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Towards a political economy framework for wind power

Does China break the mould?

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Abstract: We propose a general taxonomy of the political economy challenges to wind power development and integration, highlighting the implications in terms of actors, interests, and risks. Applying this framework to three functions in China's electricity sector—planning and project approval, generator cost recovery, and balancing area coordination—we find evidence of challenges common across countries with significant wind investments, despite institutional and industry characteristics that are unique to China. We argue that resolving these political economy challenges is as important to facilitating the role of wind and other renewable energies in a low carbon energy transition as providing dedicated technical and policy support. China is no exception.

Keywords: wind power, energy policy, political economy, electricity regulation, China
JEL classification: Q42, P16, L51

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1 Introduction

Wind power has the potential to be a critical part of future electricity systems, offering a zero-carbon dioxide energy source. However, achieving higher penetrations of wind energy presents a number of unique development and integration challenges. Although there is now substantial literature on these challenges, most of it has focused on general solutions to technical engineering and economic problems, as well as the design of dedicated policy support. There has been much less focus on broader political economy features of countries, regions, and systems that shape incentives for developing and integrating wind power. Given that the institutions that facilitate electricity sector investment and operations sit at the intersection of politics and economics, this is an important gap.

Drawing on global experience, this paper develops an analytical framework for understanding the spectrum of political economy conflicts that arise when introducing and scaling wind power within an electricity system. We apply this framework to China, a country that has very different electricity sector institutions from those found in most other countries. We argue that China's wind development and integration challenges can indeed be understood through a general political economy framework, and show how high levels of wind energy curtailment in China are an expected result of clashes among actors and interests.

2 Background: why a political economy framework for wind

The physical properties of wind energy—specifically, its variability, forecast uncertainty, and location relative to demand centres—create technical challenges for existing systems. Electricity systems have historically been designed to accommodate generation over which operators had greater certainty and more control. Accommodating wind requires revisiting established planning and operational procedures, challenging prevailing political and economic authorities under institutional arrangements.

Similar to other large-scale technological changes, delivering wind into the electric grid places new demands on political and economic institutions. A decision to prioritize wind alters the distribution of winners and losers with lasting effects on the origins of political influence (Jacobsson and Johnson 2000). The magnitude and, perhaps even more importantly, the distribution of economic rents are critical: actors—in the case of electric power, government and regulatory officials, system operators, vertically integrated utilities (VIUs), generation companies, and network companies—perceiving threats to their political and economic influence will be motivated to minimize adverse impacts through political channels (Stigler 1971). Prolonged resistance in one or more parts of the system can slow the pace of institutional change and thereby exert significant shaping influence on outcomes (Mahoney and Thelen 2010). Large-scale sustainability transitions, it has been observed, may ultimately run up against politics in efforts to design and implement superior technocratic solutions (Scrase and Smith 2009). As just one of many examples, Viétor et al. (2015) suggest that the slow uptake of efficient, decentralized combined heat and power in the German Ruhr region was due in part to the influence of vested interests in the coal and gas industry, among other factors.

In the case of wind, such conflicts are numerous and include: (i) economic transfers among wind and conventional generators, (ii) prioritization with respect to other energy and economic policies, (iii) allocation of wind subsidies (where necessary) among different electricity customer classes, (iv) allocation of wind-induced investment risks across developers and customers, (v) benefit-cost allocation for more integrated regional dispatch, and (vi) central–local government relationships. These have been identified in a handful of markets (Fischlein et al. 2010; Kahrl and Wang 2014; Krishna et al. 2015; Lehmann et al. 2012), although much analysis of political impediments to wind adoption tends to focus more on public acceptance rather than institutional design (Haggett 2008). We extend this literature with a systematic examination of the institutional context for adoption of wind energy.

Within the electricity sector, various actors are constrained by existing regulatory structures of the sector and a country's political institutions. Thus, technically efficient wind integration strategies, such as new market designs or enlarging balancing authority areas, may be slowed, altered, or dropped altogether when they challenge established practices, norms, and interests. Alongside a wealth of studies focused on technical challenges, these institutional challenges are becoming increasingly salient for policy-makers and researchers.

For example, larger investments in wind power may require additional investments in generation, storage, and transmission to maintain system reliability, with characteristic political economy conflicts of siting and cost and investment risk allocation. Real-time operational adjustments incur additional costs and complexities—such as more frequent cycling of conventional generators, increased transmission congestion, and the need for changes in operating reserve practices to address larger net load forecast errors (GE Energy 2010; Holttinen et al. 2009; Xie et al. 2011)—which may or may not be remunerated under market or regulatory rules. Penalties for over-generation and compensation for curtailment, essentially transfers among market participants to cover system-level costs, vary significantly by region (Porter et al. 2013).

Wind power development and integration is interlinked with broader drivers of change in electricity sectors worldwide. Since the 1980s, a number of countries have restructured (or 're-regulated') their electricity industries, transitioning from regulated, vertically integrated natural monopolies to unbundled ownership structures and competition in the generation and, in some cases, retail segments of the industry. Each jurisdiction has its own unique pathway related to prior institutional context, proximate justifications for reform, and the degree to which market competition can be facilitated. Costs, economic transfers, and economic behaviour associated with wind development and integration occur, and must be understood, within these unique institutional contexts. Theories and empirical data on restructuring have established a number of lessons and valuable case studies (Joskow 2008; Sioshansi and Pfaffenberger 2006).

Developing countries share some similarities in approaches to restructuring. Typically, developing or emerging countries with a rapidly expanding 'green-field' electricity system will emphasize attracting capital over efficiency gains that result from competition. Public ownership is more prevalent and may be retained even following unbundling. Providing electricity services at prices affordable to low-income populations complicates liberalizing retail tariffs and may hide inefficient cross-subsidization. Weak or resource-limited government institutions for administration, information collection, and verification can hinder cost-effective regulatory design and implementation (Besant-Jones 2006; Jamasb et al. 2005; Williams and Ghanadan 2006; Zhang et al. 2008). Combined with the experiences of advanced industrialized countries, this diversity of political and regulatory contexts underscores the need for a broad analytical framework with which to characterize and understand the political economy of wind integration.

One might expect China to be different from other emerging economies because of its unique institutional history, which before market-oriented reforms in 1978 consisted of a planned economy layered on top of a largely federalized system of governance established over centuries of dynastic rule. China's transition away from communism has been distinct from the trajectories of Eastern Europe and the former Soviet Union (Nee 1992), leaving a shortage of comparable post-Communist settings, although strategic sectors providing basic services such as electricity may exhibit stronger parallels. Although today China has a market system with significant regional variation, it remains distinct from other large developed and emerging market states. In China the government is broadly more involved in economic decisions; for example, in the development of the wind industry in China, the government has played a stronger shaping role, whereas in India development has been more market-driven (Walz and Delgado 2012). On the political side, China is often differentiated on the basis of its one-party government and absence of institutionalized checks and balances.

But is China really different? Other studies point to general contours of energy transitions, formalizing frameworks to describe transition dynamics as a function of pressures and available resources that are not specific to national context (Smith et al. 2005). Counter-arguments to Chinese exceptionalism point to common phenomena: for instance, scholars find evidence of lobbying and influence across layers of government (Mertha 2005), and from the private to the public sector (Deng and Kennedy 2010), which are well documented in large federal democracies. The extent to which China's experience with renewable energy in its electricity system reflects a more universal set of political economy challenges is ultimately an empirical question.

