Network governance and effectiveness on renewable energy integration: A comparative case study on power transmission networks in the United States

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Abstract
This paper examines how network structure and coordinating mechanisms in the US power transmission system affect the integration of wind energy through comparative case studies. The two transmission network cases represent two major transmission network governance models in the US power sector. Using archival data from all network participants and interviews with key stakeholders, we find that a centralized transmission network coordinated by an independent network administrative organization (NAO) is more effective in integrating wind power than a less centralized structure. Particularly, the concentration of decision-making authorities is a more substantial determinant than the structural centrality of the core agency. The two cases also highlight that hierarchy, collaboration, and market mechanisms coexist in a transmission network to manage the tension between stability and flexibility. When the network operates in a turbulent environment with great uncertainties, different coordinating mechanisms complement each other to improve system resilience.

Keywords
Network governance, network effectiveness, renewable energy, power transmission network

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Introduction
To reduce carbon emissions and achieve energy sustainability, multi-level governments in the United States are promoting renewable energy in the power sector through a variety of policy tools. Among all renewable energy, wind power, because of its unpredictable intermittent production features, imposes a high level of variability and uncertainty on the power system. Massive integration of this variable energy resource (VER) in the current power system requires regional collaboration among power producers, transmission system operators, load-serving entities, and different levels of regulatory agencies. These organizations interact in the regional transmission networks to maintain system resilience and ensure reliability (Klass & Wilson, 2012; Koch, 2009; Lenhart et al., 2016).

Following the Federal Energy Regulatory Commission (FERC)’s orders to develop a competitive and transparent electricity market, the restructuring of the US electricity wholesale market resulted in two different models of regional transmission network governance in the early 2000s. In most regions, as shown in Figure 1, transmission networks are coordinated by seven Independent System Operators or Regional Transmission Organizations (ISO/RTOs). These ISO/RTOs are nonprofit and interest-neutral network administrative organizations (NAOs) created by partnered power producers, utilities that own transmission assets, and load-serving entities. While they do not own any transmission or generation assets, they serve as regional transmission system controllers, coordinate transmission

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services, and organize the electricity wholesale market. In other regions (i.e., Non-RTO West and Non-RTO Southeast in Figure 1), the transmission system is controlled and managed by one or multiple integrated utilities that own both generation and transmission assets. Without a centralized independent transmission operator, these large utilities coordinate with each other to ensure the region-wide reliability of the power system. In these shared-governance networks (Provan & Kenis, 2008), external regional coordinating agencies also exist, which only take on some governance activities while leaving transmission system operation and market coordination to those integrated utilities.

A few empirical studies have shown that the growth of wind generation capacities and wind farm performance in ISO/RTO-governed transmission networks are significantly higher than in non-RTO regions (Hitaj, 2013; Tang, 2018). However, the underlying mechanisms through which a particular transmission governance model facilitates or impedes wind power deployment are not fully revealed, particularly from the perspective of network governance. This paper fills this intellectual gap and examines how transmission network governance affects wind power integration. Based on the network governance theoretical framework, this paper addresses two research questions: (1) How structural properties of a transmission network affect its effectiveness in integrating wind power? and (2) How coordinating mechanisms in a transmission network affect its effectiveness in integrating wind power? Using archival data and interviews with key network participants, a comparative case study is conducted between an ISO/RTO-governed transmission network and a transmission network in a non-RTO region.

This paper contributes to both literature on network governance and studies on renewable energy diffusion. Previous literature on network governance has proposed theoretical frameworks to evaluate network effectiveness and identified contingencies that explain why a certain governance mode is likely to be more effective (Provan & Kenis, 2008; Provan & Milward, 1995). Most empirical studies testing these hypotheses concentrate on public health (Milward et al., 2010; Provan & Milward, 1995), education (O’Toole & Meier, 2004), economic development (Feiock et al., 2010), watershed management (Cui & Yi, 2020; Scott, 2015, 2016), and emergency management (Kapucu et al., 2010; Kapucu & Garayev, 2012; Moynihan, 2009). This paper is one of the first studies to examine the relationship between network governance and network effectiveness in the power sector. On top of that, the transmission network cases extend existing theories by highlighting the underlying mechanisms through which particular network structural properties or coordinating processes can achieve both system stability and flexibility, particularly when the network is embedded in a turbulent environment with uncertainties and disruptions. These new findings can be applied to studies on other environmental or energy resource management and delivery networks that operate over large spatial scales.

While most literature on renewable energy diffusion in the United States is at the state level and focuses on investment in renewable energy or renewable generation (Buckman, 2011; Carley, 2009; Carley et al., 2018; Gaul &
Carley, 2012; H. Yin & Powers, 2010), this paper adds to existing studies a regional perspective and makes a substantial contribution to understanding the links between regional transmission network governance and their outcome in terms of renewable energy integration (Baldwin & Tang, 2021). It also informs electricity market design to accommodate high renewable energy penetration and sheds light on how to forge effective collaboration among power producers and transmission system operators to manage variable energy resources in different types of the electricity market.

In the remainder of this paper, Section “The context: Power system operation and renewable energy development in the United States” briefly introduces the institutional context of transmission network operation and renewable energy development in the United States. Section “Theoretical framework: Network governance and effectiveness in power system” reviews theoretical foundations and develops propositions to be examined. Section “Methods” describes case selection and data collection, and Section 5 “Findings” analyses the two cases. The last section concludes the major findings and discusses their theoretical and practical implications.

