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Reshaping roles and value logics among distributed system operators for future electricity systems

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Abstract

Background This paper seeks to explore the roles of distribution system operators (DSOs) in future energy systems. Measures to combat climate change have led to a transition in the energy sector, where old system fundamentals are becoming obsolete, which results in changing rules for incumbent actors, such as DSOs. These actors must uphold heavily regulated operations within their distribution networks, while landscape trends are changing with a growing number of prosumers and distributed energy resources. To understand these future roles and increase the preparedness for future scenarios and facilitate thinking beyond current lock-ins, action-oriented workshops were held with two Swedish DSOs, departing from pre-developed future imaginaries, structured through transition theory. Researchers were actively involved in the workshops, to guide the participants in the discussions and to provide additional knowledge from transition processes. This was structured through transition theory, mainly in terms of linking transition management fundamentals to the topics in the workshops and basing the workshop discussions on an imagined future socio-technical system-wide approach using four focus areas.

Results Results included descriptions of roles within future energy systems and their connection to specified value logics from different target groups which would, from the DSO perspective, create value in a future energy system. Roles included sustainable developer, facilitator for increased collaboration, balancing actor, and communicator. In addition, competence requirements were outlined concerning the described roles. The future logic was also described in a conceptual value model for an active DSO in a prosumer-oriented energy system, creating value in all different value logics. Moreover, it provided the steps necessary to develop a pathway aimed at the transformation of DSOs.

Conclusions The study provided a constructive approach for DSOs to prepare for a future, more prosumer-oriented and flexible energy system, avoiding being locked in current system thinking and focusing on necessary roles and competencies suitable for a DSO. In addition, the utilization of the value logics approach helped place the prosumers in a differentiated manner, which can have implications for strategies among DSOs to create the necessary relations and collaborations for an efficient and value-creating future energy system.

Keywords Distributed system operators, Energy transition, Value logics, Future roles

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Background

The ability of an actor to transform from old to new logic is fundamental in societal evolution. Though, transformation requires vast efforts and risk taking in exploring unknown environments. Measures to combat climate change have led to an energy sector in transition, where old centralized system fundamentals are becoming obsolete, and the beginning of a new decentralized logic changes rules for incumbent actors [1]. Lower-voltage network operators have a particularly central role in national energy infrastructure, sometimes referred to as distribution system operators (DSOs). These DSOs must uphold heavily regulated operations which, coupled with changing landscape trends, put pressure on DSOs to update their business model [2]. As consumers invest in distributed energy resources (DERs), mostly solar photovoltaics (PV), and connect to the grid, they become prosumers (for definitions, see, e.g., [3, 4]). This creates bidirectional flows of electricity which must be managed within grid infrastructures that were designed for unidirectional flows. However, as less electricity is bought by the prosumer this lessens traditional income from transferring electricity for DSOs, at the same time prosumers request, often backed by national legislation, unconditional connection to the local distribution system. In general, and particularly in a Swedish context, electrification of transport and industry sectors increases pressure on existing infrastructure and uncertainties around future capacity are beginning to become the focus of a public and political debate which may increase political interventions within the energy sector. This creates an even larger uncertainty for regulated DSOs and, thus, creating readiness for future changes will be critical.

Changes are already apparent in national and regional regulatory frameworks, e.g., the European Union launched several directives within their package *Clean Energy for All* in 2016 [5]. The electricity market directive, which was launched in late 2019, provided new rules for flex markets and energy communities as well as widened the distributed network operator role to become an active balancing system operator within the distribution grid [6]. The reasons are, as described in the directive, to bring more flexibility to the distribution grid, thereby avoiding more traditional investments in reinforcing grid infrastructure, and providing additional possibilities for communities to enhance local values through reduced hindrance to investment in local energy infrastructure [7]. Although described in the directives, an ongoing debate over the implications and challenges in alignment with national legislations in the different European countries shows that these directive proposals differ fundamentally from previous business models and activities in the electricity system [8]. Therefore, the question of how to handle these developments from a DSO perspective becomes critical. Here, future roles, competencies and activities for DSOs will be important to investigate and discuss to be able to create preparedness and agency within the changing landscapes.

Different means to create agency in a changing environment have occupied scholars from a variety of fields. In this article, we depart from the research field of sustainability transitions (ST), which is dedicated to processes that influence socio-technical transitions in society. In addition to developing knowledge around certain recurring processes in societal transitions, the ST field also includes more action-oriented tools in the sub-area usually referred to as transition management (TM) [9]. A central concept in TM is "transition arenas" which are structured spaces, where actors meet, learn, and create solutions and common transition pathways with necessary actions for future developments [10]. Often foresight analysis and future scenarios are used as tools to develop pathways within the transition arenas. However, this is a multi-actor perspective and does not focus on solely on actors such as DSOs to develop transitional agency. Future studies are often used directly with single actors, e.g., to develop desirable scenarios and backcast actions necessary to achieve that scenario [11]. Although structured in its processes, the content of these backcasting events is usually developed by the actors in place [12]. Under these circumstances, actors may not include certain transition processes which could create increased agency in changing environments. Therefore, discussing DSO perspectives on radical futures and necessary transition pathways is a way of preparing for possible changes.

Decentralization of the electricity system via policy updates and the growing prosumerism movement also contains heterogenic institutional logics about which actor is focused [13]. This indicates that the previous single logic, regulated market, in an electricity system organization is exchanged for multiple logics, e.g., individual, community, municipal, market, etc., depending on the design of future distribution networks. For these prospected changes there are vast complexities in coordination and preparation for a multi-actor active inclusion and flattened hierarchical organization from a DSO perspective. Irrespective of the chosen strategies, there needs to be an awareness and capacity to manage uncertainties and different development paths. One such increased preparation measure is to facilitate understanding of which different value logics relate to various future roles and activities in the electricity system. The concept of value logic stems from the use of institutional logics [14] and was introduced in the energy transition field by Laesch [15] and further developed in relation to prosumerism by Brown et al. [16]. In this paper, we will base our work on value logics to analyse how different prospected roles in a future energy system can facilitate value creation for DSOs and additional stakeholders.

The study collected data from a Swedish context, and the participating DSOs are Swedish entities. There are more than a hundred DSOs in Sweden, most of them serving small networks, often municipal areas. Unbundling is implemented across the whole actor map with no exemptions for smaller entities that are seen in other jurisdictions [17]. Revenue frameworks are given preperiod and are based on four cost estimations: capital cost for grid assets, depreciations and new investments; operating costs for influenceable factors, such as operations, maintenance, and measurements of active facilities; other operating costs, such as external overlaying network, authority fees and network losses; incentive costs based on quality (mainly minimize >1 min disruptions) and efficient grid utilization [18]. Thus, the DSO is incentivized to provide a stable and high-quality network which can motivate increased tariffs if more distributed resources are added that cause pressure on the network. With the revenue frames, a DSO is limited in agency for transforming its activities and business models to suit a future electricity system with increasingly distributed resources, and this can of course risk the relation to customers investing in resources that potentially can be utilized for the grid [17]. The term "utility death spiral"[1] has been used to show the discrepancy between new distributed technologies and prosumer orientation, thus the current DSO locked position with traditional regulations and business models, risks prosumers leaving the grid altogether [19].

Therefore, it becomes of high interest for DSOs to find strategies in which they can act and offer value in a future energy system with increasing decentralization. The aim of the article is to investigate future roles for DSOs with the meaning of increasing preparedness in a transitioning sector.

Three research questions are proposed for the research: i) what are the necessary roles for DSOs within a future decentralized energy system? ii) What do these roles require to be fulfilled? and iii) How can a future value model for a DSO be conceptualized through connected roles and value logics?

The contribution is twofold. First, it provides empirical insights into future DSO roles together with necessary actions to be able to prepare for a highly decentralized electricity system; and, second, it provides a structured concept to work with the transformation of incumbent actors in a changing environment which destabilizes current business models.

Theoretical background

The theoretical framework of this study covers a combination of value logics and ST, focusing particularly on the emerging theme of future reasoning which is rooted in TM and future studies.

