discusses the basic conceptual building blocks of energy transition theories with particular focus on the multi-level perspective (MLP): A prominent framework in the study of energy transition (Kanger et al., 2020). Guided by this framework, this section also identifies a set of factors in the wider electricity and socio–economic systems that could affect the progress of electricity transition. Section 3 reconceptualises these factors into four policy entry points for facilitating electricity transition and discusses specific areas for policy intervention within each of these points. Section 4 presents the main conclusions of the study.

2 Theoretical background

An electricity system can be considered a socio–technical system, where technologies interact with human agency and social structures in fulfilling societal demands for electricity, such as for industrial heating, street lighting and operating electrical appliances (Geels, 2005). Several theoretical frameworks exist in the literature for understanding the transitioning process of a socio–technical system. Based on a preliminary review of these frameworks, the MLP framework stands out as the "global" framework that convincingly captures the essence of the entire process of socio–technical transition (electricity transition in our instance), which encompasses changes in the focal socio–technical system and the underlying contexts within which it is operated (Kanger et al., 2020).

The MLP conceptualises socio–technical transition as an outcome of co-evolutionary interplay between three different levels: Niche, regime and landscape (Geels, 2002). The niche represents "incubation room" for radical innovations (e.g., low-carbon technologies) that are protected or insulated from the selection pressure in the dominant, fossil fuel-based electricity regime (Schot, 1998). The regime refers to the specific suite of socio–technical "rules" that govern a particular system (e.g., the electricity system). Some examples of these rules are engineering practices, ways of handling relevant artefacts, market mechanisms and regulatory arrangements (Rip and Kemp, 1998). They provide orientation and coordination to the interactions between various actors in the system. The outcome is a dynamic stability of the system, wherein the regime acts as selection and retention mechanisms that favour incremental innovations to refine or improve the function of the existing system (Geels, 2002). An example of this initiative would be reducing air pollution and CO_2 emissions from electricity generation by improving the technical efficiency of coal-fired power plants. The landscape comprises a set of macro-level structural factors (e.g., rising gas prices or anti-nuclear sentiment) that shape niche innovations and socio–technical regimes (Geels, 2002).

According to the MLP, the stimulus for socio–technical transition (electricity transition in our instance) comes from landscape changes (e.g., growing public concern about climate change challenge) that put pressure on the dominant, fossil fuel-based regime to redress its perceived functional problems (e.g., high emissions). This aspect is normally conducted through incremental innovations, such as the replacement of inefficient subcritical coal-fired power plants with more efficient supercritical and ultra-supercritical ones (Geels and Schot, 2010). The landscape pressure also creates the "windows of opportunity" for niche innovations on renewable technologies to take place (Kern et al., 2014; Smith et al., 2014). This phase of transition is known as predevelopment phase. It then shifts to the next, take-off phase when novel technologies become mature and start to diffuse rapidly. As this diffusion accelerates, it prompts the need for efforts to destabilise the dominant, fossil fuel-based regime for creating room for niche technologies to break through. This stage is referred to as breakthrough phase. This phase is also characterised by major structural changes in the regime to accommodate accelerated adoption of the novel technologies (Kivimaa and Kern, 2016). As the regime reaches a new equilibrium, the transition comes to the last, stabilisation phase (Rotmans et al., 2001). Figure 1 presents the broad contours of the four phases of electricity transition.

Markard et al. (2020) suggested that the global electricity transition is currently shifting from the take-off phase towards the breakthrough phase given that some renewable technologies (i.e., solar and wind) have become mature and started to challenge the dominant position of fossil fuel technologies. Indeed, a perceptible fuel switch in electricity generation-mix towards renewable energy has occurred in recent years, with its share rising from 18% in 2010 to 24% in 2019 (IEA, 2021b). According to the MLP, four key factors are worth considering whilst designing policies to facilitate this phase shift process.

Firstly, the MLP holds that electricity transition towards a higher reliance on renewable energy does not happen merely because of technological maturity. The electricity regime also needs to be destabilised to create room for them to break through, especially when novel renewable technologies have become mature and started to diffuse rapidly (Kivimaa and Kern, 2016). Regime destabilisation serves to weaken incumbent actors' commitments to the regime by impairing the lock-in factors (e.g., sunk investments) (Turnheim and Geels, 2013), which causes a major structural change in the generation-mix possible.