The context: Power system operation and renewable energy development in the United States

Multiple public interests in transmission network operation

The US power system is a vast network that consists of two layers. Physically, the power system is a network of electric generating units, loads, and transmission and distribution systems that move electric energy from generators to ultimate loads. From an organizational perspective, it is a cross-sectoral network of power generators, transmission system operators, load-serving entities, end consumers, and other administrative entities involved in the electricity market (MIT, 2011). These two layers of networks are interdependent. This paper examines both layers of the power network with a focus on the electricity wholesale market operated within the transmission network, where most regional coordination occurs.

While electricity delivery services are provided mostly through market, the power system also serves multiple public interests. The primary goal of the power system is to ensure the reliable delivery of electricity at the lowest cost to consumers. Because electricity demand is variable in time and uncertain in quantity, power producers, transmission system operators, and load-serving utilities must be constantly coordinated in real time to ensure the balance between generation and demand in the power system. Otherwise, power system failure, such as outages, will cause huge societal costs. This balancing service is coordinated by a balancing authority (BA), which matches generating resources to electricity demand within its territory—the balancing area.

In response to climate change and energy security concerns, increasing the share of renewable energy in electricity generation is an emerging public interest that the power sector serves. Boosted by federal-level and state-level renewable energy policies, generation from variable energy sources such as wind and solar has increased substantially in the United States during the last decade. High penetration of variable generation in the power system creates new challenges to the operation of the power system and wholesale markets. First, it increases the variability and uncertainty of electricity supply due to the intermittency of wind or solar energy. In addition, VERs have unique diurnal and seasonal patterns which may not correspond to the electricity demand pattern (MIT, 2011; Bird et al., 2014). Therefore, it requires the transmission network to have enough resilience from reserves, storage, or other forms of backup to accommodate high-level renewable penetration and maintain system reliability.

Restructuring of the electricity market and transmission network governance

The restructuring of the US electricity market from the mid-1990s has gradually formed different transmission network governance models across regions. Before the restructuring, electricity markets were served by vertically integrated utilities (Figure 2), which possessed and operated all parts of the power system including generators, transmission, and distribution systems. In the wholesale market, electricity transactions were between these utilities based on short-term or long-term bilateral contracts. These transactions were regulated by federal or state regulators. Balancing authorities that match electricity generation and demands to keep system balance were mostly overlapped with major large utilities.

Following the FERC’s deregulation orders that promoted competition in the electricity wholesale market, vertically integrated utilities were required to divest all or some of their generating assets to third parties. Independent power producers also entered the wholesale market. New forms of transmission network governance emerged in regions that are deregulated in the 2000s. Seven ISO/RTOs were set up as user-supported and interest-neutral nonprofit companies overseen by FERC. The ISO/RTO operates as a consolidated BA over a large jurisdiction that consists of multiple balancing areas before restructuring. As a centralized transmission network coordinator, it controls transmission system operation and organizes regional wholesale market transactions using a competitive bidding system. Currently, ISO/RTO-governed transmission networks serve two-thirds of the electricity consumers in the US (ISO/RTO Council [IRC], 2022). The Southeast and
most Western states are still dominated by the traditional vertically integrated utility model. In these non-RTO regions, transmission networks are controlled and operated by utilities that own the transmission systems, and the wholesale market transactions are mostly based on bilateral contracts.

Understanding whether and how these two different transmission network governance models affect the power market to achieve its multiple public goals is important for future institutional designs in the power sector. This paper focuses on the goal of integrating renewable energy. Existing literature on transmission planning has identified regional collaboration on transmission planning and siting as a barrier to renewable energy development and has introduced recent efforts in both RTO regions and non-RTO regions to overcome this barrier (Bloom et al., 2010; Brown & Rossi, 2010; Fischlein et al., 2013; Klass & Wilson, 2012). Studies on the transmission operations are mostly from a technical perspective, which conducts engineering simulations to evaluate the performance of different electricity wholesale market designs assuming different levels of renewable energy penetration (Aggarwal & Harvey, 2013; Ela et al., 2014; Hunsaker et al., 2013; Milligan & Kirby, 2007; MIT, 2011; Schlag et al., 2015). However, there has been a lack of governance perspective to compare the two transmission network governance models and analyze how they might be related to different outcomes of renewable energy integration across regions. This paper draws upon network governance scholarship to fill this intellectual gap.

**Theoretical framework: Network governance and effectiveness in power system**

When studying public service delivery or policy implementation, networks are often viewed as groups of legally autonomous organizations that work together to achieve collective goals which cannot be effectively achieved by one single organization (Agranoff & McGuire, 2001; Keast & Mandell, 2014; McGuire, 2006; O’Toole, 1997; Provan & Kenis, 2008; Milward & Provan, 2006). In light of this definition, the US power system can be viewed as service delivery networks, which consist of multiple electricity market participants that are connected both physically through power grids and institutionally in the electricity market to deliver electricity from generators to end consumers. Due to policy interventions and technological innovation that drives down the costs of renewable energy, wind and solar power have grown rapidly in electricity generation in the US. However, these VERs increase the variability and transmission constraints in the power system (Klass & Wilson, 2012; Lenhart et al., 2016). Maintaining reliability and affordability while integrating massive VERs requires regional collaboration among all network participants (Koch, 2009; Lenhart et al., 2016).

