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Energy democracy: A digital future?

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ABSTRACT

Academic exploration of energy democracy has produced a rich theorization of its foundations that exhibits significant pluralism in response to different geographic, social, ideological and technical contexts. This paper develops the literature by considering how sociotechnical transitions associated with energy system digitalization may affect the theory and praxis of energy democracy. Our analysis draws on three dimensions of energy democracy: popular sovereignty, participatory governance, and civic ownership. Digitalization is shown to both present challenges and new avenues for the exercise and study of energy democracy. Firstly, digitalization simultaneously enables and constrains the exercise of popular sovereignty by diversifying energy citizen roles and complicating accountability. Secondly, digitalization creates new dimensions of risk around skills, knowledge and resource access, which can exclude citizens from participatory governance. Thirdly, digitalization challenges common conceptions of civic ownership by introducing new material-software dependencies and re-defining the assets that underpin the energy system. Finally, digitalization fundamentally changes the nature of decision-making, potentially undermining current understandings of the concept and its democratic function. Further exploration of 'digital energy democracy' would hold value for research and practice in the sector.

1. Introduction

Democracy, the reciprocal link between popular expression and political authority, has held the attention of scholars and practitioners of politics and philosophy since antiquity. It is perhaps the most fundamental and, at the same time, most complex and contested concept in the social and political sciences. Current global trends have brought the ideals and practical implications of democracy into sharp focus in several areas. On one hand is the tumultuous international political climate characterized by a rise in 'strongman' political leadership styles [1], a swing towards conservatism and populism [2], and decreasing trust in liberal democratic forms and figures of government [3,4]. The erosion of the norms and institutions that support democratic governance in this context has led to concerns about the durability of democracy and growing scholarly interest in processes of 'autocratization' and how they may be reversed [5–7].

On the other hand, recent developments in other less overtly political arenas give rise to an interest in the possibilities or necessities of 'democratization' in, for example, sociotechnical fields such as finance [8], urban transport [9], and food systems [10]. Equally prominent is the tsunami of digital innovations unleashed by the internet, heralded (at least by their creators) as democratizing technologies. Examples range from promises by Wikipedia to rearrange and democratize the 'politics of knowledge' [11], to claims from platforms services to democratize areas such as transport, the media, or accommodation rental. The myriad conflicting interpretations of the nature and objectives of democracy mean that many such declarations of technological 'democratization' remain contested among scholars, political and business elites, as well as within society-at-large. The extent and accelerating pace of change in how society and technology shape one another opens up numerous questions about how democracy is conceived, pursued, and practiced [12,13].

Ongoing shifts in energy systems manifest in turbulence at the confluence of decarbonization, decentralization, democratization and digitalization [14]. Rapid transformation of the material basis of energy production, distribution and consumption has inspired heightened interest in democratic principles as both instruments and objects of sociotechnical change [15–17]. At the same time, the technological environment in which 'energy democracy' is understood and pursued is continuously being reshaped by the processes and outcomes of digitalization. The application of digital technology is opening up new modes of economic exchange, new sources of value, new interactions, and the potential for greater operational efficiency through automation and computational (machine) decision-making. However, it also presents

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new challenges for notions of energy democracy, and for associated concepts such as inclusion, transparency and power.

In this paper, we conduct a brief review of key concepts within the energy democracy literature, to consider the implications of ongoing energy system digitalization for the conceptualization and practice of energy democracy. We make use of an established conceptual framework to argue that digitalization is having profound but as-yet overlooked implications for fundamental precepts of energy democracy including popular sovereignty, participatory governance, civic ownership, and collective decision-making.

This paper proceeds as follows. A brief review of energy democracy literature is followed by an examination of the phenomenon of energy system digitalization as a sociotechnical transition with the potential to influence the shape of democratic activity. The main dimensions of the framework are then analyzed in relation to areas of digital change in the energy sector. The paper concludes with a discussion of how digital change affects decision-making – an underpinning concept woven across the framework – and suggests areas of research that could support further study of the topic area.

2. What is energy democracy?

Democracy, both the broad political concept and its constituent components, is a highly contested area of political philosophy. Within energy democracy research, a vision of democracy is forwarded that centers on the concept of political equality, extended across three dimensions of power: 'decision-making', 'agenda-setting' and 'preference-formation' [15,18]. Democracy is thus defined as 'a way of making binding, collective decisions that connects those decisions to the interests and judgements of those whose conduct is regulated by the decisions' [15], emphasizing the concept of collective decision-making.

