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Technology, Business Model, and Market Design Adaptation Toward Smart Electricity Distribution: Insights for Policy Making

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Technology, business model, and market design adaptation toward smart electricity distribution: Insights for policy making

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Abstract

The ongoing European Union sustainable energy transition has a disruptive potential regarding the role of infrastructure and utilities in the electricity sector. The increased spread of digital technologies, renewable energy sources, and prosumers calls for a swift and well-guided adaptation of the electricity distribution industry towards a smart grids context. We analyze the challenges and opportunities associated with this adaptation through nine multi-stakeholder workshops, held in Germany and Portugal in 2016 – 2017, engaging distribution system operators (DSOs), researchers, academics, and integrated utility companies to obtain up-to-date insights. Our results indicate uncertainty regarding the value of large-scale rollout of smart meters for DSOs. Also, a corporate culture with resistance to change is observed, challenging the integration of novel technologies and processes. Traditional regulation is seen as a barrier to smart grid investments, is associated with job losses, and knowledge destruction. Policy-makers can benefit from these insights by taking them into account in policy design and market restructuring.

Keywords

Electricity distribution; smart grid; technology; business model; market design; policy.

JEL Codes

O18; O25; O33; Q41

1. Introduction

The transition towards a low-carbon energy sector is currently a priority in most countries, at least since the climate treaty was signed in 2015 at the COP 21 in Paris. Many European countries have set targets for the share of renewable energy: Germany, for example, aims to reach a share of 35% renewable energy by 2020, while Denmark and Sweden have set 50% as a target (Anaya and Pollitt, 2015). Commonly envisioned transition paths include the integration of the heating and the mobility sector into the electricity sector on the consumption side (sector coupling). The generation of electricity is typically planned to shift from centralized thermal power plants to distributed energy resources (DER), which either feature high energy efficiency levels, due to combined heat and power generation, or are based on renewable energies, and thus carbon-free during operation (e.g. wind turbines and solar photovoltaics) (Palensky and Dietrich 2011).

Smart grids will play a key role in integrating these flexibilities, increase energy and economic efficiency, and empower customers (EC 2012), which is why the EU prompted its member states to ensure the rollout of intelligent metering systems in the near future (EC 2009b). These developments can be expected to strongly impact DSOs; as Lavrijssen et al. (2016) formulated, in terms of:

- economic issues dealing with the business model and the organizational structure;
- legal issues including the market design and regulation; and
- technical issues regarding the operation, the technology itself, and the management.

While there has been some general discussion on challenges and opportunities for DSOs in a smart grid future (Siano 2014; BMWi 2014; Droste-Franke et al. 2012; Lavrijssen et al.

2016), few insights on recent developments and on how DSOs face this transition can be found in the literature so far. Therefore, this paper fills an important gap.

This paper presents up-to-date, real-world insights on the challenges and opportunities that the energy transition as well as the transition towards smart grids represents for DSOs, and for the transformation of the electricity distribution industry as such. The findings presented result from a series of nine multi-stakeholder workshops, conducted in 2016 – 2017, engaging experts in the field, in Germany and Portugal, as two representative EU member countries. Participating stakeholders include experts from research, academia, and industry exposed to both the national and European context on the energy transition. This research was developed within the scope of the project *"The Electricity Sector Transition – Transnational Experiences from DSOs and Cooperatives*" jointly developed by the Energy for Sustainability Initiative, University of Coimbra, Portugal, and the Institute for Future Energy Consumer Needs and Behavior (FCN) at the E.ON Energy Research Center, RWTH Aachen University, Aachen, Germany.

The remainder of this paper is organized as follows. Section 2 provides some background information on the business model, legislative aspects, and technology developments that influence DSOs. Section 3 introduces the research design, after which section 4 presents and discusses the findings. Finally, section 5 summarizes the main challenges and opportunities identified, whereas section 6 draws some conclusions and provides policy implications and recommendations.

2. Background

In this section we provide some background concerning: (1) the status and developments in the field of DSO business models; (2) the legislative and regulatory framework for DSOs within the EU; and (3) recent as well as emerging key technologies that might significantly impact the electric distribution grids and their operation.