The term value logics stems from business model theory but also has influences from institutional logics. Business models usually have a strict commercial value logic; Osterwalder and Pigneur [20] describe the business model as the "money-earning logic of a firm". However, the concept has also been applied directly to organizations and can, therefore, be described as an "organization's core logic for creating value" [15]. Institutional logics is concerned with explaining organizational raison d'être and, thus, has a close connection to value logics applied to organizations. When a business model concretizes the way an organization creates value, the value logics are then related to how an organization views and understands value, i.e., what is the philosophical and normative understanding of value [16]. Different organizations provide meaning to their social reality by adhering to social constructions around practices, assumptions, beliefs, values, and rules which guide individuals in the respective organizations [21]. A single institutional logic may be present within an organization although plural logics are often present [15]. To place the changes in value logics and roles in a transforming context, the theoretical field of ST has been utilized.

The ST field was developed to understand the processes involved in transforming a socio-technical system (regime) toward increased sustainability. These processes are complex and involve deploying new technologies with financial incentives and regulatory provisions, political, social and cultural processes, and consumer practices influencing the transition process [22]. In sustainability transition research, transformative innovations such as prosumer-oriented and decentralized energy systems emerge in mainstream selection-protected niches [23, 24], fed by changing landscape trends [25], which can lead to the destabilization of regimes [26]. The current societal order is made up of regimes including incumbent actors and institutional frameworks which have evolved over a long time creating a stable structure [27, 28]. DSOs are incumbents in the current centralized energy system and are thus facing structural changes stemming from landscape trends (renewable energy implementation and decentralization) and niche innovations. Although incumbents are locked into the current regime, they do not always resist changes which has been shown in several studies [29, 30]. Characteristics of DSOs have instead

[1] The Utility death spiral refers to a scenario where consumers are increasingly adapting solar PV, which leads to increasing costs for utilities to manage distribution and transmission. This in turn make the utilities raising the fees for the consumers, and the consumers become even more motivated to invest in own generation and reduce dependence on utility fees, and the negative spiral continues.

been several different logics and thus a semi-coherency for both current regimes and new niches [31]. Even though the incumbents are open to change, there are still great challenges with a transformation.

DSOs can display different logics, some of which may be coherent to an electricity system in transition. However, transforming roles and adapting to future system logics creates challenges for incumbent actors [32]. Although roles are indeed changed when new technologies are implemented, e.g., consumers become producers when implementing their solar PV panels, the new roles require some type of active agency to transform the actor's previous roles and responsibilities [33]. An actor who provides the most influential agency also affects the outcome, where the incumbents tend to desire similar organizations as the current state, and niche actors reformulate the organizations [34]. Agency is related to which type of values different organizations adhere to; these are altered when systems transform which creates a need to understand different values and how the respective actors understand and act upon these, i.e., follow a certain value logic. In energy system transition, this is especially relevant for the growing prosumer population.

Brown et al. [16] connect the growing prosumerism movement with the concept of value logics. According to Brown et al. [35], there are three different value paradigms present within prosumer groups: market, municipal, and community. Value assumptions in the market paradigm have their roots in the neoclassical economy model, where the self-interested individual (or a firm) is in focus. Improved social outcomes will come from rational individuals acting in competitive markets. In this paradigm, maximal shareholder dividends are targeted, and value is related to marginal utility. Private actors in free markets are usually connected with this paradigm, and prosumers are assumed to react to price signals and hedonic self-interest. The municipal value paradigm is, on the other hand, rooted in social democratic movements and communalization of state affairs which evolved with the growth of the welfare state in the twentieth century [36]. Here, values are especially important toward collective value and democratic processes, often overthrowing individual desires which are outside the collective. The community paradigm is rooted in a cooperative, autarky and grassroots movement [37]. It also emerged as a critique toward both the market and municipal paradigms, the former for its inability to create value for everyone and the latter for its unnecessary bureaucracy and its dehumanizing aspect [38]. The community members are in focus, and a community-oriented collective value assumption is applied. With these value logics, it is possible to distinguish different types of prosumers, and potential future value logics in the energy system may be more accessible to grasp.

Although transition studies have been developed from historical analysis of greater socio-technical transformations, such as the move from gas to electric light [39] or sailing ships to steamboats [28], current use also includes a more prospective dimension with the aim to support a decision for policy and market strategies [40]. In this sense, transition studies are closely related to future studies, which aim to detect and understand social changes, to help actors prepare and react to those changes [11]. A classical distinction in future studies is the probable, preferable and possible futures which have different approaches and analysis tools connected to each distinct future [41]. One recurring discussion in future studies is the resistance toward deterministic futures [11, 12]. Rather than presenting a most likely future, several possible alternatives should be created, since humans and societal institutions can and will influence the future [42]. Some scholars suggest that deeper and more radical futures should also be presented, as a means to challenge thinking and move away from incremental changes based on current systems [43, 44]. Future orientations have been practically used in the context of transition studies, especially in the transition management approach.

Several hands-on tools, developed from sustainable transition theories, are commonly gathered under the concept of TM [45]. It is referred to as a governance model to "*resolve persistent problems in societal systems, which is based on insights from transition dynamics. An important assumption is that persistent problems are not possible to fully control and manage, but it is possible to partly 'manage' these problems by influencing the societal system by organizing joint searching and learning processes toward long-term sustainable solutions*" [46]. TM includes some governance principles which are: multi-actor policy-making, multi perspectivity, innovation nucleus, transition and long-term, keeping options open, experimenting and innovation, dealing with uncertainties, and learning and reflexivity [9]. A central concept within TM is the transition arena. It embodies the TM principles in a multi-actor virtual arena in which different perspectives, expectations and agendas are confronted, discussed, and aligned where possible [47]. Following the principles in TM, a transition arena should include equal representatives of different actors, an integrated systems approach, a small group of innovative actors (frontrunners), long-term visions as a frame for short-term actions, multiple target images and transition paths, experiment portfolio, using scenarios and cyclical adaptation process design, and monitoring and evaluation [45]. These inclusions provide for a structured network, where a combination of analytical and process approaches are

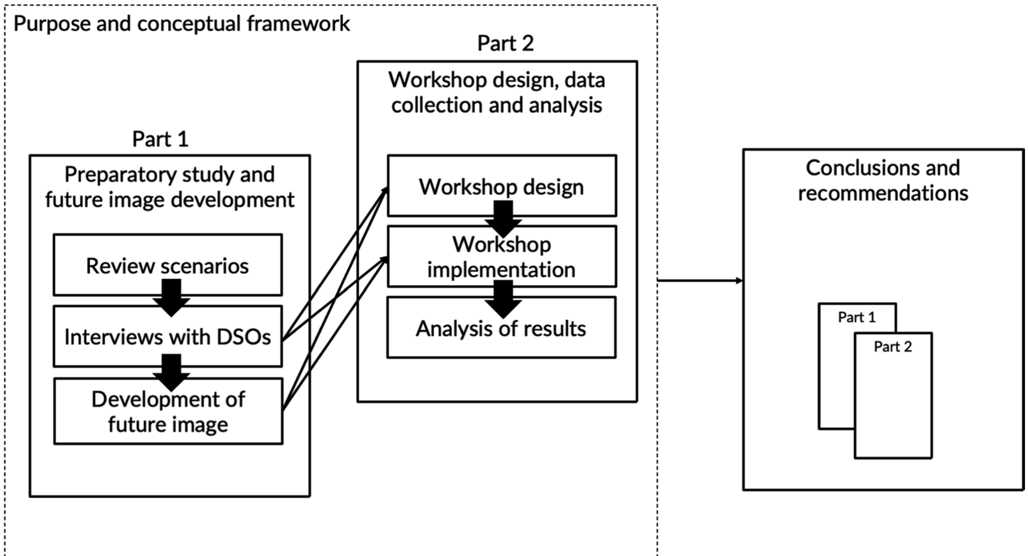


Fig. 1 Research design

made possible. Thus, the transition arena is an action-oriented approach which can function both for research and practical purposes. It also combines transition theory by integrating different levels, i.e., macro, meso and micro, with practical tools such as building a transition image to develop transition pathways[48].

For the above reasoning, sustainability transition theory is used to frame the study. In the analysis, this is combined with the concept of value logics, following Brown et al.'s [16] delimitation to market, municipal and community logics for different prosumer groups.