Energy democratic goals include political activism targeting environmental pollution, resistance to the concentration of socio-economic power held by fossil fuel companies, and social emancipation [19–24]. The theory and practice of energy democracy have been heavily influenced by sociotechnical transitions in energy systems towards decarbonization and decentralization [16]. The development of renewable energy technologies such as onshore wind and solar PV has been particularly influential in shaping energy democracy discourses in many liberal democracies of the industrialized global north [19,25–28]. As well as reducing greenhouse gas emissions, the scale and cost of these technologies in relation to traditional models of power generation have enabled electricity generation to become increasingly geographically decentralized [29–32].

Decentralization, and in particular the ability of citizens to own energy assets as individuals or collectives, has expanded possibilities for geographically localized energy activism focused on ownership and management of electricity generation at the 'grid edge' [33–37]. This activism has not eclipsed other methods of citizen-driven political engagement with the energy system – such as campaigns, voting or responding to policy and planning consultations [38], but it has diversified the political 'surface' of the energy system with which people can interact. It has also inspired the creation of new 'democratic imaginaries' of energy politics and participation, among which the imaginary associating democratic praxis with community or cooperative ownership of decentralized energy generation assets has achieved particular prevalence [39,40].

Over recent years, theorization of energy democracy has brought additional nuance to practice-based imaginaries and associated definitions. A thriving plurality of 'energy democracies' have emerged in which different energy system actors understand the concept as relating variously to processes, outcomes and goals [16]. Among this plurality, strengthening community resource ownership is a commonly discussed element of democratic activity associated with positive distributional and justice-based consequences [19,41] as well as concepts of economic democracy [42]. It can also both enact and strengthen 'community as solidarity', making space for more tightly bonded local energy 'publics' [43].

As energy systems evolve, early notions of energy democracy based on energy production are being reshaped to reflect the incorporation of new technological assemblages, value propositions and spatialities. The ways in which novel sociotechnical assemblages such as community energy storage or smart local energy systems affect energy democracy is one area of ongoing critical engagement with the concept [39,44].

In a prominent contribution, Szulecki [15] synthesizes the literature to propose a three-dimensional framework for understanding and analyzing energy democracy. As outlined in Table 1, Szulecki argues that energy democracy can be an 'ideal political goal' in which:

1. Citizens are at the center of the energy system (**popular sovereignty**)
2. Decisions are taken within a profoundly plural system of governance with high levels of information, accountability, and transparency (**participatory governance**)
3. Civic empowerment is fostered via ownership of the core means of energy production and distribution through cooperative or communal organization (**civic ownership**).

Szulecki's framework offers a useful starting point for thinking about energy democracy in the context of renewable energy deployment. However, we argue here that recent developments in the expansion of digital technologies and related infrastructure require us to reflect on what these ongoing shifts in sociotechnical arrangements may mean for energy democracy.

3. A sociotechnical perspective on energy system digitalization

In considering how energy democracy is shaped by the confluence of

Table 1
Energy democracy from conceptual to analytical/decision-making tool [15].

Main dimensions	Components	Indicators
Popular sovereignty	Citizens as recipients of energy policy Citizens as stakeholders (producers and consumers) Citizens as accountholders	Welfare and energy access as key benchmarks Consumer prices and quality of service Prosumer legislation and grid access Prosumer support schemes Public accountability of energy decision-makers
Participatory governance	Inclusiveness Transparency Access to information Energy education and awareness raising	Incorporation of public consultations at all levels Citizen interest/opinion on par with expert agenda Due process and clear procedures Regulated lobbying Reporting on legislation and deliberation Independent research possible and available Existence of dedicated educational programs
Civic ownership	Civic ownership of power generation Civic ownership of transmission/distribution infrastructure	Renewable energy deployment, dispersed energy capacity Share of energy from private, cooperative and communal sources Ownership structure and power in the political economy of energy Share of grid infrastructure co-owned by municipalities/ communal

digital innovation and social structures, we follow Burke and Stephens [45] in taking a sociotechnical perspective on energy democracy. Here, technologies and society are conceptualized as being mutually-shaping phenomena [46], that develop through co-evolutionary processes [47].

The relationship between society and digital technologies has been explored in a variety of other literatures such as that on smart consumption and smart homes [48,49]; the incorporation of digital technologies within artefacts such as electric vehicles [50]; and in work on smart cities [51]. Others have taken broader views to consider a sociotechnical perspective on the interaction between digital technologies and wider society, for example through the lens of 'Industry 4.0' [52].

