Technological Forecasting & Social Change 183 (2022) 121884

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

# Will power be local? The role of local power organizations in energy transition acceleration

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ARTICLE INFO

*Keywords:*
Energy transition
Empirical survey
Local power organizations
Spatial dynamics
Public power

ABSTRACT

A salient problem faced by governments and industry alike is how to accelerate energy transitions to enhance affordability, accessibility, and greenhouse-gas reduction. Bringing together acceleration processes and spatial scale dynamics, this study highlights the potential for electricity distribution to play a keystone role in the energy transition. We present and examine survey data of electricity distribution utilities in a region of the U.S. to show how trends in decentralization and digitization are intertwined with decarbonization. These trends rebalance economic value toward distribution networks and away from centralized infrastructure. The survey data show that electricity distribution organizations are deploying local, renewable generation projects that produce electricity for one-third (1/3) less than the cost from a centralized generation-and-transmission entity. We suggest that this change and others are likely to transform distribution operators into more broad-based local power organizations. Although the cost advantage of distributed generation seemingly marks a future of local control and decentralized organizational forms, spatial scale dynamics indicate countervailing centralization trends, including that distribution networks may evolve to dependency on external digital, engineering, and capital providers. The outcome of the resulting conflicts will affect the potential for transition acceleration to be enabled or reduced.

## 1. Introduction

One of the most salient global problems for energy transitions is developing a better understanding of how to accelerate transitions that improve affordable and accessible electricity delivery to end users while increasing energy efficiency and reducing greenhouse-gas emissions. Although transitions are often long-term, multidecade processes, their pace can also be accelerated especially with appropriate policy support (Kern and Rogge, 2016). Roberts and Geels (2019) define transition acceleration as policy and other changes that lead to a change in niches (the locus of substantial innovations in sustainable technology) from an emergent phase to a phase of more rapid diffusion. Various conditions can drive such a change including policy signals and policy mixes (often the result of political coalitions), public opinion (including consumer demand), and technological innovation.

Moreover, where innovation involves linkages across multiple systems, such as between renewable energy technology and digital technologies, new synergies may develop that accelerate transitions (Geels et al., 2017). We build on this approach by developing an empirical analysis of synergies between decentralization, digitization, and decarbonization trends in the electricity sector. In the process, we develop the analysis of how these trends are changing the relationships between electricity distribution organizations and generation-and-transmission utilities.

This study brings together the problem of transition acceleration with the interconnected trends of decentralization, digitization, and decarbonization. The analysis uses empirical research to show 1) the contradictory spatial dynamics that involve both decentralization in the relationship between distribution and generation-and-transmission entities, and also possible centralization in the relationship with the management of technology because of new entrants associated with digital technologies, 2) the importance of digitization in enabling local distribution systems to become more active contributors to energy transitions, and 3) the potential for distribution systems to contribute to the acceleration of electricity transitions toward decarbonization.

First, we highlight a change in the relationship between distribution entities and other organizations in the electricity system studied. Our study provides and examines data from a survey of U.S. distribution

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https://doi.org/10.1016/j.techfore.2022.121884
Received 11 October 2021; Received in revised form 24 June 2022; Accepted 14 July 2022
Available online 4 August 2022

utilities to track the changes. Technological innovation and cost savings are driving a trend toward decentralization, and the trajectory of distribution organizations is decoupling from generation-and-transmission entities. However, there is also the potential for distribution utilities to develop dependencies on the centralized digital technologies and companies that provide technical and management services. Such dependencies raise questions as to the processes and aims of implementation, including considerations of privacy, security, and local control.

Second, we show that digitization is fundamentally important in enabling local distribution systems to become more active contributors to energy transitions, and we develop a detailed analytic strategy for unpacking and tracking digitization progress. This result builds on research showing that a core element in the development of "smart local energy systems" is the integration of digital technologies (Ford et al., 2021), and that the integration of digital technologies with new services is one key aspect of the emerging design changes in electricity and energy infrastructure (Roelich et al., 2015). This study builds on these and other projects that have pointed to the value of examining the role of distribution systems in energy transitions and to the connections with digitization.

Third, with respect to decarbonization, we observe that distribution systems have potential for substantial innovation involving renewable energy, energy efficiency, and demand-side management. The survey data show that electricity distribution organizations are deploying local, renewable generation projects that produce electricity for one-third (1/3) less than the cost from a centralized generation and transmission entity that is highly ranked for cost efficiency in its national context, as will be further discussed. The change creates economic incentives for a more rapid transition and increases the economic value and technological importance of distribution systems in relation to the broader electricity transmission network. Our empirical finding is anticipated in prior research showing that distribution systems have broad potential for innovations in renewable energy generation, energy efficiency, and demand-side management (Bolton and Foxon, 2015).

To show these interconnected relationships between transition acceleration and the three trends, we examine a geographically demarcated region where there is evidence of these emerging sociotechnical changes. Using data based on a regional electricity system in the U.S. that has a single, large generation-and-transmission utility and many smaller local distribution organizations, we present an overview of how the interwoven sociotechnical changes are affecting the relationship between the local organizations and the regional organization. We point to both institutional conditions and strategic decisions that can enable the local electricity organizations to become the core drivers of innovation in the regional electricity system.

Although the study is limited to one region in one country, we argue that it has broad implications. The intertwined transitions of decentralization, digitization, and decarbonization, including the potential for fundamental cost savings for local generation, are creating new opportunities for electricity distribution networks to play a central role in energy transition acceleration. Thus, even though our analysis is focused on one region in one country, it points to socio-technical and scalar processes that we suggest are generalizable to other contexts.

## 2. Background

### 2.1. Local power organizations

Our focus is on the role of local power organizations ("LPOs") as potential points of innovation and sources of potential for transition acceleration. The terminology for these organizations varies widely across countries. Some of the common terms in English for this category of organizations are "distribution companies," "distribution system operators," and "distribution network operators." Although some variant of the term "distribution" is often used in other contexts, we prefer the term LPO, at least for the U.S. context, because the term "distribution" under-describes the changing role of these organizations. In other words, the term "LPO" is aligned with our central argument that these organizations are shifting from electricity distribution to full-service power companies that provide generation, distribution, efficiency consulting, and other services. In the U.S., which is our focus, there are approximately 3,000 such organizations including local public power entities (either independent governmental organizations or part of municipal or county governments), electricity cooperatives (historically formed in the U.S. to serve rural customers), and local community choice aggregators (which generally do not control the distribution infrastructure). Municipal LPOs are the most common form of LPO in the U.S. with 2,000 utilities; private member cooperatives constitute the second-largest LPO form, with approximately 900 utilities; and there are also community choice organizations and other LPO forms (American Public Power Association, 2021; National Rural Electric Cooperative Association, 2021).