Secondly, facilitating a major structural change in the generation-mix requires a reconfiguration of the electricity system, which encompasses all its constitutive elements, such as infrastructure, market rules, regulatory frameworks and consumer practices. These elements interact with one another in an array of complementary and interlocking relationships to ensure a proper functioning of the electricity system. Therefore, changing one element of the system (e.g., a shift in generation-mix towards increased reliance on renewable energy) will inevitably require changing other interconnected elements. If this aspect is not conducted, then a disconnect could emerge that may undermine the overall functioning of the system (Markard and Hoffmann, 2016).

Thirdly, a shift away from the fossil fuel-based regime, as an outcome of regime destabilisation and reconfiguration, will obviously lead to a decline in the share of fossil fuels generation. This situation is likely to cause widespread ramifications, which extend into socio–economic realms of the society. For example, the economic dependence of many regions on coal producing activities and associated electricity generation (e.g., pithead power plants) means that coal power phase-out will affect regional economic development and jobs, which places pressure on policymakers to guarantee a "just transition" (Sartor, 2018).

Fourthly, the interdependencies and interconnectedness of abovementioned changes (i.e., regime destabilisation and reconfiguration and socio–economic restructuring) could engender a proliferation of complexity, which could span individual lives to local and national economies and cut across diverse policy domains including energy security, economic development and social well-being (Valkenburg and Gracceva, 2016). Perception on this complexity and the potential solutions that are offered may also vary from actor to actor, which may depend on individual viewpoints, perspectives and interests

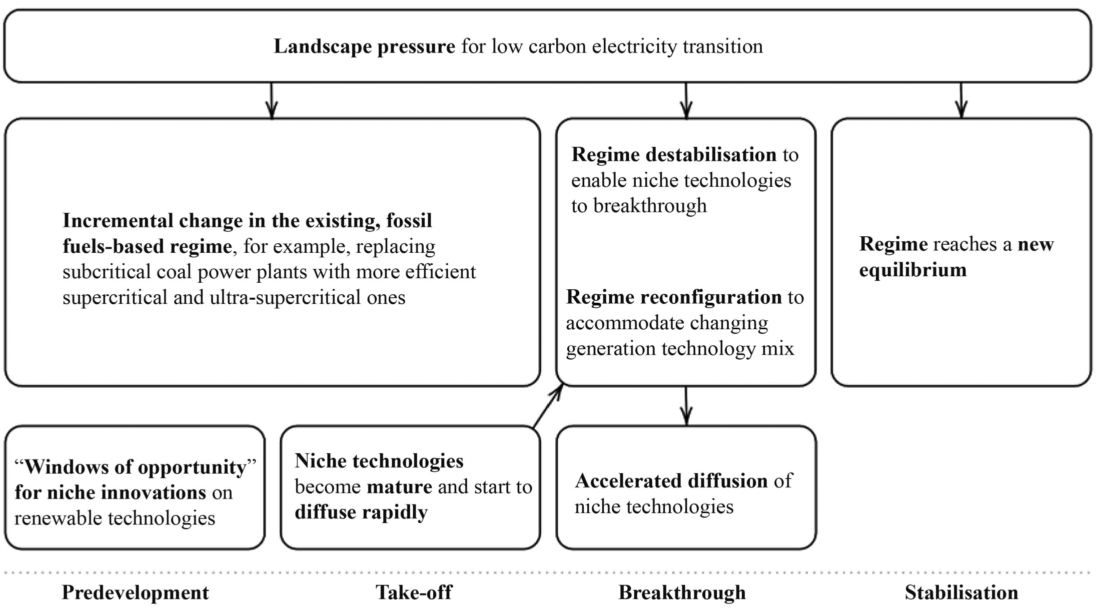

Fig. 1 Four phases of the electricity transition process.

(Meadowcroft, 2009). All these factors effectively make electricity transition a "wicked problem" (Murphy, 2012) that is not expected to have one "single, correct, optimal solution" (Balint et al., 2011). A shift in transition governance towards increased reliance on a learning-based, reflexive process is required to meaningfully engage with the wicked problem and adapt to changing situations (de Schutter and Lenoble, 2010; Susur and Karakaya, 2021). This process goes beyond the conventional linear process of firstly defining normative goals and then implementing measures to attain the goals, instead focusing on "mulling over, evaluating, recapturing experiences and re-orienting on actions" (Sol et al., 2018).