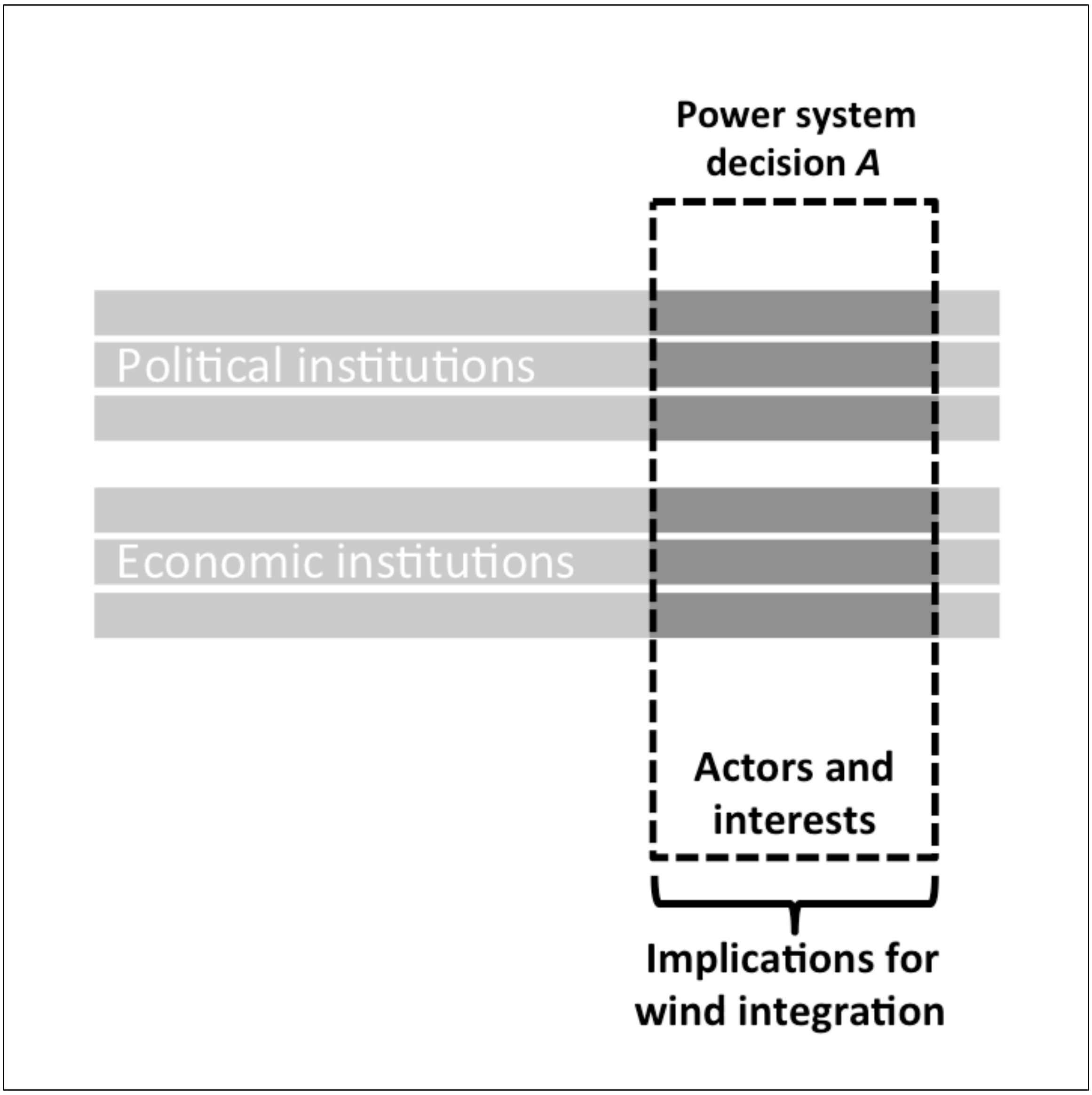
3 Political economy framework for wind power development and integration

The political economy of developing and integrating wind power, like other large-scale transitions in the electricity system, involves a number of public and private actors. Motivated by the need to identify roadblocks and inefficiencies in this transition, we develop a taxonomy of the most significant challenges that arise through the lenses of actors and their interests. The framework is designed around institutional context: we consider the degree of centralization and regulatory philosophy of political institutions, and the industry structures and approaches to price formation of economic institutions. We integrate these two contexts into a framework of political economy by focusing on how they shape actors and their interests, arguing that different institutional configurations can lead to different outcomes for wind investment and integration (see Figure 1).

Our framework is rooted in a broader literature that evaluates the impact of political and economic institutions on the rate and direction of transition within large-scale fixed infrastructure systems with long lifetimes (Markard 2011). We focus on political and economic institutions as well as the interaction between them, adopting the Northian definition of institutions as 'humanly devised constraints' that shape interaction and can be both formal and informal (North 1991: 97).

Our analysis proceeds to develop a framework grounded in available research on the political economy of wind deployment. We then ask whether this framework holds in the case of China, drawing on rich experience in wind development witnessed in recent years. The answer to this question is highly practical. Grid integration of wind energy in China has lagged far behind capacity growth. By applying our framework, we can begin to gain a qualitative sense of whether, and how, political economy challenges explain wind development and integration outcomes—or conversely, whether technocratic fixes in the form of capacity targets, price support, transmission build-out, and wind dispatch requirements will be sufficient or sufficiently accepted by the affected parties—to catalyse a low-carbon electricity transition in China.

Figure 1: Framework to identify institutional implications of a given power system decision on wind integration



Source: Authors' representation.

3.1 Political institutions

Political institutions engaged in the governance of the power sector comprise the first dimension of the framework. Here, we define political institutions as governmental roles housed within political bodies, and the vertical and horizontal relationships that connect them. Broadly, these roles can be divided into policy and regulatory roles. Policy roles include treatment of state and non-state entities, environmental protection, promotion of energy types (e.g. renewables targets), long-term plans for electricity reforms, and in some cases pricing. Regulatory roles typically involve implementing the policy regime in a fair and efficient manner, such as policing abuses of market power, determining costs, and overseeing pricing, planning, dispatch, and other electricity sector functions.

Governance of power systems: dimensions of diversity

We consider four distinct dimensions in the governance of power systems, with systems lying on a spectrum between extremes within each dimension (Table 1).

Table 1: Four dimensions of governance that affect power system outcomes

Governance dimension	Description
Horizontal separation	To what extent are policy and regulatory functions distinct and separate?
Vertical separation	To what extent are policy and regulatory functions concentrated at the central government level or decentralized to local governments?
Ownership	To what extent is ownership public or private?
Economic planning	To what extent are economic planning and investment planning centralized in government agencies or decentralized to market participants?

Source: Authors' compilation.

First, countries and supranational bodies differ in the extent to which policy and regulatory functions are distinct and separate. We refer to this as 'horizontal separation'. The canonical model of power system design emphasizes the importance of separating policy and regulatory functions to ensure system operation is free from interference by the regulated economic actors and the political actors that set the rules (Joskow 2008). The argument for separation extends to ensuring that regulatory bodies have sufficient authority to compel changes in the sector. In the United States, this separation is more pronounced, with the Federal Energy Regulatory Commission (FERC) at the federal level and public utility commissions at the state level responsible for coordinating regulation, and Congress, state legislatures, and executive agencies charged with formulation of policy. In China, earlier attempts at delegating regulatory functions to the State Electricity Regulatory Commission (SERC) were scuttled in 2013, when its functions were merged into the National Energy Administration (NEA), which is largely responsible for energy sector policy and planning, together with the National Development and Reform Commission (NDRC).

Second, countries and supranational bodies differ in the extent to which policy and regulatory functions of the power sector are concentrated at the central level, or vested with subordinate levels of government, as in a federal system. We refer to this as 'vertical separation'. In many cases, functions are spread across different levels of government, and may come into conflict. For instance, in the United States regional wholesale markets are overseen by the FERC, but infrastructure siting decisions and retail electricity prices within those markets are overseen by state regulatory commissions.

Third, countries differ in the extent to which the government directly controls power generation, transmission, and distribution assets through direct ownership or majority or minority controlling stakes. Government ownership of electricity system assets also varies widely across countries and contexts. Developing countries, in general, tend to maintain higher government ownership of assets, particularly if direct ownership is deemed central to 'developmental state' priorities. Developed countries vary in government ownership of assets. In France, the dominant electricity provider, EDF, is a government majority-owned utility. In the United States, most electricity is provided by investor-owned utilities, although the federal government continues to own a significant amount of generation capacity and publicly owned municipal utilities continue to be important providers.

Fourth, countries differ in their historical and current relationship between the government and the economy more broadly. Some countries still rely on elements of central planning based on historical legacies, whereas other countries have a long history of regulated markets, which shapes governance of the power sector. The relative reliance of governments on markets versus planning—either in the present, or historically—to run their economies is often reflected in governance of the power sector. For example, economies such as China, India, and the former Soviet Union used to be planned economies, and despite adopting capitalist structures, elements of central planning still persist in their power sectors to this day.

Implications for wind

The policy and regulatory roles of political institutions play a key role in determining the flexibility of the system and its openness to new generation types. Depending on the form of arrangements, political institutions may simultaneously enable and constrain wind: for instance, if policy sets targets for expanding the share of renewable electricity in the generation mix, but also determines dispatch on time scales not amenable to the real-time adjustments necessary to efficiently integrate wind, conflicts can (and do) emerge.

First, the horizontal separation of policy and regulatory functions affects the alignment of objectives towards the development and integration of wind energy. Close coordination between policy and regulatory functions may have benefits, especially in countries that have achieved political consensus on the benefits of renewable energies. In this case, regulatory and market institutions may be more easily revisited or altered through administrative measures to reflect how policy incentives play out in the actual operation of the power system and the settlement of its costs. However, if closely entwined policy and regulatory functions are vulnerable to capture by powerful incumbent interests (including pre-existing fossil generators) that view expanded renewables as a threat to profitability, the incentives for wind integration will be weaker. Even if interest politics plays a smaller role, more frequent interference with the regulatory system may lead to economically suboptimal outcomes and harm long-term development potential of the sector.

Second, the relative centralization of decision-making authority affects wind development and integration across many electricity system functions. When expanding wind generation, centralization can ensure that new capacity is optimally located to reflect resource quality and generation needs, whereas greater autonomy for decision-makers at subordinate levels could (though not necessarily) lead to suboptimal allocations based on local political conditions. Likewise, if transmission and system operation decisions are made over wider areas, this is favourable to wind integration because it expands the area over which supply and demand can be balanced. In the United States, on the other hand, transmission siting authority is concentrated at the state level, even within larger multi-state balancing authorities, limiting the ability to achieve more comprehensive transmission siting and operation (MIT 2011).

Third, the degree of state ownership[1] of the power system has the potential to enable or constrain wind generation. Outcomes hinge on the extent to which state-owned enterprises (SOEs) effectively capture regulatory and policy functions, or conversely, the extent to which SOEs act as agents subordinate to the state. In China, this is perhaps most easily understood from the perspective of local governments, who rely on incumbent generators (especially SOEs) as a source of tax revenue, making them more resistant to pleas to accept imported electricity sourced from distant wind. If policy priorities at the top shift in favour of wind, state-owned wind developers are direct beneficiaries.