Methods

For the benefit of investigating possible future scenarios and increasing DSO preparedness within these scenarios, an action-oriented research method is applied. The close connection between TM and future studies theories is applied to structure the method which allows DSOs to share their experiences as well as their thoughts about the future. The reason for choosing an action-based approach is, as Brydon-Miller et al. [49] writes, "to move beyond the current state of mind and be facilitated by the researchers". With that in mind, the results should be interpreted from the DSOs' reactions to this future prospect. However, since the aim is to investigate preparedness toward an unknown future, an action orientation does not aim to provide a realistic future scenario but rather a degree of radicality which will stimulate reactions from the participants. The work is divided into the following parts: a preparatory study and development of a future image (Part 1) and action-oriented workshops with DSOs (Part 2), using transition theory and future studies as the conceptual framework for structure and analysis. The research design is presented in Fig. 1.

Insightfully, the TM approach seeks to provide a smaller societal representation to influence a sustainable transition as society contains multiple perspectives, agendas and complex relations between actors at different levels. As this study aims to depart from a single-actor perspective, a great challenge lies in the provision of multiple perspectives as a frame for transition activities toward a specific actor. Here it is critical to depart from general and specific insights from the sustainability transition field yet utilize action-oriented concepts from the TM approach.

Part 1

A central part of the process is the development of a future image, and two actions were completed. The first action was a literature review of existing scenarios and trend reports which describes several alternative scenarios. The chosen scenarios were all from well-known organizations, such as governmental agencies, trusted NGOs, and well-known consultancies. These scenarios were deemed trustworthy for the connection to the stated actors as well as transparency in the scenario build-up. The reason for including several different scenarios was to achieve similar pointers from several different sources and thereby increase the reliability of the developed future image. Being aware that the existing scenarios are not similar in their presentation, e.g., different ending years, scope of consumption etc., the authors were careful not to use any exact numbers when developing

Table 1 Participating DSOs

DSO	Ownership	Access points	Context	Workshop participation
1	Municipal	250,000	Urban	Yes
2	Municipal	5,000	Rural	Yes
3	Private	Several DGs	Urban/Rural	No

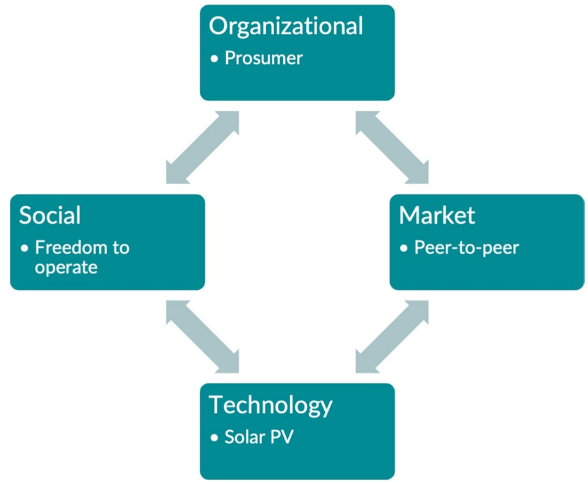


Fig. 2 Interrelated focus areas in future image

the images. A summary of the included scenarios can be found in Appendix A.

In the second action, interviews with chosen DSOs were performed to add relevant information from their specific context. The selection of DSOs was based on achieving a range of perspectives, especially in terms of the number of access points and whether the DSO was based on a rural or urban context. Moreover, as this was a two-stage process, it was important that the interviewed DSO could remain in the study to participate in the later workshop. With these important conditions, we found two DSOs that were willing to participate in the whole process. An additional DSO did not participate in the workshop but was interviewed to provide data to help create future images. Participating DSOs are summarized in Table 1.

Interviews were conducted in person, following a developed interview guide with semi structured questions. These questions were based on the theoretical framework and included insights from the studied scenarios and general aspects of being a DSO in changing energy landscapes. Each DSO representative gave their specific view on challenges and changes in future distribution grids. The interviews were then transcribed and analysed to provide categories of important challenges to include in the development of future images. With the reviewed scenarios and the interview results, future images of the distribution area were developed.

Using the concept of transition image and challenging established thinking by reference to the purpose of future studies, the future images included several focus areas and were quite radically different from current situations. However, as these also included perspectives from interviews with DSOs and established scenarios, the aim was to provide images which could be accepted by participating DSOs. In transition arenas, images are often developed by the participating actors, which is often the case in future studies as well. The reason is that with a jointly developed future image, there is increased readiness to unify and develop common strategies to attain the goals. As the aim of this intervention was to move thinking beyond current lock-ins, an inclusive approach was chosen, where participating DSOs provided insights into where they saw important issues in the future. However, the final action to set the images was performed by the action researchers in the project. Referencing the width of system dynamics, i.e., how a socio-technical system (regime or niche) includes social, political, financial, technological or other structures, described in the theoretical chapter and important areas of intervention, the future images featured four different foci which are interrelated: technological, organizational, economical, and social. Changing one focus area affects the others and will give rise to further circles of interventions. The cause-and-effect circles stemming from the theoretical framework with concrete examples of each category are shown in Fig. 2.

It was important to include cause and effects in the workshops, since these provided a holistic image of what a future technology intervention could mean for the societal system around it. Hence, it was a way of directing the discussions to the relevant topics of concern, which risks being undervalued from the participants' first associations when being presented with a possible future.

Part 2

Designing the workshop included structuring of the initial workshop content as well as choosing participants from the different DSOs. These internal participants were chosen by the DSOs with guidance from the researchers. A fundamental issue was to agree that the developed images displayed a possible future to depart from. As these images already were developed, not much space was given to discuss the content in the image, rather a presentation with comments and clarifications was deemed optimal to reach the stated aims. The emphasis then lays on discussing which different roles are necessary and value-creation within these future distribution grids, as put forward in RQ1. After deciding which roles were necessary as well as feasible, discussions followed focusing on whether these could be implemented and the necessary conditions to realize them in the context of the DSO's organization, adhering to RQ2. Here, the future image was used as an external frame which influenced necessary steps or internal transformations to reach desired outcomes. In addition, structured backcasting was performed to cover necessary steps toward role fulfilment in the future. To promote discussion about these role developments, some relevant categories were given: collaborative efforts, competence requirements, and value and business models.

Workshops were performed with between three to six participants from each DSO. The guidance for the DSOs was to include a variety of job titles from respective DSOs that cover many internal perspectives. The job titles of the participants varied, e.g., CEO, marketing manager, smart grid developer, communicator, etc. All workshops were held digitally, were recorded, and lasted approximately 2.5 h. Participants received a summary of the future image beforehand and a description of categories with questions to discuss. Categories included roles, collaborations, competence and critical issues, and the connected questions were semi-structured. The researchers leading the workshops made sure that all the questions were discussed. In addition, the researchers constantly referred to the future image as it was a fact so that the participants always had to keep in mind the features of the future energy system, and not fall back on the current situation. Moreover, the researchers ensured that all participants gave their views by distributing the speaking time between the participants, since many perspectives were represented. The input was given orally but also in writing by the participants using a shared online document. Notes were also taken by the researcher during the workshops.

The workshop results were captured by listening to the recordings and developing the notes and input already given. Then, the analysis was made following a qualitative content analysis methodology, where each topic mentioned by the participants was either saved as a category or integrated into an overarching category. As there was already an established discussion structure, each category, whether it had to do with roles, competencies or other explicit needs, was ordered into the given structure. The analysis continued with attaching value logics to the roles, and these were used to develop the future value model as an illustrative example of the future DSO roles and value transactions, as directed in RQ3.

Limitations and future perspectives

The study addresses the DSO perspective and does not include other relevant actors in todays or future energy systems. When considering roles necessary for a future energy system, new technologies create the opportunities to redistribute current roles onto, for example, prosumers. This is also for future roles. Moreover, it includes a limited number of DSOs, which should be considered when accounting for the generalizability of the specific WS results.

These limitations also provide some directions for future perspectives to be included in research. Adding a prosumer perspective in relation to these images could enhance the adaptability of the solutions suggested by the DSOs and help crystallize the responding roles from the user side. In addition, widening the perspective to include DSOs and prosumers in different countries would provide a more generalized view of the potential roles and value logics in the future electricity system.

Results

The result section will begin by briefly summarizing the development and result of the future images. Then the DSO roles will be presented as well as the needs to fulfil them. The last part of the section will start with the current DSO business model and, from there, conceptualize a value model in which the DSO includes different value logics in connection with the new suggested roles.

Development of future images to increase preparedness

Both scenarios and initial interviews are included in the future images.