As a foundation for examining the interplay between energy system digitalization and energy democracy, this section outlines four key observations relating to sociotechnical dimensions of digitalization, all with potential ramifications for energy democracy. First, while digitalization is increasingly understood as a necessary part of sustainable energy transitions, there is a need for more critical engagement with the environmental and social sustainability of digitalization as a broader process. Second, understanding digitalization as involving niche innovations (e.g. data, analytics, connectivity) and actors foregrounds some of the agents (human and non-human) shaping energy digitalization. Third, the advantages digitalization may bring are not evenly distributed and, for many people, it is a disruptive force, rather than an inherently valuable phenomenon. And fourth, as with any other sociotechnical transition, digitalization brings with it shifting power relations.

3.1. Digitalization as a set of sustainability innovations

From a system perspective, data and digital technologies are increasingly regarded as critical enablers for decarbonization. For example, power output forecasting and demand-side flexibility can support optimized power system dispatch in a manner that makes best use of renewable generation output while reducing generation curtailment and network reinforcement costs [53–57]. Furthermore, growing electricity demand resulting from the electrification of heat and transport is likely to increase the need for flexibility services as requirements for load balancing and peak management become more urgent. These services will be enabled by the integration of assemblages of hardware and software technologies (e.g. 'smart' appliances, smart EV chargers, platforms etc.) [58,59] and associated business models [60]. Digitalization also supports 'whole system' approaches to decarbonization through the coupling of electricity with heat and mobility systems, for example through 'vehicle to grid' technologies [61]. Furthermore, data and digital technologies may be able to play a role in both direct and indirect energy demand-reduction. For example, optimization algorithms have the potential to significantly reduce energy consumption in Google's data centers [62]. Alternatively, teleworking has been demonstrated to reduce travel in certain scenarios, reducing the use of fossil-fueled transportation [63].

However, energy system digitalization also brings with it the possibility of unintended environmental and related social harms. As such, the net effect of digitalization on emissions and wider environment pollution-reduction remains nuanced and debated. For example, problems have been raised related to: higher demand related to digital infrastructure, 'rebound effect' [64] consumption increases, and life-cycle environmental and human welfare costs of mining, manufacture and waste disposal [65–67]. Digitalization itself is also as relevant to fossil-fuel industries as it is to the renewables industry [68]. In summary, while energy system digitalization has been accepted as an enabler for energy system decarbonization, the full range of impacts on the environment and society require further attention.

3.2. Digital innovations as niches

As a process through which digital hardware and software are integrated into energy systems, digitalization might be understood as a process of innovation in which multiple (digital) technological assemblages, developed by niche actors, are increasingly finding traction within established sociotechnical regimes and supporting sustainable energy transitions.

The notion of digitalization is, in broad terms, concerned with the increased collection and use of digital data, and the development and adoption of digital technologies, i.e. the incorporation of both hardware and software into existing systems. In the energy sector, digitalization is characterized by the creation and development of cyber-physical systems [69] that integrate computing and information-based processes, with physical processes, infrastructures and assets in energy systems. The International Energy Agency identifies 'three fundamental elements' of digitalization: data, analytics and connectivity [70], while other scholars' analysis also highlights non-technological components such as 'new business models and interaction opportunities these support' [71].

While digitalization includes material technologies and infrastructures, the role of data as a non-material component of digital innovation is important, not least because of the emergent legal, political and cultural issues around the generation, retention and manipulation of data. The ability to collect and manipulate data underpins much of energy system digitalization, enabling far greater access to information and analytics than has previously been available to the sector. This vast increase in data collection and processing happening across all parts of the energy sector also increasingly incorporates related cross-vector or cross-sector datasets, such as buildings use or planning. The phenomenon is sometimes termed 'big energy data' and its role in energy system management is growing [72].

3.3. Digitalization as disruption

As highlighted previously, digitalization is not unique to energy systems in the same way that technologies such as solar photovoltaics are. Rather, digitalization in energy systems often involves adoption of general-purpose innovations (e.g. processors, sensors, user interfaces, and data analytics) that have been developed for other industries, or indeed without a specific industry in mind. Tracking and managing the development and deployment of such innovations is thus potentially more challenging than might be the case for energy-specific innovations, where end-uses and impacts can be more closely predetermined [73]. This presents challenges to actors interested in steering digitalization pathways and governing digitalization outcomes.

For this reason, many aspects of digital innovation may be considered exogenous to energy systems. A multi-level perspective on sustainability transitions might therefore characterize digitalization as a 'landscape' factor with the potential to destabilize incumbent energy regimes. Digitalization has been identified, for example, as a key disruptor to incumbents unable to secure digital opportunities within the constraints of established business models [74]. In doing so it challenges established business models to adapt to new revenue and value streams, as well as new opportunities to interact with energy consumers [71,75].

