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Research Article

The Political Complexity of Regional Electricity Policy Formation

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The integration of renewable power supplies into existing electrical grids, or other major technology transitions in electric power, is a complex sociotechnical process. While the technical challenges are well-understood, the process of adapting electricity policy and market rules to these new technologies is understudied. Planning and market rules are a critical determinant of the technical success of renewable energy integration efforts and the financial viability of renewable energy investments. Organizational adaptation can be particularly complex in electric power, where transmission grids cross multiple political boundaries and decisions are made not by central authorities or governments, but in cooperative regional frameworks that must accommodate many divergent interests. We add to a recently emerging literature on the governance of regional organizations that plan and operate electric power grids by developing and illustrating a novel approach to the study of political power in multistakeholder electricity organizations. We use semistructured interviews with participants in a specific regional electric grid authority, the PJM Regional Transmission Operator in the Mid-Atlantic United States, to elicit perceptions of where tensions arise in stakeholder-driven processes for changing PJM's rules and perceptions of those groups of stakeholders that possess political power. We treat these perceptions as hypotheses that can be evaluated empirically using five years of data from PJM on how stakeholders voted on a wide variety of regional electricity policy issues. Representing voting behavior as a network, we use a community detection method to identify strong coalitions of stakeholders in PJM that provide support for some stakeholder perceptions of political power and refute other perceptions. The degree distribution of the voting network exhibits a fat tail relative to those in other canonical graph models. We show, using relatively simple network metrics including degree, betweenness, and the mixing parameter, that the reason for this fat tail in the degree distribution is the existence of "swing" voters in RTO stakeholder networks. These voters are identifiable in the tail of the degree distribution of the voting network and are influential in pushing highly contentious rule change proposals towards passage or failure. The method we develop is generalizable to other contexts and provides a new framework for the study of regional electricity policy formation.

1. Introduction

As large-scale electric power systems undergo various types of technological transition, including the integration of large amounts of renewable power generation and an increase in adoption of distributed power generation and electrification of transportation, the rules that govern markets, planning, and operations of the power grid need to adapt along with technology [1–6]. These rules are important for determining the value of technology options that explicitly or implicitly compete to provide electric generation and transmission services [7]. The challenges in integrating weather-dependent wind and solar power into regional electric grids have provided some recent examples of how grid operators have needed to adapt their rules, especially when those grid operators span multiple political jurisdictions (e.g., regional grid operators covering all or parts of several states in the United States or coalitions of national grid operators in Europe). In the United States, grid operators have adapted to rapid growth in wind energy by changing market and generator dispatch rules to minimize the frequency with which wind energy output must be curtailed [5] and have adopted new power transmission planning procedures aimed at finding synergies between wind energy development and other electric transmission needs [8]. In California, growth in solar energy has challenged that state's power grid to be able to balance the rapid decline in solar output that occurs at the end of the daytime period with a coincident increase in demand [4]. The response of the California grid operator has been to establish a new market construct for "imbalance energy" services that are able to increase and decrease output quickly in response to changes in state electricity demand or solar power production. The Irish electric grid operator has responded to increased wind penetration by adjusting market rules to require other generation resources to provide a certain level of system support.

The necessity of power grid operators to adapt planning and operational rules to handle the increased penetration of renewable energy or other technologies on the electric power system is clear, but an underappreciated aspect of this adaptation is that in many jurisdictions the market, planning, and operational rules are made in a collective decision process requiring coordination and negotiation among multiple parties rather than by a government or other central authority [7]. The process of integration of renewable energy or distributed energy resources into large-scale power grids is thus not simply a problem of engineering and technology but is a complex sociotechnical process in which the process for enacting changes in the rules governing power grid planning and operations can have a measurable impact on grid performance after the rule changes have been made [4, 7, 9].

In contrast to the large literature that has used models of distributed decision-making or multiagent models to analyze the impacts of consumer or distributed energy decisions on power grid operations (examples from this voluminous literature include [7, 10–14]), the analysis of how regional power grid operators make decisions has emerged only recently. This literature has largely focused on the governance of regional power grid operators and the relationship between these grid operators and their regulators [2, 4, 15, 16]. Particularly in the United States, however, the rules governing the operation and planning of regional power grids are made in a stakeholder-driven setting that resembles a negotiated political process more than a regulatory process (although the stakeholder-driven proceedings will typically end with the regulatory approving or disapproving of the rule changes supported by the stakeholder group) [17, 18].

Some very recent analyses of these stakeholder processes in regional power grids in the United States have suggested that the decisions emerging from these processes are highly influenced by the structure of the process itself [16–19]. Which parties have standing to participate formally in the stakeholder process, the way that stakeholders are segmented into coalitions, and the voting mechanisms can all shift political power in ways that can be consequential for the performance of the electric power system. Political power within the stakeholder process has been identified in the literature as particularly problematic when stakeholders are asked to make collective decisions on highly contentious issues such as the rules governing incentives for new power plant construction [18]. This literature, however, is not in agreement as to which interests may or may not wield political power in different circumstances.

We provide and illustrate a network-based method for identifying political power structures in the stakeholder-driven organizations (Regional Transmission Organizations or RTOs) that govern the electric power grid in many jurisdictions that have adopted some form of electricity restructuring and deregulation. We illustrate this method using a detailed case study of one particular jurisdiction in North America but the method itself is portable to other contexts. The issue of how RTOs engage in stakeholder-driven self-governance has been raised as an important energy policy issue in the academic literature and by policymakers [15–19], and the approach that we develop and implement opens up the study of restructured electricity market processes to the use of network-based tools. Our paper makes three distinct contributions addressing RTO governance and the development of network tools for electricity policy analysis. First, we synthesize qualitative information from semistructured interviews with participants in RTO stakeholder processes to formulate hypotheses about the distribution of political power in these processes. Second, we use quantitative information from RTO voting histories in the PJM Interconnection to evaluate these hypotheses. We find empirical support for some perceptions of the distribution of political power but not others. Third, we show how relatively simple network metrics contain information that can identify "swing" voters in RTO stakeholder networks. These swing voters have previously been shown to play an important role in enabling or thwarting the ability of the RTO to make changes to its market rules and procedures [17, 18].

We apply this analysis framework to the PJM Regional Transmission Organization in the United States. PJM Interconnect operates the electric grid in all or parts of thirteen states plus the District of Columbia in the Mid-Atlantic region of the United States. In addition to being one of the largest regional power grid operators, PJM makes public highly detailed data on the proceedings of its stakeholder process. The special role and decision structure of the Regional Transmission Organization is described in the remainder of this section. In Section 2, we describe our analysis framework and the process for conducting the semistructured interviews. In Section 3, we provide qualitative evidence from our stakeholder interviews for multiple perceptions of political power; these perceptions serve as hypotheses that we evaluate with our voting network data in Section 4. Based on our analysis of voting data, we find some evidence in support of some of these stakeholder perceptions and evidence that refutes some stakeholder perceptions. We are also able to refute some of these perceptions based on the voting network data. Finally, we show that some simple properties of the voting network are sufficient to identify participants who may possess pivotal voting power in highly contentious issues. Section 5 provides some concluding thoughts and future directions for integrated qualitative and quantitative research into the governance of large energy organizations.

1.1. The Role of Regional Transmission Organizations in North American Electric Power Planning and Operations. The electric power system integrates a highly diverse set of technologies and organizations by means of regional high-voltage transmission grids that can span multiple political jurisdictions. Most of North America, for example, is served through three large-scale power grids that cross state and national boundaries. Many parts of the electric power industry have undergone a process of restructuring and deregulation over the past two decades, involving the unbundling of electric utilities into separate companies for power generation, transmission, and distribution; the creation of competitive markets for power generation (effectively replacing the function of the electric utility or state-owned electricity authority with competitive market signals for power system planning and investment); and, in North America specifically, the increased regionalization of power grid operations through the creation of Regional Transmission Organizations (RTOs). Currently, approximately 70% of all electricity demand in the United States, along with some Canadian provinces and portions of Mexico, is served through Regional Transmission Organizations. A map of those areas in North America that lie within RTO footprints is shown in Figure 1.