Reviewed scenarios

Seven scenarios were reviewed and included in the future image. The ending year was between 2040 and 2050, but an exact year is not important when aiming to review several scenarios within a sufficient time frame to accommodate large changes. Although there are differences within the scenarios, some trends are similar: there will be increasingly variable production from wind power and solar PV. An important point is that almost all scenarios only include a slight increase in consumption, albeit expected population growth. This is due to energy efficiency measures which have historically kept total electricity consumption unaffected. However, as these scenarios are a few years old, a recent trend is challenging previous scenarios, which is the electrification of the industry and transport sector [50]. In the Swedish context, two examples are the Hybrit project [51] and H2 green steel [52]. Both initiatives focus on fossil-free steel production through electrification and using green hydrogen to produce sponge iron in steelmaking. When

Table 2 Interview findings to include in future images

Finding	Description	Focus area
Increase of distributed production resources (solar PV)	More bidirectional flows and variable production patterns in distribution grids require better measurement and prognosis tools	Technology
Modular systems	Future energy systems are based on small-scale resources which can easily be added or removed	Technology/Organizational
Peer to peer (P2P) markets	Prosumers trade electricity and other services between themselves, possibly without middlemen, if using, e.g., blockchain solutions	Market and Economy
Growth of electric vehicles	Massive growth of electric transport requires high power and can limit grid function	Technology
Electrification of industry	Industrial electrification requires vast amounts of power and, as a result, increased transmission capacity	Technology
Flexibility services	Flexibility markets are promising but require a new organization including new and reshaped roles, business models and the division of responsibilities between DSO and flexibility provider to be fully realized	Organization/Market and Economy
Fair distribution of rural/urban	How to create an equal and fair transition to more privately owned energy resources	Social/Organization
Energy communities	Regulations must be clear, and responsibilities explicitly stated	Social/Organization

this production is proposed to be at full scale in 2035, the electricity consumption will have increased by 55 TWh [53]. Together with the electrification of the transport sector and additional demand, e.g.: data centres and battery production facilities, a total electricity demand of between 240 and 310 TWh, compared to today's 140 TWh, is proposed leading up to 2045 [54]. Thus, this significant trend disruption in recent decades will impact the national electricity system heavily if it is implemented, and, therefore, should be considered in future images. Recent developments with the Russian invasion of Ukraine in March 2022 have contributed toward energy supply uncertainty in Europe and resulted in high energy prices. This has cast light on energy security issues and increased the incentives for furthering energy efficiency and investment in local energy supplies within European countries [55]. This has further motivated the choices made in the future images.

Findings from interviews

There is a general expectation from the respondents that there will be considerable changes in the future, and that current business models will have to be updated to meet future market demands. Uncertainties regarding "how much" and "when" are described, which also creates difficulties in preparing for future changes. Table 2 includes a summary of the findings which are important to include in the future image.

Future image

In line with the study's method, scenarios and initial interview results are fed into the future image which departs from the year 2040. The increase in national consumption from sector electrification creates a need to implement local solutions for supply, storage, and smart control, since external influx to DSO grids will be less reliable and possibly more expensive. An overview of this image is provided in Fig. 3 followed by more detailed results of the scenario and interview feeds in respective foci.

Technology

As all scenarios included vastly increased renewable production, these are judged to influence the respective DSO grids. As solar PV continues to decrease in cost and governmental incentives still contribute to increased markets, this results in coverage of around 80 per cent of all roofs and many facades for buildings. Furthermore, additional PV parks are installed within the DSO grid as the costs for these large installations also decrease. Despite public opposition, some nearby wind power plants will be installed. With increased variable production and price decreases for energy storage, large numbers of batteries will be installed locally. In addition, sophisticated digital tools to measure and control variability are used. Local hydrogen will be produced from excess production, which is likely from a heavily increased green hydrogen

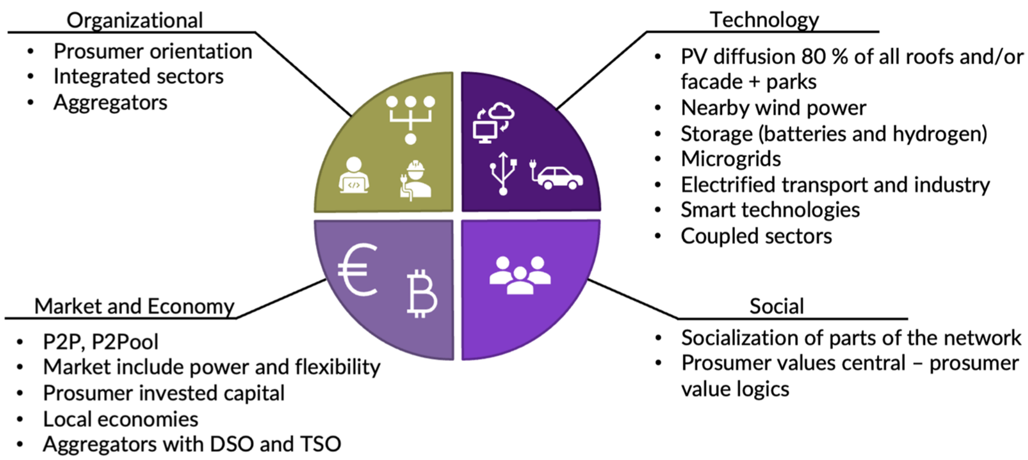
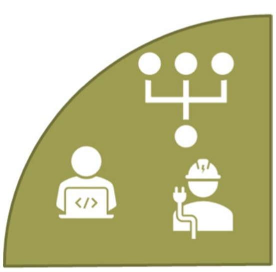


Fig. 3 Overview of future image with the explicit content of the four focus areas

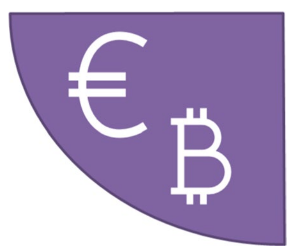
use affecting the value chain and price reduction, and the need to seasonally store wind and solar PV production. Some local energy systems will be designed as microgrids, providing the possibility to separate from the distribution grid. New technologies will be more small-scale and modular compared with traditional large-scale production plants. This has advantages, since they can be deployed relatively quickly and flexibly according to varying future needs. In addition, all transport will be electrified with most vehicles containing batteries and some fuel cells which utilize hydrogen. Furthermore, many industries will be electrified which increases electricity demand heavily. The electricity system can utilize flexible resources, such as heat pumps and ventilation, and demand response solutions are implemented.

Organizational



As many of the technological resources are small-scale and local, the majority will also be owned or connected with consumers directly. Thus, there will be prosumer-oriented systems which means that quite large parts of the electricity infrastructure will be partly or fully controlled by prosumers, such as real estate companies, housing companies, local businesses and industries, as well as private persons. Thus, there are a lot of actors active in the electricity system, not only as consumers but also as suppliers, infrastructure providers, balancing actors, flexibility providers, etc. In addition, as the electrification of industry and transport develops, these sectors will be more reliant on the production of electricity, be involved directly in the electricity system, and sector coupling will be heavily implemented. Energy communities will also grow in future containing several different actors and businesses and expanding the local energy system structure.

Market and economy



With increased distributed resources, prosumers and other actors directly involved in the electricity system, the market will be much more related to these new actors. Local markets and local value will be emphasized as prosumers such as real estate companies will make sure that their invested capital provides value for their business. Markets will include flexibility services and be arranged in all types, i.e., between businesses and consumers, and among consumers, i.e., P2P. The DSOs will trade flexibility in the future energy system. Many new actors will be active on the market, both individually and in the form of aggregators, providing a collection of resources to use for flexibility and power balance. The economy around the electricity system in general will be increasingly local and shaped toward prosumers and energy communities, although the traditional spot markets will co-exist.

Social

The increase of prosumers and local energy resources contributes to increasing socialization (cf. Brown [16] and Miller et al. [56]) of the electricity system, where it is operated directly by the public, real estate companies and other actors who own large building portfolios. This means that social values in relation to the electricity system become more explicit. Values such as sustainability, welfare, local economy, engagement, democracy, justice, etc. are increasingly being associated with the electricity system and its distributed resources. This does not necessarily mean that these values are fulfilled for every actor. Instead, there will be new challenges regarding energy fairness and greater variability in electricity costs as it will invest capital toward lowering costs while increasing quality (e.g., resilience for grid disturbances with backup storage), but only for those who can afford the investment. Further challenges include different physical conditions for rural and urban distribution grids. Although it is possible to easily increase further renewable energy infrastructure in rural locations due space availability, this requires network reinforcement which will increase costs for the local citizens.