3.4. Shifting power relations

As with all major infrastructure, energy digitalization has the potential to (re)constitute politics and thereby reshape power relations [76]. Awareness of shifting power relations is perhaps particularly important at the early stages of digital systems development. Well-known characteristics of digital markets such as network effects, low marginal costs can lead to 'winner takes all' markets in which early movers enjoy dramatic advantages [77,78]. Such effects permit rapid technological and business scaling with the potential for new monopolies, norms and institutional arrangements to become established before regulation and governance can 'catch up' [13]. The rapid adoption of socially harmful technological or business practices can be difficult to remedy once entrenched. These concerns are not new and have been explored extensively, particularly in grey and policy literature, across parts of the digital economy concerning infrastructures related to media, speech and democracy [79–81]. However, these issues remain under-explored in relation to the digitalization of critical infrastructures such as energy, as well as in relation to environmental harms. As energy system digitalization progresses, the functioning of this infrastructure is likely to become increasingly mediated by digital companies, technologies, assets and processes that may fall outside the scope of traditional regulation. This raises serious questions about public accountability and transparency.

As the case with sociotechnical transitions more broadly, the political dimension of digitalization plays a key role in shaping processes and outcomes across society. However, issues of politics are often obscured in a discourse in which technology's role is assumed to be neutral *vis-a-vis* human power relations. Sadowski and Levanda term this phenomenon 'anti-politics' [82], exploring it as a form of erasure that can prevent inequalities and the exercise of interests in digital spaces from being detected and challenged by citizens and governments, despite their tangible consequences.

In summary, energy digitalization can be conceptualized as incorporating multiple sociotechnical assemblages into energy systems, developing both within energy sector niches and exerting landscape pressure on existing regimes. Moreover, the technological shifts implicit within digitalization coevolve with changes to value propositions, organizational strategies, business models, market structures, user practices and power relations. As with decentralization and decarbonization, digitalization too conditions the social and material contexts within which energy democratization can be understood.

4. Conceptualizing digital energy democracy

Analyzing the impact of digitalization on understandings and practices of energy democracy pulls into sharp focus the roles and responsibilities of people and publics in the changing energy system. We now consider the impact digitalization may have on each of the main dimensions of energy democracy identified by Szulecki [15]: popular sovereignty, participatory governance, and civic ownership. The analysis is based on a critical assessment of the early literature on energy system digitalization and democratization. Given that digitalization is continuing apace, our focus is on emergent challenges and issues, and consequently draws from nascent academic and grey literatures on energy system digitalization published up to 2022.

4.1. Popular sovereignty

The 'popular sovereignty' dimension of energy democracy centers the energy system on citizens. Szulecki's image of energy democracy proposes that the energy system exists for the benefit of citizens – as stakeholders, consumers, and producers – and that decision-making is ultimately accountable to citizens. Digitalization can have profound but paradoxical effects on the sovereignty of the 'energy citizen'. On one hand, digital technology offers consumers the promise of new and better products and services. Enhanced operational efficiency means consumers can expect markets to provide choice and access to high quality services at low prices, as seen in other areas where digitalization has taken hold such as goods retail. Similarly, digitalization can expand the horizons of citizen participation in energy markets as producers. Here, new digitally-enabled flexibility assets, markets and operational models potentially create new arenas and publics with the potential to become new sites of democratization [39].

On the other hand, despite the promise of new and better services, digitalization challenges popular sovereignty in important ways. Trends such as automation have the potential to blur how public accountability of energy decision-making, an indicator of energy democracy, is understood and ensured. Automation, considered to be among the greatest 'prizes' of energy digitalization [71], is growing in significance for many industries including manufacturing, healthcare, transport, agriculture, energy, and scientific research, among others [83,84]. While popular imaginaries of automation may focus on the physical side, such as that delivered by robotics, the automation of cognitive or decision-making processes using computational tools is another important area of development [85]. Automation challenges popular sovereignty by introducing new decision-making 'actors' into the energy sector. Actors include automated and semi-autonomous computational machines, such as automated agents or models. They also include collectives of human and machine actors, including both the developers and users of automation technologies. These additional actors complicate democratic notions of who (or what) is making decisions about the energy system, and how these decisions are being made.

New forms of decision-making raise questions about how decisions are held accountable by citizens. For example, the push towards 'data-driven policy making' presents questions as to how data is used and processed; for example which models, statistical techniques or algorithms are employed [86,87]. These new considerations can add complexity to decision-making chains, as well as new challenges to determining where liabilities and responsibilities are held, and by whom. These questions are even more salient if technologies used in decision-making systems are technological 'black boxes' such as neural networks; whereby humans do not necessarily fully understand how the model reaches its conclusions [88–91]. If the concept of accountability is transfigured by digitalization, it follows that the question of on whose behalf decisions are being made is equally open for debate.