2.1 The business model of incumbent DSOs

For the EU, '*distribution system operator' means a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity*. (EC 2009b). For this service, DSOs can request remuneration, partly resulting from the electricity distributed to consumers through their network. While this description might sum up the incumbent role of DSOs in the past quite well, it falls short when it comes to the recent developments in the context of the energy transition.

The traditional, asset-focused task of operating, maintaining, and developing distribution grid assets is today already extended to the operation of smart metering devices, with the DSO becoming a data hub operator (Sandoy et al. 2010, p. 7). The rollout of distributed generation and storage assets as well as the coupling of the heat and the mobility sector result in the problem that private households can be less and less represented by standard load profiles, which means that more detailed information on local grids gains importance. Furthermore, the historical hardware solutions to grid shortages focused on grid expansion can be complemented by operational solutions such as flexibility management.

Another aspect not considered in the traditional definition of a DSO is the degree of supply-side concentration, where significant differences exist across Europe. Germany, for example, at about 880 DSOs, is on top of the list among the EU member countries, whereas countries such as Ireland, Portugal or Lithuania have a single DSO (Prettico et al. 2016; Eurelectric

2013). However, all these different markets are subject to EU legislation, and the transition from natural monopolistic markets with vertically integrated companies to liberalized markets and unbundling, both of which are outlined next.

2.2 Legislation and regulation of European grids

The European Commission (EC) set security of energy supply, sustainability, and competitiveness as the main goals for the energy market. The introduction of competition was identified as a key element for achieving these, which is why the EC implemented three energy packages (1996, 2003, and 2009) that pushed for the liberalization of the electricity market and the unbundling of the vertically integrated electric utilities (EC 2016; Ringel and Knodt 2018). These policies were implemented by national law in most EU countries, which is why the operation of electric grids can today be an independent business that may largely exclude other activities e.g. in the fields of electricity generation or retailing; note, however, that some exceptions for small operators with less than 100,000 customers do exist, cf. EC (2009b).

A second important aspect on European legislation is the guaranteed grid access for electricity from renewable assets (EC 2009a). For grid operators this implies that they must adjust and expand their grid according to the ongoing diffusion of renewable energy generation capacities, potentially causing significant costs. Since grid operators function as natural monopolies, countries had to find ways in their national legislation to incentivize their grid operators to minimize the expenditures for grid operation and expansion. In Germany, which hosts around 880 DSOs, an incentive regulation method was enacted in 2007, and applied since 2009, which tries to implement an artificial competition between grid operators with a comparison of key performance indicators, thus promoting efficiency (BNetzA 2015;

Dt. Bundestag 2007). Portugal, only hosting one major DSO, focuses more on finding ways to incentivize innovation activities, while also focusing on operational efficiency improvements (Eurelectric 2016)

Smart grids can contribute to reduce the need for grid expansion, and consequently costs (Pudjianto et al. 2007; Lavrijssen et al. 2016; Siano 2014). An essential element for reaping this benefit are smart meters. Considering this, the EU requested cost-benefit analyses of smart meter rollouts in their member states in 2009 and compared the insights gained in 2014. While 16 states decided to go for a comprehensive rollout until 2020, 7 states (including Germany and Portugal) remained skeptical (EC 2014a, Edelmann and Kästner 2013). While German policy-makers finally agreed to a moderate rollout until 2032 in the "Act on the Digitization of the Energy Transition" endorsed in 2016, no national rollout plan exists in Portugal until today. One final aspect to mention are concession rights, which are used as the contractual arrangement between public authorities and grid operators. The EC gave some guidelines in their Directive 2014/23/EU on the design of these contracts; however, no final directive on the maximum duration of these contracts was provided (EC 2014b).