There is substantial background research on LPOs, and it has helped to clarify the diverse challenges that they face. For example, researchers in the engineering and management fields have identified and analyzed major areas of digital changes, such as grid operations, customer relations, and workforce management (e.g., Schmaranz et al., 2019). They have also examined some of the technological challenges that LPOs face, including advanced metering infrastructure and cybersecurity (Sullivan et al., 2017) and coordination of congestion with transmission organizations (Hadush and Meeus, 2018). Another set of challenges that the literature has identified involves changes in the electricity system such as electrification of transport. For example, a study in Sweden found that integrating electric vehicles with distributed energy presented challenges with voltage bottlenecks and regulation (Johansson et al., 2020).

Beyond technological challenges, LPOs in some locations have faced broader landscape changes, including social movements and liberalization trends. For example, LPOs can face community-based mobilizations that call for energy reform and greater democratic participation (Lenhart et al., 2020; Pohlmann and Colell, 2020; Scherhaufer et al., 2021). In some cases, coalitions have led successful elections of reform candidates and have brought about changes in decision-making transparency. Moreover, in the U.S., grassroots reforms have included calls from city and state governments to procure 100 % renewable electricity from constituent utilities (Hess and Gentry, 2019). In some countries, market liberalization policies have also significantly interacted with energy transition policies (Graf and Jacobsen, 2021). Both digitization and liberalization have contributed to an additional challenge: developing a strategy for working with or competing against new third-party actors in energy markets (de Bakker et al., 2020). In the U.S., third-party actors prominently include energy-as-a-service companies that are leading a variety of changes related to energy transitions (e.g., customer financing and efficiency programs).

Research on how LPOs are adapting to local generation and distributed technology has found that their response and strategy varies by the size of the organization and the broader policy regimes in which they operate (Chan et al., 2019; Lockwood, 2016). In the UK, a study showed that similar organizations called "distribution network operators" were resistant to innovation and tended to focus on a narrow mission of reliable, affordable service (Lockwood, 2016). However, some LPOs are redefining their fundamental mission, and LPOs with adequate strategic and other resources are actively innovating, especially in the areas of community solar, energy services, electrification, and microgrids (Chan et al., 2019; Lenhart and Araújo, 2021; Lenhart et al., 2020).

### 2.2. Digitization

We argue that a significant factor in the acceleration of a sustainable energy transition is the transition to digitization. Digitization holds a greater potential to impact distribution networks, and the LPOs that manage them, than it does for centralized generation and transmission entities whose functions have long been managed at a distance. We have recently described certain of the technical reasons for this gap in potential (Trahan and Hess, 2021). Broadly, we view digitization as both an infrastructural change to a cyberphysical system and a change in the organizational field as new entrants from the information technology and services sector assume greater control and responsibilities of distribution networks. The digitization transition may enable the broader decarbonization transition, where implemented, to bolster customer-generated electricity, independent electric vehicle charging and energy storage, and distributed energy services. As local distribution networks become cyberphysical systems, real-time monitoring and response tools enable the effective and efficient management of disparate and intermittent distributed resources. In addition to offering new technical possibilities, digitization opens the electricity sector to new organizations, expertise, and sources of capital. Although the technological promise is apparent, the extent to which the new entrants accelerate energy transitions depends on how implementation is pursued in a given context.

To better understand the specific connections among decentralization, digitization, and decarbonization, it is necessary to open up the black box of "digitization" to identify the tools of digitization in this context. In this context, digitization refers to the combination of real-time communications with data management and analytics enabled by the transition from analog to digital technologies. Digital tools enable many aspects of electric grid management to occur at a distance and (essentially) in real-time. As we have described elsewhere (Trahan and Hess, 2021), the new digital technologies represent a step change in electricity management that can be represented in a schematic model depicting the key elements of a digitized electricity infrastructure (see Fig. 1). This step change represents a transition from human, hands-on analog management of electricity distribution procurement (e.g., sending an electrician line technician to physically evaluate a fault in a distribution line) toward automated processes reliant on algorithms and machine learning (e.g., remote and automatic sensors that monitor and identify line faults and, in some cases, take remote corrective action). These changes are often embedded in service contracts between LPOs and leading software vendors that provide software suites and tools to electricity systems throughout the globe. The figure depicts data inputs consisting of what we have termed "operations data feeder systems" and "enterprise data feeder systems."

Examples of operational data include feeds from geographic information systems (GIS), automated metering infrastructure (AMI), and supervisory control and data acquisition systems (SCADA), each of which is briefly described below. An enterprise data feeder system is a separate suite of software addressing non-grid functions, e.g., customer data and organizational functions. The model depicts a customer relation management system where customer functions are centralized.

The protocols that translate these various data feeds for use are depicted in the model as a single communications gateway that feeds into a master network control. As the hub for managing the digitized grid, the master control network draws and shares data with the processing cores that store data and conduct data queries, represented in the model as (Control of) Data Management. We prefer the term "control of data management" to emphasize that the site of the processing cores (whether a local mainframe, a single cloud, or multi-cloud) is an important factor for determining future control of electricity grid operations reliant on data.

The data that we collect below will examine in more detail the extent to which LPOs in one region are engaged in a digitization transition. We provide this technical introduction because it enables us to break down the digitization transition into constituent units and to assess how far along the LPOs are in the transition. As described above, having an integrated cyberphysical system in place is an antecedent condition for enabling the full potential of LPOs to engage in transition acceleration processes.

### 2.3. Institutional and electricity market background

In the U.S., the electrical grids are organized into three main interconnections that further break down into a patchwork shaped by historical and political expediency as well as engineering considerations, including the challenges and limitations of long-distance alternating-current power transmission (Trahan, 2017). In some regions, electricity generation is controlled by large, investor-owned utilities that were vertically integrated from generation through transmission to distribution. In other regions of the U.S., the grids are not vertically integrated, and LPOs provide electricity distribution services.

LPOs in the U.S. serve tens of millions of customers and include local public power entities (either independent governmental organizations or as part of municipal or county governments), electricity cooperatives (historically formed in the U.S. to primarily serve rural customers), and