Finally, the institutional legacy of a country's economy has implications for system flexibility and ability to generate or adapt to new technologies and practices (Porter and Stern 2001). It is often neither possible nor practical to say that a country should attempt to alter the relationship between its political and economic institutions, and the potential for change may be limited even on extended time scales. It is also very difficult to claim that one institutional form is universally superior for wind energy integration and therefore should be grafted onto another with an expectation of similar performance impact. Nevertheless, as will be discussed later on, there are

[1] State ownership refers to any form of government ownership.

aspects of how legacies of planned economic systems result in rigid quota setting (on generation within and trade across provinces in China, for example) that are not compatible with the short-term flexibility required to efficiently integrate wind power.

3.2 Economic institutions

The second key dimension of this framework is the structure of the producers involved in the power sector, their relationship to consumers, and the institutions that allocate costs and shape economic behaviour. The generation, transmission, distribution, and sale of electricity were historically viewed as a natural monopoly because of the economies of scale. By the 1990s, many doubted whether economies of scale continued to exist in generation and sales, prompting governments to attempt to make these portions of the supply chain more competitive—a process that differs in focus and pace across markets. Both traditional regulation and competition differ in their implications for wind energy, depending on where they occur in the system. In particular, how generation prices are determined and how investment in renewable resources is incentivized has a significant impact on the political economy of wind.

Industry structure: traditional and 'standard' restructuring models

Delivering electricity requires the coordination of five main activities: generation, transmission, system operation, distribution, and retail. In systems with limited distributed generation (i.e. electricity supply technologies connected to low- or medium-voltage distribution networks), this results in a hierarchical electricity flow: centralized generation facilities produce electricity on a common high-voltage transmission network spanning across and between countries. Distribution networks connect the transmission network to individual consumers of various types, facilitating retail purchases of electricity. A system operator coordinates the dispatch of generators to meet demand and maintain security (voltage, frequency) of power flows over the network.

In most countries, the first large-scale electricity companies were VIUs, which owned and controlled all five aspects under a single roof. Owing to the clear public welfare interest in electricity supply, many countries opted to create a government ministry to own and operate the VIUs, a process which sped up in the post-Second World War era. A related model, popularized in the United States, created private regional franchises that preserved the economies of scale of integration by granting exclusive rights to supply electricity within jurisdictions (Gomez 2013). These franchises led to the traditional 'cost-of-service' model of a regulated natural monopoly, with various methods of regulated tariff design described in the next section.

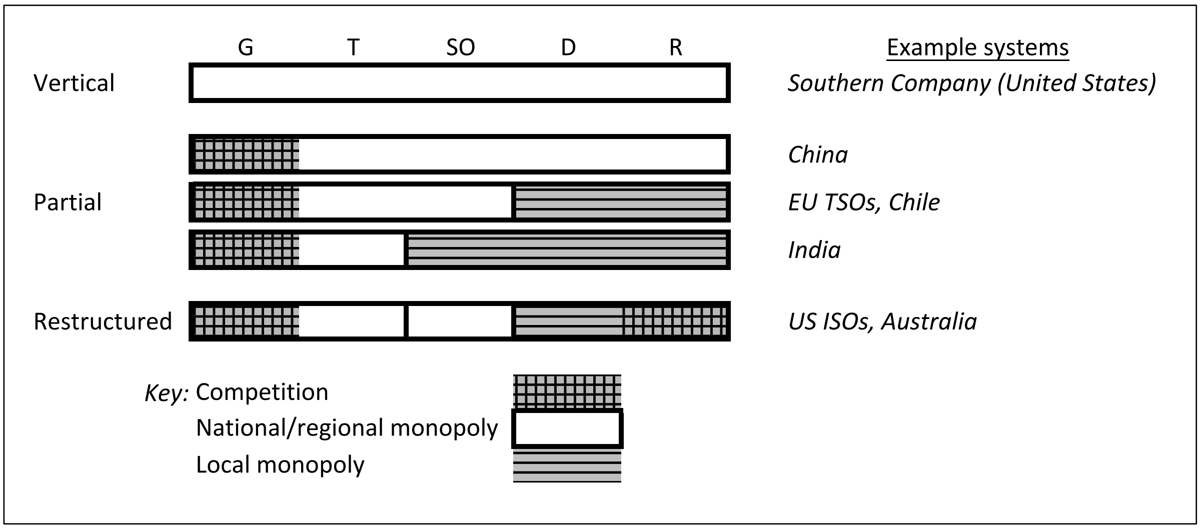
As in many other network industries (e.g. railroads, telecommunications) with some form of 'cost-of-service' tariffs, the regulator faces significant information asymmetries with respect to which costs the utility should be allowed to pass on to customers. In response to a wide array of economic factors, as well as political concerns such as concentration of power, many countries have introduced competition at various levels, completely reorganizing the sector in a process known as liberalization, restructuring, deregulation, or 're-regulation'. The economic logic behind separating competitive functions was laid out much before the liberalization wave began in the 1990s (Joskow and Schmalensee 1983).

Based on three decades of reforms, there now exists a 'standard liberalization prescription' that specifies which and in what order certain activities should be made competitive, the appropriate methods for regulating traditional natural monopolies, and the necessary institutions to ensure cost-effective, reliable, and equitable access to electricity (Joskow 2008: 11–13). In the ideal model, generation is made competitive with open access to regulated network utilities. An independent system operator (ISO) ensures non-discrimination between competitive and monopoly segments. Sufficient horizontal de-integration of generation reduces the potential for market power; markets are created for various aspects of the system including ancillary services, and independent regulator(s) established to monitor them. Retail competition, with similar guarantees of non-discriminatory access to distribution networks, should be created at later stages. There is robust economic literature on the theoretical equivalence of such a system compared to VIUs, in particular that market actors' profit-oriented goals align with social goals (Hogan 2002; Ventosa et al. 2013).

Spectrum of restructuring approaches

In practice, owing to differing motivations for restructuring as well as varieties of institutions, countries have rarely implemented the textbook liberalization approach. The range of resulting industry structures—from VIU to textbook restructured—along with some example systems are shown in Figure 2. The integration or independence of network functions (transmission, system operation, and distribution), in particular, takes a variety of forms.

Figure 2: Varieties of industry structures of five power sector segments



Note: G, generation; T, transmission; SO, system operation; D, distribution; R, retail; ISO independent system operator; TSO transmission system operator. This figure is intended to be illustrative. In the United States, for instance, there are a number of vertically integrated utilities that are part of regional transmission organizations and participate in wholesale markets.

Source: Gomez (2013) and Joskow (2008).

These arrangements differ in their requirements on regulatory institutions. As can be seen in Figure 2, the 'standard' restructured model has the largest diversity and complexity of actors, whereas more vertical arrangements have fewer regulated entities. Across industry structures, the regulator must develop sufficient expertise to evaluate cost estimates and projections given by network companies, with distribution networks perhaps most challenging. In addition, it must evaluate costs and projections for generation and large transmission projects, although these are easier to audit because of their scale (Gomez 2013).

The creation of markets, on the other hand, brings additional regulatory complications, as the need for specialized knowledge to validate some costs gives way to the need to recognize and quantify the exercise of market power. In countries with a large public sector and less experience with competition regulation—the case for many developing and former centrally planned economies—this may be even more challenging.

Generation price formation mechanisms

Prices throughout the electricity supply chain influence the political economy of wind generation, but mechanisms for generation price formation are particularly germane to the political economy of wind power. Generation price formation in contemporary electricity sectors falls into three generic categories, as shown in Table 2. Under the cost-of-service model, regulators periodically establish wholesale or retail prices that are based on the embedded (average) cost of generation, designed to exactly recover all prudent costs. With benchmark prices, regulators set prices based on the costs of a benchmark technology. Generation operators assume the risk that their costs will exceed the benchmark, which may change to reflect efficiency improvements over time through 'yardstick' competition based on the costs of similar regulated entities. The benchmark may also be adjusted to account for changes in costs over time (e.g. fuel costs, inflation) (Gomez 2013).

Table 2: Three main generation price formation mechanisms

Mechanism	Description
Cost-of-service	Prudent costs approved by regulator and included in rates
Benchmark	Price based on the (usually average) cost of a benchmark technology, possibly determined through 'yardstick' competition
Organized markets	Energy-only market: energy prices determined through bilateral contracts and short-term wholesale market
	Capacity market plus energy market: energy market with separate centralized market for capacity

Source: Authors' compilation.

Organized markets typically provide a more diverse range of generation price formation mechanisms, as buyers and sellers have a larger number of options for negotiating prices and managing risk. Most organized markets mix longer-term contracts and centralized short-term markets. A key difference between organized markets is whether a separate market for capacity exists. In areas without capacity markets (e.g., Germany, Texas), generators recover a larger share of their fixed costs through short-term markets.

Higher penetrations of wind generation generally incur increasing system-wide costs of accommodating wind variability and uncertainty, often referred to as 'integration' costs. Under cost-of-service regimes, these costs will be paid for as prudent operating expenditures. In organized markets, they are at least partially covered through ancillary services markets and, in some cases, real-time markets. Benchmark generation pricing may not incorporate these costs, leading to cost under-recovery for generators that provide wind integration services.