The RTO was originally created in the United States to meet regulatory standards for regional coordination in power system planning [21] and broadening of electricity markets to enable generation resources from multiple utilities to compete with one another using the regional transmission grid as a kind of market platform. The formation of RTOs in the United States has been voluntary. Utilities are not required to form or join one of the RTOs but are encouraged to do so by the Federal Energy Regulatory Commission (FERC), which regulates RTO practices. Broadly, the role of the RTO in North America can be described in a few distinct functions:

(i) The RTO is responsible for determining investment needs for power generation and transmission to meet standards for reliable power system operations, but it does not own any physical assets and must provide financial incentives for generation and transmission firms to make needed investments. Many of these incentives come through market signals.

(ii) The RTO is responsible for real-time operations within its footprint (dispatching power generation to meet electricity demand) but the command-and-control capabilities of the RTO are very limited. Most RTOs use market mechanisms to provide financial incentives for power plants to offer electricity production services.

(iii) RTOs are intended to be technology-neutral (they cannot favor one technology or fuel over any other, including renewable and distributed power generation) and the FERC has asked RTOs to operate in a very stakeholder-driven way.

1.2. The Decision Structure of RTOs. With relatively few exceptions, changes to market rules or operational and planning protocols within RTOs happen through a stakeholder-driven process that reflects the many different organizations and interests that make up the electric power sector. Organizations that are typically recognized as stakeholders within the process include power generation and transmission owners (including renewable energy and distributed energy), electric distribution utilities, large electricity consumers (such as manufacturing facilities), and firms that engage in the wholesale trade of electric power. RTOs typically have a large number of formally recognized stakeholders: PJM, the focus of the illustrative analysis in this paper, had 525 recognized stakeholders at the time that we conducted our analysis. These stakeholders are stratified according to one of five defined industry sectors, as shown in Table 1. These industry sectors include End Use Customers (EUC), which primarily represent large industrial electricity users; Electric Distributors (ED), which primarily includes utilities that deliver electricity to retail consumers; Generation Owners (GO), which own and operate power plants; Transmission Owners (TO), which own the high-voltage transmission wires; and Other Suppliers (OS), a diverse group of financial players in electricity markets and firms who offer services like demand curtailment to electricity markets but do not fit easily into any of the other four sector categories.

While the structure of these stakeholder processes varies somewhat by RTO, the movement of a rule change generally involves a few different steps [2, 22]. Proposed RTO rule changes are first debated and discussed in one of a number of thematic working groups or task forces, where there may be more limited participation. Rule changes that are approved by the working group or task force are elevated to a vote by a central committee consisting of all stakeholders. Successful issues are then passed to the RTO Governing Board and then on to the FERC for regulatory approval. It is important to remember that the scope of stakeholder involvement in the RTO is limited to rule changes and not real-time operational decisions or planning outcomes. For example, the stakeholders in an RTO might determine the specific reliability criteria that are used in a transmission planning study or they might determine the level of the price cap for offers into an RTO's electricity market, but the stakeholders would not have any direct involvement in the conduct of planning studies or the clearing of markets.

The analysis in this paper uses the PJM stakeholder process and voting data from that process as an illustrative case study. The central committee in PJM, which votes on all proposed rule changes, is referred to as the Members Committee (MC). All stakeholders are eligible to vote on any issue that is brought before the MC. The MC in PJM is interesting not only because of how much detailed voting data

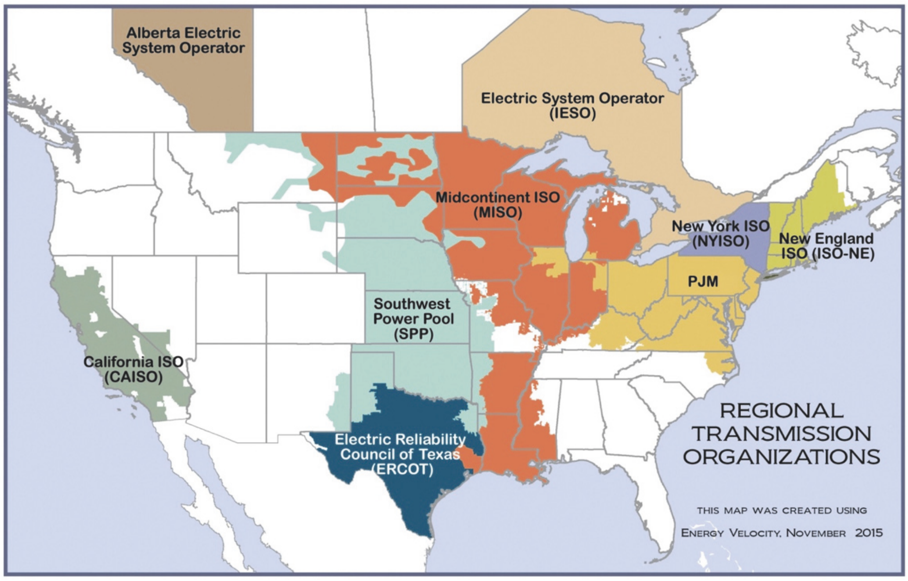


FIGURE 1: RTOs in North America. The PJM RTO, which is the focus of our case study, covers the Mid-Atlantic United States. *Source: Federal Energy Regulatory Commission.*

TABLE 1: Composition of voters in the PJM Members Committee (MC). Source: [18], based on data from [20].

Sector	Number of Firms (%)	Example Firms
End Use Customers (EUC)	21 (4%)	Air Products, Proctor & Gamble
Electric Distributors (ED)	43 (8%)	Old Dominion Electric Cooperative, Northern Virginia Electric Cooperative
Generation Owners (GO)	95 (18%)	Calpine, NRG
Transmission Owners (TO)	14 (3%)	Duquesne Light, PSEG
Other Suppliers (OS)	354 (67%)	Direct Energy (Curtailment Service Provider), Citigroup Energy (Financial), EDF Trading (Marketer)

is available from the proceedings of this committee, but also because the PJM MC has perhaps the greatest degree of rule-making authority of any North American RTO. They make decisions on behalf of all the others who could not participate on operating rules and policies. The MC uses a system of *sector-weighted voting* in which all five industry sectors (as outlined in Table 1) are equally weighted and the vote of each individual member carries identical weight within a sector. When voting, all participants vote yes or no or abstain on a single issue, producing a sector-specific voting score that measures the proportion of voting stakeholders in that sector supporting the rule change. The final voting score $\boldsymbol{V}$ is the sum of all sector-level scores, defined as

$$\boldsymbol{V} = \sum_{k} \sum_{j=1}^{(n_k - a_k)} w_{jk} = \sum_{k} \sum_{j=1}^{(n_k - a_k)} \frac{\delta_{jk}}{n_k - a_k} \qquad (1)$$

where δ_{jk} is an indicator variable equal to one for a yes vote of voter j in sector k and zero for a no vote. n_k is the total number of voters in sector k, and a_k is the number of abstention votes in sector k. Abstention votes are excluded when counting the total number of votes and thus have the same effect as a smaller number of sector voters; i.e., abstentions increase the weight of an individual voter. Note that as the number of voters in a sector increases, the weight of an individual voter in that sector $(1/(n_k - a_k))$ declines. In the PJM stakeholder process, an issue passes if the final voting score $\boldsymbol{V}$ exceeds 3.335, roughly equivalent to a two-thirds majority among the five sectors. This implies that any two sectors could jointly prevent passage regardless of the number of voters in those sectors.