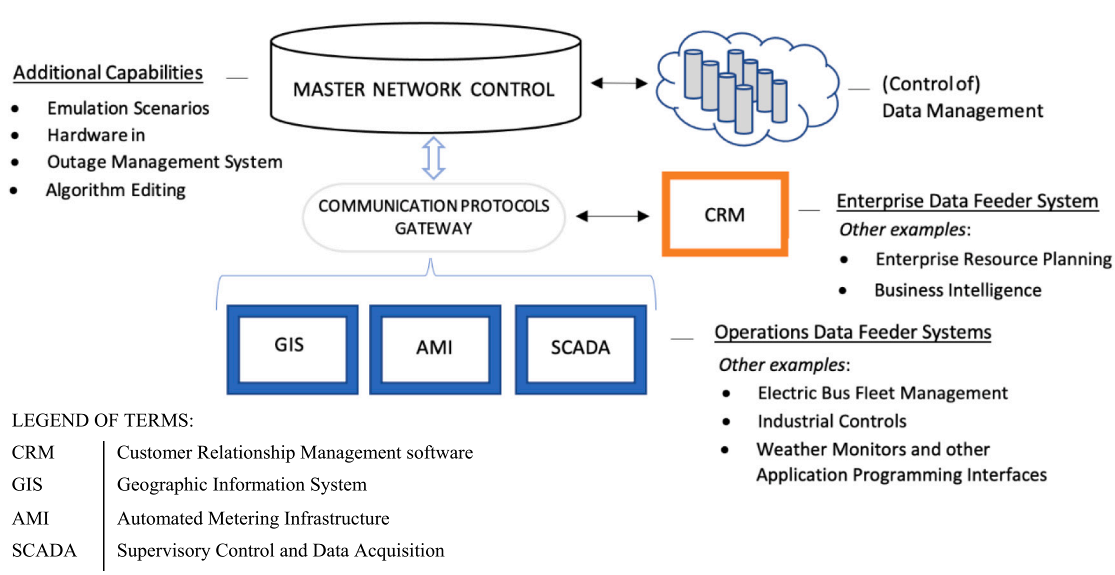


**Fig. 1.** Cyber-physical model of digitized electricity network management.
Source: Trahan and Hess (2021).

local community choice aggregators (which generally do not control the distribution infrastructure). In the U.S., most LPOs remain distribution organizations that purchase power from a range of generation entities. However, certain LPOs are already procuring some electricity from their own generation facilities, including examples of large, prominent LPOs (e.g., Austin, Los Angeles, Sacramento, and Seattle).

In this study, we consider one type of LPO, municipal utilities, and in one location, the state of Tennessee. Tennessee is located in the southeastern U.S., has a diversified economy that is increasingly attracting high-technology firms, and is home to a rapidly growing population (currently about 7 million). LPOs in Tennessee distribute power purchased from the Tennessee Valley Authority (the TVA), a federally-owned and subsidized generation-and-transmission utility serving parts of seven states in the U.S. The TVA's sources of generation in fiscal year 2020 were nuclear (42 %), natural gas or oil-fired (22 %), coal (13 %), hydroelectric power (10 %), and purchased power (13 %, including non-renewable 8 % and renewable 5 % (Tennessee Valley Authority, 2020).

The specific relationship between the LPOs and the generation-and-transmission entity in this region is somewhat unique, as we will discuss. Yet, it is of general interest because it allows us to see clearly how the three trends above are placing pressure on a generation-and-transmission entity as LPOs begin to produce their own power. To better understand the broader relationships among these trends, it is useful to have more institutional background. These changes are already substantial enough that the TVA has placed limits on self-generation by the LPOs and taken other self-protection measures.

The LPO structure in Tennessee has been largely unaffected by restructuring efforts elsewhere in the U.S. The efforts, termed "electricity deregulation" in the U.S., started in the 1990s, accelerated in the early 2000s, and sought to create stylized quasi-markets for electricity generation (Peskoe, 2021). The changes had little impact on the TVA system because, among other reasons, its service area is regulatorily ring-fenced to prevent other utilities from delivering power within its service boundary, and the TVA acts as the primary energy regulator within its service boundary (Trahan, 2021). The TVA structure therefore stands as a basis for comparing system costs in a ring-fenced system against "deregulated" markets wherein a select group of power generation companies is regulatorily granted the right to bid to deliver power over transmission infrastructure. The cost comparison has been favorable for the TVA system: it ranks in the top third of the 100 largest U.S. utilities in overall cost of electricity and twelfth lowest in industrial rates (U.S. Energy Information Administration, 2021).

Apart from the TVA's competitive electricity rates, the TVA's structure makes it an interesting laboratory for the study of LPOs for at least two other reasons. First, LPOs serve all of the electricity to customers in the TVA service region, excepting for fifty-seven large industrial customers and seven federal installations, rather than a mix of vertically-integrated investor-owned utilities or other forms such as retail competitors. Second, the TVA is the sole generation and transmission entity supplying all power to its seven-state service region. These features create a natural line of demarcation for studying costs and other performance metrics of electricity distribution, on one hand, and generation and transmission, on the other hand.

The historical reasons for the TVA structure retain special immediacy for considering approaches to modern electricity procurement. The TVA began its organizational life as a 1930s-era, government-subsidized, economic development project directed toward addressing rural electrification and poverty (Hargrove, 1994). At the time of the TVA's founding and for decades thereafter, electricity generation was necessarily centralized due to human safety considerations and economic efficiencies in scaled generation of, first, hydropower, then coal, and later nuclear and natural gas. The TVA structure was an organizational means by which the U.S. federal government could socialize the enormous upfront capital costs of centralized generation and transmission in the region. Electrification was thereby subsidized, initially for the benefit of rural communities and farmers and, today, for the benefit of industrial and commercial organizations. Among the most prominent forms of subsidy, the TVA reports that it is implicitly treated as a governmentally-guaranteed entity, thereby allowing it to negotiate its acquisition and maintenance of capital at substantially lower costs and to take on greater debt leverage than its non-governmental peer utilities (Trahan, 2021).

The idea to divide control of electricity such that distribution was controlled locally in the Tennessee Valley was both a business and political compromise (Hargrove, 1994). It provided assurance to a skeptical populace that the federal government would not wholly take over and control an economic sector of such fundamental importance, including for mechanized farming. The slogan coined by the TVA's political proponents, "power to the people," expressed the sentiment. Today, the slogan has taken on a different meaning associated with the protection of centralized generation and transmission and its growing conflict with local energy generation and other innovations that could benefit its grassroots constituents (U.S. District Court Western District of Tennessee, 2021).

This conflict is occurring in a U.S. policy context that increasingly supports a transition to clean or zero-carbon electricity by coalitions of environmentalists, community groups, and businesses. The preference of generation and transmission utilities is to develop low-carbon energy under a centralized model (Hess, 2016; Trahan, 2017). The TVA has also demonstrated a similar preference for centralized generation but one less concerned with renewable energy generation (Trahan, 2021). For example, although the TVA has produced a carbon planning process dated to 2050, that planning is untethered from ten-year capital expenditure plans and other customary process implementation measures. Within this context, LPOs in the TVA region have increasingly sought more options for renewable electricity generation. The prospects of both defection and increased local generation have resulted in institution-protecting strategic decisions by the TVA. One change has been to increase the term of LPO purchase contracts and extend the time of notice of termination from three years to as much as twenty years, and some LPOs are litigating these changes even though the TVA serves as their regulator (Southern Environmental Law Center, 2020).

To make the longer-term contracts and other regulatory changes more palatable, the TVA has, since 2020, allowed LPOs that sign new power purchase agreements to generate up to 5 % of electricity locally (Tennessee Valley Authority, 2020). Reflecting the uncomfortable compromise of its position, the TVA has subsequently employed various calculations to further reduce deployed projects to below the five-percent cap (Shober, 2020). Nonetheless, some LPOs can now generate some electricity to improve their economic performance and environmental stewardship. As regulation, litigation, and/or defections begin to release the strictures on local generation, the TVA (like many other centralized generation-and-transmission companies) will need to evolve, reorient, and right-size to an organizational form reflecting technological and social realities. The efficiency of that process is one factor that will enable or reduce the acceleration of transition.

