Idries *et al. Energy Informatics* (2022) 5:8
https://doi.org/10.1186/s42162-022-00193-9

Energy Informatics

REVIEW

Challenges in platforming and digitizing decentralized energy services

Ahmed Idries[1*], John Krogstie[1*] and Jayaprakash Rajasekharan[2*]

*Correspondence: ahmed.y.m.idries@ntnu.no; john.krogstie@ntnu.no; jayaprakash.rajasekharan@ntnu.no

[1] Department of Computer Science, Norwegian University of Science and Technology, Trondheim, Norway
[2] Department of Electrical Power Engineering, Norwegian University of Science and Technology, Trondheim, Norway

Abstract

This paper aims to identify and classify the challenges and issues faced by the energy sector in digitizing distributed energy operation and services using digital platforms. It contributes to two fields: information systems (IS) in the domain of platforms ecosystems and digital services innovation and the field of energy informatics in the domain of digital business models and service innovation. Through a systematic literature review, we investigate current research on digitalization and digital platforms in the context of electrical energy services and identify challenges and areas for future research. The key challenges are then classified into two categories, each with three subcategories: Architectural challenges, including aspects of design, ecosystem management, and agility and openness; and business and regulatory challenges, including contracts and relationship management, business models, and standards. The main limitation of this study is that it does not focus on a specific geographic domain, which means that the results are somewhat general and may not be applicable to certain countries or regions. The paper concludes with recommendations for future research directions in the digitalization and platformization of the energy sector in all six-sub-areas.

Keywords: Digitalization, Decentralization, Platformization, Distributed energy resources, Ecosystem

Introduction

The core motivation of this paper is the fact that organizations in the electrical energy sector are transitioning toward a decentralized and platform-based operating model. This transition is part of the 5 Ds that are driving the current electrical energy transition, namely, decentralization, digitalization, decarbonization, democratization, and decreasing consumption. This transition is affecting distribution-related services. Also, the transition towards a platform-based model is opening up many opportunities for service innovation (Ma et al. 2021). As a result of this transition, many services will be able to take place on these platforms, such as peer to peer trading, flexibility trading and many other services. This variety of services will allow many stakeholders and actors to participate in these platforms ecosystems. Nonetheless, the most significant disruption to the existing system will consist of business model innovations such as peer-to-peer (P2P) electricity trading, virtual power plants (VPPs), flexibility management, local energy markets or the vehicle-to-grid concept, and VPPs aggregated from households with newly available technologies (Xu 2019; Dietz-Polte et al. 2020; Ilieva and Rajasekharan 2018). Also, the disruption caused by electricity trading platforms with distributed and decentralized assets (Ahl et al. 2019) involves complementary dimensions, which are as follows:

1. Technology: Energy management systems, power grids, peer-to-peer (P2P) networks.
2. Economy: Energy market mechanisms, prosumer business models, smart contracts.
3. Social: Socioeconomic incentives, stakeholder interest management, community engagement, self-sufficiency, and life-cycle impact.
4. Institutions: Market policies, grid codes, P2P policies, mechanisms for institutional innovation.

This transition has many implications and faces multiple challenges on different levels, including the technological and regulatory levels, and from other aspects, such as service innovation, since the digital ecosystem will be complex. Many stakeholders will participate in this ecosystem. The traditional electricity system involves producing, transporting, and consuming power from large, centralized plants through grids at different voltage levels to end customers who consume whatever level of electricity they want whenever they want it. The need for supporting prosumers changes the hierarchy of electrical energy distribution and offers a potential role to new technologies such as distributed ledger technologies (DLTs). With the introduction of new digital technology and distributed renewables and storage, local systems will demand flexibility and locally supported system services. However, this process also gives incentives to innovation in market design, market operation, dispatch management, and the real-time operation of even the most minor power resource. As a result, there will be new platform models and unique ecosystems confronting the many challenges that await us (Antolić et al. 2020; Ahl et al. 2019).

In addition to the above mentioned issues, the services delivered by service platforms in the energy context include flexible markets, P2P energy trading, metering and settlement operations, market surveillance and auditing, asset monitoring, customer profiling, and market integration. This wide variety of tasks brings multiple actors into the ecosystem, including market operators, both distribution system operators (DSOs) and transmission system operators (TSOs), energy producers, and customers (Antolić et al. 2020; Livik et al. 2020).

The rise of new technologies contributes to platform-based business models and services across different domains. Hence, these technologies are changing the landscape of current facilities and businesses. The increasing adoption of distributed energy resources (DERs) and storage systems, along with technological disruptions in the energy sector, pose challenges and create opportunities for both existing and new stakeholders (Ilieva et al. 2018a).

As it is used in the field of IS, “platform” is a broad term that varies from the digital marketplace to a virtual site that delivers a variety of services to individuals, governments, and organizations (Han et al. 2018). Hautamäki and Oksanen (2018) highlight the need to digitize the public sector, since governments and public sector entities are seeking to enhance efficiency, cut costs, deliver better outcomes, and expand citizen choice. Many customers, who are enabled by the convergence of new, widely available technologies that can automate and monetize their energy resources, have begun to take more direct control of the cost, reliability, and green mix of their power supply (Ilieva and Rajasekharan 2018). Generally, the goal of digitalization is to build a deeper interaction between citizens, service providers, and the public sector.

According to Statnett (2021), an electrical energy marketplace (such as a flexibility market) provides an opportunity for new players to enter the energy sector. To succeed in the marketplace of distributed and small resources, one needs to be market-aware, dynamic and able to deal with market changes. This may be more difficult for traditional large providers than for new "young" providers whose products and services are designed to be fully digital from the start. Another perspective of the energy marketplace is that digitalization and the adoption of digital technology, which refers to the ability to adjust to the new digitized world with its cybersecurity challenges and the increased inter-dependencies between IS and operational technologies (OT), will disrupt the market (Statnett 2021).

Decentralization in distributed energy services can lead to the generation of products and services that become accessible at any time through continuous integration with the customer. Service process modules that create value for both the customer and the firm can be developed (Löfberg and Åkesson 2018). Reliable and accurate information is critical for building sustainable energy systems, as such information supports decisions about investing in and managing infrastructure and technology. Moreover, this information can help overcome market failures (Alstone et al. 2015). Therefore, more understanding of the actual practices involved in energy services platformization and digitalization is required in the IS literature.

According to Wagner and Götz (2021), energy service is defined as the physical benefit, utility, or good derived from a combination of energy with energy-efficient technology or actions, which may include the operations, maintenance, and control necessary to deliver the service based on a contract; under normal circumstances, such service has been proven to result in verifiable and measurable or at least estimable energy efficiency improvement or primary energy savings. As a result, the use of technology will help in connecting DERs for the delivery of distributed energy services.

The next disruption appears to be aggregators, who act as digital intermediaries in regard to centralizing the interactions between the wholesale market and thus balancing demand and production between grid operators and consumers. As a result, two-sided and multi-sided market platforms have appeared, and more could follow. Service providers could be successful in following the New York State authorities' plan for digital platforms and running open distribution grids where buyers and sellers can make deals for a wide range of new products according to their own wishes and needs (Sioshansi 2019; Orsini et al. 2019). Going a step further, "high interaction platforms" could appear by creating trust between the transacting parties as a prerequisite for the start of trading. Examples include the P2P trading of distributed renewable self-generated power, P2P storage, and P2P electric vehicle charging stations (Sioshansi 2019). To this end, our main research question is as follows:

- RQ1. What are the challenges for service innovation in the electricity energy field when moving toward a digital platform model for the delivery of energy services?

  This research question will be answered by answering the following three sub-questions through a systematic literature review:

1. RQ1.1 What are the current research limitations?
2. RQ1.2 What research topics are being addressed?
3. RQ1.3 Who is leading the research and in which domains is the research conducted?

This section has attempted to provide a brief introduction to the topic, the motivation for this study, the research question and the goal of the study. The remainder of this paper is structured as follows. The Background section introduces the main definitions used in the paper, and the Research Methods section presents the methodology adopted by this study. The Challenges of Energy Services Platformization and Decentralization section presents the paper's findings and proposes future research directions for each identified challenge, while the Discussion section provides an exploration of the findings and how they are related to the main RQ. Finally, the Conclusion section summarizes the findings of the study and notes its limitations.

Background

In this section, we first provide an overview of service platforms, which is the main concept related to this research. We then introduce service platforms in the context of electricity energy services, which serves as the study's conceptual foundation of investigating the challenges relevant to electricity firms' transition toward a digital platform model.

Service platforms

Different definitions exist in the literature regarding the term "service platforms," which is the source of the term "platformization." Researchers have provided a definition of a service platform as a modular structure that contains both tangible and intangible resources that ease and facilitate the interaction between actors and resources (Constantinides et al. 2018; Ardolino et al. 2018; Löfberg and Åkesson 2018). These platforms are also a way to reduce the level of complexity because they use modular parts and components that can be integrated into many types of services. In service platforms, the alignment of the platform's capabilities with regard to interoperability and portability offers an advantage to the platform in terms of growth and added value. Researchers have also discussed the architecture of service platforms, since they enable the gathering in one place of the products, services, and infrastructures that facilitate and ease users' interactions, transactions, and communication (Tiwana 2014). As a result, in DERs, the primary role of a platform is to act as a flexible medium that can match supply and demand for energy products and services.