Table 2 illustrates a *hypothetical* voting result, taken from [18], that results in passage, with a total voting score of 3.457. The column showing the percentage of votes in favor is

Table 2: Sector-weighted voting example. Source: [18].

Sector	For	Against	Abstain	Total	Total - Abstain	% in favor
Transmission Owner (TO)	8	2	4	14	10	0.8
Generation Owner (GO)	15	0	1	16	15	1
Other Supplier (OS)	10	10	5	25	20	0.5
Electric Distributor (ED)	3	7	15	25	10	0.3
End Use Customer (EUC)	12	2	0	14	14	0.857
					Final voting score $\boldsymbol{V}$	3.457

calculated by taking the proportion of *For* votes relative to the total of *For* plus *Against* votes. Abstentions are not counted at all in the voting process.

The decisions made by the PJM MC are highly consequential to the functioning of PJM's electricity markets and the economic incentives faced by different power generation technologies: these rules and incentives effectively emerge from the many individual voters in the stakeholder process, which have their own commercial interests. The relative power of various coalitions (groups of stakeholders whose interests are aligned across one or more issues) and the behavior of voters that do not neatly align with identifiable coalitions play an important role in determining which power grid rules are adopted and which rules are not adopted. The performance of the physical power grid is thus inextricably tied to the behaviors in the stakeholder process. Some recent work has questioned the effectiveness and of PJM's stakeholder process [16, 19], pointing out that rule changes have become so contentious as to make the passage of any rule change very difficult, and also questioning the degree to which the sector definitions themselves may concentrate political power and influence voting outcomes.

Our work addresses a number of important RTO governance issues raised by this body of literature by describing and illustrating a novel approach that uses mixed methods of qualitative interview data with voting network analysis to identify strong voter coalitions that could act in a coordinated fashion and screen for the existence of pivotal voters who may be able to swing voting outcomes in certain directions.

2. Methods

In this section we provide a high-level overview of the analytical approach that we use to identify political power in RTO stakeholder processes. This method integrates qualitative information gleaned from semistructured interviews with a network analysis of RTO stakeholder voting data to develop quantitative measures and draw conclusions about political power. The method that we employ draws from two distinct research philosophies, the theory of engaged scholarship as described by van de Ven [23] and the grounded theory approach from Strauss et al. [24–26]. The engaged scholarship approach to developing organizational knowledge emphasizes the need for repeated practitioner interaction to define and refine relevant research questions and ensure that research results are relevant to the organizational frameworks being studied. Our analysis has some common threads with grounded theory in that we allowed our interactions with practitioners, through semistructured interviews, to assist in defining the problem and identifying relevant analytical hypotheses.

A schematic of our overall approach is shown in Figure 2. Semistructured interviews were conducted with several dozen stakeholders in multiple RTOs, and the qualitative information from these interviews was used to identify perceptions of the stakeholder process by those who were participants in that process (panel A in Figure 2). These perceptions will be discussed in more detail in Section 3. Taking some of those perceptions as hypotheses provided a framework through which we could build voting networks and examine properties of those networks (panel B of Figure 2). These network properties then gave us metrics or other information that could be used to determine which stakeholder perceptions were consistent with the voting data and which were not (panel C of Figure 2). Specific voting issues could be analyzed using the voting network data or other models to generate predictions about the outcome of similar voting issues (as was done in prior work on "capacity markets" in RTOs, which are forward markets for electric generation capacity), and computational experiments can be run to examine possible voting outcomes under different stakeholder process structures or voting rules and how those voting outcomes manifest themselves in the performance of the power grid or of electricity markets (panel D). The whole research process can eventually circle back to the stakeholders themselves (moving from panel D to panel A).

The analysis in the present paper is focused primarily on showing how qualitative information can be used to build quantitative theories in electricity policy formation through RTO stakeholder processes. It thus effectively covers panels A through C in Figure 2.

3. Using Semistructured Interview Data to Generate Perceptions of Political Power in RTO Stakeholder Processes

During the summer and fall of 2014, approximately 70 individual interviews were performed with stakeholders and RTO staff at three RTOs in the United States: PJM, the Midcontinent ISO, and the California ISO. Figure 3 shows a breakdown of the types of respondents in our interviews. A group of initial interviewees spanning the industry sectors identified in Table 1 was initially selected, and additional

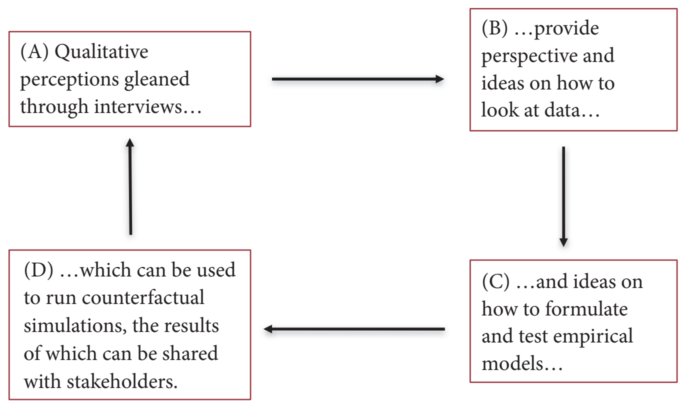


Figure 2: A model of integrating qualitative and quantitative data on electricity policy formation.

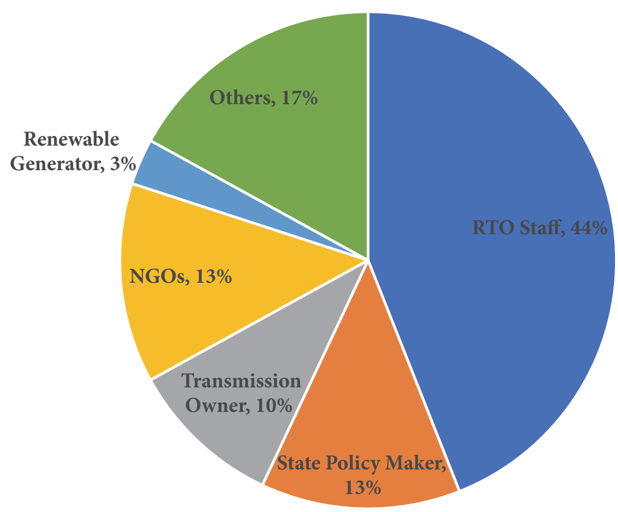


Figure 3: Distribution of respondents to semistructured interviews.

respondents were identified via the snowballing method. One-third of these interviews were with stakeholders and RTO staff in PJM, which is the focus of our illustrative case study. The interviews were conducted in-person as well as over the telephone and ranged from 45 to 90 minutes in length. In addition to interviewing stakeholders, we reviewed a number of public documents related to the stakeholder process and attended several working group meetings as well as meetings of the full Members Committee in PJM.

Respondents were chosen based on a review of PJM documents and identifying individuals and organizations that were active and experienced, particularly in issues related to the integration of renewable energy into large-scale power grids. Our initial group of respondents also spanned the industry sectors identified in Table 1. We engaged in some snowballing to identify additional interview respondents beyond those identified in our original document search. Each interview was professionally transcribed and then coded in the NVIVO environment by the research team. Second-level coding within NVIVO focused on categories such as political power, shifts in the dynamics of the stakeholder process, and the complexities involved in seeing a proposed rule change through to completion. Quotes used in this paper are representative of perceptions shared with the research team by multiple respondents, and respondents are identified only as [PJM-XX]. We describe the context of these observations here and summarize the quotes in Table 3.

The semistructured interview format, along with the set of questions for respondents, is described in more detail in the Appendix. We note that because of the semistructured nature of the interviews few constraints were placed on the path of the conversation with each respondent other than to focus the conversation on the stakeholder process.