3 Policy entry points for electricity transition

The previous section has identified four factors that are likely to shape the electricity transition process as it shifts from the take-off phase towards the breakthrough phase. The four factors can be considered entry points for policy interventions to facilitate transformative changes required for moving electricity transition to the breakthrough phase.

3.1 Regime destabilisation for low-carbon technologies to break through

Turnheim and Geels (2013) conceptualised regime destabilisation as an outcome of increasing external pressures from economic and sociopolitical environments that could create performance problems (e.g., financial losses) for incumbent companies, which would gradually weaken their commitment to the existing industry regime. In the economic environment, pressures may come from shrinking markets due to changing consumer preferences (e.g., a strong consumer preference for renewable energy) or new entrants that outcompete the incumbents (e.g., cheaper or more efficient generating technologies), which affects the economic performance of the incumbent companies (Kungl and Geels, 2018). In the sociopolitical environment, pressures can come from policy changes (e.g., coal phase-out commitment) or social movements (e.g., consigning coal to history campaign) that could reduce the legitimacy of the existing regime for incumbent companies (Kungl and Geels, 2018).

The extent to which the performance problems (e.g., financial losses and decreasing policy support) can weaken the incumbent companies' commitment to existing industry regime will be determined by the strength of four key lock-in factors: 1) cognitive lock-in — caused by limitations in knowledge that prevent incumbent companies from recognising the benefits of regime change (Dosi and Nelson, 1994); 2) regulatory lock-in — such as fossil fuel subsidies that provide incentives for incumbent companies to stay with the existing regime (DiMaggio and Powell, 1983); 3) market lock-in — caused by established commitments (e.g., long-term supply contracts with coal producers with take-or-pay clause) to specific trade partners or supply chains in the existing regime (Christensen, 1997); and 4) infrastructure lock-in — caused by large sunk costs in the existing infrastructure that may become stranded if it retires earlier than its technical life (Tushman and Anderson, 1986).

The abovementioned discussion suggests two specific areas for interventions that can help weaken the commitments of incumbent electricity companies to the dominant, fossil fuel-based regime. Firstly, increase the economic and sociopolitical pressure on incumbent companies to re-think their commitment to the existing regime. This initiative can be achieved by a mix of policies addressing two dimensions: 1) those affecting the financial returns of fossil fuel assets (e.g., carbon pricing); and 2) those affecting the legitimacy of fossil fuel investments for incumbent companies and investors (e.g., moratorium on greenfield coal power projects and coal power phase-out commitment).

Secondly, address lock-in factors that affect the capacity of incumbent electricity companies to move away from the existing fossil fuel regimes. With regard to the cognitive lock-in, policymakers may like to consider providing technical support to incumbent electricity companies, with specific emphasis on helping them identify the benefits of moving away from the fossil fuel regime and options for realising these benefits. For regulatory and market lock-ins, policymakers may also like to consider initiating regulatory and market reforms for removing incentives for fossil fuel generation and breaking established arrangements (e.g., long-term supply contracts with coal producers) that benefit fossil fuels. Policymakers may like to consider introducing compensation mechanisms for facilitating early phase-out of existing coal-fired power plants, as well as strengthening the existing network infrastructure (e.g., energy storage and better connectivity) to promote the uptake of low-carbon technologies for addressing the infrastructure lock-in.

3.2 Regime reconfiguration to accommodate changing generation-mix

Renewable energy, especially wind and solar, is central to a net-zero electricity system. As estimated in IEA (2021b), achieving net-zero emissions in the global electricity system would require a substantial expansion of renewable generation, which would bring its share to nearly 90% by 2050. Of this, 35% and 33% will come from wind and solar, respectively. Similar results have also been found in other modelling studies conducted by the Intergovernmental Panel on Climate Change (IPCC, 2018) and International Renewable Energy Agency (IRENA, 2020).

Integrating a substantial amount of variable renewable energy into an electricity system would greatly increase the uncertainty that the system operator needs to cope with due to the intermittent and stochastic nature of renewable generation (Nikolakakis and Chatopadhyay, 2015; Wang, 2021). This situation in turn creates the need for system reconfiguration to improve its flexibility. If this task is not done, then the security and reliability of electricity supply may be affected.