### 2.4. *Transition acceleration and spatial scale dynamics*

Within the field of transition studies, we find work on geographical and spatial perspectives to be especially helpful for this study, and we both draw on and contribute to these perspectives (Truffer et al., 2015). For example, one benefit of attention to space, place, and scale is a more diversified empirical basis for transition studies in comparison with an earlier focus on national-level systems change (Raven et al., 2012). Because a national-level approach can lead to under-recognition of regional institutional conditions and variation across regions, greater attention to the diversity of the spatial scale at which transitions occur has led to increased attention to place-specificity of transitions (Hansen and Coenen, 2015). Although we recognize the importance of this development in transition studies toward greater inclusion of regional analysis, our engagement is more with respect to scalar dynamics, especially ones associated with decentralization trends. With specific respect to digitization, we build on prior spatial scale research showing that replication of institutional arrangements is dependent on multi-scalar processes, including interactions among multinational corporations (Bauer and Fuenfschilling, 2019).

Much of transition studies has focused on, and with rich empirical results, the relationship between niche actors, who are custodians of innovations, and regime actors, who manage a stabilized configuration of the technological system (Geels, 2019). The relationship can entail conflict, especially when the niche poses radical disruptions or a "stretch and transform" approach to the regime (Smith and Raven, 2012). A widely studied niche-regime conflict in the electricity sector involves renewable technologies and the existing system of baseload power from fossil fuels, hydroelectric dams, and nuclear energy. Both niche and regime can be at multiple scales. For example, solar energy generation can be at the scale of regional solar farms, community solar, or rooftops, and the regime includes generation, long-distance transmission, and local distribution networks.

Although our perspective recognizes this widely studied niche-regime dynamic in electricity systems, we are interested in an emerging intra-regime conflict between distribution organizations (which are transitioning to energy generation and energy-service provisioning) and the regional scale generation-and-transmission organizations. One way of thinking about this intra-regime conflict is as part of a decentralization process by which modular renewable energy generation that is deployable at or near population centers (especially photovoltaics, either at the rooftop scale or the community scale) increases the capacity to reduce electricity costs, as is described in the empirical findings below. However, comparing the findings against previous cost estimates by the generation-and-transmission entity evidences that, even when comparing solar-to-solar, a solar farm controlled by an LPO that produces energy close to customers can save costs against procuring solar from a similarly scaled yet distant solar farm controlled by the generation-and-transmission entity. Other overlooked complexities in that comparison are reserved for now. Both information technology companies and energy-as-a-service companies may further enhance savings and the decentralization trend by enabling synergies among local generation, distributed energy integration, and a shift into broader energy service offerings. The decentralization trend can therefore be expected to displace some costly centralized generation-and-transmission infrastructure.

Generation-and-transmission utilities are aware of these trends, and they attempt to resist or delay their fruition. We observe this pattern in the TVA service region, as described above, and in the U.S. more broadly. Conflict between the different scales of electricity supply organizations is also evident in other parts of the world, too. For example, in South Africa, distribution utilities that wish to develop local renewable energy generation face both regulatory ambiguity and resistance from the generation-and-transmission utility (Baker and Phillips, 2019). There can also be conflicts over more technical and limited areas. For example, in Germany, the digitization of the grid leads to questions about which organizations have access to customer data and how distribution organizations can become more active managers of distributed load and energy demand (Rohde and Hielscher, 2021).

More broadly, we can summarize this relationship between distribution and centralized generation-and-transmission as a long-term process of decentralization that is interwoven with decarbonization and enabled by digitization. In this sense, the three "D's" run in interactive loops, alongside other trends, such as electrification. However, we also draw on transition studies and spatial scale research to point to a countervailing trend to decentralized, local control. Although studies may focus on a demarcated region or country, there are multi-scalar horizontal or vertical interactions (Binz et al., 2020). As described above, the digitization process involves embedding LPOs in new industrial fields of companies that supply digital services, energy efficiency services, and energy generation services. Similar to work on transnational linkages (Wieczorek et al., 2015), digitization vendors (including software developers) operate at a national or international scale, and they are capable of managing aspects of LPO operations at a distance.

Thus, rather than just a decentralization trend, there is a more complex scalar interaction whereby digitization is connected with decentralization of energy generation but also with the centralization of technology and service operations. By taking advantage of experiences in diverse regulatory and cultural settings, the information technology and service companies can develop valuable new insights that can also lead LPOs to be increasingly dependent on these third-party actors. As such, the two socio-technical processes represent counter-trends of decentralization and centralization, the resolution of which is difficult to precisely predict. Local control tends to be bolstered by distributed generation, yet the implementation and management of that new generation exhibits greater dependency on centralized algorithms and software suites that favor centralized development and data storage. Regardless of the eventual form of implementation, this study highlights the shift in costs and transition opportunities to "distribution" entities, which are less constrained to traditional distribution functions. We begin the necessary process of grappling with the consequences.

### 2.5. Contribution and research questions

In this study, we develop a general picture of the trends and challenges that LPOs face in the context of the changing institutional relationship with a generation-and-transmission entity. We employ a survey method so that we can identify some patterns across LPOs in the region. Our general research goal is to improve understanding of the interconnection of the digitization transition and the energy transition at the level of the LPO, to improve understanding of the scale shift toward LPO generation, and to show how the LPO can become an effective fulcrum for an acceleration of energy-transition goals. To accomplish our objective, we ask three main research questions that also define the sections of the results. First, we provide a template for examining the basic system architecture of the LPOs as the fundamental sociotechnical structures in which they operate. Second, we open the black box of the digitization transition and explore the various features and characteristics of the profoundly changing cyberphysical sociotechnical system. This approach is in continuity with the general contribution of transition studies to broader institutional analysis by providing greater attention to the material and technological dimensions of industrial transitions. Third, we examine how the energy transition is being configured in the LPOs and the new challenges and opportunities that it creates. The three research questions are as follows:

1. Decentralization attributes: what are the meanings and implications of "grid integration" for distribution-level electricity networks?
2. Digitization: what specific digital technologies do LPOs use in their operations?
3. Decarbonization: what energy transition technologies are LPOs currently implementing?

## 3. Methodology

### 3.1. Data source

The source of data is a survey of municipal LPOs in the state of Tennessee, all of whom receive power from the TVA. Our survey was delivered by email to the constituent utilities in the industry trade group, the Tennessee Municipal Electric Power Association ("TMEPA"). TMEPA is a trade association that represents fifty-eight (58) community-owned electric power providers in Tennessee that serve over 2.4 million homes and businesses. Its municipal utility members distribute two-thirds of the power in the state, while LPOs in the form of electricity cooperatives serve nearly all of the balance.

### 3.2. Survey administration and response rate

The survey was distributed to TMEPA membership by the organization's leadership on April 28, 2021, in the form of a Word document attached to electronic mail, together with our consent and explanation letter. The extended deadline for responses was set at May 28, 2021. The survey was also shared via email with a group of fourteen (14) non-member affiliate electric utilities located in the state of Mississippi. The responses from non-member affiliates have been excluded from our results due to the small population size of that separate non-member group and the low response rate.