In our interviews with PJM stakeholder participants, we observed that many perceived the stakeholder process as becoming more complex and time-consuming, in part because the total number of stakeholders has grown as more participants have joined PJM's markets. One of our stakeholder participants observed, "You needed significantly smaller rooms to have the meetings. The intensity of disagreements was just as great as today. There were things they never reached agreement on but there was definitely more of a spirit of, 'We're all in this together and we need to make it work,' than there is today" (PJM-01). This perception was shared

Table 3: Summary of PJM Stakeholder Perceptions.

Perception in the PJM Stakeholder Process	Illustrative Stakeholder Quote
Growth in the number of stakeholders, and increasing conflicts in commercial interests among stakeholders, are creating challenges in moving rule changes forward.	You needed significantly smaller rooms to have the meetings. The intensity of disagreements was just as great as today. There were things they never reached agreement on but there was definitely more of a spirit of, 'We're all in this together and we need to make it work,' than there is today" (PJM-01).
The stakeholder process has become factionalized into consumer-side interests and supply-side interests. (Note that "load" is electricity-industry parlance for consumers.)	"The problem that some people find is that one side can stymy the other. You have generation, transmission, load, and so on. Generation's always worried that load can stop them from doing things. Load is worried about generation." (PJM-02).
Perceptions that consumer-side interests have more political power.	"There is a lot of leverage on the load side." (PJM-03); What you actually find now is the load interest, where it used to be they had about 50 percent of the vote, they now have 65 percent of the vote." (PJM-04.)
Perceptions that supplier-side interests have more political power.	"[The stakeholder process is] tilted towards the supplier side" (PJM-05); "There have certainly been complaints by load that…PJM pushed through a whole bunch of changes through the capacity market without really knowing how they were going to interact with each other." (PJM-03)

by a number of our stakeholder respondents across multiple sectors of the PJM market.

Along with the perceptions of increased tension within the stakeholder process and a greater level of effort required for the process to culminate in a passable rule change when rule changes were needed, we also observed different perceptions of which stakeholder groups were more or less influential, either in pushing rule changes through the Members Committee or in stopping rule changes from being approved. One observer of the stakeholder process noted that "The problem that some people find is that one side can stymy the other. You have generation, transmission, load, and so on. Generation's always worried that load can stop them from doing things. Load is worried about generation." (PJM-02).

We observed multiple stakeholder respondents suggesting that since consumer-side (or "load") interests dominated two of the five sectors in the PJM stakeholder process that these consumer-side interests were able to exercise substantial political power. According to one such respondent describing the voting process in the Members Committee, "There is a lot of leverage on the load side." (PJM-03). An observer of the stakeholder process reported, "What you actually find now is the load interest, where it used to be they had about 50 percent of the vote, they now have 65 percent of the vote." (PJM-04).

We also observed multiple stakeholder respondents suggesting the opposite: that supply-side (or "generation") interests were able to exercise substantial political power in the PJM Members Committee. One consumer-side respondent expressed the belief that the process was "tilted towards the supplier side" (PJM-05), while another observer noted that "There have certainly been complaints by load that…PJM pushed through a whole bunch of changes through the capacity market without really knowing how they were going to interact with each other." (PJM-03).

4. Finding Evidence of the Perceptions on Political Power via Voting Network Analysis

Multiple organizational and political processes have been represented using network-based tools [27–33]. The present analysis is the first to do so in the context of regional electricity markets and is motivated by the use of voting data to support or refute the stakeholder perceptions identified in Section 3. The perceptions about the PJM stakeholder process elicited as part of our semistructured interviews suggest two possible hypotheses about the balance of political power.

Hypothesis 1. Supplier-side perceptions are correct, and consumer-side interests possess substantial political power in the Members Committee.

Hypothesis 2. Consumer-side perceptions are correct, and supplier-side interests possess substantial political power in the Members Committee.

If the perceptions of supply-side interests are correct and consumer-side interests jointly possess a substantial amount of political power, we should observe a strong voting bloc among the two consumer-side sectors in the PJM stakeholder process (the ED and EUC voters). If the perceptions of consumer-side interests are correct, we should observe a strong voting bloc among generation firms in the PJM stakeholder process (principally those stakeholders in the GO and TO sectors). We represent several years' worth of stakeholder voting data from PJM as a network (Section 4.1) and use a community detection method [34] to identify coalitions from the voting data (Section 4.2).

Prior analysis of some specific issues in the PJM stakeholder process [19] has found circumstances in which a few voters can sway a voting result. While this prior work showed the importance of such "swing voters" in determining the outcomes of highly contentious voting issues, in the present paper we use the structure of the voting network to specifically identify these swing voters. We compare the structure of the PJM voting network with several canonical graph models of similar size to the PJM voting network. We observe similar properties in the PJM voting network as would emerge from a model of preferential attachment (we would expect such homophily if stakeholders' perceptions of a strong voting bloc are correct), but we also observe a small number of stakeholders exhibiting a higher node degree than would be expected from a preferential attachment network.

We argue in Section 4.3 that these high-degree voters are effectively swing voters who tend not to vote with any of the identified voting blocs on a consistent basis. Since betweenness centrality has been identified in the literature as an indicator of power within a social network [29, 35–38] we also examine this measure as a potential way to identify swing voters. Finally, we also use the detected community structure to calculate the mixing parameter for each voter and evaluate that as an identifier for a swing voter. We then examine the actual voting behavior for each stakeholder identified as a swing voter by each network structure measure and calculate a false-positive rate for each measure.

This section of our analysis utilizes firm-level voting data from the PJM Members Committee since detailed voting data is only available for that specific stakeholder body. We are not able to quantitatively describe political power in any of the lower-level working groups or task forces, since data from those proceedings are not made public. We gathered data from PJM that contains information on 26 voting items from 2011 to 2015, including the outcome of each vote and the way that each stakeholder voted (we note that by aggregating data across a five-year period we are ignoring any dynamic changes to the structure of the voting network. While this structure may change from year to year depending on the kinds of voting issues presented to the PJM MC, we note that over this period there were very few changes in the composition of the stakeholder group in PJM). Our dataset also includes stakeholder information such as name, sector, subsector, and other asset-related information about specific stakeholders.

4.1. Construction of the Voting Network for the PJM Members Committee. We gathered data from PJM that contains information on 26 voting items from 2011 to 2015. The dataset includes a brief description of the issue being voted on, the outcome of each vote, and that way that each stakeholder voted. Our dataset also includes stakeholder information such as name, sector, and other information about specific stakeholders. Unlike many social networks there is thus little semantic information that we can use to identify ideological preferences or alignment among voters [39]. We use this voting data to construct an undirected voting network [30, 33, 40], in which a vertex represents a single voter in the MC and is connected to another vertex when the two vertices (voters) vote on the same side, yes, no, or abstain, on the same issue. A connection in our voting network thus represents ideological alignment between two voters on a specific issue. In this way our voting network has some commonalties with the similar-view networks constructed on social media platforms [41]. The connections, or edges, are weighted by the frequency of the two connected voters voting together. Figure 4 shows the voting network in the PJM MC when connections represent two stakeholders voting "no" on a specific issue (the no network), while Figure 5 shows the voting network in the PJM MC when connections represent two stakeholders voting "yes" on a specific issue (the yes network). We did construct a network for abstentions, but this network turns out to be quite sparse so it is not shown here.

In Figures 4 and 5, vertices are located on one of the five axes representing each industry sector in an order of degree and the size of vertices is proportional to the weighted degree. Edge colors represent different detected communities, as described further in Section 4.2. Among 147 nodes in the network, there are 21 GOs, 18 TOs, 61 OS's, 30 EDs, and 17 EUCs. The no network has 8,173 edges and an average degree of 111.2 as well as an average weighted degree of 284.83; the yes network has 8,853 links with an average degree of 119.63 and average weighted degree of 505.54.