Several options are available for improving the technical flexibility of an electricity system. They mainly include fast-responsive capacity, energy storage and demand-side management (Lund et al., 2015; Söder et al., 2018). Electricity networks also need to be strengthened to enable better access to these options mainly through smartification, better interconnectivity and meshed distribution networks (Cruz et al., 2018).

Integrating a large amount of renewable generation into an electricity system also requires improving the flexibility of its short-term operational practice (Henriot and Glachant, 2013; Ela et al., 2016; Hu et al., 2018; Newbery et al., 2018). Some specific areas for improvement are as follows.

One area is electricity pricing. The temporal granularity of electricity pricing needs to be deceased to better reflect short-term variability of renewable generation (Hogan, 2010; Newbery et al., 2018). For example, the day-ahead spot prices in Europe are normally determined on an hourly basis and unable to accurately capture the sub-hourly variability of renewable generation, especially wind and solar PV (MacDonald et al., 2016). This inaccuracy could cause excessive demand for balancing services in real time and thus put upward pressure on electricity prices (Just and Weber, 2015). Nodal pricing is also more preferable in an electricity system with high levels of renewable penetration when compared with zonal pricing (especially for large trading zones). This tendency is premised on the argument that, “as the generation by intermittent resources keeps evolving, the congestion patterns will evolve constantly, and nodal pricing seems to be the only option able to match reality at all times” (Henriot and Glachant, 2013).

Another area is the provision of ancillary services. Here, suggestions are made to 1) introduce new services required to manage challenges (e.g., more frequent short-term supply–demand imbalances and a loss of inertia) imposed by rising renewable generation (Jones, 2017); 2) streamline ancillary products (i.e., reducing the number of products associated with a specific ancillary service) to improve market liquidity (Henriot and Glachant, 2013); 3) make better alignment of ancillary service markets with the spot and intraday markets to improve flexibility (Green, 2008; Nicolosi, 2010); and 4) effectively use demand-side options (e.g., demand-side response and energy storage) to reduce the need for expensive peaking units (Kapetanovic et al., 2008; Cruz et al., 2018).

Other areas for improvement include raising price caps sufficiently higher to attract investments in expensive peaking units that will be more frequently called upon to address short-term supply–demand imbalances (Henriot and Glachant, 2013), setting electricity markets’ gate closure closer to real time when more accurate forecasts of wind and solar generation are available (Ketterer, 2014), aggregating electricity markets over large regions through better interconnectivity to provide access to more flexibility options and bringing about geographical smoothing of renewable generation (Klima et al., 2018; Riesz and Milligan, 2019), and strengthening risk management mechanisms to alleviate the “missing money” problem for conventional dispatchable plants for providing reserves and ancillary services (Henriot and Glachant, 2013; Kozlova and Overland, 2021).

Flexibility planning also needs to be better incorporated into the long-term planning process of an electricity system to enable higher levels of renewable penetration. According to IRENA (2018), flexibility planning is a complex process involving three main steps. The first step is to assess the availability of flexibility in the existing electricity system for identifying the flexibility gaps in satisfying the reliability regulation. The second step is to identify a least-cost set of solutions for unlocking existing flexibility to fill the gaps. These solutions may include regulatory and market reforms to enable more effective use of existing flexibility, better demand-side management and retrofitting of existing units to provide ancillary services. The third step is to identify the need for additional flexibility capacity.

3.3 Addressing the socio–economic ramifications of regime change

The regime destabilisation and reconfiguration, as discussed above, will lead to reduced generation from fossil fuels, especially coal. This situation could affect the coal mining regions in terms of development and jobs, as evidenced by the experience of the United Kingdom, where significant progress has been made to phase out the use of coal in electricity generation (Foden et al., 2014). One example is the closure of the Ferrybridge C coal-fired power station and associated Kellingley Colliery coal mine in 2016. This situation has been widely considered a “double whammy” for the surrounding areas in terms of the local economy, although its direct job impact appears to be insignificant with less than 1000 people directly employed in these coal-related sites (Yorkshire Post, 2016). According to Elliott (2016), following the decline of the coal industry, spending power was removed from the former coal mining regions in Britain; given that high-wage industrial jobs were replaced by fewer low-paid jobs in call centres and distribution warehouses, these regions have never recovered.