DSO roles in the future electricity system

The findings from the interviews in previous sections are reflected in the conducted workshop discussions. In the discussions, the researchers together with the DSOs were able to distinguish four future roles for the DSO: facilitator for increased collaboration, Communicator, Balance actor, and Sustainable developer. Roles are updated both down the value stream, i.e., toward the consumers and local operations, and along value stream toward the transmission system operator (TSO).

Facilitator for increased collaboration

To create flexible use conditions in the local grid, the workshop participants identified a need to provide objective knowledge, create trust and facilitate collaboration between consumers in the local grid. This is a new and difficult task for a DSO and requires closer and more active relations with the consumers. In the short term, the focus should be on larger consumers, such as local industries. In the medium term, the types of consumers focused on should be larger housing companies, businesses, and housing associations, with efforts to facilitate relations between the consumers a priority. In the longer term, relations with all types of consumers, e.g., local businesses, smaller housing companies and households should be created. For rural DSOs, closer relationships to consumers exist due to relatively fewer customers, lower barriers to service support. This creates a good starting point to increase active relations in the future electricity grid development. For the larger urban DSO, more efforts are needed to initiate relations, although opportunities are greater due to more potentially flexible resources. In this role, there is a need to include the perspectives of the municipality, market, and community and, hence, the DSO must be able to manage different value logics in pursuing this role.

Communicator

This role originates from the added complexity of distributed resources, and the increased need to manage the resources efficiently to avoid costly capacity investments in the grid. As a communicator, the DSO can increase knowledge and discuss efficient demand behaviour with the consumers, thereby providing greater flexibility in the system. This role differs from the collaborator role, where the communicator is focused on increasing knowledge and facilitating efficient behaviour of the consumer, e.g., by nudging, while the collaborator role is more focused on increasing collaboration between the resource owners in the local grid. For efficient communication, it is, however, similarly important to understand customer needs, i.e., be knowledgeable about the consumers' value chains, and thereby be able to provide some incentive for the customer to be flexible. Thus, understanding customers will create synergies for both roles. The communicator role is, however, more closely connected to municipal activities toward its citizens, e.g., by nudging campaigns, and, therefore, bears a municipal value logic.

Balancing actor

Upstream, the role of balancing actor which was previously held by the TSO (although procured from balance service providers) is now, through regulatory updates, to a larger extent appointed to the DSO. In the future, it would be difficult for the TSO to balance the increasingly complex local and regional grids with similar tools and strategies as today. Here the DSO will have to provide aggregated information and actively balance local fluctuations to facilitate the TSO. Again, this requires increased knowledge of consumers along with applications which provide relevant information and the ability to control variations in production and demand. Here, local flexibility markets are described as important. In the short term, this would require increased knowledge and competencies to develop these flexibility markets. In the medium term, commercial trade with flexibility should commence which also connects the DSO more actively with providers, such as aggregators; and, in the longer term, a market to buy system services to balance the local grid should be established and put into operation. The urban DSO expresses a clear market orientation, although expressing uncertainties about how the market can be designed efficiently with physical constraints in the DSO grid. For the rural DSO, there are even more uncertainties expressed and doubts as to whether this market should be hosted externally or integrated into the extended DSO role. Much of the balancing actor role is market-oriented; however, it also has community perspectives and, therefore, includes both a market and community value logic. A specific challenge for enacting this role is the access to high-quality and standardized data from the local resources in the grid.

Sustainable developer

A recurring topic from the workshop discussion was the increased social responsibility that a DSO should/can provide in the future. This is displayed by how the DSO can facilitate consumers to become more sustainable in the energy field, and how the DSO should act to ensure social sustainability for its consumers. An issue which is brought up is that a future decentralized energy system requires investments from consumers to be able to participate in flex markets and lower the need for bought electricity. This risk creates differences between consumers who have the financial means to invest and those who do not, leading to even higher costs for consumers with lower means. Furthermore, the difference between urban and rural areas is brought up, where there are more possibilities in the countryside to develop renewable energy. Increased local concentration requires further grid investments which leads to higher costs for the local community, although the generated electricity is not used in the local area but instead exported to nearby cities. With current regulations, this would create an unfair cost difference between urban and rural areas. These described social responsibilities differ from current roles and require a greater understanding of the various types of consumers and active work with issues beyond energy. This is difficult from a strict market perspective; thus the role needs a municipal and community value logic to be pursued.

Summary roles

Table 3 summarizes the roles from a time perspective with a note on urban/rural differences. In addition, the represented value logics in the different roles are also presented.

Needs to fulfil roles

Many of the roles described require good relations and collaboration with consumers, third parties (e.g., local market providers and aggregators), other nearby DSOs, and transmission operators. This requires effort if the aim is to create a mutual understanding between users' needs and grid constraints to facilitate a development which is more resource-efficient and valuable to all actors. An important step in collaborative development is, therefore, the creation of trust in the DSO as an independent actor which aims to provide the best overall system. Hence, there is a need to reach out to consumers, to engage with them and learn about their businesses. Other dimensions of collaboration discussed during the workshop are joint collaborations and more established partnerships with actors providing and developing ancillary services, such as peak shaving, frequency regulation or congestion management. These partners could include aggregators of flexibility services, or simply technical providers of smart metering, tariffs and service settlements. This relates to the roles and functions of being a balancing actor and how the DSO can efficiently organize these functions. In addition, a joint collaboration between nearby DSOs is needed to be able to balance local and regional grids efficiently, which also creates opportunities to share investments in technologies that will facilitate the future management of the distribution grid. These collaborative efforts require additional resources in terms of an increased number of employees and specific competencies to handle these collaborations.

Competence requirements

In the workshop discussions, the future DSO would require both similar competencies as today but also several additional competencies to be able to meet the requirements of a decentralized, digitalized, sector-coupled, and relational energy system. From a transition perspective, the competencies must adopt the new rules of the game, both in terms of skills and expertise but also regarding attitudes and behaviour. Not all competencies need to be in-house; instead, working more actively with consultants and joint partnerships can be anticipated to be an important step. Some of the competencies discussed in the workshop are presented in Table 4 along

Table 3 Roles in different time frames

Role	Example	Value logics represented	Actions			Note on urban/rural setting
			Short term	Medium term	Long term	
Facilitator for increased collaboration	Coordinate collaboration between local energy resource owners	Municipal Market Community	Focus on relations with larger consumers	Increase focus on more customer types and between customer relations	Add all customer types including households	Larger urban setting is more complex, the rural DSO already has adequate relations with many user types
Communicator	Increase citizen knowledge by info sharing and active nudging	Municipal	Efficient messages to consumers on small behaviour changes will have large effects	Communicate challenges and let consumers be part of the solutions	Established relations and communication channels	Again, relations are crucial and more complex in larger urban settings
Balancing actor	DSO become a smaller scale TSO for local resources in their grid responsibility area	Market Community	Provide a local platform for trading electricity	Commercial trade with flexibility, platform provided by another part, e.g., aggregator	Buy system services from established markets to balance the local grid	Market participation is more explicitly stated by the urban DSO. Rural DSO instead discusses its responsibility for local markets
Sustainable developer	Facilitate industrial actors to electrify operations and reduce climate impact	Municipal Community	Increase the scope of current responsibilities and be active in just development for consumers		Provide sustainable and just energy systems to all consumers	Urban DSO focuses added role of sustainable developer, while rural DSO focuses just transition and user perspective

Table 4 Necessary future competencies within the DSO

New competence area	Specific competence	Motivation	Suggested strategies
Technical			
Digitalization	IT engineers Software developers AI experts M2M learning experts	New applications and digital technologies are increasingly being used for grid and distributed resources management	New recruitments Research partnership with skilled universities Strategic partnership with IT companies
Local market development	Electricity market experts Platform developers	Trading flexibility services from local resources including the use of smart metering, dynamic tariffs and automated settlements	New recruitments Research partnership with skilled universities Strategic partnership with IT companies
Cross-sector competence	Heat-electricity IT-energy	Utilizing available resources more efficiently	Internal knowledge sharing Training programs
Additional sectors	Automotive Buildings and property	Direct connections to other sectors as they increasingly become part of the energy infrastructure	Recruit competence from specific sectors
Social			
Relations	Communication experts	Create increased knowledge and understanding among consumers, improve relations	Recruit experts' Internal communication training for a broad force
Dual competence	Engineering and behavioural scientists	Increased need for socio-technical understanding in decentralized grid infrastructures	Recruit missing competence Create teams with social and technical competence

with some general suggestions on how to acquire the necessary competencies.