4.2. Detection of Strong Coalitions. We apply the Louvain method [34, 40] to discover the community structure of the PJM voting network. A number of different community detection algorithms exist [42–46]; we chose the Louvain method because our network has a relatively small number of nodes and relatively large average mixing parameters [45]. The algorithm maximizes modularity through iterative process of clustering nodes and altering community assignments. The modularity is a function that measures the difference between the number of edges within communities and the expected number of randomly placed edges; it has been used in a number of studies of community structure [33, 40, 47–51]. Thus, high modularity is desirable for searching community structure since it implies that there are more edges than expected within communities, or nodes in the same community are more connected than expected [34, 40, 47, 52]. Hence, the scheme optimizes the modularity measure over the possible segmentation of a network and finds a division that produces the largest modularity value. Equation (2) is a mathematical representation of the modularity measure [34] where Aij is the edge weight between vertices i and j, k_i represents the sum of edge weight of vertex i, and ci is the assigned community of vertex i. $m = (1/2m)\sum_{i,j} A_{ij}$ and the delta function $\delta(a,b)$ is 1 if $a = b$ and 0 otherwise.

$$Q = \frac{1}{2m}\sum_{i,j}\left[A_{ij} - \frac{k_i k_j}{2m}\right]\delta\left(c_i, c_j\right) \quad (2)$$

The community detection algorithm identifies three distinct communities in the no network, indicated by the green, yellow, and orange colors in Figure 4. It identifies two distinct communities in the yes network, indicated by the red and blue colors in Figure 5. In the context of voting, we interpret an identified community as a *coalition*, meaning voters in the same community voted more frequently together than voters of the other communities.

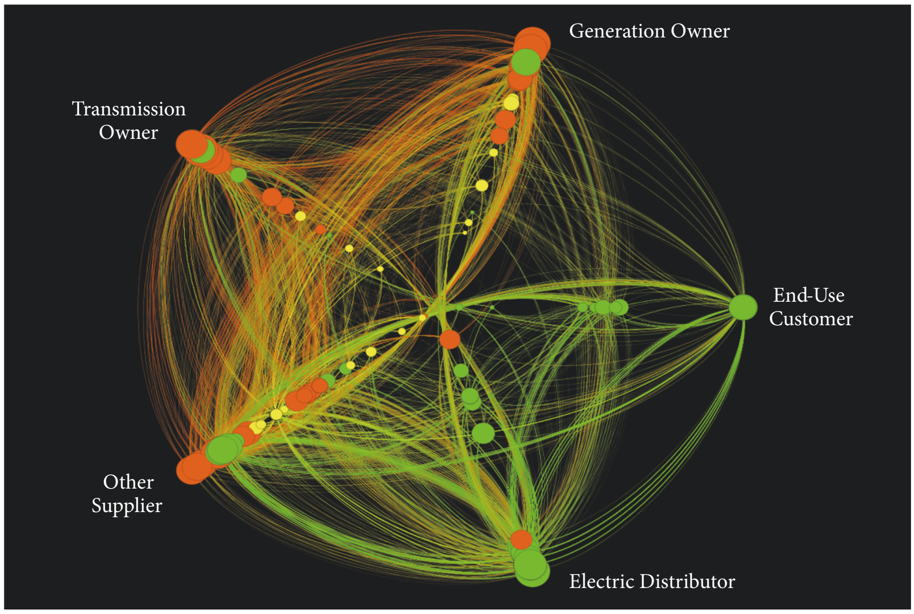


Figure 4: The no voting network in the PJM Members Committee from 2011 to 2015. The node and edge colors correspond to the three different communities detected within the no network.

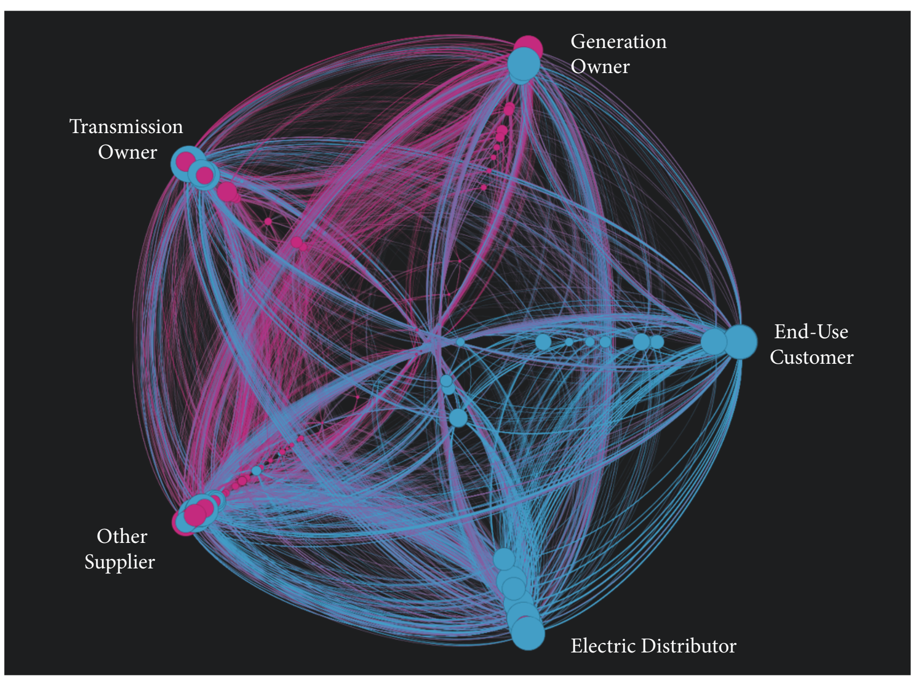


Figure 5: The yes voting network in the PJM Members Committee from 2011 to 2015. The node and edge colors correspond to the two different communities detected within the yes network.

Table 4 shows the number of voters in the communities by sectors in the no network, while Table 5 shows the yes network. Voters in the ED and EUC sectors tend to be entirely contained within the ED-EUC community, while voters in the GO and TO sectors are distributed more evenly among the identified communities.

We acknowledge that modularity may show a *resolution limit* that suggests failure to detect small size communities and there are potential improvements to this limitation [46, 53]. Although this could remain as a future work, this study focuses on identifying sizable coalitions that could exercise political power (e.g., veto power). Still, to address a concern

Table 4: The number of voters in the detected communities by industry sectors (no network).

	Community 1 (orange)	Community 2 (yellow)	Community 3 (green)	Total
Generation Owners (GO)	13 (62%)	5 (24%)	3 (14%)	21
Transmission Owners (TO)	11 (61%)	3 (17%)	4 (22%)	18
Other Suppliers (OS)	25 (41%)	21 (34%)	15 (25%)	61
Electric Distributors (ED)	2 (7%)	0 (0%)	28 (93%)	30
End-Use Customers (EUC)	0 (0%)	0 (0%)	17 (100%)	17

Numbers in parenthesis are percentages of voters in each community within a sector.

Table 5: The number of voters in the detected communities by industry sectors (yes network).