This paper focuses on how the collective actions among participants in the transmission networks are organized and coordinated. Since network governance in the power sector has not been examined extensively, we draw on existing studies on other public service networks to build my
theoretical framework (Figure 3). Particularly, we are examining how network structural properties and coordinating mechanisms affect the overall network effectiveness of integrating wind power.

**Network effectiveness**

Network effectiveness can be evaluated at the network level, community level, or individual network participant level (Provan & Milward, 2001). In this paper, we follow the network-level approach and define network effectiveness as “the attainment of positive network-level outcomes that could not normally be achieved by individual organizational participants acting independently” (Provan & Kenis, 2008). This paper examines the effectiveness of the transmission network in achieving one of the positive outcomes—facilitating the deployment of renewable energy to advance public policy energy objectives (Federal Energy Regulatory Commission [FERC], 2016; IRC, 2022; Koch, 2009; Miranda, 2009). As wind power is a major VER and the most prevalent source of renewable electricity in the United States (Energy Information Administration [EIA], 2021), we focus on the integration of wind power in the transmission network.

**Network structure and effectiveness**

Most existing studies that examine the determinants of network effectiveness identify network structure as a key factor associated with network outcomes (Medina et al., 2021; Shrestha, 2018; Ulibarri & Scott, 2017; Yi, 2018; Yi et al., 2021). Network structure concerns the degree of integration in the network (Provan & Kenis, 2008; Provan & Milward, 1995; Raab et al., 2013). Three aspects of network structure are most frequently examined: network density, level of centralization, and cliques. Density describes the general level of interconnectedness among network participants while centralization describes the extent to which this cohesion is organized around particular central agencies (Provan & Milward, 1995). Instead of considering the whole network system, cliques focus on the subgroups within a large network. A network is more integrated if subgroups within the network overlap with each other (Provan & Sebastian, 1998).

Among these three aspects, this paper focuses on examining how network centralization and cliques within the networks affect network outcomes. Density is not considered because all the network participants in the regional power system are interconnected through the physical power grids. The density of institutional linkages heavily relies on the physical density of transmission lines in the regional interconnection, which is determined in transmission siting and planning. Since this paper focuses on operations of the power system given existing transmission infrastructure rather than transmission planning, network density is beyond the scope of this paper.
Centralization. Network centralization describes the power and control structure of the network—whether links and activities are organized around any particular one or small groups of organizations (Borgatti et al., 2013; Provan & Milward, 1995). Previous studies on different public management networks measure the level of network centralization through two indicators: (1) centrality of core agencies and (2) concentration of influence. The centrality of core agencies is often measured as the percentage of the link that the core agency has in total network links, which reflects the structural position of the core agency in the network. The second indicator has been measured as whether influence over decisions related to a particular service is concentrated within a single agency or a group of agencies, which concerns more the centralization of authorities (Provan & Milward, 1995).

Centralized integration is beneficial for network effectiveness because it facilitates both integration of resources and coordination of actions among network members. In addition, a centralized network allows effective monitoring of the services because the central broker is in a better position to oversee and control the activities of network members. Existing empirical research on community mental health services, crime prevention networks, emergency management, and regional economic development all suggests that the presence of a powerful lead organization, acting as a system controller or facilitator, can be critical to the effectiveness of collaborative management (Agranoff & McGuire, 2003; Moynihan, 2005, 2009; Provan & Milward, 1995; Raab et al., 2015). For the power sector, we examine the following proposition:

**Proposition 1:** A centralized regional transmission network will be more effective in integrating wind generation than a less centralized network because it allows better resource mobilization and coordination to deal with the variability of wind energy.

Cliquages. In addition to the overall centralization of the network, the substructure of networks is also important. Within a large network, participants may form subgroups in which network members are more interconnected with each other than with members outside the groups. Clique overlap describes the degree to which subgroups within a large network overlap with each other. Network effectiveness is enhanced when subgroups of agencies have overlapping linkages (Provan & Sebastian, 1998). Where the subgroups have a large overlap with each other in terms of network members, we can expect that conflict between them is less likely than when the groups do not overlap. Moreover, the diffusion of any new technologies or practices may spread rapidly across the entire network. Empirical studies have conducted clique analysis to identify subgroups of key stakeholders with similar beliefs or with closer collaborations (Ansell & Gash, 2008; Kapucu et al., 2009, 2010; Weible, 2011). However, they did not analyze the overlaps among cliques. In this paper, the substructure of the regional transmission network and its relationship with network outcome are also examined.

**Proposition 2:** Overlap between cliques in a transmission network facilitates wind power integration because it reduces conflicts among network participants and expedites the diffusion of new knowledge.

Modes of governance. Another series of concepts that describe structural properties of network governance are the three modes of governance—shared governance, lead organization governance, and network administration organization (NAO) governance (Provan & Kenis, 2008). These three modes of governance are differentiated by two dimensions: (1) whether the network is highly centralized and (2) whether this network is participant-governed or externally governed. Shared governance is at one extreme of the first dimension since it is a highly decentralized form—each network participant interacts with others to govern the network collectively. In contrast, a network governed by a lead organization or by an NAO is more centralized. The difference between these two centralized modes is whether the core agency is a network participant (lead organization) or is a third-party coordinator (i.e., NAO).