2.3 Technological changes in grid operation

In the past, DSOs solely received electricity from the upstream transmission system, which then was delivered to the local customers. With the diffusion of small-scale generation assets on the distribution grid level more electricity has now to be fed back to the higher voltage levels. This excess of local production can lead to limitations in the thermal capacity of the local grid infrastructure or violations of the permitted voltage band. These limitations and violations can be mitigated in different ways, including a reinforcement of the local power lines, adjustable local power transformers, provision of reactive power, electricity storage devices as local buffers, re-dispatching of distributed generation assets and others, all having their specific individual pros and cons (Lopes et al. 2007). A similar topic is the one of grid stability and ancillary services where DSOs at present rely on conventional, centralized power plants. With those fading, renewable assets have to become better integrated, as the DSOs have to manage their grids in a much more active and "smarter" manner than in the past (Lopes et al. 2007; Reddy et al. 2014; Ipakchi and Albuyeh 2009).

One popular form often mentioned is the grid-friendly operation of local flexible assets such as electric vehicles in the form of demand side management. This might turn out important since increasing production and consumption peaks could potentially impose massive costs for grid expansions unless a way is found to operate these assets in a grid-friendly manner (Palensky and Dietrich 2011). However, this path to smart grids requires smart meters as a key element, as mentioned above. The rollout of these smart meters goes along with formidable new challenges for DSOs (who often find themselves in the role of meter operators), posing new challenges in terms of safe digital communication, data property and privacy issues, and new technological specifications, e.g., in terms of installation and calibration (Depuru et al. 2011; Yan et al. 2013).

3. Research design

We study the adaptation dynamics of electricity DSOs to smart grids in the EU through a qualitative research design. This approach facilitates insight collection from stakeholders and contributes to the identification of existing and emerging challenges and opportunities, as well as relevant contextual information. Moreover, it provides a flexible method through which multiple perspectives can be obtained (Yin, 2011). Our research design was implemented through nine multi-stakeholder workshops conducted between May 2016 and

October 2017. We decided to use multi-stakeholder workshops a participatory research methodology, due to their ability to generate discussion and facilitation of insight collection across heterogeneous participants (Mahroum et al., 2016; Schut et al., 2015). This was considered a valuable feature given our goal to explore the main themes associated with the impacts of the transition towards smarter grids for DSOs.

An open-ended questionnaire was designed to facilitate discussion during the workshops, focusing on business model and organizational issues, technological adaptation, as well as market design and regulation. Table 3 presents the analysis dimensions, topics, and open-ended questions (Sreejesh et al., 2014). Participating stakeholders represent two groups: stakeholders active in the electricity supply chain and stakeholders outside the electricity supply chain. The participants in the workshops are based in Germany and Portugal due to the research team knowledge of the energy transition in these regions, in combination with their established network of relationships with relevant stakeholders. Our findings and quotes resulting from the workshops are anonymized. However, we provide background information on the participating stakeholders. In terms of stakeholders active along the electricity supply chain, 4 distribution system operators participated in the workshops, operating under different structural and regulatory frameworks. The participating delegates from DSOs represent a heterogeneous group, which we deem relevant as a source of complementary perspectives on adaptation issues towards smarter grids. Table 1 provides information regarding their scale in terms of connected consumers, the degree of separation of electricity distribution activities from other activities through unbundling, as well as the regulatory framework and market structure characteristics.

Regarding the regulatory framework characteristics our participants are subject to either incentive-based or hybrid approaches. An incentive-based approach offers possibilities for DSOs to increase their financial earnings if certain efficiency improvement targets are met (Cambini et al., 2016). A hybrid approach is based on a combination of cost- and incentive-based approaches. Cost-based regulation enables DSOs to recover their investments plus a set rate of return. Hybrid approaches often result in combinations of a cost-based approach on capital expenditures and an incentive-based approach for operational expenditures (Cambini et al., 2016; Eurelectric, 2014). Considering innovation incentives, DSO C has a regulatory framework that includes an innovation incentive mechanism. Incentives for DSOs to innovate can include access to a higher rate on return for innovation-related investments, as well as a specific mechanism to adjust revenues throughout the regulatory period for research and development-related costs (Eurelectric, 2016).