The impact of coal power phase-out on development and jobs in coal producing regions could lead to worsening living conditions (Davies, 1984; Winterton, 1993; Sun et al., 2009), growing poverty (Marley, 2016) and decreased provision of social services (Haney and Shkaratan, 2003) — all of which could affect the welfare of the local communities. Notably, the immediate, localised impacts of coal power phase-out, as noted above, could extend to the surrounding areas or even the national or regional economies in some cases through their business-to-business linkages with the coal-dependent regions.

Some may argue that the job losses caused by coal power phase-out and associated decline of coal mining activities can be somewhat offset by new jobs created in low-carbon technology industries (IRENA, 2020). However, this offset effect on job losses may not always be realised due to two main reasons. Firstly, coal mining regions may not have a clear advantage over other regions in terms of the clean energy economy. Secondly, the skills and knowledge required by the low-carbon technology industries are quite different from those by the coal mining industry. This situation makes workers from coal mining industry difficult to get re-employed in the emerging low-carbon industries (Johnstone and Hielscher, 2017).

The preceding discussion should not be considered a call to halt electricity transition. Rather, it is a call, as also made by Johnstone and Hielscher (2017), to view electricity transition and associated socio–economic impacts in broader socio–economic contexts and identify practical policy solutions and plans for managing the adverse impacts of coal power phase-out that will disproportionately affect coal-dependent regions. This initiative can be done through policy interventions in three specific areas, as discussed below.

Regional economic restructuring: The adverse socio–economic impact of coal power phase-out on coal mining regions can be mitigated by economic restructuring to reduce the region's dependence on coal mining activities (Anderson, 2007). This initiative requires a mix of policies focused on 1) business attraction through the provision of financial (e.g., tax cuts and low-interest loans) and other (e.g., public support for the creation of necessary infrastructure and research and development) support to non-coal industries; and 2) educational reforms to better align the curriculum of local universities and colleges with the skills and knowledge required by the "new" industries (Furnaro et al., 2021).

Workforce support: To support coal workers, policymakers may wish to consider policy interventions in the following areas: 1) early communication of the coal power phase-out plan and its employment impact on coal-dependent communities to ease the disruption of upcoming changes (Mayer, 2018); 2) financial support for workers in transition (Furnaro et al., 2021); 3) job-seeking assistance, including training programmes (Johnstone and Hielscher, 2017); and 4) easing labour market tensions arising from a sudden inflow of large coal workers through the provision of early retirement packages to those workers above a certain age (Oei et al., 2020). Notably, some of the workforce support can be provided through the existing social security programmes. Additional support may also be provided as a complement to these programmes in helping coal workers (Furnaro et al., 2021).

Environmental restoration of the coal mining areas: The environmental restoration of coal mining areas could provide economic benefits for mitigating the adverse impacts from coal power phase-out (Haggerty et al., 2018). These benefits primarily arise from investment in the restoration of the environment and natural landscapes damaged by mining activities. Several studies suggest that such environmental restoration will employ workforce, equipment and capital similar to that displaced by the end of mining and consumptive activities (Kelly and Bliss, 2009; Hibbard and Lurie, 2013; Taylor et al., 2017). Additional benefits also come from environmental amenities, including scenery and access to recreational opportunities, which can create opportunities for regional growth and employment (Deller et al., 2001; Winkler et al., 2007; McGranahan, 2008).

3.4 Shift in governance towards a learning-based, reflexive process

As discussed in Section 2, electricity transition is often viewed as a severe problem that cannot be effectively dealt with through conventional linear processes, in which policymakers firstly define the problem precisely and then identify and implement the most effective solutions to it. This viewpoint is based on the considerations that the interdependencies and interconnectedness of electricity transition (i.e., regime destabilisation and reconfiguration, as well as socio–economic restructuring) render substantial complexity to the transition process. Perception on this complexity is also informed by social norms, cultural values and interests. Thus, it varies from actor to actor and changes across time and place. With the problem of complexity under discussion here, fully understanding it before any solutions can be offered is nearly impossible, which makes conventional, linear governance processes less effective.

Thus, some scholars have called for a shift in transition governance from existing linear process towards increased reliance on a learning-based, reflexive process (de Schutter and Lenoble, 2010; Susur and Karakaya, 2021). A key feature of this governance process, which distinguishes it from the conventional linear process, is that it involves iterative ways of knowledge production and learning-whilst-implementing (Valkenburg and Gracceva, 2016). Two basic elements of this process may be considered by policymakers to improve their own process of steering electricity transition.