The survey went to the entire population of fifty-eight (58) Tennessee municipal electric distribution utilities. The survey response rate was thirty-one (31), or 53.4 % (31/58), nearly one standard deviation (i.e., 18.8) above the average response rate in the background survey literature (Baruch and Holtom, 2008). Completed survey documents were returned directly to the lead author, via email attachment, in each case by an individual authorized by the responding electric utility. One survey was damaged in the course of our download and we contacted the respondent to resend the completed survey file. Additionally, we received supplemental information for one survey after the survey deadline. The supplemental information fell outside the survey response deadline and would not have been impactful even if included, and it was therefore excluded.

Apart from the above, our only correspondence with survey respondents consisted of delivering receipt of delivery emails and a preliminary brief of tabulated results. In an effort to improve validity, many of the survey questions allowed for respondents to elect to provide additional notes or separate comments which we considered on background. Survey respondents were also allowed to skip survey questions, and we identify the number of respondents for each question in the results below. The full set of survey questions is available upon request from the authors.

Respondent consent was obtained following procedures approved by the university institutional review board. All surveys were deidentified so that results would not be attributed to specific organizations. Results, below, are reported in three different categories: Basic System Attributes, Digitization, and Energy Transition.

## 4. Survey results

Survey results are presented in three parts that correspond with the three areas of research questions described above. However, our presentation is intended to provide context to the structural transformation of the distribution systems. As such, we do not present the questions in the order given in the survey. In a few instances, we describe results from more than one area of the research at the same time.

### 4.1. Decentralization attributes

We first asked survey participants to report the number of points of delivery from the TVA to their distribution system. The purpose was to begin to consider the degree to which the individual distribution systems of the LPOs surveyed are integrated with the greater electrical grid network. For example, if a distribution system is serviced by a single point of delivery, then the system is solely dependent on that line for power delivery. The survey results provide a useful data point for beginning the process of evaluating system integration in the Tennessee Valley service area, which covers parts of seven states in the U.S. (see Fig. 2).

As indicated, nearly 20 % of the respondent LPOs reported a single point of wholesale power distribution from the centralized generation entity, the TVA. The median recorded result was only three. For many of these systems, there is no mechanism for return of electricity to the TVA

How many delivery points are provided to your distribution system?

| | |
|---|---|
| One Point | 6 |
| Median Result | 3 |
| Mean Result | ~ 3.4 |
| Range | 8 |
| Number of Respondents | 31 |

**Fig. 2.** Points of delivery.

transmission lines. In such cases, the entire LPO distribution network depends on a single point of delivery and is functionally similar to a single, discrete end load on the larger grid network. For the TVA, local generation of electricity in these systems presents a zero-sum dynamic: the electricity produced and consumed locally does not directly interact with the TVA system and cannot be used to balance loads elsewhere. We suggest this circumstance underlies much of the political dynamics of electricity procurement throughout the TVA service area.

For LPOs, the wholesale power purchased from the TVA constitutes the bulk of their system costs, around 80 % at the median (see Fig. 3). In other words, even a small decrease in purchased power costs would make a tremendous difference in the cost of LPO operations. The reported savings from LPO systems that have begun implementing distribution-level solar projects are marked (see Fig. 4).

The four LPOs shown in Fig. 4 reported average cost savings estimated at approximately $42,000 per MW annually for local generation (all projects were solar photovoltaic generation). There were two additional reported projects that are not depicted on the chart: one project remained to be switched on and the other calculated the savings on a kilowatt-hour basis. The average cost savings across all projects was approximately one-third of the regular wholesale power rate from the TVA.

At the median, surveyed LPOs attributed approximately 80 % of total system costs to power purchased from the TVA. Saving one-third of the cost of wholesale power would be equivalent to a one-quarter (1/4) reduction of proportionate total system costs for the LPO. Those savings would accrue directly at the retail level. Such calculations do not account for other system savings that would result from reducing the size, scale, and subsidies of the TVA. Stated differently, not only can LPOs currently assume some generation services more economically than purchasing power from the TVA, but the measured savings do not include the potential savings from reducing the size of a vast centralized

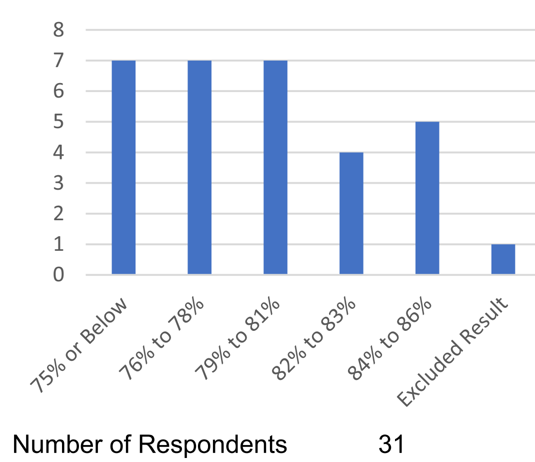


**Fig. 3.** LPO wholesale power costs as percentage of overall costs.

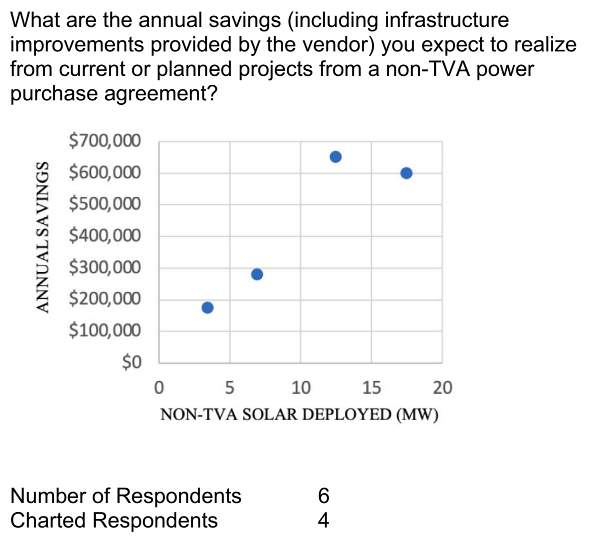


**Fig. 4.** Annual estimated savings from signed power purchase agreement.

infrastructure. The TVA's own estimates for deploying centralized solar generation projects indicate that centralized solar generation is more expensive as compared to other generation types (Tennessee Valley Authority and Integrated Resource Plan, 2019).

The survey gathered additional technical information on voltages, delivery functions, and system structure that is relevant to our parallel research on system cohesion. For present purposes, the central finding of this portion of the survey is the finding that some LPOs have identified substantial savings by producing up to 5 % of electricity locally.

### 4.2. Digitization

The survey questions on digitization track the physical infrastructure of the distribution grid—from the substations that receive wholesale power, to distribution lines that transmit electricity, down to the individual electric meters that record customer consumption. As we trace the grid infrastructure, we revisit the cyber-physical model to highlight the separate logic of digitization and its interactions with distributed energy resources. We will also identify certain of the management and control relationships that underlie the changing role of LPOs.