Different generation price formation regimes are typically, but not always, associated with different industry structures. For instance, cost-of-service pricing is more commonly found in VIUs. Benchmark pricing is more common where generation and grid functions are separate but government maintains direct intervention and there are a limited number of buyers. Organized markets typically have non-utility-owned generation, may have more competitive wholesale procurement, and have more indirect regulatory intervention.

Renewable investment incentives

In regions with competitive wholesale markets, investment in renewable energy is typically driven by incentives that exist outside of the market. The two most common forms of incentive are: (i) feed-in tariffs (FITs) or generation-based tax credits, where renewable generators are paid a fixed price per unit generation (kilowatt-hour) delivered to load-serving entities (LSEs); and (ii) renewable energy quotas, such as renewable portfolio standards (RPS), which require LSEs to procure a certain share of their sales from renewable energy. Hybrids or combinations of these price and quantity mechanisms exist: in the United States, federal tax credit for wind exists in tandem with numerous state-level RPS policies; RPS standards designed to meet targets in the European Union may co-exist in member states with FITs; and China has considered a combined FIT–quota system for several years.

Implications for wind energy

Different price formation mechanisms and renewable investment incentives shape the allocation of costs and risks among wind generators, conventional generators, LSEs, and their customers.

Under FITs, wind generators generally face less investment risk as long as wind curtailment is low. If it is high, wind generators may under-recover investment costs because they are only paid for delivered energy. Risks to conventional generators from wind FITs depend on price formation as well: in energy-only markets and with benchmark-based compensation mechanisms that pay only for energy, conventional generators are at risk from high-wind FITs that lead to rapid wind development and a 'crowding out' (i.e. lower utilization) of other generation.

FITs may also increase risks for customers because of the uncertainty of how much wind generation will come online at a given FIT level, assuming that the FIT is financed by a surcharge on consumer electricity prices. Setting FITs too high will lead to rapid resource development, increasing costs to customers and increasing producer surplus at the expense of consumers.

Under renewable energy quotas, wind generation is typically procured through long-term contracts, and wind generators face greater contract risk such as pertaining to curtailment, which is (incompletely) covered in a variety of ways (Bird et al. 2014). Green certificates, common in the European Union to achieve RPS goals, may have even greater uncertainty for generators because of price volatility. On the other hand, quotas can create greater certainty for conventional generators and customers, by allowing a more predictable pace of wind development. Quotas, because of imperfect information, are not a perfect instrument and may be overly or insufficiently aggressive, leading to: (i) risks to conventional generators (lower utilization) and customers (higher costs) in the former case, and (ii) slow pace of renewable development in the latter case, creating risks for the renewable energy industry.

3.3 Actors and interests

These political and economic institutions encompass a set of actors and their interests, which shape power sector investment, operations, and cost outcomes. In this section, we focus first on how political motivations and institutional context shape likely economic institutions. Next, we elaborate these for several key power sector functions. We conclude with challenges for wind that can emerge when the interests of actors diverge.

Countries vary in size, network structures, and resource endowments, which affect the viability of creating markets and influencing government priorities (Jamasb 2006). In general, countries with well-developed electricity systems have different goals from those still in early stages of development: the former may be aiming to optimize efficiency and provide greater choice to market participants, whereas the latter are typically trying to attract private capital to an over-burdened publicly funded system. The institutions and ideological basis for creating complex markets are also more developed in the former, whereas the latter may not share the basic regulatory premise of reduced government intervention (Williams and Ghanadan 2006).

In more vertically integrated political contexts, such as China and France, a common deviation from the textbook industry structure is retaining traditions of state intervention and ownership. The 'single buyer' model of a publicly owned utility can create conflicts of interest between political demands and proper market functioning. Even in restructured competitive markets, the former monopolist may still dominate, distorting economic signals. Finally, if markets are restructured and adequately diversified, the government may still intervene more than necessary or exercise weak regulatory oversight (Correljé and de Vries 2008).

Actors and interests in key power sector functions

Electricity infrastructure planning decisions consider multi-decade time horizons with significant social and private risks, and hence involve a wide range of private and public actors. Several government agencies may exercise direct control or oversight of the sector and may have a primary responsibility in decision-making in service of developmental state objectives. In China, for instance, national and provincial level governments set generation capacity goals and both state-owned and private generation companies make capacity planning decisions in line with government objectives. These varied interests are resolved through a heavily negotiated process quite distinct from competitive renewable procurement auctions in the United States or FITs in the European Union.

Price formation and dispatch decisions also vary by the levels of private versus public actor involvement. For traditional regulated utilities, regulators protect consumers by overseeing investments and approving end-use tariffs. In competitive wholesale markets, regulators may still determine incentives for policy-driven infrastructure but typically have more limited oversight over the formation of wholesale, and in some cases retail, prices. Dispatch is handled by a control centre in a VIU or left to the system operator in restructured markets, and these controllers/operators manage the system according to prescribed rules. In addition to cost, dispatch rules may be designed to meet many different goals, ranging from national energy security and resource efficiency to local job creation.

Inter-regional trade links multiple jurisdictions and requires special cooperative arrangements between governments. The goal of these arrangements should be to reduce barriers to trade and provide clear, efficient signals for private and government actors, although this will not always be the case, because of different policy environments, conflicting priorities, and the allocation of trade benefits and costs between exporting and importing regions.

Renewable electricity promotion policies also create conflicts among actors. Interest politics dominates in these discussions as incumbent and emerging industries fight for economic rents. Potentially all political constituencies may become active in burden-sharing discussions of subsidies. Between national and local governments or between two interconnected local governments, conflicts may also arise surrounding harmonization of different standards or whether actions in one jurisdiction count towards meeting goals in another such as through renewable energy credits.

Implications for wind energy

The nature of actors and their interests in the power sector has significant implications for the development and integration of wind energy. First, is wind owned by VIUs, or by competitive generators? For VIUs, the profit objective for deploying wind will include network expansion and operation costs, which may lead to better or worse outcomes. On the one hand, VIUs may not have sufficient incentives to control costs, or may not pursue cost-minimizing strategies owing to concerns over cost disallowance. On the other hand, coordinated network and generation expansion has the potential to reduce overall social costs when considering the interaction between geography of wind and power system impacts such as congestion and ramping requirements (GE Energy 2010).

For competitive generation markets, a different set of complications for wind integration arises. Wind may or may not be allowed to participate in markets such as day-ahead energy and balancing, impacting the profitability of a farm. Because integrating wind has different ancillary service requirements than the conventional generators most power markets were designed for, are there sufficient types of market products that incentivize all participants to invest in wind energy? For example, the profitability of energy storage—likely important for integrating large penetrations of wind energy—is highly dependent on market design (Denholm et al. 2010).

Second, who determines the terms of access of wind generators to the network? Connection is a critical step in wind farm development, and associated costs (including network enhancements) are particularly contentious. They may be socialized or apportioned to supply in some fraction and the calculation of appropriate costs will depend on whose calculation it is, whether an ISO, a transmission company, or an integrated network utility. Connection delays can also result in disproportionate hardship on farm owners as a result of cash flow issues, as almost all costs are concentrated in upfront capital instead of shared between fixed and variable components. Integrated transmission and generation companies should have a greater incentive to connect wind quickly.

Once connected, wind integration depends on dispatch rules of the system operator. ISOs and VIUs will generally try to minimize short-run operational costs, benefitting wind with near-zero marginal cost. Owners of transmission networks that also do system operation may have incentives to dispatch generators connected to transmission lines with favourable tariffs. These incentives in operation also depend on policy and regulations for curtailment, including circumstances in which it is allowed and compensation, if any.

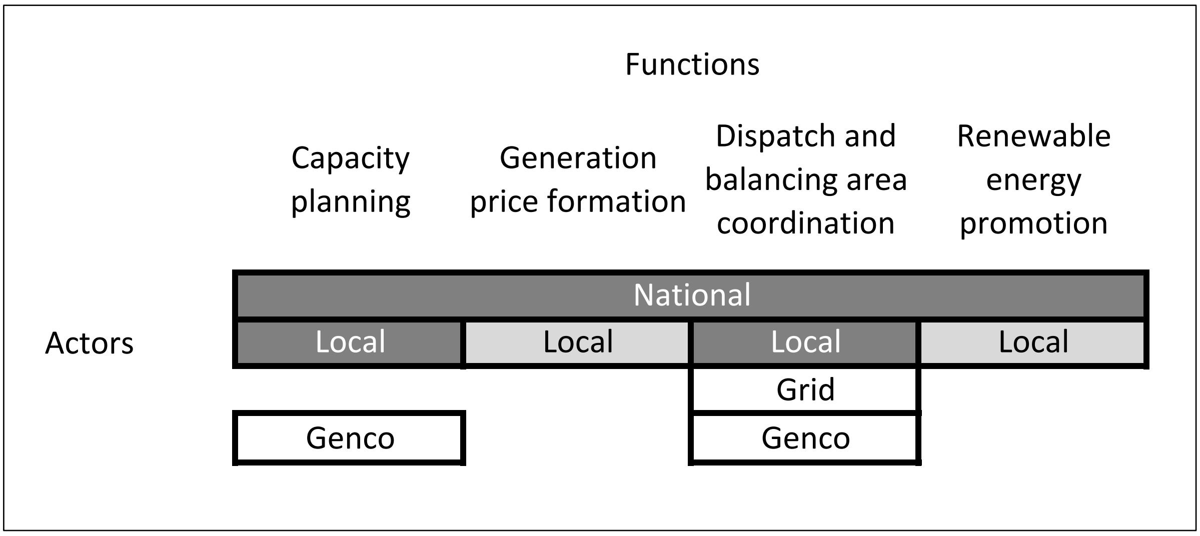
Finally, what downstream options are available? Retail markets can create more diverse tariff structures such as time-responsive pricing that can help integrate wind, or conversely cut into wind's profits during off-peak hours. Can demand participate in capacity markets as in several ISOs, thereby lowering the costs of providing balancing services for wind? A more integrated system or one with an ISO may find it easier to facilitate these interactions between distribution and transmission services.