In terms of market structure, we categorize the participating DSOs for market concentration, which is a measure of the electricity distributed by the DSOs in a Member State (Eurelectric, 2013). Considering our participants, low concentration exits when the electricity distribution market is based mostly on small, local DSOs, for which the three largest DSOs distributed less than 50% of the total distributed electricity. Medium centration occurs when one DSO is responsible for more than 80% of the total distributed electricity, or when the three largest DSOs distribute more than 60% of the electricity. The stakeholders outside the electricity supply chain include the research group conducting the study, a research center focused on smart grids, and the innovation unit of an electric utility group holding (see Table 1).

Table 1. Stakeholder description.

Stakeholders within the electricity sector supply chain.

Stakeholder	Unbundled	Connected consumers (approximate)	Regulatory framework		Market structure	
			Regulatory approach	Innovation incentives	DSO Concentration	Ownership
DSO A	Yes	4,000,000	Incentive	No	Low	Largely public, municipal ownership
DSO B	Yes	100,000	Incentive	No	Low	Largely public, municipal ownership
DSO C	Yes	5,000,000	Hybrid	Yes	Medium	Largely private
DSO D	No	15,000	Incentive	No	Low	Largely public, municipal ownership

Stakeholders outside the electricity sector supply chain.

Stakeholder	Description
Researchers and Academics A	This is the research group conducting the study. These comprise researchers from the University of Coimbra, Coimbra, Portugal and from RWTH Aachen University, Aachen, Germany.
Electricity Utility Innovation Unit A	The electric utility company represented by this stakeholder owns distribution systems in Southern America and Southern Europe, as well as other supply chain activities. The innovation unit is responsible for driving disruptive change for the group of companies owned.
Research Centre A	This research center focuses on power systems and power economics research, with a specific focus on smart grids and new electricity sector market design.

Table 2 provides details on the workshops, including the number of participants, stakeholder groups represented, workshop goals, the region where these were delivered, as well as dates (month and year) they were conducted.

Table 2. Research workshops details.

Workshop no.	No. of participants	Stakeholders groups	Workshop goals	Workshop date
1	4	Researchers and Academics A (n=4)	Establish research framework	May, 2016
2	6	Researchers and Academics A (n=5), DSO A (n=1)	Semi-structured interviews, and data collection	May, 2016
3	6	Researchers and Academics A (n=4), DSO B (n=2)	Semi-structured interviews, and data collection	Jun., 2016
4	5	Researchers and Academics A (n=5)	Data analysis, and refine research framework	Sep., 2016
5	7	Researchers and Academics A (n=5), DSO C (n=2)	Semi-structured interviews, and data collection	Sep., 2016
6	6	Researchers and Academics A (n=5), Electricity Utility Innovation Unit A (n=1)	Semi-structured interviews, and data collection	Sep., 2017
7	7	Researchers and Academics A (n=5), DSO D (n=2)	Semi-structured interviews, and data collection	Sep., 2017
8	5	Researchers and Academics A (n=4), Research Centre A (n=1)	Semi-structured interviews, and data collection	Oct., 2017
9	4	Researchers and Academics A (n=4)	Data analysis, and discussion of results	Oct., 2017

Table 3. Questionnaire for the semi-structured interviews.

Analysis dimension	Questionnaire topic	Questions
Business model and organizational issues	Strategy and operations	- What is your perspective in terms of the activities presented recently as grey areas to be performed by DSOs? i.e.: electric mobility infrastructure, smart metering equipment installation and maintenance, energy efficiency services, data management, and integration of distributed energy resources. - What are the main drivers for operational efficiency improvements? - What is the value of flexibility for DSOs? - Do you outsource any business activities? Which ones? - How engaged are you in the energy transition and DSO role adaptation? - Is the operation of small isolated areas a challenge for DSOs?
	Organizational change	- What are the main drivers for engaging in research and development projects? - Have any new business units or departments been created because of the changes in the power sector?
Technological adaptation	Technology and innovation	- What are your means to increase the service availability and quality of service levels? - How does the DSO handle the connection of new distributed energy resources to the distribution gird? - What forecasting techniques are applied for renewable energy plants connected to the distribution grid?
Market design and regulation	Regulatory framework and policy aspects	- What is the impact of the regulatory framework in the business operations? - Does the 100 000 customers rule for unbundling result in an advantage or a disadvantage for DSOs?
	Market design	- What is your perspective on the appearance of new market players in the electricity sector in the future? - What is your perspective on electricity distribution market structure?