Substations may be viewed as the headwaters of electricity distribution. If electricity to a substation is interrupted, supply to the balance of the distribution system is often interrupted along with it. Approximately 70 % of surveyed LPOs reported that all constituent substations were connected with remote communication abilities, most frequently via fiber rather than radio or other wireless technology. Substations are often the largest capital line item in an LPO's infrastructure budget and are likely to play a more dynamic role in systems with high levels of distributed energy resources. As such, we see a first measure of readiness for incorporating far greater levels of renewable distributed generation. Substations present a specific decision point for LPOs between planning toward a distributed future or servicing a centralized past.

Moving down the traditional physical distribution infrastructure, we examined the equipment that connects charged lines from substations to customers. The survey questions here were again focused on understanding how this physical infrastructure is connected with communications technologies and what capabilities those connections engendered. We considered the digitization process in the three operations data feeder systems identified in the model: geographical information systems (GIS), supervisory control and data acquisition (SCADA), and automated metering infrastructure (AMI).

GIS in the electric utility context enables LPOs to geolocate equipment, lines, and other assets in real-time and to provide a visual mapping of the distribution system operations and management. Reflecting the near ubiquity of GIS solutions, only two of thirty-one respondent LPOs reported not using a GIS software suite, instead relying on traditional utility mapping solutions. Although the use of GIS digital tools was near universal, the control of the tools themselves varied. For example, 43 % of respondents reported using an outside vendor for GIS coding and programming, whereas only 23 % reported coding internally, and the remainder of respondents were unsure. Like many other established software suites, the market for GIS solutions is highly concentrated among a few vendors that provide solutions for electric utilities. The market concentration indicates a potential centralized dependency as GIS tools continue to assume operational and management functions.

SCADA systems were the next operations data feed considered, and these systems may be thought of as providing digital management of the physical infrastructure that connects electricity from substations through end customer meters. (GIS interacts with this system by allowing its constituent equipment to be geolocated and visualized.) A SCADA systems architecture supervises and manages grid equipment and operation through a combination of data communications, computer processing, and remote automated devices such as switches, relays, and other peripherals. These are necessary capabilities for managing a more dynamic distribution network. Yet, 20 % of respondents did not report employing a SCADA system at all, while approximately one third reported a system that was not fully integrated with operational control. Even among LPOs that had deployed a SCADA system, variation in capabilities was reported. For example, some systems did not report the ability to “see” voltage problems through system relays or to respond to line problems by active management or automated algorithmic response. Because SCADA systems enable more effective and timely management of grid operations, a facile conclusion might be drawn that a number of the surveyed LPOs should quicken the pace of investment in SCADA technologies. Although the conclusion is arguably warranted, the design and aim of this digital investment and others is a leading consideration as LPOs attempt to service existing distribution infrastructure while beginning to embrace future operations distinguished by local generation and services.

Continuing down the path of physical electricity delivery, we next examined the point of delivery and the use of AMI (also known as smart meters or digital meters). Here, we found in the adoption of AMI the highest incidence of digitization. Nearly all respondents reported that meters could both monitor consumption (27 out of 29 respondents) and operations data (26 out of 29 respondents), whereas most conducted certain two-way communications and operations interventions (23 out of 29 respondents). This functionality is important for managing a more dynamic grid characterized by greater penetration of distributed energy resources. Although respondents reported widespread use of automated metering infrastructure, individual LPO systems displayed substantial variability in the frequency of data transmission. Only 34 % reported a frequency of 15 minutes or lower for residential customers, whereas 46 % met this frequency interval for industrial customers. We will return, below, to a discussion of the customer consumption data produced by AMI technologies.

To this point in this subpart on digitization, we have reviewed parts of the physical grid infrastructure and described certain corresponding digital tools. The purpose of these survey questions was to illustrate what it means for a distribution grid to evolve to a “digital” or cyber-physical infrastructure. We have also sought to highlight certain specific management decisions on digitization that enhance or reduce the ability of LPOs to accelerate the transition to renewable energy generation and resources management.

Central to all of those management decisions is the approach that an LPO takes to the control of data management, i.e., the mechanisms by which the data from the feeds we have reviewed have been stored. This facet of the model is shown above as the location where data queries are performed and on which data algorithms run and rely. The data sets are also a key element for an electricity provider's current and future relationship with end consumers. For example, data feeds from AMI implicate privacy concerns and operational capability, and they provide a constant source of contact between and LPO and its customer. The survey results indicate that 63 % of LPOs employed a local storage solution for data storage, retrieval, and processing, whereas only 33 % employed a cloud storage solution. The pattern may indicate a reliance on past investment in legacy systems or a hesitancy in utilizing cloud solutions because of the prominent security failures of cloud approaches to data management.

Regardless of the approach to control of data management, more and richer data is an expected outcome of the digitization transition. For LPOs, this development presents the opportunity to acquire both internal capabilities and knowledge relationships with outside vendors, yet those same relationships can create new and sticky dependencies. Over recent decades, software suites have usurped management and control functions across a range of sectors, both in the U.S. and internationally. On this point, we asked whether LPOs were interested in solutions that would instead require the development of their internal technical abilities. We view this decision as time-sensitive, a narrow opening while the trend of automated software controls remains in its early stages for electricity management and LPOs remain their customers' primary point of contact. Approximately two-thirds of respondents indicated that they were open to the possibility of collaborating with other local power companies to develop specific open-source software solutions.

### 4.3. Decarbonization

The third main area of the survey focused on general issues related to the energy transition. Here again, the first and most fundamental step in the energy transition is for LPOs to assume control or management of some portion of electricity generation. At least two, non-exclusive approaches are apparent: LPOs generating electricity and LPOs providing management services related to electricity produced by individual customers from rooftop solar or similar sources. The survey results focus on the first set of considerations (our current in-process research addresses the latter).

Approximately one in five LPOs reported taking the initial step to generating a portion of their own electricity (see Fig. 5). Many of the LPOs were also seen taking steps to address electrification of transportation, a market opportunity for LPOs (see Figs. 6 and 7). By contrast, none of the LPOs reported operating a battery energy storage system, and only one LPO reported operating or experimenting with a microgrid.