4 China case study

We apply this framework of interactions of political and economic institutions to help shed light on wind integration outcomes in China, the world's largest energy consumer. China has the world's highest installed capacity of wind energy, but also faces the most severe wind integration situation: curtailment rates—forced spillage of available wind electricity by the grid operator typically for economic or grid stability reasons—have been in the double-digits for at least five years, reaching 40 per cent in some regions during 2015 (NEA 2016). Delay in grid connection to wind farms is another important barrier to smooth expansion of wind energy, with wind installations lacking appropriate connection surpassing 16 GW in 2015 (GWEC 2016).

Many of China's market-based electricity sector liberalization efforts during the early 2000s have been abandoned or significantly altered from their ideal prescription owing to a product of historical legacies and interrelated institutional priorities. These echo challenges in other country and regional settings, and hence provide a valuable case of the varied political economy impacts of wind energy transitions across the developing world. Figure 3 shows the actors in China that participate in decisions related to electricity system functions (capacity planning, generation price formation, dispatch and balancing area coordination, and renewable energy promotion policies) most relevant for the development and grid integration of wind, as a function of industry structures (national, local).

Figure 3: Economic and political actors in key wind sector functions in China



Note: National, national government agencies; Local, local government agencies; Grid, grid companies; Genco, generation companies. Within government, dark shading indicates primary role, light indicates an oversight role.

Source: Authors' compilation.

The combination of significant horizontal integration in national level policy and regulation, as well as multiple vertical layers guide two key research questions with implications for China as well as other formerly planned economies and economies in transition:

- How does close horizontal integration of policy and regulatory functions in political institutions influence economic institution designs and implications for wind?
- How does vertical separation of political institutions (i.e. degrees of federalism) affect wind integration costs and potentials?

4.1 Planning and project approval of wind farms

Planning and project approval are critical determinants of wind development and grid integration outcomes. Planning involves deciding on future generation capacity, including its location and transmission needs. Systems vary in the degree to which planning functions are carried out by technical or political bodies. Project approval, also generally by a government or affiliated office, is required before initiating construction of new capacity and transmission projects. Coordination of approvals for generation capacity and transmission planning, and alignment with system-wide operational realities, can significantly influence the pace and extent of wind energy expansion and grid integration.

In terms of political institutions, China is perhaps most distinct in its extent of government involvement in both the planning and project approval process as well as in industry decision-making through state control of agencies and firms engaged in all stages of wind farm construction and operation. This reflects, in part, the institutional legacy of China's planned economy, which has persisted longer in electric power than in many other sectors. In practice, it means that generation capacity and transmission planning is largely driven by the supply side, in a top-down manner, targeting a specific installed base without explicit incentives to optimize around system operation.

Planning for wind capacity expansion largely occurs at the central level. The NDRC (together with the NEA, after it was created in 2008) sets the national wind capacity target through medium- and long-term industry development plans (Ling and Cai 2012). The national target is then allocated to provinces, on the assurance that, once constructed, wind farms will be connected to load centres via long-distance transmission. Provinces can also volunteer to host large wind bases, as happened in Gansu in 2006–07, and which later obtained NDRC approval (Davidson et al. 2016). Provincial as well as national officials have incentives to target capacity expansion as it adds to investment, boosting gross domestic product. It also creates local jobs and demand for the output of one of China's strategic renewable energy industries, which was just emerging in the late 1990s and early 2000s. In China, minimizing cost is only one consideration in planning decisions, which reflect many other factors including local economic goals, industrial policy, technological feasibility, and profit-sharing arrangements among local stakeholders.

Wind projects can be divided into government contract projects and concession projects (Han et al. 2009). Before 2003, government contract projects dominated, in which the government directly awarded project development rights to one consortium (Han et al. 2009). After 2003, the concession model was introduced, in which the NDRC selected favourable resource locations for projects and allowed potential developers to bid through a tender process (Han et al. 2009). Although the concession system enabled rapid development of wind capacity, several features undermined its effectiveness. First, projects were initially selected on a least-cost basis, prompting bidders to offer unrealistically low prices that later undermined quality (Han et al. 2009). Second, pressure to bid at low cost was exacerbated by targets on the largest generation companies to expand renewables to 5 per cent of their total capacity (not generation) (Liu and Kokko 2010). In 2009, bidding with an electricity price was replaced with region-specific benchmark pricing for wind projects based on resources. By this time, there was already evidence that some capacity was of exceptionally poor quality, with turbines producing far less than rated output, requiring more downtime for maintenance, or even collapsing (Han et al. 2009).

Capacity thresholds that determine the level of government at which authorization could be granted also created conflicts between stakeholder interests and wind integration. In the early years of wind development in China, all new wind projects required central approval (Han et al. 2009). Development accelerated significantly when approval authority for wind farms sized <50 MW was granted to provincial development research centres; indeed, a large number of wind farms built during this period have a capacity of 49.5 MW, as provincial government approval was often the preferred, often faster option to launch wind farm construction.[2] However, at this size, the grid company was even more reluctant to connect capacity, especially capacity in remote areas that required significant additional transmission (Yang et al. 2012).

The mismatch in the pace of wind farm and transmission expansion is widely cited as one of the main causes of wind curtailment in China. Approval and construction of wind capacity has typically taken less time than the siting of long-distance transmission lines needed to deliver the electricity to load centres (Yang et al. 2012). When the NDRC stated that infrastructure and transmission would be made available to support newly constructed wind farms, time frames

[2] Cities also competed by offering favourable arrangements for obtaining land for siting wind farms (Liu and Kokko 2010).

were not specified, nor was the capacity of the connection, which was in some cases insufficient to handle delivered electricity safely (Han et al. 2009). This omission was not a major concern, at least at the outset, for local governments and wind farm developers. Many wind farm developers at this time were SOEs with access to low cost financing and were rewarded principally according to capacity constructed.[3] However, some local wind farm developers in the Inner Mongolia Autonomous Region and Heilongjiang eventually funded the construction of transmission themselves, instead of waiting for their respective grid companies to do it (Yang et al. 2012).

As these examples suggest, the conflicts related to the planning and project approval process in China were not entirely unique; in other markets, such as the United States, it is easier to build new capacity than to site new transmission. In terms of this mismatch, the high degree of federalism plays a similar role in both the United States and China. Crossing state (provincial) lines with new transmission requires additional coordination and approvals in both countries; however, in China grid expansion arguably faces less resistance from citizens and groups concerned about aesthetic or environmental impacts. Nevertheless, coordination has not been superior in China, because the interests and constraints of grid authorities are fundamentally different from those of wind farm developers and their local government champions.

Interestingly, the disconnect among the interests of actors persists despite the fact that policy and regulatory functions are largely intertwined and engage the same set of actors. It appears that the vertical separation of interests trumps these horizontal linkages, especially during periods in the mid-2000s when provincial authorities had incentives to rapidly scale wind to boost local economic performance. When it comes to planning and project approval, the autonomy of local governments as a result of vertical separation seems to have enabled rapid wind farm construction without commensurate build-out of transmission. Horizontal integration of planning and regulatory functions was unable to close the gap, because the mismatch resulted from the distinct incentives facing generation and transmission planners and a lack of coordination between them.

4.2 Generator cost recovery

The transition to higher wind penetrations often creates economic conflicts between wind and thermal generators. The extent of these conflicts depends on four factors: (i) mechanisms for supporting wind generation, including price- and quantity-based mechanisms and priority dispatch; (ii) the approach to determining dispatch order; (iii) the price mechanism that determines how generators recover fixed costs; and (iv) the price mechanisms that compensate generators for operating costs.

'Cost premium' recovery is also often a political economy issue for wind generators, as they are paid a premium over the cost of conventional generation that is often recovered through extra-market transfer mechanisms, such as tax reductions or surcharges. These mechanisms are determined through policy and are at the mercy of political whim.

Support mechanisms and dispatch

In China, as in most of the European Union, wind energy is incentivized through FITs. FITs fix the price, but not the quantity, of wind power. If the FIT price is sufficiently high, renewable

[3] At the end of 2008, 90 per cent of China's wind developers were state-owned enterprises (SOEs) (Liu and Kokko, 2010).

energy developers may rapidly expand installed wind capacity, reducing operating hours, market prices, and revenues for thermal generators. In countries with economic dispatch, this physical and economic displacement of thermal generation occurs primarily through the dispatch merit order, as wind has very low marginal costs.