Provan and Kenis (2008) propose several contingencies that affect the effectiveness of these three forms of governance. They predict that lead organization or NAO governance is likely to be more effective than shared governance when trust among network participants is moderate or low, when the size of the network becomes larger, when the network has diverse goals, and when the need for network-level competencies is increasing. Between the two brokered forms, Raab et al. (2013) argue that an independent external agency would be more effective to coordinate a diverse set of participants because it is not embedded in the logic or culture of any groups within participants and will be more neutral. However, they do not empirically confirm if NAO-governed networks lead to better effectiveness than lead agency governed networks. In the power sector, the transmission network has multiple goals to meet and demands high level of network competencies to manage both internal and external uncertainties. Thus, we develop the following proposition:

**Proposition 3:** An ISO/RTO-governed transmission network is more effective in integrating wind power than the non-RTO model because this independent external agency can be more neutral and competent in coordinating participants.

Coordinating mechanisms and processes

In addition to the structural attributes of the network, the coordination mechanism and decision-making process in the network also affect its outcome. Unlike traditional
network literature that treats network as a unique form of governance (Powell, 1990), more recent research suggests that inter-organizational networks are governed through a blending of multiple coordinating mechanisms. A case study on environmental governance networks (Robins et al., 2011) shows that older governance forms, including hierarchies and markets, are embedded in their own forms of network-like relationships among institutions and actors. Networks governed by NAOs or lead organizations in economic development or emergency management are often coordinated through command and control procedures by the central coordinators while network participants work together collaboratively (Agranoff & McGuire, 2003; McGuire, 2006; Moynihan, 2009).

While existing research has not extensively examined the effectiveness of these coordinating mechanisms, the strengths and weaknesses of each form are discussed in previous literature. As a paradigm of “individually self-interested, non-cooperative, unconstrained social interaction,” competitive market offers choices and flexibility. In hierarchies, communication and exchange are organized through clean lines of authority, detailed reporting mechanisms, and formal decision-making procedures, which provide reliability and accountability. In collaborations, inter-organizational exchange of resources is mostly based on reciprocal relationships between network participants. They gain through the pooling of resources and synergies (Jones et al., 1997; Powell, 1990; Raab, 2004).

In a transmission network, a combination of hierarchical control, collaboration, and market mechanisms is used to coordinate the power transmission and electricity market transactions. Effectively integration of renewable energy requires both system reliability and flexibility. Reliability is the primary goal for power system operation while a certain level of system flexibility is required to respond to the external uncertainties from variable wind resources. Based on the two goals of transmission networks, we propose:

**Proposition 4:** Hierarchy, collaboration, and market mechanisms coexist in a transmission network to achieve stability, synergy, and flexibility, which are all essential for wind power integration.

**Methods**

We use the comparative case study method (R. K. Yin, 2018) to examine the impacts of transmission network governance on renewable energy integration between two transmission networks with different governance models. With qualitative and quantitative data collected from interviews and archives, we start the coding process guided by propositions developed in my theoretical framework. New themes and insights that emerge from the two cases are then used to extend the theoretical framework.

**Case selection: Internal validity and external validity**

Among all regional transmission networks in Figure 1, we select two cases to compare: (1) the Midcontinent ISO (MISO) network—an ISO/RTO-governed regional transmission network, where the electricity wholesale market is organized by MISO; and (2) the Non-RTO West network, which are transmission systems in the Western Interconnection excluding ISO/RTO-governed areas. The two cases are selected based on network size, electricity demand, renewable energy policy support, wind resource endowment, existing wind generation capacity, transmission infrastructure, and other factors that affect network governance and/or wind power generation.

As shown in Table 1, the two regional transmission networks have similar sizes in terms of service territory, network participants, electricity demand, renewable energy policy support, and wind resources. Although MISO has significantly less transmission infrastructure than Non-RTO West, available wind generation capacities in these two regions were very close from 2009 to 2014 (Figure 4) after MISO network had consolidated as one balancing area since 2009. However, wind generation capacities in MISO increased at a faster rate than Non-RTO West after 2014. Given the similarities in most confounding factors, the comparative case analysis will focus on network governance and examine how these governance attributes affect wind power integration in these two networks.

In addition to the internal validity established through case comparison, insights drawn from these two cases can also inform transmission network governance design in other regions in the United States. MISO and the Non-RTO West represent two major transmission network governance models in the US—the ISO/RTO model and the non-RTO model, respectively. While there are some variations among regional transmission networks within each category, there has been a large degree of convergence in general principles of market design and transmission system operation among regions governed by the same model (Miranda, 2009).

**Data collection and analysis**

To develop an in-depth picture of each case, we draw on extensive qualitative and quantitative archival data collected from all network participants in each case, US Energy Information Administration (EIA), FERC, and Factiva news database. The secondary data are supplemented by interviews with key stakeholders from each network. A detailed account of each case is established based on the triangulation of these different sources of evidence, which reassures that the interpretations of these two cases are not shaped by single-source evidence (R. K. Yin, 2018).
For network structural properties and coordinating mechanisms in MISO network and the Non-RTO West, we collected archival documents from all network members, coordinating agencies (i.e., MISO, West Electricity Coordinating Council (WECC), and other subregional coordinators in Non-RTO West), state regulators that involved in the two regional transmission networks, and FERC. To triangulate with this archival data, we also extracted news articles about transmission system operation and renewable energy integration in these two regional networks from Fectiva database. These news articles cover the years from the formation of MISO till the end of 2020.11

In addition, we used data from semi-structured phone interviews with a diverse set of stakeholders from MISO network and Non-RTO West (see Table 2) to supplement the findings from secondary data sources. In all interviews, people were asked about their agency’s daily operation regarding power scheduling and real-time dispatching, and the advantages or barriers for the regional transmission network to integrate wind power. Through coding this interview data, we get more insights into transmission system operation, market coordination process, and how these coordinating mechanisms or organization structural designs have promoted or impeded the utilization of wind power.