Transdisciplinary, iterative knowledge production: Given the complexity involved in electricity transition, different disciplines that specialise in particular aspects of the transition process need to be brought together for developing a better understanding of issues that could affect the transition progress and possible solutions to them. This process also needs iteration because the object of discussion is changing as the low-carbon transition of the electricity industry moves forwards (Funtowicz and Ravetz, 1993).

Participatory consultation and deliberation: The complexity of electricity transition can be considered to have two dimensions: Factual and normative. Factual complexity makes it difficult to fully understand what a matter is. It can be addressed by mobilising additional sources of knowledge and expertise (Valkenburg and Gracceva, 2016). Normative complexity is about how factual matters should be assessed. Answers to this question are frequently informed by ever-evolving beliefs, ideologies and interests. This complexity can only be reduced by intensive consultation and deliberation with participation of all relevant stakeholders — a way to make all trade-offs visible that can then be negotiated. This way provides a basis for facilitating reconciliation amongst various stakeholders regarding how factual issues about electricity transition should be approached (Valkenburg and Gracceva, 2016). The government should play a leading role in the consultation process to ensure effective discussion and prevent policy consultation from slipping into a talk shop.

3.5 Proof of concept: The case of China

So far, this section has identified four policy entry points for facilitating electricity transition from the take-off phase towards the breakthrough phase (see Table 1 for a summary). It now turns to demonstrate the usefulness of these entry points by using the case of China. This part is meant to serve as a proof of concept rather than an extensive study.

Renewable generation in China has exceptionally grown over the past few years with wind and solar being the main driver. The renewable generation of the country has increased from about 790 TWh in 2010 to more than 2200 TWh in 2020. Of this, about half is from wind and solar (Ember, 2021). The strong growth of renewable generation has led to a rapid transition away from coal for electricity generation in China with the share of coal generation falling from over 70% in early 2010s to 61% in 2020 (Yang et al., 2022). As the transition progresses, it is approaching the breakthrough phase, where higher levels of wind and solar penetration have gradually become a major concern for the electricity sector and the society (especially the coal-dependent communities) to accommodate.

In the electricity sector, rising wind and solar generation has created the need for improved flexibility of the electricity system. One attractive option for fulfilling this

Table 1 Policy entry points for electricity transition

Policy entry point	Specific points for policy interventions
Regime destabilisation to enable low-carbon technologies to break through	**Increasing the economic and sociopolitical pressure on incumbent companies by policies focused on:** – Reducing the financial returns of fossil fuel assets mainly through carbon pricing – Reducing the legitimacy of fossil fuel investments for incumbent companies and investors mainly through public campaigns **Addressing regime lock-ins:** – Technical assistance to incumbent companies to redress their cognitive lock-in – Removal of regulatory arrangements (e.g., fossil fuel subsidies) that benefit fossil fuels – Breaking market arrangements that favour fossil fuels – Compensation mechanisms, which are most preferably market-based, to facilitate early retirement of coal power assets, and public support for network infrastructure update
Regime reconfiguration to accommodate changing generation-mix	**Technical flexibility:** The uptake of fast-responsive capacity, energy storage and demand-side management as facilitated by network infrastructure updates **Short-term operational practice:** – Decreased temporal and spatial granularity in electricity pricing – Improved provision of ancillary services mainly through better streamlined products in the markets and better alignment of ancillary service trading with the spot and intra-day electricity trading **Long-term planning process:** Better incorporation of flexibility planning into the process
Addressing the socio–economic ramifications of regime change	**Regional economic restructuring:** – Business attraction with particular focus on non-coal industries – Educational reforms to better equip young graduates with the knowledge and skills required by the “new” industries **Workforce support:** – Early notification to ease the disruption of upcoming changes – Financial support and job-seeking assistance (e.g., training programmes) for workers in transition – Early retirement packages for workers above a certain age to alleviate job market pressures **Environmental restoration of the coal mining areas**
A shift in governance towards learning-based, reflexive process	**Transdisciplinary, iterative knowledge production** to develop a better understanding of issues that could affect electricity transition and their possible solutions **Participatory consultation and deliberation** with involvement of all relevant stakeholders to make all trade-offs visible and negotiable — essential for developing a reconciliation amongst various stakeholders regarding how electricity transition should be approached

need is to retrofit some of the existing coal capacity for providing ancillary and backup services to the grids (Zhang et al., 2020). The 2022 *Report on the Work of the Government* of China called for a transformation of coal power to provide flexibility services for supporting higher levels of renewable penetration, as well as provide heating — industrial and residential — for reducing the use of emission-intensive loose coal for that purpose (Yang and Shi, 2022).