In China, dispatch order is determined administratively rather than according to marginal cost, and the operating hour impact of higher wind penetrations on thermal generators is, to some extent, negotiated. In most provinces, operating hours for each generating unit are determined through an annual planning process (described in Section 4.3), and system operators (grid companies) dispatch units to meet targets set through this process.[4] This is a legacy of planning under the former ministry-run VIU and the concentration of economy-wide levers in the hands of government departments. In a small number of provinces, dispatch is based on a preset order, with non-dispatchable renewable energy receiving dispatch priority.[5]

Nationwide, China has had a 'mandatory procurement' (全额收购 | *quane shougou*) policy for renewable energy since 2005, which was intended to encourage priority dispatch of renewable generation. Wind curtailment rates, however, have been much higher than those seen in other countries with similar levels of wind penetration (Kahrl and Wang 2014). In April 2015, the NDRC issued new rules requiring local planning departments to prioritize renewable generation in annual plans, as part of a broader reform package (NDRC and NEA 2015). In September 2015, 'green power dispatch' was a key element of the US–China Joint Presidential Statement on Climate Change (White House 2015).

The ongoing nature of dispatch reforms to promote higher utilization of renewable energy in China reflects, in part, the conflict between: (i) renewable energy generators and the political establishment, which are keen to promote renewable energy and reduce renewable energy curtailment, and (ii) thermal, and particularly coal, generators, which are keen to limit reductions in their operating hours.

Fixed-cost recovery

Lower operating hours have a significant impact on coal generators' ability to recover their fixed costs in China, because of the energy-only benchmark approach to setting their wholesale tariffs. Under this approach, all coal generators receive the same price for each megawatt-hour of output, with the price benchmarked against the levellized cost of a supercritical coal unit. This benchmark tariff requires an estimated number of fully loaded operating hours, which for coal units in China is typically around 5000 hours, to convert fixed costs (in yuan per megawatt-year) to a variable price (yuan per megawatt-hour).[6] Schemes to introduce marginal cost-based bidding have failed for a variety of reasons (see Section 4.3), but one key barrier is the desire of the horizontally integrated power system and other economy-wide policy-making bodies to control inflation.

As the number of operating hours falls, the wholesale price that generators require to recover their fixed costs increases nonlinearly. As the example in Figure 4 illustrates, a fall from

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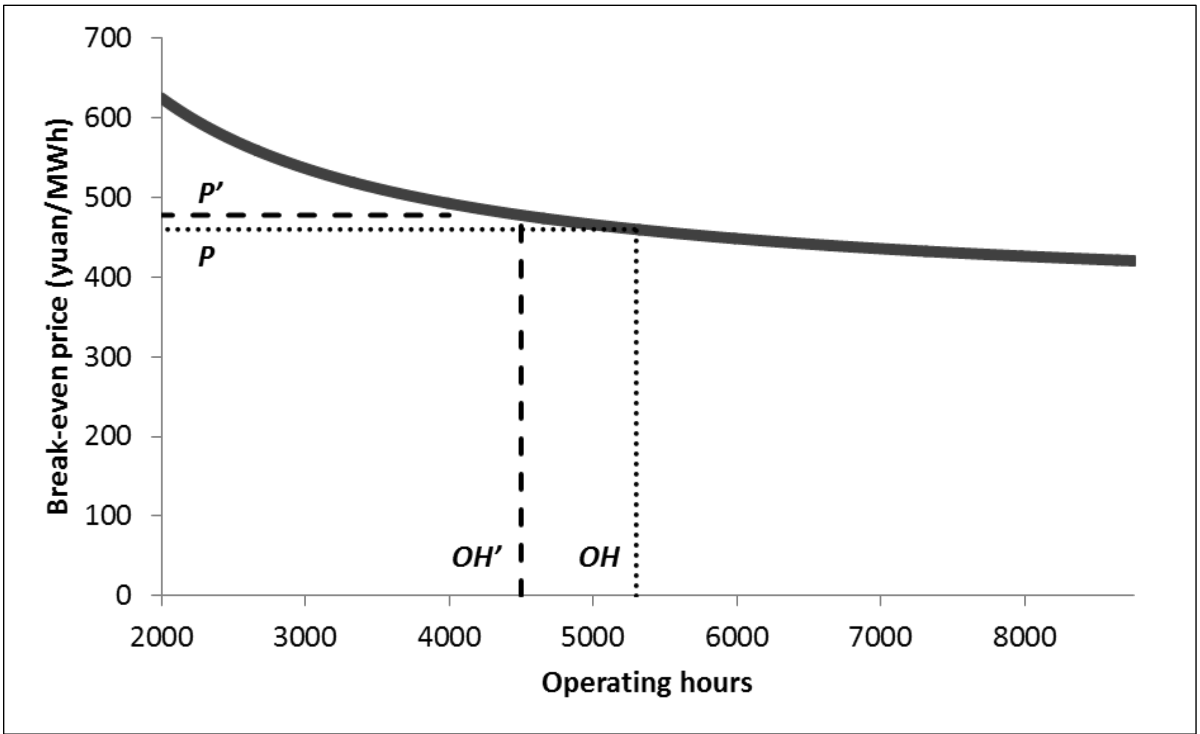
[4] For more detail on this planning process and how it intersects with system operations, see Kahrl and Wang (2014).

[5] This policy is known as 'energy efficient dispatch' (节能调度 | *jieneng diaodu*). For political economic reasons, energy efficient dispatch has proved difficult to extend to other provinces (see Kahrl et al. 2013).

[6] More specifically, the levellized fixed cost (*LFC*, in yuan per megawatt-hour) is calculated as $LFC = AFC / AOH$, where *AFC* is the annual fixed cost (in yuan per kilowatt-year) and *AOH* is the annual operating hours (in hours per year).

5300 hours (*OH*) to 4500 hours (*OH'*) increases the price needed for full fixed-cost recovery from 460 yuan/MWh (*P*) to 478 yuan/MWh (*P'*). Without a change in price, and holding fuel costs constant, decrease in operating hours leads to under-recovery of fixed costs. In this example, a decrease from 5300 to 4500 hours for a 600 MW coal unit is equivalent to a revenue loss of around 50 million yuan per year, which would erode all of the unit's equity return.[7]

Figure 4: Break-even price for a supercritical coal unit in China as a function of operating hours



Note: This example assumes a capacity cost of 530 yuan/kW-year and an energy cost of 0.36 yuan/kWh.

Source: Authors' calculation based on E3 (2015).

In reality, because the benchmark price is not indexed to fuel costs and because the price of coal has declined significantly over recent years, wind's impact on coal generators is not as pronounced as it might otherwise have been. Spot prices at the coal port hub of Qinhuangdao fell by over half in nominal terms between 2011 and 2015.[8] Although the NDRC has adjusted provincial benchmark tariffs for coal generation downwards to reflect falling coal prices, they have not fallen as fast as the coal spot price, likely allowing coal generators some headroom to recover previously under-recovered costs.

For natural gas generators in China, the impact of higher penetrations of wind generation on fixed-cost recovery varies by province. A number of provinces are moving towards a benchmark tariff with separate capacity and energy prices for gas generators (*Chinese Business Herald* 2015). For these provinces, gas generators will recover fixed costs regardless of operating hour impacts from wind generation.

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[7] Based on standard financing assumptions for SOEs in China from E3 (2015).

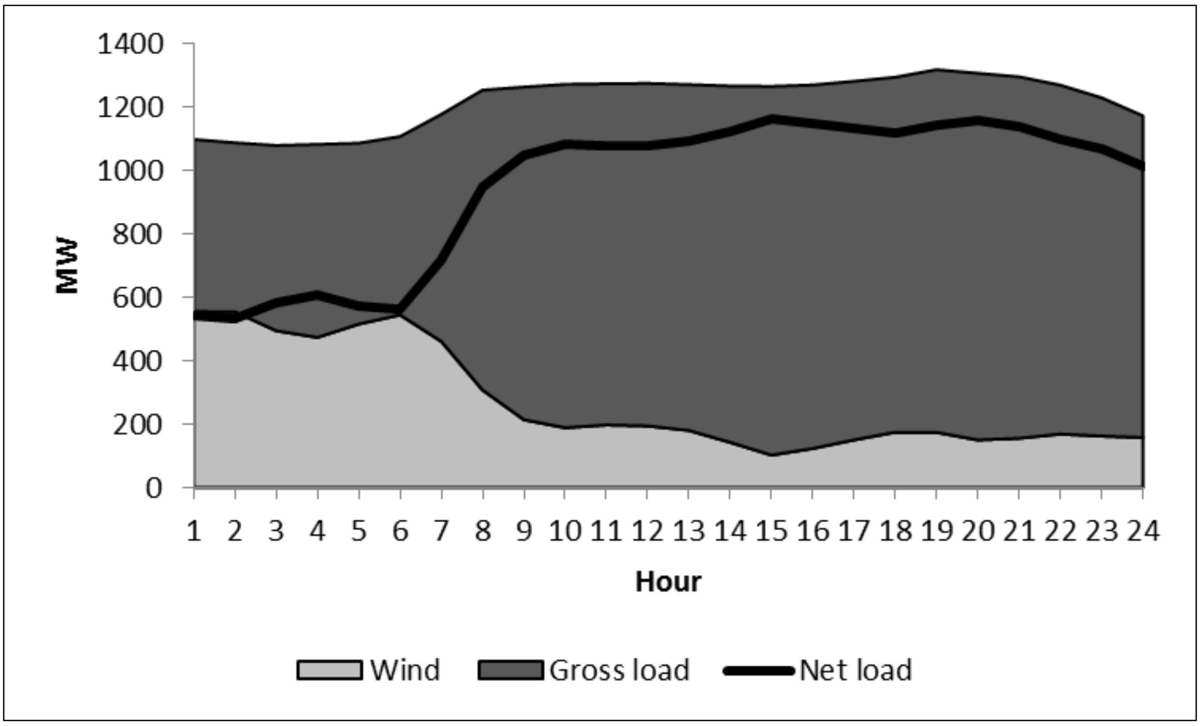
[8] Spot prices for 5550 kcal/kg coal at the port of Qinhuangdao were 390–400 yuan/ton in October 2015 (Qinhuangdao Coal Network 2015), down from around 775–850 yuan/ton in 2011 (Coal.com.cn 2015).