Ardolino et al. (2018) acknowledges that the main idea behind any service platform is to combine all products and services that can improve efficiency and reduce cost. This approach can also make the service more tangible and easier to understand. Service platforms facilitate processes at three levels, namely, the service, procedure, and organization levels. This facilitation has led to the conceptualization of service platforms as also a way to enhance the customer experience. According to Constantinides et al. (2018); de Reuver et al. (2018); Hagiu (2014), a few concepts must be clarified in order to study platforms, platforming, or any issue related to digitizing. These concepts are as follows:

1. Digital and multi-sided platforms: Constantinides et al. (2018) defines "digital platforms" as a set of digital resources that includes services and contents that enable value creation and interactions between external consumers and prosumers. Digital platforms can also be defined as an extensible code base to which complementary third-party modules can be added. In addition, a digital platform is a service, technology, or product that lets two or more customers or participant groups interact directly (Hagiu 2014).
2. Ecosystem: An ecosystem is defined as a collection of complements (apps) to the core technical platform, which are mostly supplied by third parties, i.e., a collection of firms that interact and contribute to these complements. Ecosystem actors are natural or legal entities that augment the platform with modules, services, or sales channels. Any social and economic agent who provides input to and takes advantage of value co-creation is part of the ecosystem.

Multi-sided platforms such as Airbnb, Amazon, and Uber, similar to ESP and SmartMeasure in the energy sector, are known for having a service platform architecture since they can handle a high volume of transactions between different actors. Therefore, service platforms follow a multi-sided approach in which the platform acts as an intermediary that brings different players and actors together to contribute to the platform with their products or services. All this activity creates value for the platform. This approach is familiar to current energy providers because of services like demand management and energy trading.

Overall, studies by Constantinides et al. (2018); de Reuver et al. (2018); Hagiu (2014) have highlighted how platforming is affecting not only technologies but also policies, actors, and ecosystems and the interplay between them. The evidence presented by de Reuver et al. (2018) suggests that the exponential growth in disruptive technologies, decentralized distributed architecture, and digital artifacts will allow more complexity because of the involvement of independent actors. The authors also note that the decentralization of digital platforms will have transformative and disruptive impacts on both organizations and their business models. Moreover, platforms have certain unique characteristics. Ilieva and Rajasekharan (2018) identifies the presence of network effects as their central feature. What the authors mean by the term "network effects" is that more users beget more users, which is a dynamic that enables a self-reinforcing cycle of growth.

Decentralized energy is energy that is produced closer to where it is used rather than being drawn from a large plant located on a regional or national grid. Local generation reduces transmission losses and lowers carbon emissions. The security of supply is increased for all customers because they do not share a single limited supply or rely on relatively few large and remote power stations (Alstone et al. 2015). According to Adil and Ko (2016), energy decentralization has three configurations: Distributed generation, micro-grids, and smart micro-grids. Distributed generation is the backbone of energy decentralization; it is defined as an electric power system that is connected either within distribution networks or on the consumer side (Altmann et al. 2010). A more detailed account of service platforms in the distributed energy sector and services is given in the next subsection, along with an overview of the functions of service platforms in the distributed energy sector.

Service platforms in the distributed energy sector

Disruptive technologies such as the internet of things (IoT) and artificial intelligence (AI) more generally allow decentralization in market and service platforms by resolving conflicts of interest and providing information symmetry to all platform participants, which leads to cost-effective transactions. For decentralization to be achieved, all the technologies mentioned above are required. Another specific feature of platforms is that they rely predominantly on digitalization; that is, they capture, transmit, and monetize data by means of internet connectivity. Thus, many successful platform companies are centered on a software engine (Ilieva and Rajasekharan 2018).

Many authors have sought to describe the characteristics of energy platformization. For example, Richter and Pollitt (2018) note that an energy service is smart if the power management mechanism and energy device management use a specific algorithm and if there is a communication protocol or means present between grids and devices. Recently, there have been several changes made to European Union (EU) energy regulations that have encouraged consumers to enter into electricity contracts with micro-grids. Such development gives service platforms an excellent opportunity for growth. However, an obstacle to such development is the gap between the technology and the required level of engagement of the customer (Richter and Pollitt 2018).

Furthermore, Thomas et al. (2019) describe the energy system as a collection of distinct networks, sources, the parties responsible for them, and the associated physical and information flows. The complexity of energy networks is forecasted to increase with higher volumes of information and larger numbers of controllable components. When accompanied by the decentralization of responsibilities, this growth will either lead to the creation of more information interfaces or require more information to be processed at existing interfaces (Thomas et al. 2019).

Energy service platform ecosystem

According to de Reuver et al. (2018), in the energy sector, many stakeholders will function as actors in the ecosystem, such as service providers, payment services providers, and energy sellers. Figure 1 illustrates the expected roles that actors will play in the ecosystem of these platforms. In addition, the interactions between this actors could be in form of data,information and monetary value (Hack et al. 2021).

1. TSOs are responsible for the reliable transmission of power from generation plants to regional or local electricity DSOs by way of a high-voltage electrical grid. Since TSOs are usually a natural monopoly within a country, they are subject to state regulation. TSOs provide grid access to electricity market players—thereby generating compa-

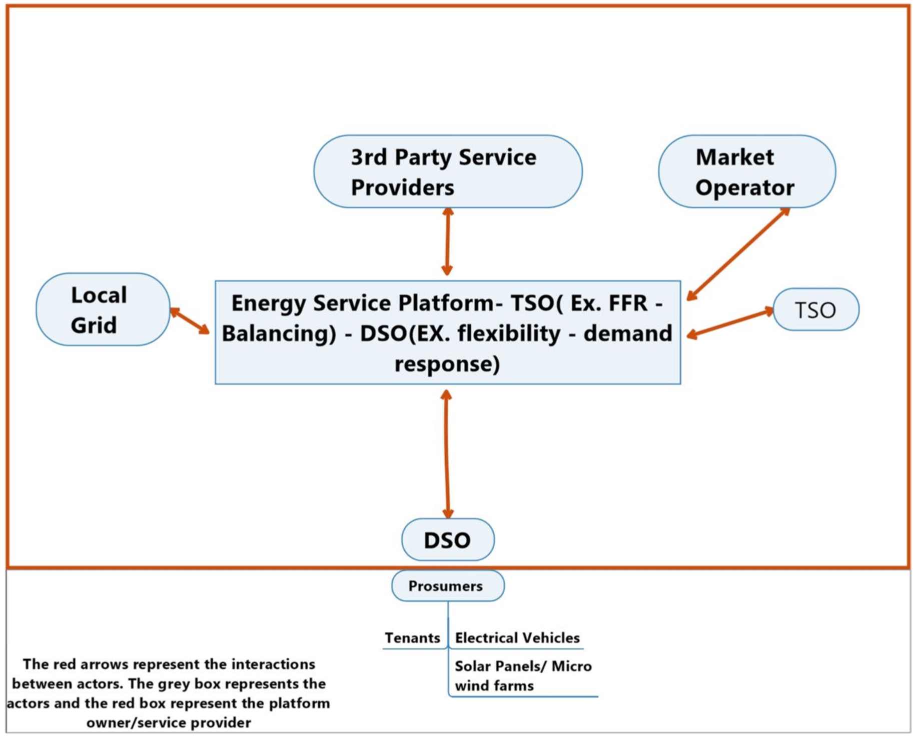

Fig. 1 Expected ecosystem actors

nies, traders, suppliers, distributors, and directly connected customers—according to non-discriminatory and transparent rules.

2. DSOs are the operating managers (and sometimes owners) of energy distribution networks, who operate at low-voltage (LV), medium-voltage (MV), and, in some EU member states, high-voltage (HV) levels. Transmission grids transport large quantities of HV and extremely high-voltage (EHV) electricity across vast distances, often from large power plants to the outskirts of large cities or industrial zones, where it is transformed into lower voltages before it is distributed to end users through the distribution network. The overhead and underground cables leading to homes and businesses are operated by DSOs.

   A prosumer is someone who both produces and consumes energy; this is a shift that has been made possible, in part, due to the rise of new connected technologies and the steady increase of more renewable power such a solar and wind making its way into the electricity grid.
3. A local grid or micro-grid is a power distribution system of limited management scope (and thus geography). It is also a group of interconnected loads and DERs within clearly defined boundaries that acts as a single controllable entity with respect to the grid (Ton and Smith 2012). Its electricity distribution systems contain loads and DERs such as distributed generators, storage devices, and controllable loads that can be operated in a controlled, coordinated way while remaining connected to the main power network (SGIP 2016).
4. A market operator is an entity that performs certain system-level roles in the electricity market such as balance scheme management, recording closed contracts and

operational forecasts, balancing the market, and imbalance settlement; market operators may not exist in every country, as their tasks are often performed by a TSO (SGIP 2016).

5. Prosumers are those who benefit from the services delivered and include electrical vehicles, end users, consumers, tenants, and solar panel and wind farm owners and some of them are producers as well (Ex.Electrical vehicles).

A decentralized energy system is characterized by locating energy production facilities closer to the site of energy consumption. A decentralized energy system allows for the more optimal use of renewable energy by combining heat with power, reducing fossil fuel use and increasing eco-efficiency. A decentralized energy system is a relatively new approach being used in the power industry of most countries. Traditionally, the power industry has focused on developing large, central power stations and transmitting generation loads across long transmission and distribution lines to consumers in a given region. Decentralized energy systems seek to locate power sources closer to end users. As end users are spread across a region, sourcing energy generation in a similarly decentralized manner can reduce transmission and distribution inefficiencies and related economic and environmental costs (Sioshansi 2014).