We used content analysis to identify the common themes in the textual data and analyze the relationships between themes. A total of 4,026 text units (including technical or market reports, news articles, and interview transcripts) were coded using NVivo. The initial codebook was constructed deductively based on the key concepts of network structure and coordinating mechanisms identified in the theoretical framework. In the codebook, we defined each concept, provided operational definitions, and added references from the textual data as examples for each node. Based on the four propositions in our theoretical framework, we also included relationship nodes in the codebook and provided rules on how to code these relationships between transmission network features and wind power integration. We focused our coding on “units of meaning” rather than keywords as the interviewees, archival reports, and news articles usually expressed a complete point in several sentences. Coding based on keywords or phrases may misinterpret the data (Campbell et al., 2013; MacPhail et al., 2016).

The coding process was iterative and involved multiple rounds of revisions to our codebook. Two coders independently coded each textual unit based on the initial codebook. If new themes or relationships emerged from the data, we created new nodes and added them to the codebook. The research team discussed all modifications to the codebook, including the definitions, references, and coding

Table 1. Comparison between MISO and Non-RTO West on case selection criteria (based on 2020 statistics1).

| Transmission network | MISO | Non-RTO West |
|----------------------|------|--------------|
| Size of the network  |      |              |
| 1. Number of states in its service territory | 15 states | 15 states |
| 2. Number of network participants | 471 | 420 |
| 3. Annual electricity demand (GWh) | 673,579 | 660,081 |
| Policy support for renewable energy; no. of states having renewable portfolio standards (RPS) | 8 | 8 |
| Wind resources (average wind quality class of all wind farms) | 2.30 | 2.28 |
| Existing wind installed capacity (MW) | 26,101 | 19,486 |
| Transmission infrastructure |      |              |
| 1. Circuit miles of transmission lines | 65,800 | 110,000 |
| 2. Average interconnecting voltage of wind farms (kV) | 130.93 | 173.53 |

Source. 2021 WECC state of the interconnection report (WECC, 2021); 2020 annual report on market issues and performance (CAISO, 2021); MISO Corporate Fact Sheet (MISO, 2021); EIA 860 survey (EIA, 2020).

Note. Wind Resources: The Energy Information Administration (EIA) distinguishes between seven classes of wind power resources based on wind speed at a height of 50m. In general, areas designated class 3 or greater are suitable for most utility-scale wind farms, whereas class 2 areas are marginal for utility-scale wind plants.

1The 2020 data are most recent and comprehensive data available for both regional networks.

Figure 4. Existing wind generation capacity in MISO and Non-RTO West.
instructions for new nodes, to ensure the validity of our coding. We tested the intercoder reliability using percent agreement, which suggests a high level of agreement between coders on each node (above 90%) (MacPhail et al., 2016). The coding process shapes the relevance, meaning, and interconnection of concepts. The interconnections of key concepts in the context of transmission networks emerged through recursive cycling among case data, existing literature on network governance, and propositions in Section “Theoretical framework: Network governance and effectiveness in power system.”

Findings

Network effectiveness in wind power integration

In this paper, we first use the average capacity factor of wind power in the network to measure the network-level effectiveness of wind power integration. This measurement captures the utilization/performance of existing wind generation capacity in the power system (Tang, 2018; Tang & Popp, 2016; Wiser & Bolinger, 2011, 2012). Since wind generation capacities and wind resources for those generating units were similar between MISO-governed network and non-RTO West from 2009 to 2014, higher utilization of existing capacity indicates that the regional transmission network has better performance on wind energy integration. Figure 5 shows the average capacity factor of wind power in these two regional networks over the period 2010–2014, which covers the period after MISO network has consolidated as one balancing area since 2009. While the utilization rate of wind power increases about 10 percentage points in both regional networks, the average capacity factor of wind power in MISO is 3 to 4 percentage points higher than in Non-RTO West across all these 5 years. This is approximately equivalent to a 10% difference in wind energy utilization between the two networks.

When the two networks have different levels of wind generation capacity, we can use the generation capacity to measure the network-level effectiveness of wind energy integration. From 2015 to 2020, MISO has a significantly higher level of newly installed wind power capacity in its network than the Non-RTO West (Figure 4), which suggests that MISO has integrated more wind energy in its network than the Non-RTO West.

At the individual wind farm level, as shown in Figure 6, MISO has a larger share of wind farms with higher capacity factor than Non-RTO West among wind farms in each wind quality class. Thus, the comparisons at the network level and individual wind farm level both indicate that the MISO network performs better in wind energy integration than the Non-RTO West.

Since the case selection process has controlled other confounding factors that may affect wind power utilization, different effectiveness in integrating wind power between MISO and Non-RTO West may be attributed to network governance factors. Following the theoretical framework in Section “Theoretical framework: Network governance and effectiveness in power system,” we analyze how network structure and coordinating mechanisms in these two networks affect wind power utilization and the key findings are summarized in Table 3.