Operating cost recovery

Even with lower operating hours, at higher wind penetrations thermal generators are generally required to change their operating practices. This includes (i) maintaining higher reserve levels, or operating further below rated capacity, to account for the higher uncertainty in wind availability; (ii) more frequent, faster, and deeper changes in output ('ramps') to respond to changes in wind availability; and (iii) more frequent start-ups and shutdowns to respond to the uncertainty and variability in wind output.

The need for deeper system ramps is illustrated in Figure 5, which shows wind output, gross load, and net load (i.e. gross load minus wind output) for a hypothetical electricity system where wind energy accounts for 25 per cent of total generation. As the figure shows, wind output drops off rapidly between 06.00 and 09.00 hours, requiring other generation to almost double output over a span of three hours. Whereas gross load is relatively stable, larger ramps in dispatchable generation are required to accommodate higher variability in net load.

Figure 5: Wind output, gross load, and net load, showing large required ramps for dispatchable generation with higher wind penetrations



Note: This illustration is based on the Alberta Electricity System Operator (AESO), at a hypothetical 25 per cent wind penetration; current wind penetrations in the AESO are much lower than this. Load data for the AESO are forecasted for 2024, from the Western Electricity Coordinating Council's Transmission Expansion Planning Policy Committee database. Wind data are based on a generic profile for western United States, from the National Renewable Energy Laboratory's Western Wind Resources Dataset.

Source: Authors' representation.

These kinds of changes in operating practices increase costs for dispatchable generation. Higher reserve levels mean that generators operate further below their rated capacity, which reduces their efficiency and increases fuel costs. Deeper ramping increases maintenance costs. More frequent start-ups increase generator start-up costs. These costs are highly system-dependent: in a survey of studies estimating impacts of wind penetrations up to 20 per cent, additional system-wide 'integration' costs were 1–10 per cent of the wholesale value of wind, which includes changes in plant operations as well as reserve procurement (Holttinen et al. 2011). In organized markets, these costs may be variously recovered through direct remuneration of start-up costs, or by incorporating into energy and ancillary service bids.

China does not currently have wholesale markets for generation, and these kinds of cycling costs are exclusively recovered through a series of mechanisms that partially compensate generators for ancillary services. The scope of compensation, service definitions, and payment levels are set by regional grid companies and vary significantly across regions. Despite attempts to more closely match the costs and remuneration of generators that provide ancillary services, thermal generators are still not directly compensated for a significant portion of their additional cost of accommodating wind and solar generation.[9] Recently restarted reforms in China aim to initiate a gradual, longer-term transition towards wholesale markets for generation. In the nearer term, making benchmark prices more adequately cover cycling costs, or moving towards a cost-of-service tariff, would necessarily require greater horizontal separation of price-making and regulatory authorities, particularly at the central government level.

Cost premium recovery

China's 2005 Renewable Energy Law created a national surcharge to pay for the higher cost of renewable energy FITs, relative to the benchmark tariff for coal. This surcharge, initially set at 0.001 yuan/kWh, is collected in each province through a 'renewable price surcharge' (可再生能源电价附加 | *kezaisheng nengyuan fujia*), with only agricultural customers exempted (NDRC 2007). Grid companies collect these funds separately and use them to pay premiums to renewable energy generators within their own province. Where revenue collection exceeds payment obligations, the funds are collected centrally and redistributed to provinces where payment obligations exceed revenues.

The drawback to this approach is that, if renewable generation grows faster than total demand and/or if the price of coal falls, the pool of revenues to pay premiums to renewable generators will be insufficient. In response to rapid growth in renewable energy, government agencies have increased the surcharge twice, to 0.008 yuan/kWh in 2011 and to 0.015 yuan/kWh in 2013. However, the lag between surcharge increases has led to significant gaps between what renewable generators are owed under the FIT, and what they are actually paid. By the end of 2011, government agencies estimated that the cumulative gap was 10.7 billion yuan, a debt that continued to increase until 2014 (Yu and Xiao 2014). This gap creates significant revenue uncertainty and risk for renewable energy companies.

Increasing the renewable energy surcharge is inherently a political move because: (i) increasing the surcharge raises electricity prices that are already perceived to be high, and (ii) the surcharge is collected nationally and involves significant transfers among provinces. Residential and agricultural customers were exempted from the 2013 surcharge increase, shifting more of the cost premium for renewable energy to industrial and commercial customers. Provinces that have significant renewable resources receive large premium payments from those that do not. Resolving the transfer issues associated with renewable cost premiums, for instance through overhauling the current approach, is critical for wind and the broader renewable energy industry going forward.

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[9] In particular, thermal generators are not compensated for providing ramping or load-following services. The latter entails adjusting output between a day-ahead schedule and what generators actually produce. If wind generation is higher than anticipated, generators would need to operate at levels lower than anticipated, decreasing their operating hours and increasing their operating costs as a result of less-efficient operation.

4.3 Balancing area coordination

A properly functioning electricity system needs to instantaneously balance supply and demand within a small tolerance. Meeting uncertainties in demand and supply while respecting various system security constraints traditionally requires centralized system operation of dispatching plants (i.e. specifying production quantity). The geographic purview of a system operator is known as a balancing area.

Coordinating neighbouring balancing areas has important benefits for integrating high penetrations of wind and solar energy: aggregating geographically distant resources tends to reduce resource variability; aggregating conventional energy sources increases total system flexibility; and access to more balancing options reduces integration costs such as reserves (GE Energy 2010). As a result of the grid operation institutions in China—including significant vertical separation of operations and planning, and complex horizontal overlapping authorities—the benefits of the large transmission network are not fully realized for wind integration.

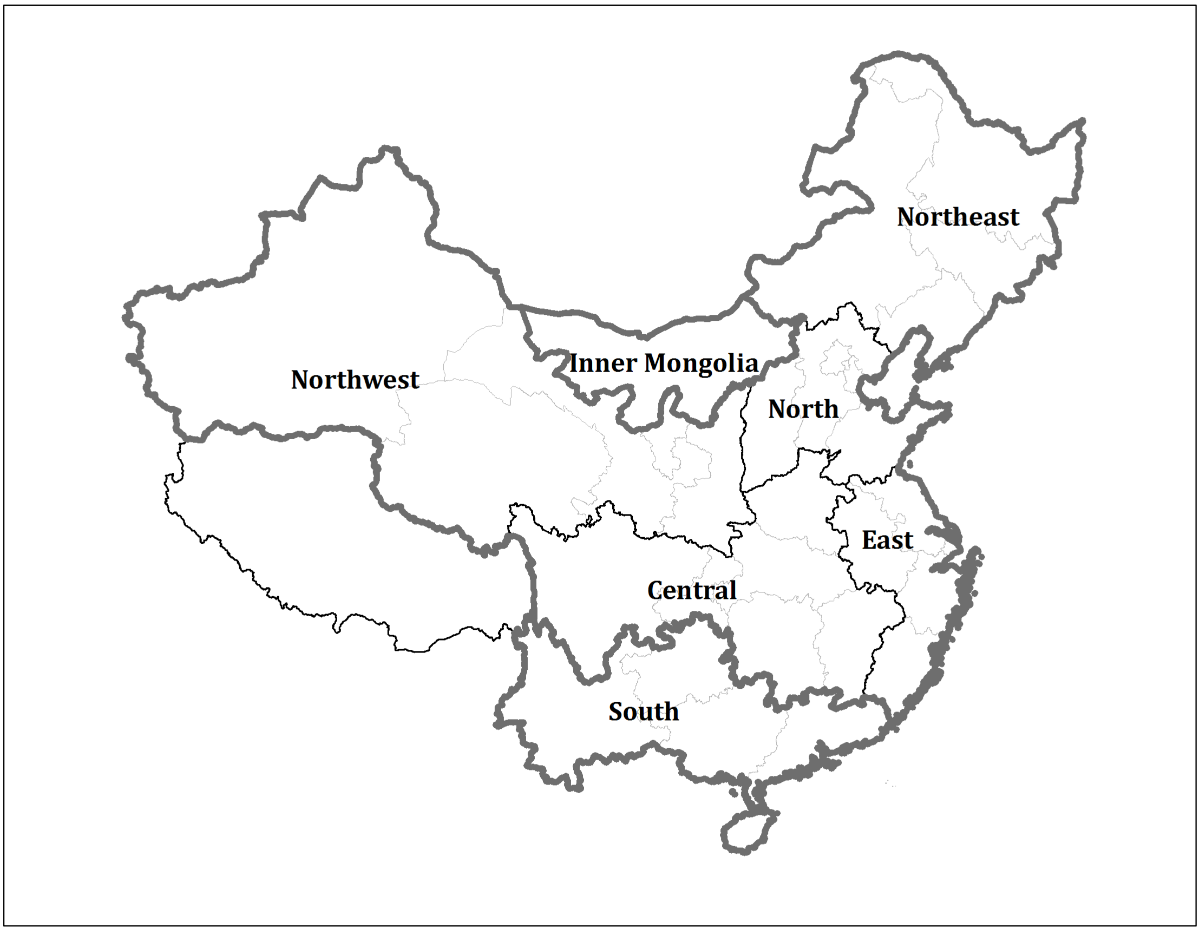
Structure of China's grid operations

Electricity in China is served primarily by two large central state-owned grid companies, State Grid Corporation of China and China Southern Power Grid Company, and one local grid company, the Inner Mongolia Power Grid. State Grid is further organized into five grid regions, each consisting of roughly five provinces (see Figure 6). Within State Grid and Southern Power Grid, direct subsidiary relationships of provincial grid companies within regional grids create nominal lines of authority. This basic structure was created in 2002 when the previously vertically integrated State Power Corporation was broken up, although the geographic relationships including the organization into grid regions existed under earlier pre-2002 government ministries.