Foundationally, the primary function of platformization in the context of energy is to exchange information between the physical facilities and all market participants and stakeholders (Tikka et al. 2019; Wehlitz et al. 2017; Wang et al. 2018). The challenge here is the lack of an interoperable data exchange interface that can be accessed by all system stakeholders and meets their business requirements. In the energy sector, these stakeholders are aggregators, micro-grid operators, and system operators. Wang et al. (2018) defines the energy internet as the integration of energy distribution technologies, smart metering technology, real-time monitoring technologies, and adjustment-controlling techniques. Furthermore, the energy internet supports access to large-scale distributed generation and to distributed energy storage systems. The energy internet is mainly focused on different types of DERs (predominantly renewable and environmentally friendly resources), while the smart grid is controlled by a regional system. Wang et al. (2018) compares the smart grid and energy internet in terms of technology integration, centralization, architecture, and manner of communication and finds the energy internet to be a facilitator of decentralization processes.

Preliminary work on energy trading platforms has been undertaken by Yuan et al. (2019), who has investigated the role of big data in power trading platforms, based on AI and deep learning technologies. The authors propose a platform that relies on micro-services and blockchain technologies to deliver products and services. They discuss how big data performs demand and supply forecasting on power trading platforms and how it manages stakeholders in terms of profiles and relationships. These are historical and behavioral data and classifications within the platform. The significant role of data is not limited to the previously mentioned functions. This role also involves analyzing power trading operations to obtain an in-depth understanding of the relationships between stakeholders. Furthermore, an understanding of the actual practices involved in energy services platformization and digitalization is required in the IS and energy informatics literature. In the next section, the empirical methods followed in this paper are presented.

Research method

Overall research approach

Informed by Dybå and Dingsøyr (2008), Kitchenham et al. (2009) and Webster and Watson (2002), this study is anchored in a systematic literature review that seeks to organize and synthesize the current body of knowledge and identify gaps and future research opportunities for digitalization in DERs from a service innovation and platformization perspective. In this case, the systematic review aims to assess the existing literature; thus, this study is categorized as a systematic literature review. The steps in the systematic literature review method are documented below.

The primary search process identified 1300 papers related to the topic. In the next stage, after exclusion based on title and reported outcomes, content and duplicates removal, 200 papers were identified (see Fig. 2). Then, after excluding papers based on the quality assessment process (see Table 3), 40 papers remained. In the end, based on the synthesis, 32 papers were chosen for deeper investigation. The next subsections discuss and elaborate on the search and quality assessment processes. Figure 2 shows the stages of the systematic literature review and the number of papers identified in each stage.

Search process

The search process was also guided and informed by Kitchenham et al. (2009) and Dybå and Dingsøyr (2008) to improve its quality. This involved an online search of specific conference proceedings and journal papers since 2016. The papers were chosen because they reported on empirical (whether quantitative or qualitative) studies and were published in well-known venues. The data collection included database searches and searches of journals and conferences proceedings from the following databases:

1. ACM Digital Library
2. Nature Magazine
3. IEEE Xplore

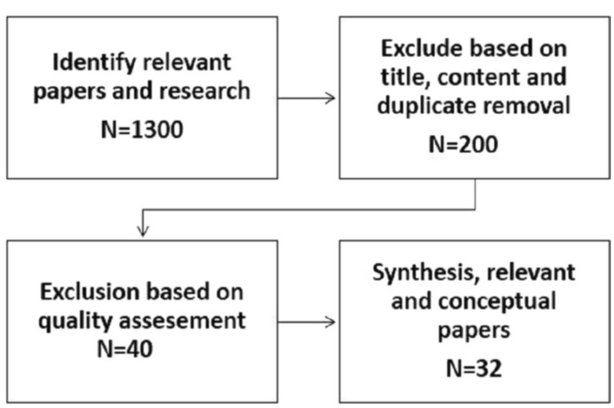

Fig. 2 Paper selection process

4. Springerlink
5. AIS E-Library
6. Elsevier / Science Direct

In the first stage of this review, abstracts and keywords in the targeted databases were searched using the following terms

1. ((energy) AND (service platforms)) OR
2. ((energy trading) AND (service platforms)) OR
3. ((decentralization) AND (energy) AND (ecosystem)) OR
4. ((digitalization) AND (distributed energy resources)) OR
5. ((platforms) AND (distributed energy resources))

Table 1 shows how the search strings were used in this study.

Inclusion and exclusion criteria

Informed by Dybå and Dingsøyr (2008), the researcher responsible for searching a specific journal or conference applied the relevant papers' detailed inclusion and exclusion criteria. Table 2 illustrates the publication venues.

Studies were eligible for exclusion if did not specify the targeted criteria, the authors read the paper to determine whether it applied to the research context. A study was included if it appeared relevant to the service platforms and energy contexts; otherwise, it was excluded. The exclusion criteria included the following:

Table 1 Search strings and databases

	Results in database						
Search string	**ACM library**	**Nature energy magazine**	**IEEE digital library**	**Springer link**	**AIS E-library**	**Elsevier/ ScienceDirect**	**Sum**
((energy) AND (service platforms)) OR ((energy trading) AND (service platforms)) OR ((decentralization) AND (energy) AND (ecosystem)) OR ((digitalization) AND (distributed energy resources)) OR ((platforms) AND (distributed energy resources))	120	50	220	300	140	470	1300

Table 2 Publication venues

Year	Venue	Type of venue
2019	IEEE ITAIC	CONFERENCE
2018	IEEE Systems Journal	Journal
2018	Computers and Chemical Engineering	Journal
2020	Journal of Cleaner Production	Journal
2018	IEEE International Energy Conference (ENERGYCON)	Conference
2018	Future Generation Computer Systems Journal	Journal
2018	Ecological Economics Journal	Journal
2018	IAEE International Conference	Conference
2016	ACM International Conference on Management of Emerging Ecosystems (MEDES)	Conference
2016	Bit Bang 8 Aaalto University Multidisciplinary Institute of Digitalisation and Energy	Conference
2018	Infsys Research Journal	Journal
2019	BUIS—TAGEN/Smart cities—Smart Regions—Technical, Economic and Social Innovations	Conference
2019	Journal of Clean Energy Technologies	Journal
2018	AIS Journal—Journal of the Association of Information Systems	Journal
2017	University of Zurich	Research Report
2016	European Parliament	Research Report
2018	European Conference on Information Systems (ECIS) - Workshop on Platformization in the Public Sector	Conference
2019	Renewable and Sustainable Energy Reviews	Journal
2020	Baker Mckenzie	Research Report
2019	IEEE Milan PowerTech	Conference
2019	CIRED—International Conference on Electricity Distribution	Conference
2019	IEEEFA—Institute for Energy Economics and Financial Analysis	Research Report

1. Title and outcomes
2. Papers written in any other language than English;
3. Papers without any empirical evidence and those only based on expert opinion;
4. Editorials, keynotes, panel discussions; and
5. Papers for which the full text was not accessible or available.

Studies were eligible for inclusion if they met the following criteria:

1. Presented empirical (qualitative or quantitative) data on service platforms and energy service platforms.
2. Were published in 2016 or later (to focus on the latest developments and research directions in the field).
3. Were written in English.
4. Were published in a journal or conference proceeding.

Table 2 shows where the selected papers were published:

The next subsection shows the criteria used in the quality assessment process for selecting papers.

Quality assessment

Quality assessment was informed by Dybå and Dingsøyr (2008); we considered three quality criteria for quality assessment, namely, the rigorousness, credibility, and relevance of each study (see Table 3).

The quality assessment focused on 6 main criteria, which are: Empirical research, the aim and objectives, the context, research design, data collection, data analysis, findings and value of research (see Table 3).

Research questions

The research questions were previously presented in the Introduction section. The study has three sub-questions that help answer the main RQ. The aim of asking these questions is to understand how the included 32 papers contribute to the topic and to propose future research directions in the field. The sub-questions are as follows:

1. RQ1.1 What are the current research limitations?
2. RQ1.2 What research topics are being addressed?
3. RQ1.3 Who is leading the research and in which domains is the research conducted?

We considered several issues regarding the sub-questions:

1. Were the research topics limited?
2. Does the publication contribute to practice by defining practice guidelines?
3. Is the quality of the literature appropriate?
4. Is there evidence that the use of a systematic literature review is limited due to a lack of primary studies?

Table 3 Quality assessment Table

Quality criteria	Assessment questions
Empirical research	Is this paper based on research or merely expert opinion?
Clear statement of aim	Is there is a motivation for why the study is undertaken?
	Is the study's main focus on service platforms or energy service digitalization?
	Does the study present empirical data?
	Is there is a clear statement of the study's primary outcome?
Description of context	Who is the target audience?
	In which environment was the research carried out ?
Research design	Has the researcher described or justified the research design?
Data collection	Is it clear how data are collected (e.g., semi-structured interviews, focus groups.)?
	Has the researcher made the methods explicit (e.g., is there an indication of how they conducted interviews? Did they use an interview guide?)
Data analysis	Have sufficient data been presented to support the findings?
Findings	Are the study's limitations explicitly discussed?
	Are the findings discussed in light of the original research question?
Value of the research	Does the researcher discuss the contribution the study makes to existing knowledge or understanding?
	Does the research identify new areas in which research is necessary?

Concerning RQ1.3, we followed a multi-disciplinary scope that gathered literature from different domains, since the topic is digitalization and service innovation in energy systems.

Data extraction

We extracted data from 32 studies according to a predefined tables (see Tables 3, 4) and a predefined process is presented in Fig. 2. This form facilitated the recording of each reviewed paper's details, which enabled us to record the full details of all the studies in the systematic literature review and specifics about how the studies address our research question. We extracted the data and then cross-checked the extracted papers to ensure the consistency of the data extraction process (see Table 4). Further details are presented in the "Results" section.