In summary, digitalization may impact the popular sovereignty dimension of energy democracy in two main ways. Firstly it increases the range of activities, roles and arenas in which energy citizens operate; potentially broadening the avenues through which citizens can exercise popular sovereignty. Secondly, it introduces new complexity to the stakeholder landscape, potentially bringing new actors and collectives into notions of the popular in ways that complicate accountability to citizens.

4.2. Participatory governance

As digitalization changes the boundaries and forms of energy democratic collectives, it alters the opportunities and requirements for their members to participate in collective governance of energy systems. These changes are happening in two key areas: digital skills and knowledge, and access to data and software code. Some points raised in this section are also applicable to investigating the participation of individual citizens in digital technology *use*. This can be a part of democratization by establishing citizens as direct stakeholders of energy system digitalization. However, our main focus here lies one step further in exploring the participation of citizens in digital energy *governance*: "the extension of rights and responsibilities to shape the rules of the game" [32].

Firstly, democratic participation in digital energy governance – whether at community or system level – requires participants to gain new skills and knowledge. This is necessary for 'traditional' governance participation (e.g. committee service or trusteeship) and emerging 'e-participation' tools [92,93]. In the energy sector, echoing patterns across the broader economy and recognized as part of distributional energy (in)justice [94], there is emerging evidence that gaps in digital skills are linked to other socio-geographic features such as age, socio-economic status and geography, among others [95–98]. This set of linked phenomena is often referred to as 'digital exclusion', sometimes also known as the 'digital divide' [99]. The scale and nature of digital exclusion is complex to track because of the evolving nature of digital technologies and the need to update measures of exclusion. For example, in the UK the number of 'internet non-users' – a proxy for digital exclusion – has almost halved in the last 10 years to sit at around 10 % of the population [100]. However, government research into the effects of

COVID-19 highlighted more complex factors contributing to a potential rise in digital exclusion over the last two years. Such factors include home internet bandwidth, the ability to use mobile applications, and access to devices [101]. These findings are relevant considerations for the evolution participatory governance into digitalized spaces as they indicate unevenness in digital skills and knowledge, potentially compounded by a lack of access to digital devices, across populations, even in wealthy countries.

Participation in governance activities requires a depth of knowledge exceeding that needed for participation in technology use alone. For example, a person could use a home energy management service without understanding the details of how the software works, or its impacts on the wider grid. While this knowledge may not be important for the individual user, it is significant for collective governance of digitalized energy systems. This implies that the level and types of skills or knowledge required for participatory governance are *higher* than those explored by literature focusing only on digital technology use. Reflecting these additional demands, we suggest that inequalities in digital skills and knowledge could impact participatory governance in a profound way. Participatory governance may be disrupted by limiting meaningful participation to those with a certain level of technical competence. Returning to Szulecki's framework, this suggests that digitalization may bring particular new challenges to the 'inclusivity' component of popular sovereignty.

There is potential to address knowledge gaps, for example by producing resources supporting non-expert participation and improving industry standards for product or service interpretability. However, in an evolving field where the sociotechnical context and expert understanding of the issues continue to change rapidly, the knowledge required to participate will remain a moving target. With similar challenges echoed across the digital economy [102,103], there is clear demand for policy and practitioner development in this area.

Second, access to data and software code is important for participatory governance, with significance for transparency and access to information. Adequate access to data and software code is particularly pertinent to aspects of participatory governance associated with scrutiny, deliberation and decision-making. These aspects of democratic practice are important, as they are broadly applicable to participatory governance across different scales, from auditing the activities of local energy collectives through to participation in national energy governance. Currently, there are multiple reported barriers to accessing and using energy sector data that include: poor data discoverability, data quality issues or missing data, data biases, inconsistent access conditions, high pricing and restrictive licensing, among others [71,104,105]. Furthermore, access to code can be restricted by legal protection of intellectual property or high pricing of proprietary software [104].

Although there are strong arguments for data protection (particularly of personal data) and security requirements (particularly around critical national infrastructure), there are increasing demands for transparency and accessibility of energy data to legitimate actors [106]. Access to smart meter data is also being explored in some contexts [107] though personal data protection regimes may limit the purposes and conditions under which it is shared. While in many countries there is currently no legal compulsion for energy companies or authorities to share data, some emerging trends may support future participatory governance. For example, in Estonia and Denmark, energy market and system data is now accessed in a standardized way through a national data 'hub' [108,109]. While not all data is open (i.e. freely available for anyone to use for any purpose [110]) this mechanism still reduces uncertainty and friction in energy data access which is potentially supportive of participatory governance activity. Additionally, recent changes to UK regulation now mandate energy networks to assess and publish data and software assets openly, unless evidence can be presented to support restrictions [111].