	Community 1 (red)	Community 2 (blue)	Total
Generation Owners (GO)	18 (86%)	3 (14%)	21
Transmission Owners (TO)	13 (76%)	4 (24%)	17
Other Suppliers (OS)	41 (65%)	22 (35%)	63
Electric Distributors (ED)	1 (3%)	29 (97%)	30
End-Use Customers (EUC)	0 (0%)	17 (100%)	17

Numbers in parenthesis are percentages of voters in each community within a sector.

of the quality of detected communities, we adopt a measure called *mixing parameter* [42, 54]. This parameter is defined as

$$\mu = \frac{k_i^{out}}{k_i^{in} + k_i^{out}}, \tag{3}$$

where k_i^{out} is the external degree of node i, meaning the number of edges connecting node i outside its community (or, intercommunity edges), and k_i^{in} is the internal degree of the node or the number of intracommunity edges. If μ is high, the communities are not well defined. In other words, a high value of the mixing parameter indicates that vertices are more connected to vertices of different communities than within the community. The threshold for a "high" value of μ varies in the literature. Reference [55] suggests that any value of μ greater than 0.5 is considered large, while [42] suggests a criterion for μ to be smaller than $(N - n_c)/N$, where N is the total number of nodes and n_c is the number of nodes of the community c. Tables 6 and 7 show the mixing parameters by identified communities in the no and yes networks, respectively. All communities identified in the PJM voting network satisfy the condition suggested by [42], having lower average μ than $(N - n_c)/N$. Only community 2 in the no network (made up largely of voters from the ED and EUC sectors and thus representative of a consumer coalition) has average μ lower than 0.5, which would satisfy the mixing-parameter threshold suggested in [55]. The consumer coalition in the both the no and yes networks has the lowest average mixing parameter, suggesting that voters in the consumer coalition tend to have the same position with the coalition more frequently compared to voters in the supplier coalition.

The strong consumer-side coalition that we identify is consistent with the perception of some of our interview respondents that consumer-side interests wield a greater amount of political power than supplier-side interests. Recall that because of the structure of the voting system in the PJM Members Committee; two sectors that vote in the same way can effectively prevent any potential rule change from passing. The strong ED-EUC coalition suggests that consumer-side interests do possess structural voting power. We do see evidence in the voting data set of four instances in which a proposed rule change failed to pass because the ED-EUC coalition. We do not, however, see evidence in our voting data of a strong supplier-side coalition that is able to ensure or prevent passage of any proposed rule change. Information from our interviews does shed some light on why consumer-side interests are able to form a stronger coalition than supplier-side interests. As one of our stakeholder respondents put it, "Therefore, when there's a load interest or industrial interest vote, you . . . get Generators voting yes, and the reason is because they're actually industrial customers disguised as Generators." (PJM-04). The implication from this quote is that stakeholders in the GO and TO sectors have a more heterogeneous set of interests than voters in the ED or EUC sectors.

4.3. Topological Structure of the Voting Network. Although there have been numerous studies of identification of communities, to the best of our knowledge, topological structure of a voting network is not well-explored, especially given the lack of studies on RTO governance. In this section, we compare degree distribution of PJM MC's voting network to those of common abstract network models: Erdős-Rényi (ER), small-world (SW), and preferential attachment (PA). By doing so, we would be able to check whether the voting network has similar properties of abstract network models and to put the PJM's voting network in the context of existing social network literature.

Table 6: Mixing parameters in detected communities in the no network.

	Community 0 (Supplier coalition)	Community 1 (Supplier coalition)	Community 2 (Consumer coalition)
Number of nodes in the community	51	29	67
Range of mixing coefficient μ within a community	[0, 0.667]	[0.48, 0.769]	[0.147, 0.514]
Average mixing coefficient μ of a community	0.556	0.682	0.449
$(N - n_c)/N$	0.653	0.803	0.544

Table 7: Mixing parameters in detected communities in the yes network.

	Community 0 (Consumer coalition)	Community 1 (Supplier coalition)
Number of nodes in the community	75	73
Range of mixing coefficient μ within a community	[0.049, 0.485]	[0.088, 0.61]
Average mixing coefficient μ of a community	0.417	0.464
$(N - n_c)/N$	0.493	0.507

A summary of our synthetic networks is shown in Table 8. The synthetic networks that we generate are designed to have the same number of nodes and a similar number of edges as the PJM voting network. Our structural analysis uses a version of the PJM voting network with near-unanimous votes removed, since these votes will tend to inflate the node degree distribution. After producing synthetic networks, we tested whether they have a power-law degree distribution by Kolmogorov-Smirnov (KS) goodness-of-fit test (based on 1,000 simulations) [48, 56–58]. Parameters for generating an ER random network [59] are the number of nodes and the probability for drawing an edge between two arbitrary nodes, which in our case is the total number of edges divided by all the possible number of edges with 147 nodes. The parameters for generating small-world networks [60] are dimension of the lattice, number of nodes, number of neighbors, and rewiring probability. We use one dimension, 147 nodes, 28 neighbors, and a rewiring probability of 0.3. The number of neighbors, 28, is set to yield a similar number of edges as the actual PJM voting network (4,116 edges). We generate three small-world networks by three different rewiring probabilities (0.2, 0.3, and 0.5) [60–62]. Finally, we created a scale-free network with 147 nodes and 4,290 edges. To have similar number of edges to the PJM voting network, we specified 33 edges to be added in each time step of the network growth.

Even though the average degrees are similar, the degree distributions show different shape: Figure 6 shows cumulative degree distributions (in log-scale) of all three synthetic networks and the PJM no voting network. The degree distributions of the ER random and the small-world networks are more concentrated around their average degrees than commonly observed synthetic networks, which is due to a small number of nodes ($n = 147$) with high probability of drawing edges ($p = 0.408$). The degree distribution of the PJM MC voting network exhibits similar shape to that of the preferential attachment network but the longer tail is more pronounced.

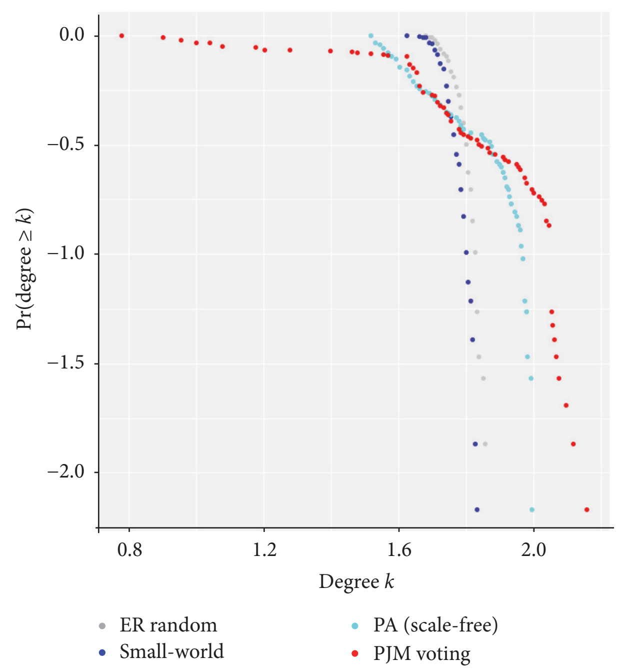


Figure 6: Cumulative degree distribution of the ER random (grey), the small-world (blue), the scale-free (cyan), and the PJM voting (red) networks.

Kolmogorov-Smirnov (KS) tests, also shown in Table 8, reject the null hypothesis that the tested sample is drawn from the power-law distribution. While this is surprising (particularly for our synthetic preferential attachment graphs), examination of the tails of the degree distributions shows why. Figure 7 shows the power-law fit for both the synthetic preferential attachment graph and the PJM voting network. Both have fast-decaying tails but have a small number of nodes with a larger than expected degree.

Based on the structure of the PJM stakeholder process, we argue that these tail voters are likely swing voters, who

Table 8: Comparison between the PJM voting network and synthetic networks.