Results

We identified 32 studies that are relevant to our research topic and the present study's main research question. We categorized the studies into two main groups of challenges, namely, architectural challenges and business and regulatory challenges. Architectural challenges refer to factors related to agility and openness, ecosystem governance, and design. Business and regulatory challenges refer to a lack of standards, business models, and contracts and relationship management. The papers were selected from well-known venues, as presented in Table 2. Figure 3 gives an overview of the studies and the categorization of the findings.

The figure below shows the findings of the systematic literature review and the related categories (see Fig. 3).

This section has described the methods used in this paper. The next section details the principal findings of this study.

Table 4 Data extraction table

1. Study overview	
Study identifier	(Author)
Extraction date	
Bibliographic reference	
2. Design of paper	
Study type	Qualitative or quantitative
Research methodology	Case study, action research, interview, survey, other methods
Research questions/hypotheses	Statement of hypotheses, research questions
Research context and targeted platforms/services	What are the aim and objectives and the aim of the study ?
3. Identified issues	
What are the identified issues in each paper	
Targeted Community of researchers	
4. Results and findings	
Findings	
Implications	
Limitations	

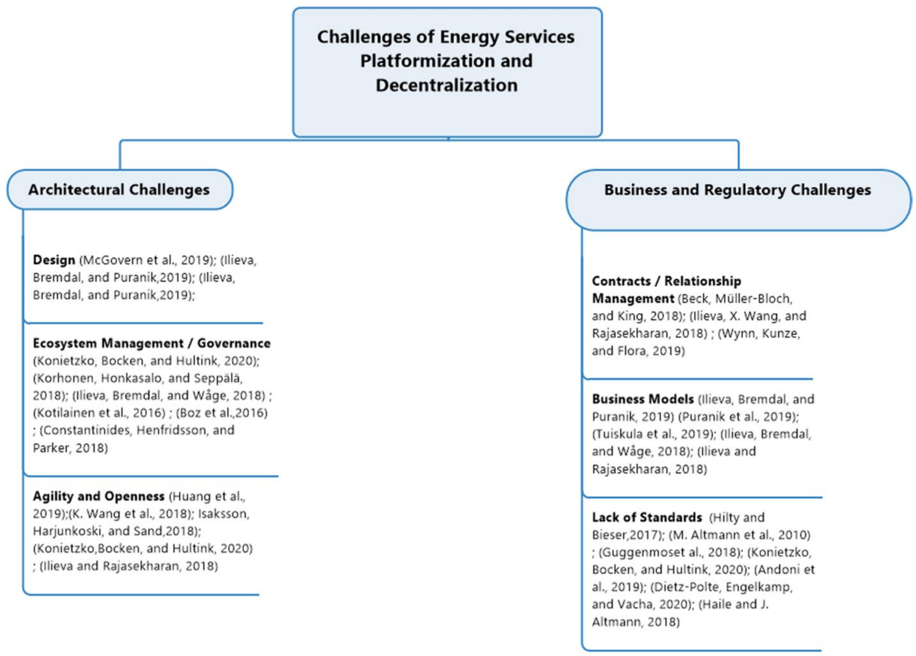

Fig. 3 Systematic literature review findings and categories

Challenges of energy services platformization and decentralization

This section presents the findings of the study and arguments related to the platformization and decentralization of distributed energy services; this systematic literature review aims to develop opportunities for future research directions. The following pages offer a thematic analysis of the findings; these themes and challenges are viewed and discussed from the perspectives of architectural challenges and business and regulatory challenges.

Architectural challenges

A technical report published by Dietz-Polte et al. (2020) notes that many technical aspects must be combined to make service platforms truly effective. These aspects include the latest sensor technology, forward-thinking infrastructure for data exchange and data processing, big data, AI, 5G and distributed-ledger technology to improve forecasts, remote monitoring and the management of decentralized productions, and increased plant optimization. In the section that follows, it is argued that how service innovation transitions toward the platform model is subject to agility and openness challenges.

Agility and openness

In a digitalization scenario, smart grids are at the core of the digitizing the domain. Hence, the main challenge is how a platformization or system can achieve and maintain highly efficient demand-side management. On the one hand, there is a high demand for distributed renewable energy resources; on the other hand, there is limited control over distribution and storage. Furthermore, the platform must have the ability to function closely with the real operation system, since the trading period will extend to real-time operation (Huang et al. 2019; Wang et al. 2018).

Agility refers to the platform's ability to leverage the voices of ecosystem actors to gain market intelligence and detect competitive opportunities for action. According to Isaksson et al. (2018), there is an agility challenge related to the emerging digitalization approaches. Modern generation utilities already have a high degree of automation at the device and unit levels, but the networking between units, plants, and organizations remains limited.

Several previous studies have investigated the platformization process in different areas. Konietzko et al. (2020) find that one challenge in platformization and decentralization processes is the level of platform openness. The more open a platform is, the more innovation and more value creation can be achieved. This might be a double-edged sword in the domain of distributed energy service platforms. Furthermore, in the case of energy services platformization, openness must be considered because of the concept that assets of the distributed service ecosystem aim to achieve mobility services with maximized resource efficiency and minimized excess capacity, which is a concept that is critical to the energy business.

In the process of decentralizing energy distribution, some services can be provided by the platform owner, but the connection to external service providers, which are also known as complementors, could be crucial for a given platform's success. Indeed, platforms that are open and multi-sided have proved to be the most competitive. While complementors enrich the range of services and products offered through the platform and enhance network effects, the platform aggregates storage resources with the option to trade energy with and offer flexibility to TSOs, DSOs, and other buyers (Ilieva and Rajasekharan 2018). This context is affected to some extent by the level of platform openness.

To this end, further research can more explicitly focus on the IS-driven resources and capabilities of electrical energy providers. Two relevant research questions are as follows: *How does platformization cultivate IS-driven resource-interdependent capabilities to achieve operational agility for energy services providers? How can the level of cross-organizational collaboration and networking reflect the platform openness?* In the following paragraphs, we demonstrate how ecosystem management is challenging the transition to the platform model.

Ecosystem management and governance

Konietzko et al. (2020) identifies the challenge of accomplishing the circular economy as it related to platformization; this challenge can also be phrased as how platform architecture can help achieve the circularity of economy. In the context of distributed energy systems, a circular economy refers to an industrial system that is restorative or regenerative by design. It replaces the end-of-life concept with restoration, shifts toward the use of renewable energy, eliminates the causes of carbon emissions that impair reuse and return to the biosphere, and aims for the elimination of waste through the superior design of materials, products, systems, and business models. Generally, it covers all activities that reduce, reuse, and recycle materials in the processes of production, distribution, and consumption (Korhonen et al. 2018).

In practice, this process implies keeping waste at the very minimum. When a product reaches the end of its life, its materials are kept in the economy to the greatest extent possible. They can be productively used again and again, thereby creating further value. However, most of the platform complements, services providers, and app developers are rewarded through the platform pricing structure. They are all affected by platform control mechanisms. Therefore, designing a sustainable pricing structure is a challenge that must be addressed by studying the platform information control in term of customers, actors, and end users.

According to Ilieva et al. (2018a), the future value chain of distributed energy ecosystem will be more interconnected than ever before and will ultimately form an integrated ecosystem of unique but highly interrelated elements. The emerging ecosystem will consist of the following aspects: Distributed generation, bulk generation, transmission, distribution, retail, customers, new entrants, micro-grids, storage, and demand response.

Kotilainen et al. (2016) have proposed a producer-centric ecosystem framework. The authors discuss the barriers of production from an ecosystem perspective. Any energy services ecosystem is led by two core actors, namely, TSOs and DSOs. A TSO is responsible for coordinating the supply and demand for electricity in the wholesale market, managing system security, and handling interactions and cross-border trade operators, while DSOs transfer electricity from transmission facilities and grids to individual users. However, in the current platformization models and schemes, DSOs are expected to handle the data and manage privacy and security requirements.

As stated above, the decentralization, digitalization, and platformization of energy services might contribute to achieve the circularity of the economy. Indeed, a new model is starting to appear in energy services, namely, P2P trading. This model refers to the buying and selling of energy between two or more grid-connected parties. Often in connection to solar energy, any excess energy can be transferred and sold to other users via a secure platform. P2P energy trading gives consumers the choice to decide where to purchase their electricity and to whom they sell it. In the platform scenario, there is pseudo-sharing, which involves profit-making, an absence of communal thinking, and expectations of a direct principle of reciprocity. This type of sharing has thus led to increased levels of selfishness and mistrust among peers and has limited the kind of exchanges that can occur (Boz et al. 2016).

Beyond technical issues, there is a need to establish a governance mechanism that approximately binds participant behavior without excessively constricting the intended level of generativity. In our scenario, the organization is designed to maintain a balance between connectivity and control in the platform. In addition, governance structures define the platform and the app-based decision-making rights of platform stakeholders (Constantinides et al. 2018). This scenario is possible within energy trading platformization.

It is possible, therefore, that a digital ecosystem for decentralized energy services can attract users by providing augmented services and apps related to billing, marketing, P2P operations, and community benefits (through a lock-in strategy). A global ecosystem could hierarchically connect regional and local ecosystems and then add local producers and consumers, local DSOs, and local service providers. The expected benefits of such an ecosystem that acts as a partner of partners, a product innovator, and a value-added enabler could include increased market power, better resilience, and new revenue streams, along with improved branding and data management for the participants (Ilieva et al. 2018a). Therefore, the ecosystem must maintain the following:

1. An API-oriented open ecosystem to enable actors to exchange data and functionality easily and securely;
2. A customer-oriented focus for all actors in the energy market ecosystem; and
3. Support for digitalization in the DER market (AI, sensors, IoT, machine learning, and machine-to-machine communication).