As discussed in the introduction, the U.S. policy context increasingly reflects support for a transition to clean or zero-carbon electricity by coalitions of environmentalists, community groups, municipalities, and

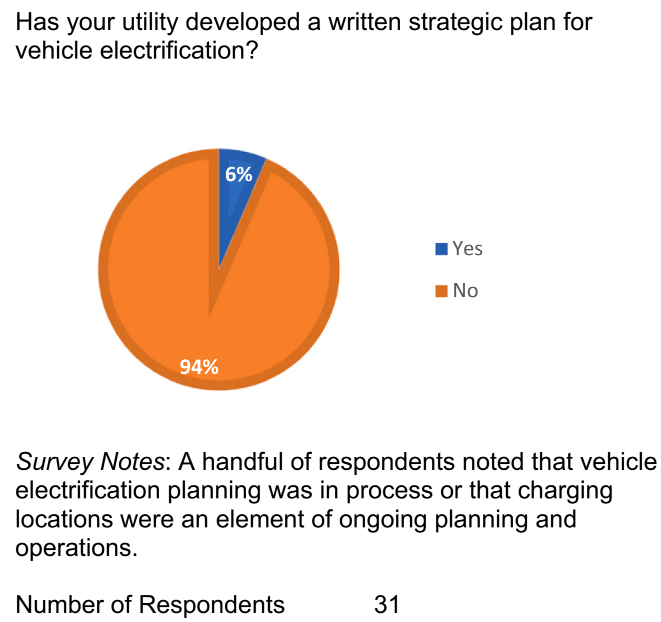


**Fig. 6.** Electrification of transport plans.

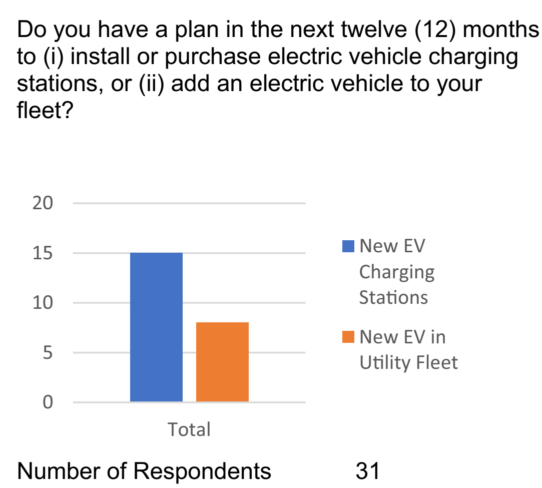


**Fig. 7.** Electric vehicle plans next 12 months.

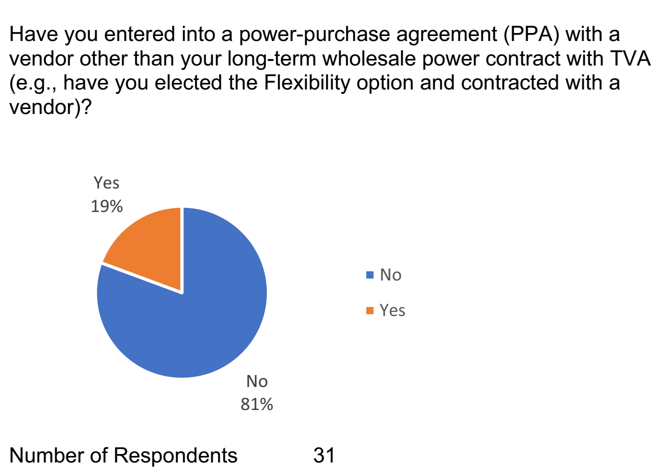


**Fig. 5.** Contracts for distributed energy generation.

businesses. This general trend indicates a permanency in these issues for LPOs and not solely due to improved economic performance. Approximately a third of LPO respondents have engaged with their customers to discuss and plan for corporate sustainability needs. Twenty of thirty respondents indicated awareness of corporate sustainability needs and requirements but have not yet had discussions or conducted planning, nine of the respondents reported having conducted discussions with customers, and only one LPO reported that their industrial and commercial customers had never raised the issue of sustainability. LPOs further varied on their reported strategic perspective (see Fig. 8).

A lack of customer engagement on sustainability presents a short and long-term strategic weakness for LPOs. Energy-as-a-service (EaaS) vendors—third-party companies that offer turnkey (funding, installation, and maintenance) electricity generation and energy monitoring solutions for utilities, companies, and other direct customers—may have an open field to develop expertise and cultivate customer relationships where LPOs fail to do so. The essential business case for EaaS vendors is receiving payment to implement new more sustainable and cost-saving technological solutions as compared to existing utilities that do not or

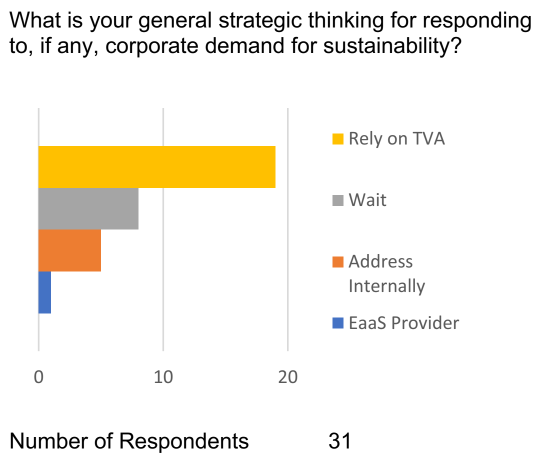


**Fig. 8.** Strategic sustainability plans.

will not offer such products and services. Of thirty (30) respondents, two reported proactively engaging an EaaS vendor: one cited the need to preserve capital and the other stated the engagement would reduce operating expenses. Another eight reported that none of their customers had engaged an EaaS vendor, whereas four reported that they had. Markedly, 18 respondents reported that they were unsure whether any of their customers had engaged an EaaS provider. This is information that an LPO may proactively seek out, especially in the context of discussing what corporate and other customers need or will require with respect to sustainability.

## 5. Discussion

A principle finding of the first section of the results is that LPOs have recognized substantial cost savings from generating some electricity locally. This finding is consistent with a spatial-scale dynamic of decentralization, yet it also shows how decentralization is associated with increased value of local electricity networks in comparison with long-distance, centralized, generation-and-transmission. We developed an estimate that some LPOs were already saving about one-quarter of proportionate overall costs and identified the need for future research.

One topic for future research would be to estimate additional savings from the lack of expenditures for long-distance transmission infrastructure and energy loss. Our results do not include an estimate of those savings. Another topic that follows from this finding is empirical research on the overall potential level of penetration of distributed and other local energy resources. In other words, can an LPO obtain 75 % of its power locally, or a higher or lower percentage?

Our study of the TVA system indicates that these topics benefit from attention to local socio-technical constraints and circumstances within the broader energy landscape. Generation resources and political support vary by geographical and other factors, yet municipalities in the U. S. are unlikely to muster the political consensus necessary to deploy non-renewable generation sources at or near their population centers regardless of local energy resources, thereby constraining the cost savings from decentralization to renewable generation options. Rather than conjecture, this observation acknowledges traditional concerns that have motivated the placement of centralized generation resources away from population centers in the U.S, including among other things, siting problems reflecting the need for huge scale (especially for Carnot processes in steam turbines); security risks (especially so for nuclear power); or, in the case of fossil plants, distance from generation wastes that are not neatly compatible with promoting immediate human health (e.g., local air and water pollution from coal plants) (Trahan, 2017).

With respect to the results on digitization, our survey results help to clarify the conditions under which some LPOs may be better positioned to contribute to distribution-level energy transition acceleration. Those with the most strategic progress in digitization are likely to be better positioned to assume more local energy generation to replace some purchases of centralized power. Such advantages are likely to compound as leading LPOs gain the financial and sustainability advantages of transitioning to a generation-plus-services model of operation. Again, our approach opens up several new research possibilities. For example, the survey questions could be used to develop a variable based on the measure of an organization's progress on digitization. The variable could be used in quantitative and comparative research and also for identifying areas to target for policy support.