Network structure and resource sharing

Level of centralization. One major difference between the two transmission networks is whether the operation of the transmission system and wholesale market is integrated and coordinated centrally through an independent system operator. For both cases, the most recurring theme that came up from the data regarding wind power integration and grid operation is “consolidation” or “centralized operation.” Following previous network governance research, we also examine two aspects of network centralization: core agency centrality and concentration of influence (Provan & Milward, 1995). In a transmission network, the first aspect concerns whether network links are organized around one or small groups of organizations, whereas the second aspect captures whether influence over decisions related to system operation and electricity market coordination is concentrated within a single core agency.

The MISO network has a highly centralized structure. MISO is the single core agency that connects all power producers, transmission system owners, and load-serving

| Stakeholder type                        | MISO network | Non-RTO West |
|----------------------------------------|--------------|--------------|
| Transmission operators or balancing authorities | 5            | 7            |
| Wind power producers                   | 5            | 3            |
| Electricity market regulators          | 2            | 2            |
| Researchers                            | 1            | 1            |
| Total number of Interviews             | 13           | 13           |

Table 2. Distribution of interviews.

Figure 5. Utilization rate of wind power in MISO and Non-RTO West.
entities within its territory. As for the concentration of influence, MISO serves as the central authority that controls and oversees the transmission system operation and coordinates the wholesale electricity market.

In contrast, the non-RTO West has a more decentralized network structure, where the transmission system and electricity wholesale market are jointly coordinated by 33 balancing authorities (BA).\textsuperscript{13} These BAs are each responsible for balancing the generation and electricity demand within its balancing area so that their combined efforts will keep the entire non-RTO West balanced and reliable. A stakeholder in the Western Interconnection commented that “the divided operation of the interconnected western grid is not unlike having a bus with 38 drivers.” From the perspective of linkage-based centrality, each BA connects and coordinates limited generators and load-serving entities within its balancing area.

Compared to decentralized system operation in Non-RTO West, centralized system operation and market coordination in the MISO network allow resource pooling. The larger resource pool provides MISO with more options that can be used to accommodate variations in electricity supply and demand. This resource pooling is even more important for wind power integration. Since wind power increases the variability and uncertainty in power system operation, it requires more fast-response operating reserves\textsuperscript{14} in the system to deal with the imbalances when any wind generator fails to commit to the scheduled generation. As mentioned in the reports and interview data, “MISO can take on more renewable energy with minimal curtailment because this...
pooled market has more generating units to ramp up and ramp down quickly to balance the variable generation.” In addition, variation in aggregate wind output tends to be less correlated over larger geographic regions, which is another benefit of resource pooling. In contrast, BAs in Non-RTO West can only mobilize resources within their territory to accommodate the variation and uncertainty caused by wind power. Existing studies have demonstrated that “this method drives up integration costs, and limits the amount of wind and other variable generation that can be connected to the system in a region” (Samaan et al., 2017).

**Resource exchange among cliques.** We now turn to examine the subgroups within the network, which are referred to as “cliques” in the network analysis literature. The transmission system operation and wholesale market in Non-RTO West are not governed by a central agency. It consists of 33 subregional balancing areas coordinated by separate BAs. These cliques are formed based on geographic proximity. In theory, an alternative approach to network integration is through the overlap of cliques (Provan & Sebastian, 1998). However, we did not find any document or interview mentioning “overlap” between group members. Instead, they mentioned the “interchange” or “exchange” of resources between neighboring cliques. One interviewee from the Non-RTO West commented that “increased coordination between neighboring balancing areas allows greater utilization of load and resource diversity, which reduced the magnitude of wind curtailment.” This improved coordination occurs either through increasing the frequency of resource exchange between neighboring balancing areas or by reducing the interchange limits between them. For example, the Western Interconnection initiated the “Intra-Hour Transaction Accelerator Platform (I-TAP)” to facilitate intra-hour energy and capacity transactions online between balancing areas, which can provide each clique with more ramping capacity to manage the variability and uncertainty of wind power (Hunsaker et al., 2013).

While the Non-RTO West does not have one single centralized third-party agency to coordinate energy transactions like MISO, our data suggest that some balancing areas in the Non-RTO West reduced wind curtailment and improved wind power integration through the increased exchange of resources among cliques.

**Mode of governance.** According to Provan and Kenis’s (2008) classification, the MISO network is an NAO-governed network, where MISO serves as the single NAO that coordinates transmission operation, system reliability, and market transactions. The mode of governance in Non-RTO West is more ambiguous. It is a hybrid of a lead organization governed network within each balancing area and shared governance among these lead organizations at the aggregate level. However, several external brokers have organizational links across different balancing areas, or even connect all network participants in the Non-RTO West. One example of these external brokers is the West Electricity Coordination Council (WECC)—an independent non-profit that coordinates all network participants to achieve mandatory reliability standards from FERC. While the centrality of WECC is equivalent to MISO from a linkage-based perspective, it only takes on part of the governance activities that MISO does, which is ensuring system reliability. The authority over system operation and market coordination is fragmented and shared among 33 balancing authorities in non-RTO West. On the contrary, MISO is the sole decision-making authority for electricity scheduling and dispatching, market coordination, and reliability coordination.