To this end, further research needs to grapple theoretically with aspects of the governance of electrical energy service platforms. Some relevant research questions are as follows: *How can several platforms be integrated into one ecosystem? How can the platform architecture and governance facilitate and scale up flexible trading with DSOs? How do service providers and other energy players build dynamic capabilities for their platform ecosystem? What are the dynamic capabilities required for platform ecosystem well-being in an energy services context?* . Below is a description of how the design is challenging the transition toward a platform model for energy services.

Design

McGovern et al. (2019) highlights a design challenge in the current trend that encourages energy trading within local communities, namely, designing a stakeholder management strategy. Based on a longitudinal study, McGovern et al. (2019) suggests that the local population and stakeholders should be part of the design and that decentralization must facilitate a vision for generating renewable energy, stakeholder roles, operational functions, and crowd-based stakeholder enrollment. Due to the large variety of decentralization requirements, the heterogeneity of the actors within DERs and P2P resources, and the resulting diverse business processes, the functional complexity of any software tools that are used will be very high. Therefore, there will be a challenge related to the user experience not only because of the abovementioned issues but also because electricity is more of an experience than a tangible commodity. Ilieva et al. (2018a) have suggested that there must be a real-time requirement and other features that are critical to the system. Specifically, the authors suggest the following:

1. Infrastructure must be supported by software technologies to allow flexibility operators to effectively meet demand with sufficient supply. In addition, the design of a cyber-physical layer must be considered since the nature of the future IoT opens a more dynamic concept, where devices such as load controllers or charging spots may sign up with a network such as that offered by a flexibility operator on its own.
2. Efficient data flow must be secured so that the hardware that controls loads or feeds can be deactivated and reactivated in different ways, based on a call initiated by those who wish to secure such a benefit.

Therefore, there must be an IS that is agile and scalable through open, cloud-based, and multi-speed technology architecture. The strategic concept of any platformization within the domain of DERs is to create an open platform where competitors of the core product can become complementors, thus contributing to joint value creation (Ilieva et al. 2018a). Therefore, platform owners must understand that future markets may often contain or even consist entirely of networks of participants (value networks) engaged by new engagements, partnerships, and collaborations.

From the design point of view, researchers have attempted to evaluate the impact of design on total social impact. The aim would be a design that meets the flexibility requirements, and the integration of technology and communication would ensure accelerated deployment of flexibility. This could save society significant amounts of money and enable more decarbonized solutions, protect privacy with respect to data management and IoT functionalities, and bolster governance issues related to these issues (Ilieva et al. 2019).

All the design proposals are aimed at achieving flexibility, which is an instrument for engaging local and environmentally friendly energy production and consumption. Flexibility describes the degree to which a power system can adjust electricity demand or generation in reaction to both anticipated and unanticipated variability. Flexibility indicates the capacity of a power system network to reliably sustain supply during transient and large imbalances; in the context of platforms, this approach consists of an IS platform where the coordination, trading, dispatch, and support services for flexibility markets take place (Babatunde et al. 2020). In this context, platform owners can capitalize on the emerging flexibility market by adopting the role of flexibility operator and providing services to the regional balance-responsible parties, DSOs, and other market actors. In addition, the platform owner should take socio-technical impacts into consideration when designing a platformization strategy.

In a related matter, platform owners and developers must take incentives into consideration when designing a platform, since incentives are critical to the platform's ultimate success. Furthermore, incentives motivate actors and end users to interact within the ecosystem. In the context of distributed energy decentralization, the incentives have to be aligned with platform design since a system with aligned incentives allows agents to freely choose their own behaviors. At the same time, incentives should incline users to choose actions that coincide with the broader goals of the system's overall design (Beck et al. 2018).

For this purpose, further research into design will need to consider both the underlying digital infrastructure value creation mechanisms for electrical energy service platforms. Two relevant research question are as follows: *How can platform design facilitate incentives for prosumers? What are the socio-technical impacts of transition toward platform-based and digitalized business model for flexibility service providers?*

To conclude this section, the literature identifies the architectural challenges that can affect the transition toward a platform model in the context of energy services. The next part of this paper describes in greater detail the business and regulatory challenges related to the transition toward a platform-based model for energy services.

Business and regulatory challenges

The next paragraphs and sections present the principal findings of this paper regarding the regulatory and business challenges that are faced in the transition toward a platform model.

Lack of standards

As stated above, electrical energy services digitalization is one of the 5 Ds (democratization, decarbonization, deregulation, decentralization, and digitalization) that are driving the electrical energy sector. Digitalization is a tool for both decentralization and reducing emissions. Hilty and Bieser (2017) highlight the challenges of digitalization for climate protection and energy system sustainability. However, regulatory and business concerns raise three types of challenges, namely, technical, organizational, and behavioral challenges. In our case, regulatory challenges refer to how the standard will ensure interoperability; this proves the claim of Altmann et al. (2010) about the portability and interoperability challenges of platformization.

Another issue is interoperability, which refers to the ability of a component to work simultaneously with one or more elements of a platform. Furthermore, the conceptualization of portability and interoperability affects service platforms since end users can port and combine services regardless of the platform. Portability is the characteristic of a service component that can be executed and implemented in a platform in a way that is different from how it was first designed and deployed on the platform (Haile and Altmann 2018).

Another issue is how the collaboration between actors will be managed through contractual technologies, since there is currently a lack of standards that regulate actors' interactions to ensure that the business model is profitable and dynamic (Altmann et al. 2010; Hilty and Bieser 2017; Guggenmos et al. 2018). This is a crucial challenge for both regulators and developers since it is also related to the openness challenge identified by Konietzko et al. (2020).

Beyond the regulatory challenges, current trends in energy platforms are moving toward P2P energy trading. In this scenario, regulators must ensure that users of new businesses follow the rules. The current EU policy for energy system integration is regarded as offering a pathway toward an effective, affordable, and deep decarbonization and decentralization of the European economy. This pathway will provide, among other benefits, the potential for energy efficiency and will enable a better integration of electricity from distributed and renewable sources.

Energy system integration is defined as "the coordinated planning and operation of the energy system 'as a whole', across multiple energy carriers, infrastructures, and consumption sectors". One aspect of decentralization is P2P trading platforms, which remain in the early stages of development. Therefore, the scale of their adoption is limited. However, these platforms have the potential to radically change the established roles of incumbent energy companies, such as energy suppliers and grid operators, who in most countries are regulated monopolies that own the physical infrastructure (Andoni et al. 2019).

Moreover, regulatory authorities are responsible for setting the rules for consumer data protection. A recent example is the new EU policy on consumer data known as the General Data Protection Regulation (GDPR)(Andoni et al. 2019). The current EU policy on system integration aims to speed up decentralization and facilitate digitalization. This policy will allow for dynamic and interconnected flows of energy, linkage of markets, and the provision of data required to adjust supply and demand in a more flexible way and in real time (Dietz-Polte et al. 2020).

The challenge that regulators face as they try to craft a response to disruption is to avoid capture by the incumbent firms that would prefer to use government authority to avoid competition; this is quite impossible within the current energy transition. To conclude this section, future research should investigate the following research questions: *How will future electricity platforms emerge and survive? How can appropriate technology standards that enable interoperability and encourage economies of scale to be established?*

Business models

Incumbent market actors often lack the tools necessary to introduce business model innovation to their businesses. This is a major obstacle for the further deployment of the decentralization of distributed energy systems (Puranik et al. 2019). Business models are needed to ensure that any developed technologies can be brought to the market and that the technologies and platform infrastructure used are compatible with business models. They must also consider energy storage, flexibility, and regulatory and policy issues. The integration of all the developed technologies will leverage a new concept of smart grids capable of flexibility management at the grid level. This concept will provide greater efficiency and resilience in the presence of distributed energy services and resources and will resolve inconsistency issues (Ilieva et al. 2019). As result of decentralization, there will be a demand for flexible and dynamic business models that must be innovative and satisfy many criteria, such as the intensive inclusion of stakeholders in the business model development process. Innovations can, on the one hand, be used by prosumers that own flexible assets and thus exercise their prosumer assistive purpose. On the other hand, innovations can be grid-assistive by enabling, for example, bottleneck management on the grid. The market-assistive use of innovations serves to optimize electricity consumption and the procurement structure of stakeholders (Tuiskula et al. 2019).

Generally, the business model must meet certain minimum criteria:

1. Support a setup that allows everyone to increase self-consumption and aid the community by optimizing and sharing storage solutions;
2. Facilitate the interaction between users and the cyber-physical layer through disruptive and digital technologies to share energy where and when it is needed; and
3. Reduce overall energy costs and help achieve decentralization.

According to Ilieva et al. (2018a), the participants in decentralized energy ecosystems must reconsider their business models. For many power market actors, this means that their current business models will have to evolve beyond the traditional structure of energy economy. However, the path to success in business model innovation may not be clearly laid out. According to Ilieva and Rajasekharan (2018), a P2P business model must provide the democratization of market access and on-demand access to service. Thus, it must allow local producers to access the local marketplace while making use of opportunities to be actively involved in and aware of their energy needs and consumption patterns. Another aspect identified by Ilieva and Rajasekharan (2018) is that the emerging business models in energy decentralization are divided into three classifications based on the scale of energy storage systems. These classifications are as follows:

1. Grid scale: based on TSO- or DSO-owned assets, third-party assets, and shared assets.
2. Behind the meter: VPP-centered business models, where VPP model 1 refers to a flexibility aggregator model and VPP model 2 refers to a generation company aggregator model or a technology and service provider model.
3. Community scale: based on a community-based energy trading system and a district storage system.