These new competencies are needed in addition to existing competencies today, and even with some internal education of current employees, additional competencies will add costs to the DSOs. This is logical, since the roles are also extended but need to be reflected in the regulation incentives and resources to be put into practice.

Conceptualized value model and relation with value logics

Roles are closely connected with different value logics. Figure 4 presents the traditional business model for a (municipal) DSO. In this model, the DSO operates under quite strict market value logics represented by the blue colour in interaction arrows. It should not be confused with a deregulated market, as for the electricity retailers, but the way the DSO monopoly market is regulated, it bears market value logics in the trading of goods between the supply side and the demand side. The arrows represent value flows between different actors in the model. Even though a customer seldom cares about anything else than reliable electricity supply with reasonable quality, this is still represented by three different arrows, since in practice, this is what the customer receives for paying his tariff (given how the DSOs are regulated within the law). The DSO is also connected with the balance responsible party (BRP) who interacts directly with the TSO and is responsible for any imbalances that may occur. Here, the DSO share information of available capacity in their grid which is utilized in the balancing process. As the investigated DSOs in this study are municipally owned, influence directly from the municipality is represented by the green circle. Consumers are described as customers within the grid. The judicial space (e.g., regulations for a distribution system operator) is directed toward the DSO in the current model and is represented, in Fig. 4, by the beige area with the red dotted line.

The findings show that the new roles described extend the previously strict market logics. A facilitator for collaboration is represented in all three logics. Municipal logics are represented in that it facilitates collective value creation through increased collaboration, where finding solutions which are valuable to all collaboration actors is desired together with the increased ability to influence the network and market design of the energy system, which increases energy democracy. It also contains market logics as it is a facilitator for increasing market transactions between collaboration partners and the TSO through a collective balance service offer. The role also includes community logics for its efforts to create close relations with the community and facilitate understanding of community-specific needs and desires. Moreover, the communicator role aims to increase knowledge for the citizen to facilitate small behavioural changes to increase overall efficiency in the energy system. Thus, it holds that municipal logic empowers citizens through collective benefits, which is a core feature of a democratic state. The role of a balancing actor is described as providing a local trading platform for electricity and flexibility services. This is largely connected with a market logic

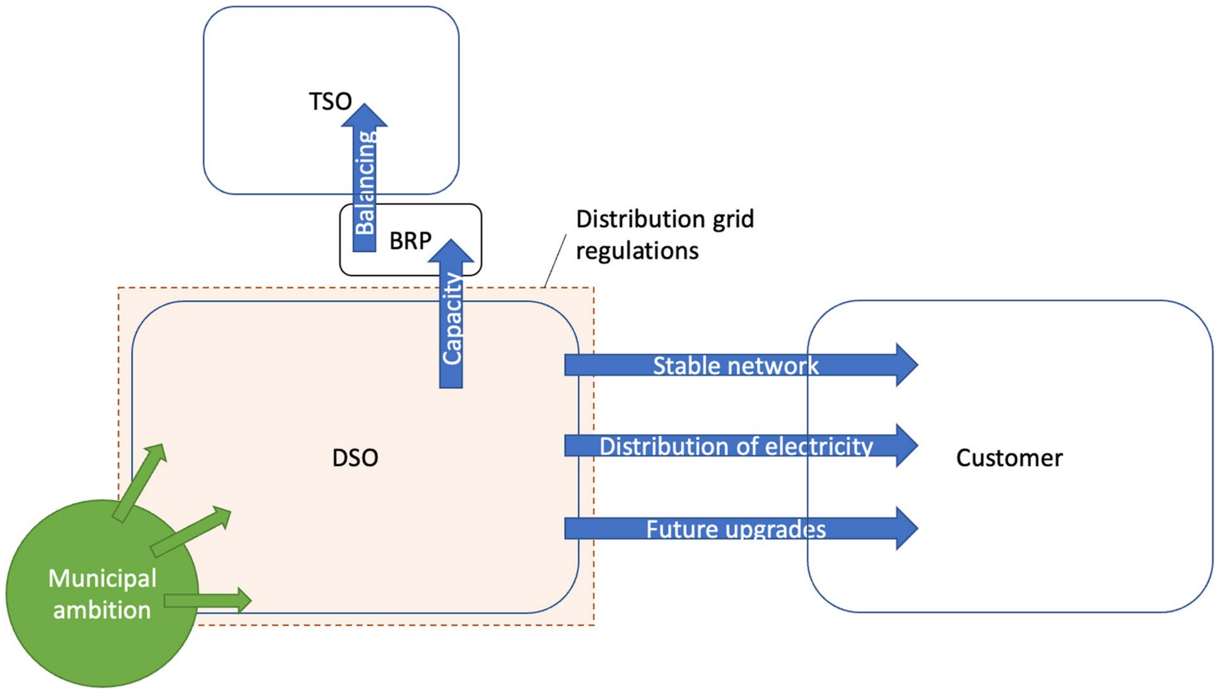


Fig. 4 Traditional value model

due trading with bids and closures among market agents, reflecting the existing electricity market. However, as it is small-scale and local, it also offers the opportunity for individuals and communities to participate as active traders. This implies that community logic is also present in the balancing actor role. The broader role as a sustainable developer, which also includes providing a just energy system for all, relates to municipal logic and a collective value target. In addition, the role may include direct efforts toward communities, e.g., by consulting sustainable solutions for the specific community, and is, therefore, also connected with community logic. As a result, an updated value model is presented in Fig. 5.

What is important in the updated value model are the bidirectional arrows between the DSO and the prosumers. The blue arrows include electricity (kWh) and flexibility (e.g., peak shaving, frequency regulation etc.), the yellow arrows include value streams from collaboration, and the green arrows include value from increased resilience. In addition to the value streams connected to market logics (blue), two other value flows, resilient network and co-creation, connect with municipal (green) and community (yellow) value logics. Resilient network is related to the communicator role, and the facilitator for increased collaboration includes value streams of flexibility, resilient network and co-creation. There are also interactions between the prosumer and TSO, usually via a new type of flexibility aggregator, when providing ancillary services related to national grid needs (e.g., frequency regulation) from owned resources; however, when the prosumer supports the distribution grid with ancillary services (e.g., congestion management, voltage control etc.), this interaction is overseen and coordinated by the DSO in their balancing actor role. The aggregator can also directly link to the DSO for certain local flexibility needs. In the future value model, there is also increased interaction within the prosumer group, on all different value logics, e.g., electricity trading, resilient infrastructure and co-creation, illustrated by the circular arrows in the prosumer box. Even though the interactions between prosumers could occur without the DSO, e.g., through P2P markets, coordination is necessary to balance the flows through the grid infrastructure. This also links with the role of a sustainable developer, where facilitating the prosumer's efforts to reduce climate impact, links with the necessities of the grid infrastructure. Furthermore, the increased municipal value logics influence is represented by the larger circle and arrows in Fig. 5. The municipal ambition for a sustainable future electricity system also includes the prosumers, since they are now an active part of the distribution grid. The judicial space is also extended to influence both prosumers and the TSO, since the DSO roles provide additional activities and responsibilities for these groups.