The comparison between MISO and Non-RTO West indicates that structural position is not equivalent to the actual influence (Provan & Milward, 1995). The concentration of influence tends to be a more essential aspect of centralization. The mere existence of an NAO does not necessarily lead to better network outcomes, it is more important that decision-making authorities on all relevant aspects of transmission network operation are concentrated in that single agency.

Coming back to the two dimensions that characterize different modes of governance, the two transmission network cases suggest that the level of centralization does matter for network effectiveness, particularly the concentration of influence. However, it is not clear whether the centralized control from an external agency or a lead participant results in better network outcomes.

**Coordinating mechanisms: A hybrid approach to flexibility and stability**

As introduced in Section “The context: Power system operation and renewable energy development in the United States,” the primary goal of power system operation is to ensure its stability or the “reliability of the bulk power system” as used in electricity regulatory documents. However, the integration of renewable energy, particularly the variable generation such as wind power, challenges system stability because wind output is less predictable than traditional generating resources. Maintaining system reliability requires a certain level of flexibility in the power system to manage the uncertainty imposed by the environment.

To achieve system stability, both the MISO network and the Non-RTO West network use hierarchical control schemes. As coordinating agencies, MISO and BAs in the Western Interconnection continuously balance generation and load in the system. While these agencies have coordinating authorities over different levels of territories, their functions are similar. They collect information from load-serving entities to conduct demand forecasting for their balancing areas, schedule, and dispatch generators to meet the demand and employ different types of operating reserves to
offset the deviations due to changes in generation or demand in real time. All these operations are conducted according to established protocols approved by FERC. In addition, compliance with reliability standards in the MISO system and Non-RTO West is monitored and enforced by reliability coordinators. MISO is the reliability coordinator while the Western Electricity Coordination Council (WECC) ensures reliability for the Non-RTO West.

Despite similar hierarchical control to maintain system stability, the wholesale markets in these two networks are coordinated differently, which leads to different levels of flexibility between the two networks. MISO coordinates the wholesale market through a competitive bidding mechanism while most of the electricity transactions in Non-RTO West occur through long-term bilateral contracts negotiated between generator and buyer directly.

As the central system operator and balancing authority in the network, MISO uses a competitive bidding process to organize and co-optimize the energy market (i.e., match generation with electricity demand) and the transactions of operational reserves. This bidding process allows system operators to schedule and dispatch generating resources at their most efficient operating point based on their bid–cost curve. The bidding process for operational reserve transactions incentivizes generators to offer their surplus generating capacity into the reserve market pool based on the marginal cost of reserve supply and provides flexibility for MISO to mobilize reserves when they are needed.

In Non-RTO West, most electricity transactions operate through bilateral contracts. Within each balancing area, generators with bilateral contractual commitments provide the balancing authority with scheduled output before the market clears, and this schedule is fixed regardless of the market price. Although the balancing authority still dispatches these resources to meet the expected demand in its balancing area, it cannot utilize these generating units as operational reserves to respond to changes in generation or demand in real time. Thus, considerable generating resources scheduled based on bilateral contracts reduces the flexibility that the system/market operator has in order to respond to variability or uncertainty in the system. As mentioned in reports from several BAs in the Non-RTO West and interviews, this insufficient flexibility drives the need for more expensive resources to provide flexibility, such as regulating reserves and storage, which increases costs to accommodate a high level of variable generation in the grid.

**Conclusion and discussion**

Massive integration of variable renewable generation imposes a high level of variability and uncertainty on the power system and requires better coordination among transmission network participants to maintain system resilience. Using comparative case studies, this paper examines how network governance affects the effectiveness of power transmission networks regarding wind power integration. We compare the performance and network governance between two regional transmission networks in the US—the MISO network and the Non-RTO West network. They represent two major types of transmission network governance models in the United States, which are different in terms of network structure and coordinating mechanisms/processes. MISO network is an NAO-governed network with MISO as the only core agency among stakeholders from different segments of the power sector. In contrast, Non-RTO West is a hybrid of shared governance among local balancing authorities at the regional level and lead-organization governance within each balancing area.

Consistent with previous studies on network structure, this paper finds that a centralized transmission network is more effective in integrating wind power than a less centralized structure. Moreover, the transmission network cases extend the existing theory by highlighting the linkage between centralization and network effectiveness. As suggested in Proposition 1, a centralized network coordinated by a single core agency allows resource pooling and optimal resource allocation by the central coordinator. This is crucial for the entire system to effectively manage uncertainties imposed by the environment.

In addition, this paper also suggests an alternative path to improved network effectiveness for a less cohesive network, which is through more frequent resource exchange among subgroups within a large network. This finding has the potential to extend the existing theories on cliques, which argues that overlap among cliques enhances network effectiveness (Provan & Sebastian, 1998). Instead of having overlapped members, network performance may also be improved through more frequent resource exchanges between neighboring cliques. The resource exchange is based on geographic proximity rather than shared group members, which can be further tested in other natural resource management networks that operate over large geographic scales.

Regarding the three modes of governance (Provan & Kenis, 2008), the transmission network cases indicate that network governance configurations are sometimes ambiguous to be captured by a single mode. Thus, Proposition 3 needs to be revisited from the two principal dimensions that characterize different modes of governance—level of centralization and source of control. While it is still not clear whether control from an external agency or a network participant leads to better outcomes as a previous empirical analysis indicates (Raab et al., 2013), this paper suggests that the level of centralization does matter for network effectiveness. Particularly, the concentration of decision-making authority is a more substantial determinant than the structural centrality of the core agency.