Thus, platform owners are challenged to design a unified business model that integrates all the above classifications and acts dynamically in the face of market changes. Since P2P models are part of the decentralization of energy services, there are some obstacles to achieving the abovementioned goals. Therefore, further research can more explicitly examine the following questions:*How do digitalization and platformization disrupt incumbent energy providers' business models? How can organizations have a platform business model that can cope with technological disruption?*

Contracts and relationship management

The idea of decentralization is to improve the economic conditions and environmental awareness of producers. As a result, energy services decentralization will allow P2P energy trading. Since the energy sector is critical to both society and all the activities within it and constitutes a core part of the public sector, most service providers are moving toward smart contract technologies. Another concern is how accountability is implemented, specified, and enforced through the contracts and legal frameworks governed by the platform owners; however, accountability can also be implemented through IS infrastructures, which is an important consideration for decentralization (Beck et al. 2018). Under this theme, we have identified an issue which must be considered: *How will standards cope with security, scalability, and process integrity issues?* This issue is consistent with the concerns raised in the previous theme by McGovern et al. (2019); Constantinides et al. (2018).

Theoretically, the idea of contracts in energy services decentralization is to improve the economic conditions, create value for producers, and enhance the more efficient and economically beneficial use of flexibility from DERs. In this context, the local service provider delivers energy and flexibility services to customers by inserting value-added options to existing retail contract frames (Ilieva et al. 2018b). In the domain of distributed energy services and resources, ledger and contractual technologies have introduced a premium scheme to encourage local renewable production and consumption (Thomas et al. 2019; Han et al. 2020). To generate incentives for collecting premiums, the energy tax paid by consumers could be reduced through regulatory support. Hence, there must be a regulatory framework for contract deployment (Ilieva et al. 2018b).

For this effort to succeed, contracts must contain three aspects that operate flawlessly, namely, technological, functional, and legal aspects. Therefore, any future development or use of contractual technologies in the energy domain must be aligned with regulatory and standardization requirements. The lack of standards is an issue that must be investigated from the IS point of view in future research. Technically, ledger technologies as infrastructure for platforms offer the promise of increasing the speed of exchange, reducing the number of intermediaries and associated costs, improving security, digitizing assets, providing wider access to disadvantaged groups (especially in emerging economies), and improving regulatory compliance (Constantinides et al. 2018).

As a result, this development requires a deep rethinking of governance (Beck et al. 2018; Wynn et al. 2019). The above findings show how the emphasis of ledger technologies on decentralizing decision rights in platforms and the technical enhancement of accountability underscore the need to align incentives. Another concern is that the decision rights in ledger technology-packed platforms are more decentralized than normal digital platforms (Beck et al. 2018); this concern may be critical in the context of energy services.

Further research can more explicitly examine how this coordination could be achieved and maintained in an energy service platform ecosystem. Therefore, one future research question could be as follows: *How can platforms help achieve coordination mechanisms between ecosystem actors?*

A summary of the main findings, together with discussion, is provided in the next section.

Discussion

The rise of new technologies has contributed to platform-based business models and services across different domains. Hence, they are changing the landscape of today's facilities and businesses. The increasing adoption of DERs and storage systems, along with technological disruptions in the energy sector, pose challenges and create opportunities for both existing and new stakeholders (Ilieva et al. 2018a).

The main research question of this study aims to investigate the challenges related to service innovation in the electricity field when moving toward a digital platform model for the delivery of energy services; similarly, the main objective of this study is to identify the challenges of platformization and digitalization of energy services. The sub-questions of the study elaborate on the main objective of the study. Figure 3 shows the findings of this systematic literature review and categorizes them based on the challenges identified. Regarding RQ 1.2, the research topics were categorized based on the systematic literature review findings shown in Table 5.

The paper has shown that each challenge is connected with a research gap that offers possible research direction(s) for the future (see Table 5). The present study maps all the literature that is relevant to platform ecosystems, digitalization, and digital innovation regarding electrical energy services; this systematic literature review was undertaken to not only provide an overview of the key challenges but also to identify gaps in the research.

As the concept of platforms is not yet fully understood in current electricity services, a complete mapping of the literature is recommended to investigate solutions and business models that may match the technical, market, and business requirements of a given energy platform ecosystem. Meanwhile, the technical details of the current existing platforms are not widely discussed within the literature. Therefore, this paper has proposed a future research direction for investigating these platforms. Furthermore, the emergence of service innovation in electrical energy services creates

Table 5 Proposed research directions and future research questions

Challenge	Proposed Research Direction and Future Research Questions
Agility and openness	How does platformization cultivate IS-driven resource-interdependent capabilities to achieve operational agility for energy services providers?
	How can the level of cross-organizational collaboration and networking reflect on the platform openness?
Ecosystem management and governance	How can several platforms be integrated into one ecosystem?
	How can the platform architecture and governance facilitate and scale up flexible trading with DSO's?
	How do service providers and other energy players build dynamic capabilities for their platform ecosystem? What are the dynamic capabilities required for platform ecosystem well-being in an energy services context?
	What are the dynamic capabilities required for platform ecosystem well-being in an energy services context?
Design	How can platform design facilitate incentives for prosumers?
	What are the socio—technical impacts of transition toward platform - based and digitalized business model for flexibility service providers?
Lack of standards	How will future electricity platforms emerge and survive?
	How can appropriate technology standards that enable interoperability and encourage economies of scale to be established?
Business models	How do digitalization and platformization disrupt incumbent energy providers' business models?
	How can organizations have a platform business model that can cope with technological disruption?
Contracts and relationship management	How will standards cope with security, scalability, and process integrity issues?
	How can platforms help achieve coordination mechanisms between ecosystem actors?

new roles at utility companies, such as the emergence of chief digital officers, chief transformation officers, and chief AI officers.

The investigation of the main research question sought to identify and enumerate the key challenges associated with decentralization. In addressing the second sub-question, we found that two challenges that might hamper platformization is a lack of standardization on the one hand and flexibility on the other hand. There must be standards for energy service platforms to ensure that their architecture will allow interoperability. Furthermore, the literature suggests that there will be many governance challenges associated with decentralization. Hence, the practice of platformization must be implemented through known approaches and frameworks, such as the suggestion offered by Tiwana (2014); Morstyn et al. (2018); Altmann et al. (2010); Ilieva and Rajasekharan (2018). An examination of the research question found that the efficient decentralization of distributed energy systems could be achieved through the dynamic governance of the ecosystem, with the support of network effects and disruptive technologies (Constantinides et al. 2018; Ilieva et al. 2018b). Furthermore, the long-term outputs of distributed energy services decentralization are yet to be proven, since different scenarios have been implemented, and most scenarios that are now operating do so on a medium scale at most. The systematic literature review suggests that there must be some implementation of technologies that are relevant to the regulatory and legal domain. Further decentralization could be implemented through long-term and sustainable platformization practices.

The results of this systematic literature review fit very well with the rising trend of using service and digital platforms to deliver innovative energy services. Previous research has focused on discussing the platform ecosystem without suggesting how such an ecosystem will evolve over time and how it will be sustained. Consistent with the present study's research approach and strategy, the overall findings show that the decentralization and platformization of any energy service is likely to face technical and/or regulatory challenges. Technical challenges vary from the level of openness to the level of platform service interoperability and portability, while business and regulatory challenges range from collaboration between actors to stakeholders' contractual management. All these issues must be resolved to reach a high level of dynamically delivered services and to guarantee the continuity of services. It is evident from the findings there has thus far been very little standardization of regulations made in any jurisdiction.

RQ 1.3 in this research was posed to reveal who is leading the latest research efforts and the domains in which that research has been published. Table 2 shows where the selected papers have been published. It is interesting to note that the papers reviewed in this study are a mix of different fields, including IS, electrical power engineering, and service design. The research on the topic has been led by Wang et al. (2018); Huang et al. (2019); Puranik et al. (2019) in the context of electrical power engineering, while in the fields of service innovation and IS, the research has been led by Ardolino et al. (2018); Beck et al. (2018); Hautamäki and Oksanen (2018).

We also noticed in our systematic literature review that many organizations are moving toward decentralization and that many investors are interested in this topic. These developments clearly show the potential of decentralization and platformization in distributed energy services. This systematic literature review has shown that the current IS and electrical engineering literature remain in an early stage, perhaps even in infancy, in terms of discussing the interplay between regulatory and technical aspects of energy firms' transition to platformization.

Specifically, these findings show that openness, governance, stakeholder and actor management, and standardization all have roles to play in shaping developments in this domain. Each of these challenges can be seen as a complex system. The findings also show that such challenges can affect the quality of the services delivered and how current technologies must collaborate with decentralized DERs. According to the findings, these platforms must be flexible in terms of openness to new and dynamic business models.

Service providers and platform owners must continuously engage with actors and customers to obtain insights about their activities and behaviors. To offer value propositions, it is important to use platformization to know the customers who are normally served by product-oriented platforms. Therefore, one challenge is how to engage customers in platform activities and determine how they can participate in platform design.

The study of distributed energy services platformization requires the examination of the ecosystems that surround it. While some work on distributed ecosystems has been published, as outlined above, there remains a need for a deeper scholarly understanding of the structure, dynamics, and strategy and behavior of energy services platforms and their associated stakeholders.

Moreover, the findings of the current research are prerequisites for describing and understanding the context of decentralization and platformization in the domain of energy services from the IS perspective. These findings need further development in multiple directions. Understanding different challenges from different perspectives and at different scales will help to clarify the practice of digitalization in the energy domain. Future research should consider the potential effects of digitalization and service platforms on energy services more carefully. More specifically, the present study has identified research gaps and suggested areas for future research (see Table 5).