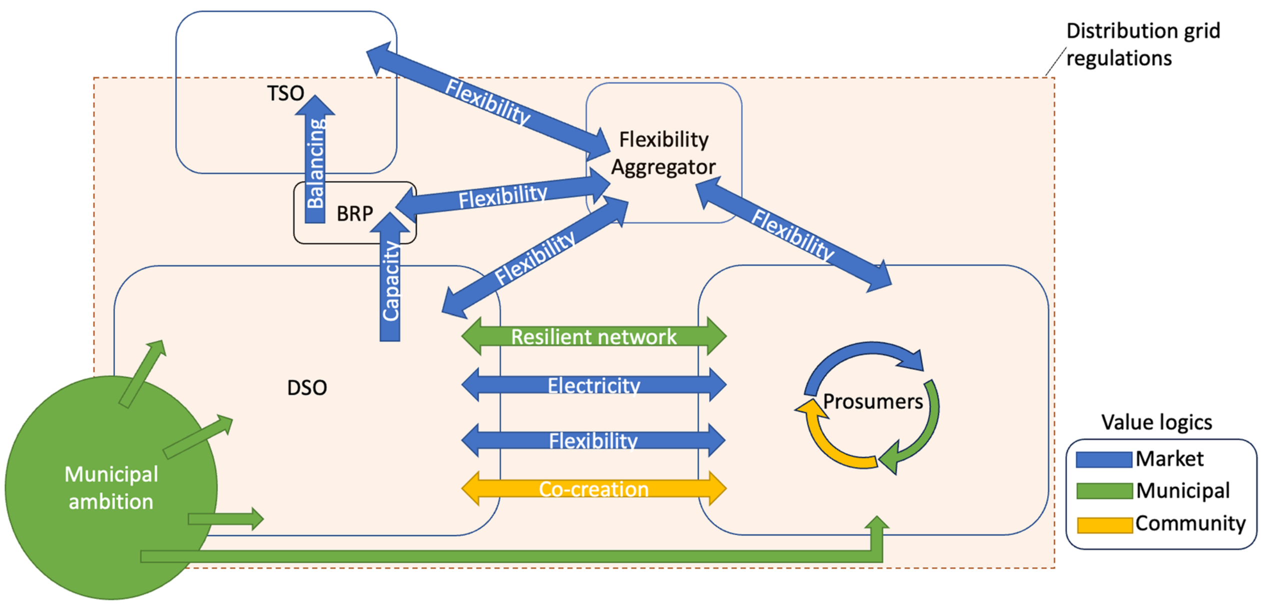


Fig. 5 Future value model

Discussion

Decentralization and increased prosumer orientation of the energy system have implications for the control and management of future grids which are expected to service a more distributed electricity system. It is, therefore, interesting to discuss future roles for a DSO in relation to how prosumers view and engage in value creation. The chosen method in the study deliberately challenges DSOs to think beyond current operations, and the results are gathered in a way that multi-perspectivity is promoted, although within the same organization. What makes the results interesting beyond actual descriptions of roles, is the shared alignment in the organizations, which also improves the legitimization of potential future role changes [57]. Sustainable transitions are dependent on actors' ability to transform mindset and operations, which is also the motivation for using TM as a facilitating tool [33]. Hence formulating roles and competence needs etc., in such facilitated environments may increase this ability, and create an outcome that is collectively and uniquely agreed upon.

This study makes several points. First, the results show that several new roles are proposed, which would create a radical transformation from a narrow focus on maintaining and operating grids to a facilitator for sustainable and energy-efficient development in prosumer-oriented systems. As a facilitator for increased collaboration, the DSO can maintain the necessary coordinating role and have an overview of active contributors to the distribution grid. With the communicator role, important knowledge and distribution grid status can be delivered to prosumers and other stakeholders. As a balancing actor, the necessary balance between energy generation and loads from the new distributed energy resources, as well as keeping a steady frequency will be maintained by the DSO who can readily sustain the long-term quality of the distribution grid. The role of a sustainable developer is more far-reaching but at the same time necessary when motivations for increased electricity consumption from the electrification of sectors indeed are driven by sustainable development. Here, the DSO will enable increased sustainability by also paving the way for electrification. In addition, the role also needs to cover additional sustainability measures, such as just transition and social inclusion. With these roles, there is an increased emphasis on learning and mutual understanding between consumers, prosumers and DSOs. As the energy landscape is becoming increasingly variable on the supply side, which needs increased flexibility on the demand side [58–60], this mutual understanding, trust, and collaboration seem crucial to the creation of an efficient organization of the future distribution grid.

As discussed in the workshop, the concluding sentiment is to enact these roles in a iterative, step-by-step fashion over time. The backcasting exercise provided insights into a potential pathway toward full role endorsements and identified increasing collaborative efforts in many directions: consumers, other DSOs, and the TSO were highlighted. In addition, a lot of emphasis was given to the needed competencies to be able to fulfil the roles. For the balancing actor, digitalization competence was pointed out as was local market development, including metering, billing, tariffing and settlement. Competencies in cross-sector and additional sectors such as automotive and industry were also pointed out for the balancing actor, facilitator for increased collaboration, and communicator. Relational expertise was deemed crucial for almost all proposed roles and something fundamental for increased collaboration in future electricity systems. Dual competence was also discussed; a combination of engineering and social science competence was deemed important, although more in a general sense than for a specific role.

It is relevant to view these roles from an international perspective, where global development toward increasing distributed and variable resources is evidently ongoing [61]. Therefore, similar needs, although with varying criticality depending on the growth speed and amount in the national share of variable distributed generation, could be expected and the described roles should also be relevant. However, specific national jurisdictions and cultures will have an impact on whether the roles readily could be enacted by the DSO itself or possibly another actor. The IRENA [60] listed some factors which are necessary for DSOs to become more active in future distribution grids: changing regulations to clearly define the new roles of the DSOs, developing standards for data management and participation in energy and flexibility markets, smart grids and digital technologies to enhance innovation in solving constraints in future grids, and improving communication with customers. These are all related to the study's results, especially the improved communication with the consumer. Many roles are helped by a closer relation to the users, and most of the DSOs in Sweden are small, which is also the case with one of the DSOs in this study. Internationally, it is common with very large DSOs, which can pose a barrier to a closer relation with its users, and thereby increase difficulties in enacting certain roles. Measures to enhance the DSO capabilities to become more active in the distribution system have been taken over quite some years, but there are still challenges in practically enacting these changed roles. One example is the competitive procurement of congestion management, which is stated in the electricity market directive [6], but has so far not been generally adapted except for some trials and demonstrations [62]. Albeit the limitation by which a specific national focus implies, the forward-looking design of the study primarily aims at increasing knowledge and preparedness for change among DSOs, and to draw general conclusions over what roles are necessary in a future energy system with increasing distributed resources. Thus, different national jurisdictions will provide varying conditions and need to be considered when developing pathways to achieve desired future roles for DSOs.

The analysis showed that all roles were connected to different value logics, and a value model for the DSO in the future electricity system was proposed. The fundamentals of the value model, compared to the current business model, were the bidirectional flows between consumers and the DSO, where, in addition to electricity and flexibility, resilient network and co-creation were also added. These value flows include municipal and community value logics and must be connected to the roles of facilitator for collaboration and sustainable developer. Moreover, market logics is still sustained in the balancing actor role; however, with an addition of community logics the local trade platform will relate to this role. The value model also assumes good communication between the different stakeholders, and so the communicator role follows a municipal value logic. The role of a facilitator for increased collaboration also includes a market logic, since collaboration many times builds on the mutual exchange of products, in this case, electricity and flexibility.

Indications of organizational and judicial updates toward increasing distributed resources from regulatory bodies, especially on the EU level [6], have already been given; however, DSOs are often left to interpret changing regulations and develop their strategy to build needed capacity. There is a risk that these efforts, whether they are undertaken in-house or by consultants, result in incremental changes and a push to keep current activities as unchanged as possible, since this provides less economic burden in the short term. Hence, this study provides a way of reflecting on possible roles needed in a future with radically changed logics and seeing the benefits of taking on these roles. Already in the workshop, the DSO participants showed an ability to imagine a radically different future and begin shaping expectations of what a DSO can contribute to this type of system. An incumbent advocating for a new organized and technologically designed system has historically been important in the transitions of socio-technical systems [25]. Thus, facilitating such a process for DSOs holds the potential to speed up necessary transitions toward increased sustainability.

In addition, as regulations are of the highest concern for the regulated monopoly that DSOs act within, the described roles can be used as a departure point for pinpointing necessary changes in legislation. To be able to act as a sustainable developer for which the DSO as an expert in efficient electrical systems in the era of electrification is suited, there must be sufficient incentivization to influence users and prosumers to electrify and invest in distributed resources that can be utilized for the grid. This may vary in different countries, but looking at the current income framework in Sweden, there are clear barriers to this future role endorsement. Roles as a facilitator for increased collaboration and as a communicator are important for managing distributed resources efficiently and may not be hindered in current legislation. However, the extra effort and costs of possibly new competencies must be sufficiently covered in a future business model for the DSO. Here, incentives must be driving the quality of performance for the DSO in terms of managing resources and their owners (consumers/prosumers). Recruiting additional communication experts is a good starting point for the DSO, which has also been shown valuable in an example when the DSO has aimed to test a new solution (microgrid) in a community [63]. However, there is also possibly the need to enhance communication skills in the general workforce, and here the experts could be suitable to conduct internal staff training. The rural DSO already has a close connection to its users, and those and similar experiences could be captured and diffused to other DSOs in Sweden and elsewhere. The role of balancing actor is already implemented for frequency regulation and compensated by the TSO; however, new flexibility services should also be integrated into some compensation scheme or market solution, to enable the holistic balance with distributed resources. This is also in line with EU electricity market directive requirements for network development plans including flexibility measures [6]. Therefore, current income frameworks should be updated to create incentives for enabling local energy systems capable of providing services to the external grid as well as attracting household and business investments in energy infrastructure. Adding to the previous discussion, an advantage of this study is the fact that DSOs have described the roles themselves, which increases the legitimacy of updating the regulations.