While access to energy data may be improving in certain areas, access to software code can be more complex. Software is an important part of businesses' intellectual property and, unless developers choose to publish it under an open license [112], it is often legally protected on the grounds of commercial interest. This can encourage the creation of a legal 'black box' around a piece of software or financial barriers to access by cash poor democratic actors or collectives. These barriers are notable as they can significantly reduce opportunities for widening participation in scrutiny and governance of software used in core energy sector functions. While such barriers may most clearly apply to public participation, they can also obstruct institutional democratic scrutiny. For example, there are growing calls for data, algorithms and software to be audited for common biases, particularly when used in areas with high public impact [113]. Without regulatory change stipulating access for assessments such as bias audits, it is possible that valuable new forms of democratic scrutiny may be restricted.

To summarize, this section identified how the exercise of participatory governance may be challenged by digitalization, based on the emergence of new skill and knowledge gaps and issues with access to digital resources. Skills and knowledge gaps can present a risk to inclusivity within emerging digital-democratic practice by reducing the scope for popular participation in governance activities at multiple scales. The high level of skills and knowledge required for effective participation in governance activities appears likely to mirror known axes of socioeconomic inequality. These issues can be further compounded by a lack of access to data and software code, potentially reducing the effectiveness and reach of new avenues for digital-democratic activity in the sector due to a lack of transparency or information access.

4.3. Civic ownership

Concepts of ownership used within the energy democracy literature may require re-examination due to the impacts of digitalization. Firstly, as discussed in previous sections, the nature of ownership of data and software code has strong potential to shape the direction of travel of digitalization. However, there is more than one way in which to approach ownership of these assets. 'Ownership' of data is complex and contested, with different legal regimes applied to personal and non-personal data, as well as between legal jurisdictions [114]. For example, within the EU, certain forms of data such as those holding commercial value may be covered by intellectual property law. By contrast, the EU General Data Protection Regulation (GDPR) does not ascribe property rights to personal data but rather ascribes individual rights or control over their personal data [114].

When data is combined, or otherwise processed, delineating ownership can become even more complex due to the introduction of mediating parties or technologies, in addition to stipulations of the original data license. For example, in UK law a form of copyright known as the Database Right (Section 13) is applied to databases 'if there has been a substantial investment in obtaining, verifying or presenting the contents of the database' [115]. While this gives rights to the original database creator, it can also be used by actors who modify or combine the database to produce a new artefact, so long as this meets the threshold for 'substantial investment'. This remains open to a degree of interpretation causing legal and commercial grey areas. Furthermore, legal regimes concerning data ownership currently exhibit gaps in protecting collective or group-based data rights. Collective data rights are one avenue through which new forms of civic ownership of data resources may be advanced. For example, this has been explored in relation to data commons [116], data trusts [117], public interest data access [118], and in several approaches to indigenous data sovereignty [119]. However, in practice it has proved practically challenging to institute establish alternative rights models in legal environments that lack of supportive rights or appropriate 'data institutions' [120].

Ownership of software is perhaps clearer from a legal perspective as it is more consistently protected by intellectual property regimes. However, there is also significant momentum in academic, non-profit and developer communities to encourage publishing of ‘open source’ code that can be both used and scrutinized by others with few (if any) limiting conditions [121]. Furthermore, in some countries such as the UK, governance bodies are also moving towards encouraging open source publishing as well as the creation of open standards governing software development in certain domains [122]. While skills and knowledge necessary to participate in software development remain unevenly distributed, as highlighted in Section 4.2, more open publishing and licensing of software code can catalyze or enable growth in related resources and skills; acting potentially as a new form of public good or knowledge commons [116]. Furthermore, types of open license commonly known as ‘copyleft’ have innovated ways to grow this type of public good by specifying that uses of the licensed code must in turn be published under the same open conditions [123].

Ownership of material energy assets is changing alongside the digital embeddedness of these assets. This phenomenon is described by Dodge and Kitchin as ‘programmability’, referring to the increasing dependency of asset functionality on data and software [124,125]. Relatedly, programmability can affect or ‘filter’ the capacity of asset owners to extract value from the asset. For example, smart electric vehicle (EV) charging and vehicle-to-grid technologies offer the potential to automate battery charge/discharge in accordance to changing price signals and demand from the wider grid. Owners of smart chargers can incur lower charging costs than those who are unable to automate the charging process [126], as smart charging and vehicle-to-grid functionality enables the asset owner to offer flexibility services that are valuable to suppliers and energy networks. This illustrates one way in which the value and costs of the material asset can be interdependent with software function. Importantly, it also highlights another way in which citizens may be excluded from the benefits of energy digitalization if they are unable to afford or access adequate hardware and software. This is described in more detail by Powells and Fell in their concept of ‘flexibility capital’ [97].