Conclusion

The purpose of this study was to contribute to the scientific literature by reviewing the available research on energy services platformization and decentralization from the viewpoint of digitalization and IS. The critical aims of this research were to identify the challenges faced by the processes of platformization and decentralization from the technical, business, and regulatory perspectives. In addition, regulatory authorities are responsible for setting the rules of consumer data protection.

This paper carried out an examination of the literature on the digitalization and platformization of electrical energy services and their associated challenges. It provides a holistic overview of the current situation and the latest research regarding these subjects. This systematic literature review has shown that the research on energy service platforms and marketplaces has increased over the last few years (Ilieva and Rajasekharan 2018; Ilieva et al. 2018b; McGovern et al. 2019). A broad spectrum of research from different industries and scientific disciplines has been covered. However, despite the increasing interest in energy decentralization and digitalization, many areas are still to be explored.

In addition, by clarifying the challenges ahead, our study can assist managers, service providers, and policymakers to anticipate issues that may arise during their attempts to transition their organizations into using platform models. Regardless of their transformation strategy's aim to leverage digital technology in reinforcing or changing their service innovation and value creation, these individuals will likely encounter challenges on different levels of platform operation and services innovation. This will have important implications for how to govern and design a platform. Our study's findings suggest that managers and service providers should critically assess the role of digital technologies, such as DLTs, in digitalization and platformization. Understanding the different roles of digital technologies and platforms can help managers contextualize digital technology within their chosen transformation agenda.

In addition, this study has identified many changes that must be taken into consideration when it comes to decentralization and platformization. These changes include market design, business models, and the value stream, in addition to social, institutional, and economic arrangements.

By considering the reviewed literature and the themes in the findings, this study has exhibited and discussed what the literature has to say about the interplay between architectural and business and regulatory aspects of transitioning to platforms models. Another shortcoming is that the reviewed literature does not cover well the aspects of strategy, governance, and architecture. Therefore, this paper has identified research gaps and proposed future research directions.

An important limitation of this study is that it does not focus on a specific geographic domain, which means that the results are somewhat general and may not be applicable to certain countries or regions. Future work could focus more on specific scenarios in certain countries. Furthermore, the transition toward the platform model and platform ecosystem does not always go as expected. Like the challenges discussed in this paper, many challenges and risks related to digitalization and the transition toward the platform model will arise in the future. Therefore, the consequences of the adoption of digital solutions in the platform ecosystem and its impacts on the sustainability, resilience, and harmonization with the whole ecosystem perspective need to be further investigated. Another limitation is the study looks at the papers from 2016 and forward, this because the interest on investigating and researching on this topic become widely known after that period and due to the lack of papers before that time.

The present study also does not take into account the implications of digitalization on energy policies. Themes were identified in the findings categories to enable a comprehensive understanding of the domain. Further research should be undertaken to investigate both service distributors and regulatory firms in order to study their capabilities for integrating bulk and distributed renewable sources into new technologies such as smart contracts. This could be done through case studies. Another future avenue of research could be examining how disruptive technologies can overcome the existing architectural and governance challenges in the platformization of DERs and their related services.

Abbreviations

RQ	Research question
LV	Low voltage
MV	Medium voltage
HV	High voltage
EHV	Extremely high voltage
AI	Artificial intelligence
IoT	Internet of things
GDPR	General data protection regulation
VPP	Virtual power plants
DER	Distributed energy resources
IS	Information systems
OT	Operational technologies
DLT	Distributed ledger technologies
P2P	Peer-to-Peer
API	Application Programming Interface
DSO	Distribution system operator
TSO	Transmission system operator
EU	European Union

Authors' information

Ahmed Idries is a PhD candidate in the Department of Computer Science at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway. Ahmed's main research interest is in service platforms, digitalization, and service innovation.

John Krogstie is Professor in Information Systems at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway, and an expert in the field of enterprise modelling. Krogstie's research interests include information systems, conceptual modeling, mobile information systems, eGovernment, and enterprise modelling.

Jayaprakash Rajasekharan is an Associate Professor in the Department of Electric Power Engineering at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway. His research activities focus mainly on energy informatics applied to flexibility systems, smart grids, electricity markets, power system balancing, electric vehicle integration, and renewable techno-economics.

Acknowledgements
This work is a part of DigEco, an NTNU digital economy project. DigEco is one of the nine NTNU digital transformation projects https://www.ntnu.edu/digital-transformation/digeco.

Author contributions
All authors discussed the results and contributed to the final manuscript. Material preparation, data collection, and analysis were performed by Ahmed Idries, and John Krogstie. The first draft of the manuscript was written by Ahmed Idries and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript. Jayaprakash Rajasekharan reviewed the manuscript and commented on it.

Funding
N/A This work is funded by DigEco as part of an NTNU digital economy project https://www.ntnu.edu/digital-transformation/digeco. DigEco is one of nine NTNU digital transformation projects. The authors received no financial support for the research and/or authorship of this article. Open access funding provided by Norwegian University of Science and Technology.

Availability of data and materials
The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Received: 20 March 2022 Accepted: 8 June 2022
Published online: 20 June 2022

References

Adil AM, Ko Y (2016) Socio-technical evolution of decentralized energy systems: a critical review and implications for urban planning and policy. Renew Sustain Energy Rev 57:1025–1037. https://doi.org/10.1016/j.rser.2015.12.079

Ahl A, Yarime M, Tanaka K, Sagawa D (2019) Review of blockchain-based distributed energy: implications for institutional development. Renew Sustain Energy Rev 107:200–211. https://doi.org/10.1016/j.rser.2019.03.002

Alstone P, Gershenson D, Kammen DM (2015) Decentralized energy systems for clean electricity access. Nat Clim Chang 5(4):305–314. https://doi.org/10.1038/nclimate2512

Altmann M, Brenninkmeijer A, Lanoix JC, Ellison D, Crisan A, Hugyecz A, Koreneff G, Hänninen S (2010) Decentralized Energy Systems. No. IP/A/ITRE/ST/2009-16 in EU Publications, European Parliament, Belgium, https://www.europarl.europa.eu/document/activities/cont/201106/20110629ATT22897/20110629ATT22897EN.pdf, [Online; accessed 19-April-2021]

Andoni M, Robu V, Flynn D, Abram S, Geach D, Jenkins D, McCallum P, Peacock A (2019) Blockchain technology in the energy sector: a systematic review of challenges and opportunities. Renew Sustain Energy Rev 100:143–174. https://doi.org/10.1016/j.rser.2018.10.014

Antolić M, Wright S, Mulugeta D, Fullam J, Stewart D (2020) Framework for community grid implementation. Tech. rep., Positive City ExChange - European Union's Horizon 2020, https://cityxchange.eu/knowledge-base/d2-6-framework-for-community-grid-implementation/, [Online; accessed 10-February-2021]

Ardolino M, Saccani N, Eloranta V (2018) Complexity management in service businesses through platform adoption. IFAC-PapersOnLine 51(11):1329–1334. https://doi.org/10.1016/j.ifacol.2018.08.34716th IFAC Symposium on Information Control Problems in Manufacturing INCOM 2018

Babatunde O, Munda J, Hamam Y (2020) Power system flexibility: a review. Energy Rep 6:101–106. https://doi.org/10.1016/j.egyr.2019.11.048

Beck R, Müller-Bloch C, King J (2018) Governance in the blockchain economy: a framework and research agenda. J Assoc Inf Syst 19:1020–1034

Boz E, McCaffrey C, Santillán Martínez G, Larnemaa A (2016) Digitalization: unlocking the potential of sharing, Aalto University's Multidisciplinary Institute of Digitalisation and Energy (MIDE), pp 237–263. http://urn.fi/URN:ISBN:978-952-60-1101-1, [Online; accessed 13-April-2020]

Constantinides P, Henfridsson O, Parker G (2018) Introduction—platforms and infrastructures in the digital age. Inf Syst Res 29:381–400. https://doi.org/10.1287/isre.2018.0794

de Reuver M, Sørensen C, Basole RC (2018) The digital platform: a research agenda. J Inf Technol 33(2):124–135. https://doi.org/10.1057/s41265-016-0033-3

Dietz-Polte C, Engelkamp H, Vacha i (2020) Germany: COVID-19—energy law updates—digitalization. Global Compliance News https://globalcompliancenews.com/germany-covid-19-energy-law-updates-digitalization-28092020/, Online; accessed 13-November-2020

Dybå T, Dingsøyr T (2008) Empirical studies of agile software development: a systematic review. Inf Softw Technol 50(9–10):833–859. https://doi.org/10.1016/j.infsof.2008.01.006

Guggenmos F, Lockl J, Rieger A, Fridgen G (2018) Challenges and opportunities of blockchain-based platformization of digital identities in the public sector (research in progress). In: Workshop on Platformization in the Public Sector, 26th European Conference on Information Systems (ECIS), Portsmouth, UK, June 2018, AIS, https://orbilu.uni.lu/bitstream/10993/44519/1/challenges%20and%20opportunities.pdf

Hack T, Ma Z, Jørgensen BN (2021) Digitalisation potentials in the electricity ecosystem: lesson learnt from the comparison between Germany and Denmark. Energy Inf. https://doi.org/10.1186/s42162-021-00168-2

Hagiu A (2014) Strategic decisions for multisided platforms. MIT Sloan Management Review 55:92–93, https://sloanreview.mit.edu/article/strategic-decisions-for-multisided-platforms, online; accessed 15-February-2020

Haile N, Altmann J (2018) Evaluating investments in portability and interoperability between software service platforms. Futur Gener Comput Syst 78:224–241. https://doi.org/10.1016/j.future.2017.04.040