This paper also contributes to the network governance literature by providing empirical evidence on how to manage the tension between flexibility and stability, particularly when the network operates in a turbulent environment with great uncertainties. Consistent with Proposition 4, both cases show that multiple coordinating mechanisms are embedded in the network governance process to address the
needs for system stability and flexibility. Hierarchical control and formal rules are essential to coordinate various network participants to achieve system stability. However, those external controls are usually created by network participants collectively to achieve shared goals. At the same time, various market mechanisms such as price and competition are also employed to provide more flexibility in the system. In a complex service delivery network, different forms of coordinating mechanisms often coexist and complement each other to enhance system resilience.

As a qualitative case study, this paper has several limitations, which require further investigation in the future. First, although our case study shows that network structural factors (e.g., network centralization, cliques, network governance modes) and coordinating mechanisms exert influences on network performance, we cannot quantitatively compare the magnitude of their effects. Which factors matter most often depends on the context. Isolating the effect of a specific network structural or coordinating factor requires quantitative research designs and data from a larger sample at the transmission network level or the state level (Baldwin & Tang, 2021; Medina et al., 2021). Second, there may be correlations between these factors as suggested by existing network studies in other policy areas (O’Toole & Meier, 2004; Scott et al., 2019). As previous research suggested, these network structural features and coordinating mechanisms are more likely to be interrelated with, moderated by, or mediated by each other (Bryson et al., 2006). However, due to the data limitation, we are unable to address these questions in the paper. Future research is needed to examine the interactions between network structure and coordinating mechanisms to capture the complexity of network governance in the power sector. Third, we only include the state RPS policies to control the confounding effect of state-level renewable energy policy support. It is worth investigating how various state renewable energy policies interact with transmission governance to affect renewable energy adoption with state-level quantitative research.

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**Notes**

1. Wind energy is often referred to “variable energy resource” (VER) because it is intermittent and the variability of generation is subjected to limited control of wind power plant operators.
2. The Federal Energy Regulatory Commission (FERC) is an independent agency that regulates the interstate transmission and wholesale sales of electricity, natural gas, and oil. For details about FERC’s deregulation orders, see FERC Order 888 and 889.
3. The wholesale market in the United States operates in two time frames: day ahead and real time. The real-time market reflects actual physical supply and demand conditions. The day-ahead market operates in advance of the real-time market. The day-ahead market is largely financial, establishing financially binding, one-day-forward contracts for energy transactions. Resources cleared in the day-ahead receive commitment and scheduling instructions from the system operator based on day-ahead results and must perform these contractual obligations or be charged the real-time price for any products not supplied. However, a number of factors, such as unexpected generation or transmission outages, and load forecasting errors, can cause deviation between day-ahead scheduling and real-time dispatching.
4. Balancing area refers to the collection of generation, transmission, and loads within the metered boundaries of a balancing authority.
5. In the bidding process, generators participating in the wholesale market offer an amount of electricity (MWh) for sale during specific periods of the next day at a specific price based on their production costs. These bids are either accepted or rejected by the ISO/RTO based on projected electricity demand within its territory. Generators are scheduled and dispatched from the least-cost bid to higher cost ones until the total demand is matched. The market clearing price is the offer of the last generator dispatched at their location, which is also called locational marginal price and paid to all the generators that are dispatched.
6. Flexibility in a power system refers to the ability of the system to cope with variability and uncertainty in both generation and demand at various operational timescales (Ela et al., 2014; Lannoye et al., 2012; Ma et al., 2013).
7. The only ISO/RTO-governed transmission network in the Western Interconnection is the area coordinated by the California Independent System Operator (CAISO), which is excluded for the purpose of comparing different transmission governance models.
8. Network participants mainly include power producers, transmission system owners/operators, and load serving entities (utilities that purchase electricity in the wholesale market), which involves both public and private entities.
9. Existing research suggests that Renewable Portfolio Standards (RPS) is a major policy tool that promotes wind power in a state’s electricity supply (Carley, 2009; Carley & Browne, 2013; Carley et al., 2018; Kim & Tang, 2020; H. Yin & Powers, 2010).
10. We collected annual market reports and/or reliability reports from 471 participants in MISO network and 420 participants in the Non-RTO West. These reports summarize market operation or transmission system operation from the perspectives of participants in different segments of the power system, including generation and transmission. Balancing authorities in Non-RTO West are mostly overlapped with large utilities that also own and operate transmission systems.
11. News articles were extracted from Factiva through keywords searching. Keywords include “transmission,” “wind power,” “renewable energy,” “interconnection,” “integration,” and “grid operation.”
12. The average capacity factor is calculated as the ratio of observed wind power generation to the potential maximum generation if all wind farms in the region were operated at
their full capacities throughout the year.

13. The Western Interconnection has 38 BAs. Here, we did not include the four BAs outside the US territory and California ISO in my case.

14. In power systems, operating reserves are the generating capacities available to the system operator within a short interval of time to meet demand in case there is an unplanned event disrupting scheduled generation or changes in demand. These may be additional generating units that are standby or generators that are already producing power but can ramp up or down their output upon request.

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