While, as discussed in Section 3, ‘smartening’ material assets through the use of data and software is valuable in supporting system decarbonization, it can also present certain accountability problems. For example, the use of third party software can increase the complexity of supply chains and decision-making processes, making it more difficult to pinpoint who is responsible in cases where faults occur. Such accountability challenges may be exacerbated if the software is unavailable for public scrutiny, as discussed in Section 4.2. Moreover, this potentially presents risks to asset owners at all scales – from national infrastructure through to community or domestic levels – that they are held fully responsible for assets over which their control is mediated by software and related input data streams that they may not own. Such disruption of assumed links between ownership and control potentially complicates the position of civic ownership as core dimensions of energy democracy in digital environments.

To summarize, this section has explored two key impacts of digitalization on civic ownership. Firstly, digitalization diversifies the types of assets owned and used in energy systems. This potentially broadens the components of civic ownership outlined in Szulecki's framework to also include data and software assets. While models for civic ownership in this space are not yet fully established, open licensing and communal ownership rights may present fruitful avenues for further exploration. Secondly, digitalization embeds complex new dependencies between software and material assets. This complicates two assumptions that position civic ownership as a core dimension of energy democracy: the assumed association between ownership and control of assets; and the capacity of asset owners to extract value from their assets.

5. Discussion

Section 4 identified a range of ways in which data and digitalization complicate how energy democracy is conceptualized and practiced, with implications across all three dimensions of Szulecki's framework. This section discusses some implications for energy democratic thinking in a digital world.

Analysis in this paper has identified certain changes resulting from digitalization, to which democratic responses may parallel existing components or indicators of Szulecki's energy democracy framework. For example, educational programs form an existing indicator for participatory governance, which could be broadened to explicitly include aspects of digital education or data skills. Alternatively, components relating to civic ownership concerning power generation, transmission and distribution infrastructure could be expanded to include corresponding data and digital assets at the core of the energy system. Although the exact nature and scope of core digital assets may not yet be known, the set of ‘public interest digital assets’ recently proposed by the UK's Energy Digitalization Taskforce [122] may act as a springboard for exploration. Further research into such adaptations is suggested, as this could provide practical support to citizens and energy democracy practitioners seeking to influence digital developments within the sector.

However, not all elements of the framework can be straightforwardly transposed into the digital environment. For example, Section 4.1 demonstrated how the introduction of automation and new computational actors challenges the very meaning and expression of popular sovereignty. Furthermore, our analysis suggests that digitalization has the potential to reshape certain core concepts underpinning understandings of energy democracy. In particular, we identify that digitalization has the potential to re-shape the nature of collective decision-making in the energy sector by affecting how decisions are made and who or what are involved in making them.

Digitalization is impacting energy sector decision-making in fundamental ways. Firstly, digitalization increases the types, volume and speed of information available to energy decision-makers [72]. As the sheer volume of data is often not interpretable to non-specialists, this also introduces new technologies (e.g. analytics) and job roles (e.g. data scientists) into decision-making chains. For example, analysis by the professional social network LinkedIn found that demand for data scientists in the US across all sectors grew by 37 % from 2019 to 2020, putting the role within the top 3 highest-growth professions [127]. The introduction of new information, technologies and expertise has the potential to create new politics and power dynamics [128] that are as yet widely unexamined by the energy democracy literature. Section 4.2 also touched on the potentially exclusionary nature of this trend for non-specialist citizens; particularly in relation to their participation in governance activities. While there has been growth in academic literature exploring digital exclusions in terms of energy system participation, particularly in the domestic space [49,95–97,129,130], significant knowledge gaps remain regarding the impacts of digital exclusion on less individualized roles and responsibilities, such as those related to governance and democracy.

Secondly, the use of automated decision-making is expanding across different energy system functions [71]. Although individual automated decisions may appear small, such as when to charge or discharge battery storage, they are potentially significant when aggregated across the system. They are also notable as they change the sector decision-making landscape from one in which humans are the primary cognitive agents, to one in which decisions are also made by machines and human-machine collectives. The energy democracy literature has not yet explored the full implications of this changing human-machine landscape. Future engagement with broader literatures concerning automation and algorithmic governance may prove fruitful.