Electric power operations in China involve a range of vertical and horizontal linkages among grid and government institutions. Power plants are for the most part dispatched by the provincial grid company, although there is large heterogeneity across regions. Larger facilities and those serving grid-balancing functions may be directly dispatched by the regional or national grids. Quota-setting and heuristic dispatch ordering (described in the previous section) take place mostly at the provincial level. Regional grids help coordinate inter-provincial connections whereas the national grid helps coordinate inter-regional connections. These two coordination processes are key to the functioning of the system, and increasingly important for integrating large quantities of variable wind energy.[10] Central policy calls for increasing inter-regional exchanges of electricity to exploit remote resources of wind, solar, coal, and hydropower (NEA 2014).

[10] For a more detailed treatment of institutional coordination issues, see Kahrl and Wang (2014).

Figure 6: Major grid regions of China



Note: Thick lines denote parent company boundaries; thin lines are provincial borders. (The Tibetan grid is currently much smaller and relatively autonomous with respect to the rest of the country.)

Source: Authors' illustration.

Coordinating wind across balancing areas

The annual generation planning process ensures that provinces can meet demand with supply and that generators will receive sufficient quotas to maintain profitability. Wind and other renewable energy may be incorporated at this stage by removing its expected generation from the total available quota. Transmission contracts for exchanges between balancing areas are negotiated in tandem with this process. The institutions involved in this process are quite varied and have a range of goals (see Table 3).

After the heavily negotiated annual plans are finalized, the grid company's goal is to ensure these targets are met by allocating to shorter time periods and adjusting for intra-annual changes in supply or demand. They may be censured by government regulators if they deviate too much (SERC 2011). At the same time, they are faced with the possibly conflicting policy for mandatory procurement of wind. Short-term balancing operations *within* balancing areas are thus heavily constrained. Short-term adjustments *between* balancing areas are even more difficult because quotas are not easily convertible between regions, and the rigid transmission contracting process is difficult to renegotiate (Davidson et al. 2016).

Table 3: Actors and interests in annual generation planning in China

Actors	Interests
Grid companies	Increase efficiency of delivery (i.e. reduce losses) Utilize transmission lines with energy-based compensation (typically, ultra-high voltage)
Coal-fired power companies	Lobby for higher quotas
Wind companies	Lobby to reduce planned quantities of conventional generation
Provincial governments	Lower local electricity price Promote local generation over imports
National government	Minimize frictions among provinces Conserve resources nationally for energy security and environmental goals

Source: Authors' compilation.

The northeast grid has faced severe wind curtailment in recent years, attributable to the inflexibility of its coal-fired combined heat and power fleet as well as numerous institutional causes. In 2015, wind curtailments were 32 per cent in Jilin and 10 per cent in neighbouring Liaoning (NEA 2016). Relaxing restrictions on inter-provincial trade could help to provide additional integration options for wind-rich Jilin (Zhao et al. 2013).

The northwest grid provides a more integrated model of inter-provincial transmission to accommodate wind power. A significant fraction of plants is directly dispatched by the regional operator, including large capacities of flexible hydropower in Qinghai province. The region also has large inter-regional transmission agreements with central and northern grids. It fulfils these using the dispatch principle of 'wind–coal hybridization' (风火打捆 | *fenghuo dakun*), which balances wind and coal plants in different provinces to maintain the agreed transmission contract (Yu et al. 2011). Nevertheless, wind curtailment in Gansu, where the majority of wind is located, reached the country's largest decrease of 39 per cent in 2015 (NEA 2016). In this case, without reforming generation planning—horizontal overlapping authorities—vertical integration has had limited benefits.

Within this rigid planning framework, policy-makers in China have piloted various mechanisms—both market and administrative—to increase renewable energy dispatch. These have primarily focused on the provincial grid. Energy-efficient dispatch, established in 2009, reorients renewable energy and high-efficiency coal to the top of annual plans, but does not compare plants in different provinces and does not completely do away with the basic quota system to ensure profitability (Davidson et al. 2016). Reforms in early 2015 highlighted reducing the total amount in the plan (hence available for quota) as well as prioritizing renewable energy in cross-region transfers as important to spur the integration of renewable energy (NDRC and NEA 2015). Detailed implementation plans have not yet been promulgated.

Regional power exchanges were piloted in the northeast grid in 2004–06 and later simulated in the east grid. Both were discontinued, nominally because of incompatibility with the unreformed administrative pricing systems that led the grid company to lose 3.2 billion yuan in 16 days (approximately US$400 million at US$2006 prices) (Dai 2013). Electricity shortages during this period are another justification given for reluctance to continue experiments. Many institutions had incentives to stall reform. According to one account, provincial governments and generation companies were united in opposition: provincial governments did not want to give up autonomy over planning decisions through a regional market, and risk-averse generation companies had already grown accustomed to the guaranteed revenue streams under the quota system (Wen 2014).

In terms of institutions involved in balancing area coordination in China, we see that there is significant vertical separation, owing to legacy arrangements between levels of governments. International experience indicates that better vertical integration, including through dispatch coordination in larger organizations or inter-jurisdiction agreements, should have a large, positive impact on wind energy integration. The results in the northwest, however, show that overlapping horizontal authorities such as through the annual generation planning process may be more influential on curtailment.

5 Conclusions and discussion

Energy system transitions, by introducing or replacing one technology or practice with another, inevitably create winners and losers. This political economy of transition is, in fact, an important barrier to renewable energy deployment and more broadly to climate policy. It is an often-overlooked part of research on low-carbon energy systems.

To better assess the landscape of political economy obstacles to energy system transition, in this paper we developed an analytical framework to understand the political economy of wind energy—a high potential source of zero-carbon dioxide electricity. The framework describes how varied political and economic organizations in the electric power sector influence key steps in wind deployment and integration, ranging from capacity planning to dispatch. It provides a basis for understanding how conflicts among actors over benefit, cost, and risk-sharing arise around the multiple functions that, taken together, create a stable and reinforcing set of incentives for renewable energy development and integration.

Among generators, the political economy impacts of wind power are driven by its physical characteristics. Wind displaces conventional dispatchable resources (e.g. coal, natural gas generation) because of its low marginal costs, but requires some of those dispatchable resources for balancing because of its limited predictability and variability. This may reduce capacity utilization of conventional dispatchable generators and force them to operate in new conditions, creating costs that may or may not be remunerated under existing market or regulatory rules.

Yet, as we showed, the political economy impacts of wind extend beyond transfers among generators. Greater investment certainty for wind generators is underwritten by electricity customers, and governments may transfer more of that risk onto specific classes of customers (e.g. residential or industrial customers). Regional dispatch can reduce the operating challenges of wind power, but integrating local electricity systems into more regionally coordinated dispatch creates economic transfers between higher- and lower-cost regions. The losers in these political economy conflicts will often resist policies that support wind, renewable energy, and energy transition.

We applied our framework to China, a country with electricity sector institutions that are very different from those in most other countries. Many of these differences are rooted in China's history as a centrally planned economy and pertain to the pervasive role of several levels of government throughout the sector. Through examples focused on generation planning, generator cost recovery, and balancing area coordination, we demonstrated how wind development and integration challenges in China can also be understood within a more general political economy framework.

Applying this framework enabled us to explore the role of vertical and horizontal separation in shaping outcomes for wind in China. On the basis of our analysis, we surmise that vertical separation (i.e. degree of federalism) plays a very important role in explaining wind integration outcomes in China, perhaps as important as in the United States and Europe. We also find evidence that underneath the veneer of stronger horizontal integration in China the disparate interests of actors can lead to poor coordination across functions such as generation and transmission planning, or generation planning and dispatch, with consequences for wind development. Fleshing out on-the-ground implications of vertical and horizontal separation for wind integration is an important topic for future empirical work.

China is, in many ways, an extreme case because of the severity of its wind energy curtailment problem. As such, China presents a cautionary tale of the perils of not proactively identifying and addressing potential political economy conflicts. We argue that, although the technical challenges of renewable integration may have reasonably straightforward solutions, addressing political economy challenges by their nature must be built into longer-term political and economic strategy. In developing policies to facilitate low-carbon energy transitions, governments should ensure that they have given sufficient attention to potential political economy conflicts and solutions.

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