An important dimension in the transition is not just what potential values and roles are ahead, but also how these can be enacted in relation to previous roles and potential target conflicts. Many of the roles and related value logics presented in the results are indeed conflicting with the market logic in which the DSO today operates and, importantly, is regulated toward. Will it be possible for the DSO to enact all roles or should there be a prioritisation over which roles should take priority? Therefore, being able to discuss both the opportunities and potentially conflicting interests along with the prioritizations that these roles imply in a facilitated environment, such as future-oriented workshops, is also important to avoid barriers to transformation.

Although the use of value logics in this study is far from complete, the insights can provide some structure for the DSO to shape their strategies and pursue their updated roles in relation to the different electricity consumers. It also displays some new competence needs to both understand the technical features of future electricity systems but also the social implications an increased prosumer orientation of the energy system creates. Wittmayer et al. [13] describe prosumer mainstreaming from three different institutional logics and, specifically, how these manifest in hybrid institutional arrangements in practice. The different roles are related to different value logics and are something that the DSO needs to combine to meet the different prosumer groups. Therefore, it is possible to call this a hybrid approach to the differences in future electricity system organization. Hybridity in this case includes agile and heterogenic consumer/prosumer relations.

To increase preparedness, the action-oriented approach together with the developed future images in the workshops was helpful and facilitated a constructive and open discussion on future roles for DSOs, even in the scenario of a radically changed context. Moreover, the approach provided a space to discuss potential implications and possibilities for future distribution grids without being constrained by current barriers. This was achieved via the preparatory work and the use of future images in the conducted workshops. It resulted in discussions regarding what the DSO roles *can be* in the future which will generate value on broader terms, i.e., for the DSO itself, the prosumer, and society. In so doing, the DSOs showed an openness in their mental models for the future. What this results in or how it will help prepare the DSO for the future is difficult to predict. However, the ideas and descriptions have been outlined which results in an increased clarity on expectations of what is to come. In its best scenario, this could reduce the efforts needed to meet future changes for the DSO.

Conclusions

This study aims to investigate future roles for DSOs with the purpose of increasing preparedness for transformation in energy sector transition. Three research questions were proposed: i) what are the necessary roles for DSOs within a future decentralized energy system? ii) What do these roles require to be fulfilled? and iii) How can a future value model for a DSO be conceptualized through connected roles and value logics?

Some new and some clarified roles are proposed for the DSO within the future, decentralized and prosumer-oriented energy system. The communicator and balancing actor are current roles in need of increasing attention, whereas the sustainable developer and facilitator for increased collaboration are considered newer roles for DSOs. All four roles are necessary for an increasingly complex decentralized energy system and suitable for a DSO with certain expertise and overall network responsibilities.

There is a need for competence updates to enact and fulfil the future roles of the DSOs. Specifically, digital skills as well as local market development cover the technical needs. In addition, cross-sector competence, specific competence from focused electrifying sectors, such as transport and industry, and relational and behavioural competence, are regarded as important to enact described roles and meet the needs of the future energy system. In addition, going stepwise toward the full role endorsements as described in this study, creates a more comprehensible pathway for the DSO in order the change current operations and refine expectations for the future energy system.

A future value model should include a hybrid approach to different relations with prosumers and consumers in the energy system. Hybridity in this case means differentiating strategies and relations with different prosumer and consumer groups to enable the capturing of respective value logics. This puts increased pressure on the DSO and it is important to find ways of allocating resources for the necessary changes, e.g., through innovative business models and/or policy incentives in the transformation phase.

It is also worth noting that the results are based on a limited number of participating DSOs. Hence, the results should not be interpreted as a statistically full sample of DSO opinions; however, the goal of the study is not to provide this view but rather to provide an environment, where DSOs can express possible roles in a future energy system with different logics than today. As presented in the results, this was also achieved. A natural further research step is, therefore, to increase the research sample and find more generalized pathways for the DSOs to develop. As the study is focused on the DSO perspective, other stakeholders such as different prosumer groups, aggregators, etc. should also be studied in relation to future preparedness. Here, it is possible to base the work on the developed method and structure of the workshops, however, adapt to the specificities of other stakeholder groups. Potential research questions should elaborate on prosumer roles and their incentives to adopt these, as well as how organizations, such as commissioning and legal entities, municipalities, or local agencies, could facilitate the role endorsements of future DSOs. In addition, and with the defined value logics and connection to certain groups of prosumers, there is a need to further understand the differences between these groups and to find suitable approaches including business models, which can be included in the hybrid approach with the DSOs. Here the research questions could elaborate certain value models, potentially from transdisciplinary fields of value theory, toward the stakeholders.

Appendix A: Summary of reviewed scenarios

Organization behind scenario	Current numbers	Naturskyddsföreningen (The Swedish Society for Nature Conservation)	100% renewable scenarios from SWECO—1 st scenario	SWECO—2nd scenario	Swedish energy agency (EM)—Forte	EM—Legato	EM—Espressivo	EM—Vivace
Year (release year in parenthesis)	2019	2040 (2019)	2040 (2017)	2040 (2017)	2050 (2016)	2050 (2016)	2050 (2016)	2050 (2016)
Consumption electricity	138 TWh 369 TWh*	176 TWh	148 TWh	148 TWh	375 TWh*	243 TWh*	323 TWh*	326 TWh*
Nuclear	65 TWh	0	0	0	69 TWh	0	3 TWh	0
Hydro	65 TWh	68 TWh	66 TWh	69 TWh	70 TWh	55 TWh	60 TWh	68 TWh
Wind	20 TWh	90 TWh	75 TWh	65 TWh	10 TWh	70 TWh	25 TWh	50 TWh
Solar	0.5 TWh	15 TWh	10 TWh	20 TWh	2 TWh	12 TWh	30 TWh	22 TWh
Combined Heat and Power (CHP)		3 TWh	3 TWh	3 TWh	25 TWh	9 TWh	17 TWh	35 TWh
Reference	[64, 65]	[66]	[67]	[67]	[68]	[68]	[68]	[68]

* Heat and transport included

Appendix B: Interview questions

Introduction

If you could get answers to three questions about the electricity grid of the future, what would you ask?

Today's situation

What values are behind your business, what is the vision and mission of your business?

What does the distribution of customer/user types look like for you?

What relationships do you currently have with these?

In what way do you communicate/interact with your users?

Is there any difference when it comes to prosumers?

Possible development and needs in the future

In the event of a sharp increase in solar cells (70–80% of users have their own solar cells, an average of 10 kWp) and possible wind turbines, what problems would arise in the network?

How would a simultaneous increase in electric cars and charging infrastructure affect your network?

Are there other likely factors that would also affect the grid in the future, for example, greater demand from electrification of industry etc., and what would that impact look like?

What solutions would be required to enable these different increases?

- Technical, user-related, business etc.?

Where is there an opportunity to work with the users themselves to a greater extent, for example, influencing their use and increasing demand flexibility, installing batteries and other storage, including the electric cars in a functioning V2G solution, etc.?

What are the obstacles to these possible solutions at present?

- Technical, regulatory, business etc.

Roles in the electricity system of the future

How can you as a distribution network manager work actively to enable a transition to increased flexibility and user involvement in the electricity system of the future?

What do you see as important that the DSO role fulfils in the future electricity system?

How could the user role evolve to support this transition?

Can the users be organized in different new ways that simplify the relationship and the exchange with you as network manager?

Are there opportunities for new players to fill different roles in the electricity system of the future?

How does this affect your relationship and activities toward the TSO?

Is there anything else you want to add that I missed with these questions?

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Author contribution
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Declarations

Ethical approval and consent to participate
All interviewees and workshop members participated voluntarily in the study. The interviewees and respective organizations were anonymized in the writing of the article. All the interview and workshop material was handled and stored securely by the authors.

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The authors declare no competing interests.

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