Thirdly, ‘predictive’ digital tools or models, often known as forecasts or simulations, are increasingly being used to inform policy and industry decision-making in the energy sector. For example, predictive modelling plays a part in creating planning tools called Future Energy Scenarios, used by National Grid Electricity System Operator in the UK [131]. This is not just an energy sector trend, but is indicative of greater use and trust of these tools across the economy. Perhaps the most recently publicized use of simulation modelling has been that conducted by public health bodies to predict the growth and spread patterns of COVID-19 and its variants [132]. The use and public awareness of these models has also resulted in rapid creation of new literature, both academic and journalistic, explaining the impacts of these models and factors, such as quality and completeness of data inputs and the veracity of assumptions underpinning a model [133], that can impact their outputs. The COVID-19 pandemic has served to illustrate in real time that models do not only simulate the world from a distance but can also practically impact it by informing policy and commercial decision-making [134]. It is suggested that principles noted briefly here could also be applied to the use of predictive modelling in the energy sector, inviting exploration of the politics and impacts of predictive modelling in the sector as an avenue of democratic inquiry.

Alongside changes to decision-making, digitalization may also redefine the power struggles that animate energy democracy. As outlined in Sections 2 and 4, digitalization could support trends towards a more decentralized energy system architecture and associated reconfigurations of socio-economic power. However, data and digital technologies, particularly 'general purpose' innovations [135], are being exploited in parallel by a range of commercial entities including oil and gas firms [136]. Future conceptual inquiry must therefore consider the broader energy sector context in which digitalization is taking place. While further research is required, our analysis strongly suggests that digitalization should not be automatically associated with democratic outcomes.

In summary, this section discussed how certain aspects of Szulecki's framework could be adapted in ways that support the continued evolution of energy democracy in a digital sector environment, i.e. towards *digital energy democracy*. However, energy system digitalization is already changing the decision-making landscape in fundamental ways. As this phenomenon accelerates, it may challenge the framework more profoundly than can be captured through adaptation of components and indicators alone. This does not imply the framework is no longer valuable in the face of digital change; adaptations can preserve its ongoing utility as an analytical tool that is relevant for citizens and energy democracy practitioners. However, digitalization presents a particular challenge to concepts of democracy that are underpinned by collective decision-making and more work is needed to fully understand the implications.

6. Conclusion

This paper explores how digitalization, conceptualized as a sociotechnical transition, can affect concepts and practice of energy democracy. Digitalization-induced changes to the energy sector were examined from three perspectives identified by Szulecki as fundamental elements of energy democracy: popular sovereignty, participatory governance, and civic ownership.

Our analysis highlighted four key findings. Firstly, digitalization can simultaneously enable and constrain the exercise of popular sovereignty. Here, digitalization broadens the range of activities and roles in which energy citizens participate, potentially diversifying opportunities for citizens to exercise agency in the energy system. However, it also introduces new human and machine actors that can reduce transparency of decision-making and complicate accountability.

Secondly, digitalization creates two new dimensions of risk that could exclude citizens from participatory governance. One risk relates to the increase in specialist knowledge and skills that democratic participation in a digitalized energy system may demand. The other risk relates to access barriers to data and software code, which carry the potential to frustrate scrutiny by citizens and civic institutions.

Thirdly, digitalization can complicate assumed links between civic ownership and democratic control of assets, particularly with regards to material assets. This is because digitalization embeds new dependencies between software and material assets that can disrupt owners' ability to control or extract value from their assets. However, if approaches to civic ownership are broadened to also include data and software assets then digitalization may present opportunities to broaden civic ownership of system data and digital infrastructure.

Our final finding indicates that it is not possible to account for all areas of digital change solely by adapting existing energy democracy frameworks, such as the one used in this paper. Digitalization disrupts the nature and exercise of decision-making; a core underlying concept in many definitions of democracy.

We recommend that further research is undertaken to better understand the impact of digitally-induced changes to decision-making and their impacts on energy democracy. A clearer understanding of digitalization as a set of rapidly evolving sociotechnical phenomena could help to better equip citizens, practitioners, researchers, policymakers and regulators to adapt to – and actively shape – forms of digitalization that are of value to society and the environment. This in turn may improve the speed and legitimacy of digitally-enabled decarbonization.

Empirical research in this area could be advanced through study of emerging forms of digital energy democracy, in particular the core concepts underpinning these models. Such research may also benefit from comparative study of models of democratic activity in other digitalized sectors. Exploring the creation of new 'data institutions' [120] in the energy sector, and any associated democratic claims, may provide an additional avenue for inquiry. Openness to pluralistic understandings of democracy [16,39], and types of 'democratic citizen' [15], would be of advantage in relation to all of these research pathways.

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Declaration of competing interest

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