In pursuit of this option, the first step is to unlock coal power from its current development pathways for enabling a shift in its use from baseload capacity to supportive capacity. This procedure requires limiting the impact of lock-in factors that have historically created a strong path-dependence for coal power development. Some of these factors are 1) local governments' fervour for coal power projects, which is primarily due to its ability to stimulate short-term socio–economic growth (Ren et al., 2021); 2) financial losses that may incur due to less operating hours as a result of providing ancillary services, but not baseload capacity, to the grids (Zhang et al., 2020); and 3) socio–economic concerns about reduced coal generation, especially in coal-dependent regions (He et al., 2020).

One area for action to address these factors is to reconfigure the electricity market for better compensating coal power to provide ancillary and backup services to the grids. This market reconfiguration may involve strengthening the ancillary services market by introducing new services required to manage challenges (e.g., more frequent short-term supply–demand imbalances and a loss of inertia) imposed by rising renewable generation and introducing capacity payment mechanisms to compensate coal power for providing backup capacity (Yang et al., 2022). Several provinces have already introduced financial incentives for coal power to provide peak shaving services. Notably, flexibility planning should be better incorporated into the long-term planning process of an electricity system to enable higher levels of renewable penetration (Yang et al., 2022).

Reduced coal generation could affect economic development and jobs in some coal-dependent regions, which places pressure on policymakers to guarantee a "just transition". In China, about 3.21 million workers were directly employed by coal mining companies in 2018. Many of them are having low education and skill levels, which make their re-employment difficult. This difficulty gets heightened given that nearly one-third of the coal workers are found in one province, Shanxi (He et al., 2020). Therefore, coal phase-out in the province may flood the local job markets with a large number of laid-off workers. If this problem is not addressed properly, then rising unemployment may cause social unrest, which may in turn make further reduction in coal generation difficult.

The brief empirical application of our ideas, as discussed above, illustrates the importance of the identified policy entry points for facilitating electricity transition in China, where coal power will be demoted to a supportive role of providing ancillary and backup services to the grids. Our ideas can also be applied to other countries to guide the transition of their electricity industries towards a net-zero future.

4 Conclusions

The global transition towards a low-carbon electricity future is shifting towards a new phase as clean generating technologies become mature and start to challenge the dominant position of fossil fuels technologies in the electricity markets. This phase of the transition calls for transformative changes in the electricity and socio–economic systems to accommodate changing generation-mix and its consequences. Guided by the "essence" of the MLP — a prominent framework for the study of energy transition, this study has identified four entry points for policy interventions to facilitate these changes. These entry points are 1) destabilising the dominant, fossil fuel-based electricity regime to create room for renewable technologies to break through; 2) reconfiguring the electricity regime, which encompasses technology, short-term operational practices and long-term planning processes, to improve flexibility for accommodating large outputs from variable renewable sources whilst maintaining supply reliability and security; 3) addressing the impact of coal power phase-out on coal mining regions in terms of economic development and jobs; and 4) facilitating a shift in transition governance towards a learning-based and reflexive process.

This study has also identified specific areas for policy interventions within each of these entry points. For example, the dominant, fossil fuel-based electricity regime can be destabilised by a mix of policies addressing two dimensions: 1) increasing the economic and sociopolitical pressures on fossil fuel incumbents to induce them to rethink their commitment to the existing regime; and 2) addressing factors that lock these incumbents into the existing regime. The flexibility of the electricity system can be improved by the adoption of various new technologies (e.g., energy storage and smart metres), improvements in the short-term operational practice (e.g., pricing and ancillary services provision) of the system and better incorporation of flexibility planning into the long-term planning process. The adverse impact of coal power phase-out on coal mining regions can be mitigated by regional economic restructuring towards non-coal industries, the provision of support to coal mining workforce and environmental restoration of the coal mining areas. The transition governance can be strengthened through transdisciplinary, iterative knowledge production to develop a better understanding of issues that could affect electricity transition and their possible solutions, as well as participatory consultation and deliberation with involvement of all relevant stakeholders to make all trade-offs visible and negotiable.

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