4. Insights from the multi-stakeholder workshops

The data collected through the multi-stakeholder workshops was coded by the research team, resulting in several topics within the broader categories considered in the open-ended questionnaire: (1) business model and organizational issues; (2) operations, technology, and asset management; and (3) market design and regulation.

4.1. Operations, technology, and asset management

4.1.1. Integration of distributed energy resources/distributed generation

The increase of distributed generation units connected to distribution grids is contributing to a more decentralized electricity system. Their integration on traditional distribution operations is a challenge for DSOs, with wind generation being the most challenging technology. *"The biggest challenge in terms of integration of renewables are wind farms, however we must also consider smaller scale technologies such as PV and the impacts these* *might have."* (representative DSO B). The extent of these challenges is stronger in rural areas, where more opportunities to deploy distributed generation exist, particularly wind, given land availability, as opposed to urban areas[1] where deployed capacity is generally lower, and mostly solar PV. *"The integration of renewable energy generation at the distribution level is particularly challenging, considering that in some areas production is between 15 to 50 times higher than consumption. This is often the case in rural areas, which require expensive grid expansion to handle the increased distributed generation."* (representative DSO A). Regarding distribution infrastructure, increases in distributed generation will impact mostly the low- and medium-voltage segments of the grid. As described in section 2.3, the growing share of distributed generation connected to the networks challenges also the traditional configuration and use of up-stream electricity infrastructure. This was confirmed by our experts who also observed an impact on network stability and a rapid increase in investments needs. "*We have to improve transformers capacity in several districts very quickly even though such measures are time and capital intensive. Several solutions exist, but the costs will be very high."* (representative DSO B).

4.1.2. Operations and maintenance

Changes on how electricity is distributed to consumers requires adaptation in terms of operation and maintenance of the grids. An exploitation of flexibility potentials within the distribution grid is one possible way to meet the upcoming challenges of a distributed energy system and could potentially reduce the need for investments related to grid expansion. *"We*

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[1] *"This is not a significant challenge for us. We have no wind generation connected to the grid, and only a small share of PV. This is related to the fact that our distribution operations concentrate in an urban area."* (representative DSO D)

have some flexibility management possibilities, but these are very limited. Flexibility management can be a solution instead of grid expansion." (representative DSO B).

Furthermore, distributed generation can contribute to significant changes in infrastructure usage in isolated areas, where consumption remains unaltered while electricity generation increases. Larger DSOs do not consider the operations and maintenance in these areas as challenging. *"Operating and maintaining small isolated distribution grid areas is not a challenge, it is in fact okay, and is a good business."* (representative DSO A). Conversely, small DSOs have a different perception, considering this as a challenge. *"Small isolated areas sometimes can be challenging from an operational perspective."* (representative DSO B). These different insights call for more attention regarding the impact of DSO size in distribution network operation and maintenance.

Redesigning the operations of distribution networks will benefit from a clearer understanding of the role of the DSO in the future. Managing system flexibility and enabling flexibilities from distributed generation, electricity storage, and demand response can contribute to value creation (Damsgaard et al., 2015). However, a consistent legislative framework is needed to settle the options and duties of (monopolistic) DSOs.

4.1.3. Smart grid technologies

Smart grid technologies were discussed as enabling components to facilitate the adaptation of distribution operations. Smart grid technologies can include monitoring and automation components that increase access to grid data and control capabilities. Moreover, these can include components that enable the integration and interaction with distributed generation and distributed energy resources. For instance, electric vehicles and the associated charging infrastructure were indicated as having the potential to bring disruption to the electricity distribution sector. However, DSOs are not certain regarding the most adequate implementation plan. "*In the current context electric mobility can be a game changer. However, we need to understand if there will be charging stations at home? if charging stations are stranded capital? And if there should be a subsidy for charging stations?"* (representative DSO A). Moreover, electricity storage represents also an interesting future option, for which a supportive regulatory framework should be established. *"In addition, storage is also seen as an opportunity for disruption. Regulation should be revised to set the right incentives."* (representative DSO A).