The study also opens up a less visible counter-trend in the spatial-scale dynamic because software information and technology companies are often global in reach, and certain functions can be managed at a distance. Although these large-scale companies offer access to capital, technology, and managerial expertise that can increase the potential of LPOs to become more active in transition acceleration, the relationships may evolve new dependencies for LPOs on distant organizations. The dependencies are not well accommodated by the more dominant view that focuses only on decentralization and misses the countervailing centralization trend.

Our third area of results focused on broader LPO strategic decisions. The results indicated that the transition to local generation and cyber-physical infrastructure was evident but limited. We attribute the lack of progress to the recency of cyberphysical technologies and to the previously described legal barriers to purchasing electricity from sources other than the TVA, which only recently partially loosened in 2020. The lack of progress has implications in engaging customers on corporate and residential sustainability requirements and on developing energy-as-a-service offerings, which remain limited. Here again, the study opens several areas of potential future research. For example, empirical research could identify specific industry leaders that have made the most progress on these issues and benchmark those actions. Another approach might focus on a specific type of emerging technological change (e.g., microgrids, local solar, electrification) and examine how the LPOs perceive the changes as potentially affecting the relationship with the centralized generation-and-transmission organization.

Additional research could also ameliorate constraints and limitations of this study. For example, despite representing billions of dollars in annual revenues, the survey population of TMEPA membership was relatively small in number and includes substantially diverse utility operations. Consequently, the statistical analysis is limited to avoid identification by segregation. Our analytic strategy uses descriptive statistics to present the results of the survey, and a larger study sample size may permit multivariate analyses.

Although the study breaks new ground by developing detailed empirical information about both the digital and energy transitions, it remains limited in several other ways. Foremost, the situation of the Tennessee Valley is uncommon in the U.S. because the generation-and-transmission utility is federally owned and subsidized. Second, we examine only one category of LPOs, municipal utilities. Although we expect that the results would be similar for electricity cooperatives, in the U.S. cooperatives frequently manage a more rural and dispersed customer base (fewer customers per line mile), and additional research is needed.

## 6. Conclusions

A central finding of this study is that LPOs can now, for many use cases, generate renewable electricity locally that is one-third less costly than purchases from a top-performing centralized generation-and-transmission utility. This seismic shift in the energy landscape coincides with a trend toward local digitization that compounds the LPO cost advantage and makes it increasingly feasible for LPOs to integrate high percentages of local, renewable generation. These shifts present LPOs with the opportunity to play a keystone role in transition acceleration. As both business and residential customers become aware of the opportunity to procure cleaner and more affordable electricity, it is likely that the pressure to release artificial regulatory strictures will rise. An example is the TVA's systemwide regulatory cap on generation that no individual LPO can contract to exceed. The subsequent release can be expected to expand the field of opportunity, and risk, for LPO management.

The outcome of these interactions is dependent in part on institutional conditions and policy support (Kern and Rogge, 2016). In this case study, we have seen that the economic and sustainability benefits for all stakeholders will be reduced or delayed unless institutional or regulatory changes are made. This circumstance appears unstable. If LPOs are permitted to expand to develop energy options in tandem with the deepening digitization process, then economic benefits will be realized more quickly and, likely, with far less disruption. By contrast, if LPOs and stakeholders are continually stymied from realizing clear economic benefits, then such a circumstance portends grid defection by LPOs or a failure of the electricity regime to be economically viable in the global marketplace. The centralized organizations could face an existential risk of stranded assets and dramatic cost hikes that would impact all electricity stakeholders, likely resulting in bankruptcy and insolvency processes to address the failures after the fact.

If LPOs are not stymied by regulatory hurdles, there is potential for them to play a central role in transition acceleration by enabling local energy resources to develop in synergy with cyberphysical energy infrastructures. Thus, one implication of the study is the need to attend to policy roadblocks that are preventing LPOs from realizing this potential. Specifically, shifts in technology that favor transition acceleration by LPOs will require attention to redefining the relationship with the large generation-and-transmission utilities, which themselves face myriad financial challenges and require a second layer of policy intervention. In this sense, there are some parallels with challenges in some European contexts, where standby subsidies have been implemented, e.g., to maintain reserve power at the grid level.

Our research has another theoretical implication for the combined perspective of spatial scale dynamics and transition acceleration. We show that the uneven development of the LPO cyber-physical infrastructure is likely to lead to disparate outcomes across LPOs even within a limited geographical region. In other words, it is necessary for the analysis of spatial scale in transition studies not only to include regional or subnational systems, which are often highly variable across a country, but also to include variation within a subnational system (such as across LPOs in the TVA region studied). The study results indicate that some LPOs are much better equipped than others to handle the emerging shift from distribution to a more comprehensive role that includes extensive digitization of infrastructure in combination with local generation, electrification of transport, distributed energy resources, and energy-as-a-service. Although these changes promise marked cost savings and increased revenue for LPOs, the required evolution represents organizational hurdles. LPOs face complexities in managing changed operations that require strategic and timely capital investments and new managerial competencies.

The implication for the analysis of the spatial dynamics of transitions is that the trend toward decentralized energy generation coincides with a less well-recognized, and often opposing, trend toward centralization in other areas. For example, digitization often requires partnerships with software providers, whose businesses disproportionately benefit from economies of scale. Moreover, a need for both managerial expertise and capital investment is driving some LPOs to examine the sale of assets, or whole systems, to nonlocal entities, including large investor-owned utilities, integrated investment and engineering groups, and others. Without new managerial thinking and strategic capital investment, third-party entities may increasingly displace LPOs (another risk of failing to reform the regulatory environment).

Finally, we suggest that the sum of many of these observations is that, writ large, LPOs are currently forging and constructing an entirely new organizational field, one that may involve myriad potential partners. Not only have LPOs formed new partnerships with software and management firms, but they have also expressed interest in technical and strategic collaboration with and among peer LPOs (in many forms beyond the ones identified in our study). As such, sustained attention to LPO organizational strategy is a central consideration in realizing their potential to contribute to the acceleration of energy transitions. Understanding the changing role of LPOs from sleepy distribution entities to dynamic and central actors in transition acceleration processes is a first step to developing informed policy that can unleash their potential.

## Funding

This article is an outcome of the Distribution of Power Project with hosting at Vanderbilt University. Partial support for this research was provided by the U.S. National Science Foundation, OISE-1743772, Partnerships for International Science and Engineering (PIRE) Program: "Science of Design for Societal-Scale Cyber-Physical Systems." Any opinions, findings, conclusions, or recommendations expressed here do not necessarily reflect the views of the National Science Foundation.

## Data availability

The data that has been used is confidential.

## Acknowledgements

We thank the Tennessee Municipal Electric Power Association with help in distributing the survey to its members. Any of the opinions, findings, conclusions, or recommendations herein are not necessarily shared by the association or its members.

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