Han X, Martinez V, Neely A (2018) Service in the platform context: a review of the state of the art and future research, pp 1–27. https://doi.org/10.1007/978-981-10-8956-5_1

Han D, Zhang C, Ping J, Yan Z (2020) Smart contract architecture for decentralized energy trading and management based on blockchains. Energy 199(117):417. https://doi.org/10.1016/j.energy.2020.117417

Hautamäki A, Oksanen K (2018) Digital platforms for restructuring the public sector. In: Smedlund A, Lindblom A, Mitronen L (eds) Collaborative value co-creation in the platform economy. Springer Singapore, Singapore, pp 91–108. https://doi.org/10.1007/978-981-10-8956-5_5

Hilty L, Bieser J (2017). Opportunities and risks of digitalization for climate protection in Switzerland. https://doi.org/10.5167/UZH-141128, https://www.ifi.uzh.ch/dam/jcr:066776d8-d2b0-4c7c-b75d-6b7283cb5791/Study_Digitalization_Climate_Protection_Oct2017.pdf, Online; accessed 20-March-2020

Huang L, Zhuang W, Zhang H, Pan J, Xu P (2019) Research on key technologies of electricity trading platform of next generation. In: 2019 IEEE 8th Joint International Information Technology and Artificial Intelligence Conference (ITAIC), pp 1797–1802

Ilieva I, Rajasekharan J (2018) Energy storage as a trigger for business model innovation in the energy sector. In: 2018 IEEE International Energy Conference (ENERGYCON), pp 1–6, https://doi.org/10.1109/ENERGYCON.2018.8398828

Ilieva I, Bremdal B, Wåge D (2018a) Digital ecosystems as a disruptive force of flexibility services in the energy sector. In: ransforming Energy Markets, Groningen, Netherlands—Jun 10-13, 2018, International Association for Energy Economics, https://doi.org/10.5281/ZENODO.3689601, https://www.iaee.org/proceedings/article/15256

Ilieva I, Wang X, Rajasekharan J (2018b) The innovative role of local system operator as a facilitator of grid and community services in the local electricity market. In: CIRED 2018 Ljubljana Workshop on Microgrids and Local Energy Communities, AIM, https://doi.org/10.34890/469

Ilieva I, Bremdal B, Puranik S (2019) Bringing business and societal impact together in an evolving energy sector. J Clean Energy Technol. https://doi.org/10.18178/JOCET.2019.7.3.508

Isaksson AJ, Harjunkoski I, Sand G (2018) The impact of digitalization on the future of control and operations. Comput Chem Eng 114:122–129. https://doi.org/10.1016/j.compchemeng.2017.10.037

Kitchenham B, Brereton OP, Budgen D, Turner M, Bailey J, Linkman S (2009) Systematic literature reviews in software engineering—a systematic literature review. Inf Softw Technol 51(1):7–15. https://doi.org/10.1016/j.infsof.2008.09.009

Konietzko J, Bocken N, Hultink EJ (2020) Circular ecosystem innovation: an initial set of principles. J Clean Prod 253(119):942. https://doi.org/10.1016/j.jclepro.2019.119942

Korhonen J, Honkasalo A, Seppälä J (2018) Circular economy: the concept and its limitations. Ecol Econ 143:37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041

Kotilainen K, Sommarberg M, Järventausta P, Aalto P (2016) Prosumer centric digital energy ecosystem framework. In: Proceedings of the 8th International Conference on Management of Digital EcoSystems, Association for Computing Machinery, New York, NY, USA, MEDES, p 47-51, https://doi.org/10.1145/3012071.3012080

Livik K, Danielsen S, Nati M (2020) Local dpeb trading market demonstration tool. Tech. rep., European Union's Horizon 2020 / Positive City ExChange, https://cityxchange.eu/knowledge-base/d2-7-local-dpeb-trading-market-demonstration-tool/, Online; accessed 20-February-2021

Löfberg N, Åkesson M (2018) Creating a service platform : how to co-create value in a remote service context. J Bus Ind Mark 33(6):768–780. https://doi.org/10.1108/JBIM-10-2015-0202

Ma Z, Clausen A, Lin Y, Jørgensen BN (2021) An overview of digitalization for the building-to-grid ecosystem. Energy Inf. https://doi.org/10.1186/s42162-021-00156-6

McGovern G, Koch B, Giesen N, Klenke T (2019) A digitalization profile for civic energy processes. In: Smart Cities/Smart Regions—Technische, wirtschaftliche und gesellschaftliche Innovationen, Springer Fachmedien Wiesbaden, pp 683–691, https://doi.org/10.1007/978-3-658-25210-6_53

Morstyn T, Farrell N, Darby SJ, McCulloch MD (2018) Using peer-to-peer energy-trading platforms to incentivize prosumers to form federated power plants. Nat Energy 3(2):94–101. https://doi.org/10.1038/s41560-017-0075-y

Orsini L, Kessler S, Wei J, Field H (2019) How the brooklyn microgrid and TransActive grid are paving the way to next-gen energy markets. In: The Energy Internet, Elsevier, pp 223–239, https://doi.org/10.1016/b978-0-08-102207-8.00010-2,

Puranik S, Tuiskula H, Ilieva I, Torrent F, Colomer J, Meléndez J (2019) Multi-vector energy optimization tools for energy islands. In: 2019 IEEE Milan PowerTech, vol 1, pp 1–6, https://doi.org/10.1109/PTC.2019.8810932

Richter LL, Pollitt MG (2018) Which smart electricity service contracts will consumers accept? The demand for compensation in a platform market. Energy Econ 72:436–450. https://doi.org/10.1016/j.eneco.2018.04.004

SGIP (2016) Local grid definitions: A white paper, developed by the smart grid interoperability panel, home building and industrial working group. Tech Rep, https://nordman.lbl.gov/, Online; accessed 25-October-2020

Sioshansi FP (2014) Decentralized energy: Is it as imminent or serious as claimed? In: Distributed Generation and its Implications for the Utility Industry, Elsevier, pp 3–32, https://doi.org/10.1016/b978-0-12-800240-7.00001-1

Sioshansi F (2019) Consumer. Elsevier, Prosumer, Prosumager, How service innovations will disrupt the utility business model. https://doi.org/10.1016/c2018-0-01192-5

Statnett (2021) Distributed balancing of the power grid results from the efleks pilot in the mfrr-market 2019/2020. Tech. rep., Statnett, https://www.statnett.no/contentassets/5f177747331347f1b5da7c87f9cf0733/2021.02.24-results-from-the-efleks-pilot-in-the-mfrr-market--.pdf, [Online; accessed 15-August-2021]
Thomas L, Zhou Y, Long C, Wu J, Jenkins N (2019) A general form of smart contract for decentralized energy systems management. Nat Energy 4(2):140–149. https://doi.org/10.1038/s41560-018-0317-7
Tikka V, Mashlakov A, Kulmala A, Repo S, Aro M, Keski-Koukkari A, Honkapuro S, Järventausta P, Partanen J (2019) Integrated business platform of distributed energy resources—case finland. Energy Procedia 158:6637–6644. https://doi.org/10.1016/j.egypro.2019.01.041, innovative Solutions for Energy Transitions
Tiwana A (2014) Chapter 6—platform governance. In: Tiwana A (ed) Platform Ecosystems. Morgan Kaufmann, Boston, pp 117–151. https://doi.org/10.1016/B978-0-12-408066-9.00006-0
Ton DT, Smith MA (2012) The U.S. department of energy's microgrid initiative. Electr J 25(8):84–94. https://doi.org/10.1016/j.tej.2012.09.013
Tuiskula H, Puranik S, Ilieva I, Kuntze C (2019) Identification and validation of new business models for dso business environment using business model canvas and stakeholder groups. In: CIRED 2019 Conference, AIM, https://doi.org/10.34890/947,
Wagner O, Götz T (2021) Presentation of the 5ds in energy policy: a policy paper to show how Germany can regain its role as a pioneer in energy policy. Energies 14(20):6799. https://doi.org/10.3390/en14206799
Wang K, Yu J, Yu Y, Qian Y, Zeng D, Guo S, Xiang Y, Wu J (2018) A survey on energy internet: architecture, approach, and emerging technologies. IEEE Syst J 12(3):2403–2416. https://doi.org/10.1109/JSYST.2016.2639820
Webster J, Watson R (2002) Analyzing the past to prepare for the future: writing a literature review. MIS Q. https://doi.org/10.2307/4132319
Wehlitz R, Häberlein D, Zschörnig T, Franczyk B (2017) A smart energy platform for the internet of things—motivation, challenges, and solution proposal. In: 20th International Conference, BIS 2017, Poznan, Poland, June 28-30, 2017, Proceedings, pp 271–282, https://doi.org/10.1007/978-3-319-59336-4_19
Wynn G, Kunze C, Flora A (2019) Electric Vehicles and Grid Services As Growth Drivers for Residential Solar and Batteries https://ieefa.org/wp-content/uploads/2019/05/EVs_Grid-Services-Can-Drive-Residential-Solar-and-Battery-Growth_May-2019.pdf, online; accessed 25-September-2020
Xu Z (2019) The electricity market design for decentralized flexibility sources. The Oxford Institute For Energy Studies, Oxford, https://doi.org/10.26889/9781784671433
Yuan M, Fang Y, Lv J, Zheng S, Zhou Z (2019) Research on power trading platform based on big data and artificial intelligence technology. IOP Conf Ser Mater Sci Eng 486(012):109. https://doi.org/10.1088/1757-899X/486/1/012109

Publisher's Note