	PJM voting network	Erdős-Rényi	Small world			Preferential attachment
			p = 0.2	p = 0.3	p = 0.5	
Number of nodes	147	147	147	147	147	147
Number of links	4381	4380	4116	4116	4116	4290
Average degree	59.67	59.59	56	56	56	58.37
Range of degrees	[6, 144]	[48, 72]	[43, 70]	[46, 69]	[42, 68]	[33, 99]
Range of betweenness centrality	[0, 0.06157]	[0.00258, 0.00595]	[0.00226, 0.00667]	[0.00224, 0.00633]	[0.00231, 0.00653]	[0.00067, 0.01134]
Power-law exponent	3.205	8.637	8.285	8.127	8.038	2.93
KS t-test result	0	0.011	0	0	0	0

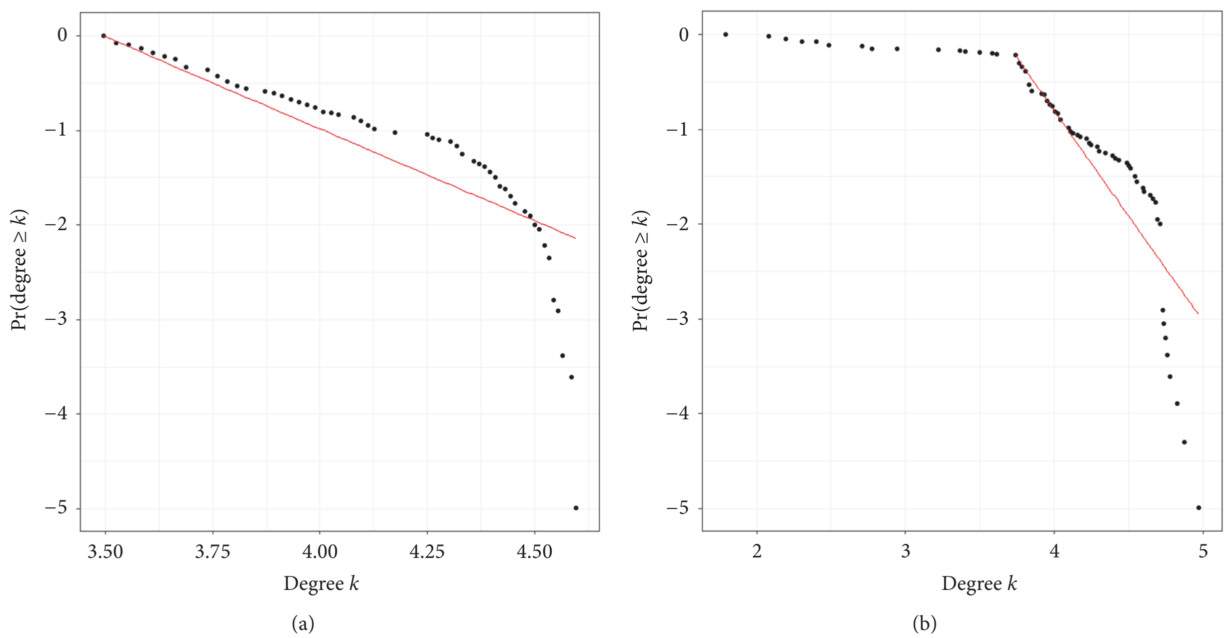


Figure 7: Power-law fitting of (a) the scale-free network and (b) the PJM voting network.

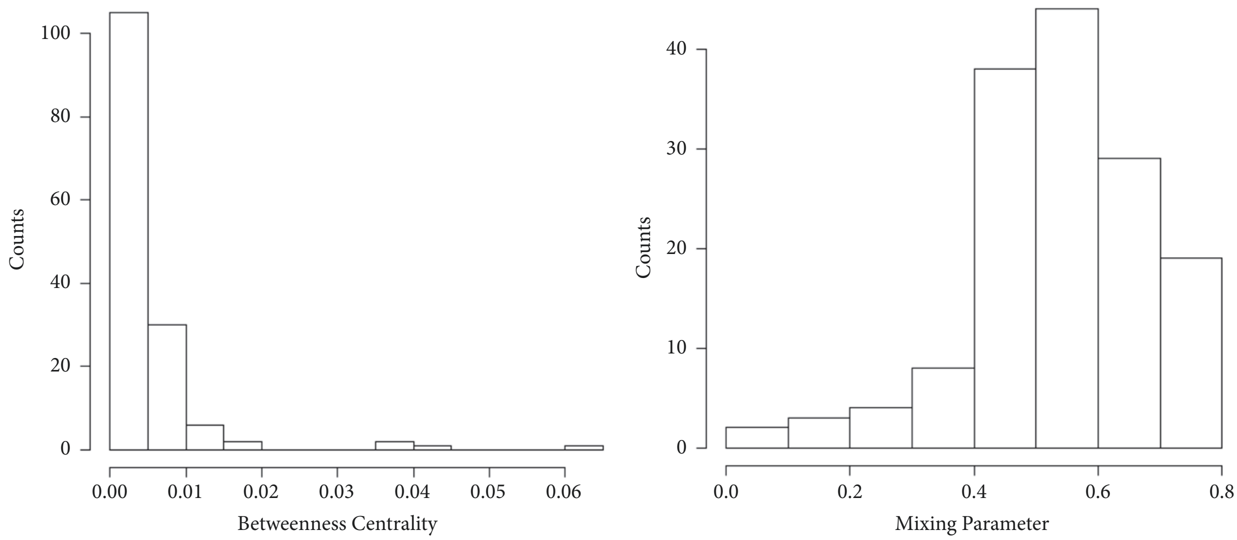
may be able to sway the final voting outcome by switching their positions. Our reasoning behind this argument is that if a voter is connected by a degree to which one can explain with homophily, then the voter is just following a common behavior: voting with others who have shared interests. If, however, a voter is connected to more voters than we can explain with homophily, then it means that the voter has voted with diverse groups of voters who might have opposite interests. In other words, given the community structure that we have detected in the PJM MC the voters in the tail of the degree distribution in Figures 6 and 7 are those who have voted with all of the coalitions at various points.

We thus have a more nuanced view of how to capture whether the tail voters are, in fact, swing voters. We have already seen how we expect swing voters to have high degree. Because our voting network covers a number of different voting issues over a period of five years, a swing voter would also be one that connected two voters that otherwise are unconnected. Thus, we would also expect swing voters to have high betweenness centrality. Finally, we would also expect swing voters to be connected to multiple detected communities (i.e., sometimes voting with consumer interests and sometimes voting with supplier interests), implying a high mixing parameter for these voters. Figure 8 shows the betweenness centrality distribution and the mixing-parameter distribution of the PJM voting network. Most voters in the network have low betweenness centrality value, between 0 and 0.01, but there are a few that have extremely higher betweenness centrality than the other nodes; four voters have the centrality over 0.03 including one voter with the centrality value over 0.06. The mixing-parameter distribution is more symmetric than the betweenness distribution, though it is somewhat left-skewed.

To examine whether our network structure measures (node degree, betweenness centrality, and mixing parameter) are sufficient to identify swing voters, we correlate these measures for potential swing voters (those in the tail of the degree distribution) with the proportion of time that these voters voted with the consumer coalition on issues that we identified as contentious: based on issue's clear divisiveness between consumers and suppliers and existence of strong coalition formation (an example of such a contentious issue was a set of proposed pricing changes in PJM's market for generation capacity, further described in [19]. Some of these proposed pricing changes would have clearly benefited suppliers and harmed consumers, while others would have had the opposite effect. We identified twelve such contentious issues for this analysis). Voting with the consumer coalition very frequently or very infrequently would suggest that the voter in question was not actually a swing voter. Thus, network structure measures can detect potential swing voters, while a review of the frequency of voting with the consumer coalition acts as a kind of false-positive test.

Table 9 shows the frequency of a false positive when we attempt to identify swing voters using each of our three structural measures. Each column of Table 9 shows the top fifteen voters (identified by name) based on node degree, betweenness centrality, and mixing parameter. The percentage figure next to each voter's name is the frequency with which that voter voted with the consumer coalition on contentious issues.

We note a few important observations about Table 9. First, there are relatively few voters that are identified as potential swing voters based on all three network metrics. Direct Energy and Enerwise are example of voters that are identified as potential swing voters regardless of the network metric used. Second, the false-positive rate for



(a) (b)

Figure 8: Histogram of (a) (normalized) Betweenness centrality and (b) mixing-parameter distribution of the PJM voting network.

Table 9: Top fifteen voters in the PJM voting network based on node degree, betweenness centrality, and mixing parameter. The figures in the % column represent the frequency with which each voter voted with the consumer coalition on contentious rule changes in PJM.

Degree	**%**	**Betweenness Centrality**	**%**	**Mixing parameter**	**%**
Brookfield Energy Marketing LP	38%	Brookfield Energy Marketing LP	38%	Direct Energy Business, LLC	50%
Potomac Electric Power Company	40%	Potomac Electric Power Company	40%	Enerwise Global Technologies, Inc	33%
PBF Power Marketing LLC	40%	PBF Power Marketing LLC	40%	MidAtlantic Power Partners, LLC	50%
Enerwise Global Technologies, Inc	33%	TransCanada Power Marketing Ltd	25%	Iron Mountain Generation LLC	33%
Direct Energy Business, LLC	50%	Central Virginia Electric Cooperative	100%	West Deptford Energy, LLC	33%
Iron Mountain Generation LLC	33%	Virginia Electric & Power Company	0%	Black Oak Energy, LLC	50%
Central Virginia Electric Cooperative	100%	Energy Consulting Services, LLC	100%	Apple Group, LLC	33%
West Deptford Energy, LLC	33%	Invenergy LLC	0%	Dyon, LLC	33%
Apple Group, LLC	33%	Enerwise Global Technologies, Inc	33%	E Minus LLC	33%
Dyon, LLC	33%	Direct Energy Business, LLC	50%	Great Bay Energy I, LLC	33%
E Minus LLC	33%	Galt Power Inc	100%	Hexis Energy Trading, LLC	33%
Great Bay Energy I, LLC	33%	Borough of Lavallette, New Jersey	100%	Mac Trading, Inc	33%
Hexis Energy Trading, LLC	33%	The Trustees of the University of Pennsylvania	100%	Monterey MA, LLC	33%
Mac Trading, Inc	33%	Borough of Madison, New Jersey	100%	Pure Energy, Inc	33%
Monterey MA, LLC	33%	Borough of Milltown, New Jersey	100%	BJ Energy, LLC	33%

betweenness centrality as a swing voter identification metric is quite high. Two-thirds of those identified as swing voters using betweenness centrality either voted with the consumer coalition 100% of the time on contentious issues or never voted with the consumer coalition on contentious issues. By this criterion, the false-positive rate for node degree is one out of fifteen, and the false-positive rate for the mixing parameter is zero. The betweenness centrality may in this case be capturing voters that make connections between the nonconsumer coalitions. Finally, we note a high degree of overlap between those voters identified as potential swing voters using node degree and those identified using the mixing parameter. Eleven of the voters identified as potential swing voters using node degree were also identified using the mixing parameter.

5. Conclusion

Technological change in electric power systems requires not only that physical systems adapt to integrate new technologies and market players, but also that policies and rules adapt to support that technological integration. The process of policy and rule adaptation in many areas of the world is not driven by the decisions of governments or other central decision-making authorities but emerges as the output of a political process involving stakeholders representing many divergent interests. These stakeholder-driven decision processes can be modeled theoretically, but the literature on governance of regional electricity organizations has only recently attempted to do so.

This work adds to an emerging body of literature on stakeholder decision processes and electricity policy formation by developing and illustrating a novel method for integrating qualitative information elicited from stakeholder perceptions with quantitative voting data; using community detection methods to identify political coalitions among stakeholders in Regional Transmission Organizations; and leveraging voting network structure to identify potential swing voters in the stakeholder group. Using the PJM Regional Transmission Organization in the United States as a case study, we elicited perceptions of the stakeholder process from process participants via semistructured interviews. We treated those perceptions as hypotheses regarding the presence and possession of political power and used a network representation of voting data in PJM to evaluate these hypotheses. We find some evidence in support of the perception that customer-side interests form a strong coalition that is able to exercise some power in defeating proposed rule changes in the PJM market. We find less evidence in support of the perception that supplier-side interests are able to exercise a similar amount of political power in the PJM Members Committee. The structure of the voting network and detected communities, particularly as embodied in the node degree and mixing parameter, also allow us to identify a number of stakeholder participants that act as swing voters on highly contentious rule changes. These swing voters tend not to vote with any one of the identified coalitions on a consistent basis and may thus be engaged in vote trading or other strategic activity.

The framework illustrated for the PJM Regional Transmission Organization in the United States is portable to other contexts and represents an approach to defining questions and hypotheses about stakeholder-driven governance, using data from these processes to build models and evaluate hypotheses and (as part of future work) using these models to evaluate alternative structures or voting rules for stakeholder processes.

Appendix

Interview Protocol and Questions

There were three versions of the interview protocol used. Shown here is the second and main version. The first version used for early interviews was modified in language, especially in the probing questions, to better reflect a natural flow of conversation. The content remained essentially the same. A customized protocol was used for the final interview to target the respondent's specific employment background. All interviews were semistructured.

Opening Script. The primary goal of our research project is to understand how the decision making process works at RTOs. We've been trying to understand the formal process; we need to understand better the experiences of those who participate in the actual process. Our questions are really a conversational guide to help us understand your experience at/with ___ [RTO].

Demographics/History

How have you been involved with _____ [RTO]?

Probe: How long have you been involved with ________ [RTO]?

Understanding the Process for Decision Making

How would you characterize the stakeholder process at _____ [RTO]?

Probe: What is a typical meeting like?

Probe: Are there any other elements in the process that I wouldn't understand from information on the website?

Probe:

It sounds like you've had a *positive experience*; can you tell me more about what works well in the process? Is there anything that you would change?

It sounds like you've had a *negative experience*; what were some of the challenges or what would you change in the process?

How would I know when a decision has been made?

Probe: Who is involved in deciding what items are put on the agenda or how quickly issues move through the process?

Probe: Could you provide an example?

Do stakeholders or staff work on issues outside of the formal meetings?

[UNDERSTAND EXPERIENCE / SENSE OF RTOs]

Probe: How does that work?

Probe: Is it important to have certain stakeholders or staff involved in an issue?

Understanding the Stakeholder Groups

Who are the stakeholder groups involved [in the issues you are working on?

Probe: Who are the stakeholders frequently involved in stakeholder processes?

How would you characterize the stakeholders?

How would you describe the influence of certain stakeholder groups?

How would I recognize different stakeholder groups in a meeting?

What is it like for newcomers to participate in the stakeholder process?

Probe: What have _____ [names of new stakeholder groups] had to do to be part of the process?

Probe: How would you know if a newcomer is doing something wrong or how would you help a newcomer figure out the process?

Understanding Influences

Are issues regarding transmission, markets and reliability related?

Are these coordinated in the decision making process?

What are some common disagreements you see in the process?

How do people enter into leadership positions?

I'm trying to understand leadership. Do stakeholder groups identify formal or informal leaders?

Can you describe the board/advisory committee nomination process?

Conclusion

That's all for my questions. What else should I know or be asking in order to understand the ______ [RTO]'s processes, stakeholder groups and participation?

Is there anything you would like to ask me?

Would you mind recommending anyone else who you think I should speak with that would be interested in participating?

Thank you for your time. We really appreciate it!

Data Availability

The data used to construct the PJM voting network are freely available from the PJM Members Committee website at http://www.pjm.com/committees-and-groups/committees/mc.aspx. Information from the semistructured interviews is restricted by the Office of Research Protections at the Pennsylvania State University in order to protect the privacy of interview respondents. Data are available from the corresponding author for researchers who meet the criteria for access to confidential data.

Conflicts of Interest

The authors declare no conflicts of interest.

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