Smart grid technologies are expected to enable new services and contribute to increased consumer management capabilities. *"Our smart grid projects focus on either smart metering or distribution automation applications. The type of remote services possible for the DSO as a smart meter operator are for instance to connect a consumer, disconnect a consumer due to a non-payment, automated billing, etc."* (representative DSO C). The added value resulting from evolving towards smart grids relates to the possibilities to access new data. *"Much of the value that can be created comes from data currently collected, and data that can be collected in the future through more sensors, smart meter deployment, and partnerships with external data providers."* (representative Electricity Utility Innovation Unit A).

Standardization is essential for a successful adaptation of DSOs given the increasing deployment of smart meters, grid automation technologies, control devices, and other smart grid technologies (representative Research Centre A, representative DSO C). Moreover, the ability of DSOs to adopt smart grid technologies is influenced by their scale. Smaller DSOs notice grater challenges for rolling out innovative technologies *"The rollout of smart grid* *technology, in this case smart meters, is challenging for small DSOs."* (representative DSO D).

4.1.4. Smart meter technologies

Smart meters provide remote measurement and communication of electricity usage in smart grids, and are often referred to as the initial step to take in a smart grid deployment plan (Kabalci, 2016; Sharma and Saini, 2015). The added value of smart meters lies on their ability to provide more detailed information about grid usage, as well as increase fault location capabilities. "*From a grid expansion perspective, having more data, through more monitoring points can help in understanding the network better."* (representative DSO D). Moreover, smart meters support observability, and can contribute to improvements in network congestion management (representative Research Centre A). However, the potential for smart meters is lowered without dynamic pricing of electricity. *"Smart meters can provide better information about the grid. However, these have little potential in a one-tariff system. Tariffs should be dynamic for smart metering to be attractive"* (representative DSO A). However, while smart metering technologies are perceived as important and of added-value, our stakeholders did not consider it necessary to have a smart meter at every end-point, and mentioned that having data from smart meters collected from 10% to 15% of the end-points only would be sufficient (see Table 4).

Table 4. Smart meter technologies

Stakeholder quotes
"*We don't see the need for a smart meter in every end-point. If 10% of the homes have a smart meter in a specific area it is enough to provide the necessary information on the status of the grid."* (representative DSO A).
"In terms of smart metering devices in every home, we don't need all that information. It is important to have some of the information but not of every customer connected to the grid, at least not now." (representative DSO B).
"A smart meter in every end-point is not necessary. If there is a smart meter in at least 15% of the end-points they are able to provide the necessary information for our operations." (representative DSO C).
"While there is value in having smart metering and more detailed data, not every end-point may be interesting to have access to, as its value can often be very limited." (representative DSO D).

These insights provide a valuable perspective on the DSOs perception on their benefits related to large-scale rollouts of smart meters. The EU's Third Energy Package has set a target of 80% of smart meters by 2020 whenever a cost-benefit analysis is positive (EC, 2014c; EC, 2009b). The observed position across DSOs can offer new possibilities for other players to support the deployment of smart meters in the EU. Despite this insight on the perceived value of smart meters the responsible party for implementation and ownership across the EU are mainly DSOs (EC, 2017a, 2017b).

Connected to the perception of limited added value from a full rollout of smart meters, alternative technology options are being considered to support DSO adaptation. The need for information on every end-point of the grid is perceived as limited. *"We are not sure if a smart meter is the right device to provide us with the information we need from the network. The interest in more information regarding the current grid conditions is rather small. We see no need for smart metering for real-time consumption measurement. Metering of only certain parts of the grids is sufficient to reveal enough information about distributed generation."* (representative DSO B).

Also, the rollout of smart meters encompasses technical and economic challenges. Technical challenges are related with the complexity around data management and cybersecurity. Economic issues are related with the potentially shorter lifespan of smart meters, in comparison to its electromechanical predecessors. *"The deployment of smart metering can increase complexity around data collection and cybersecurity issues. Moreover, the possible provision of new services and functionalities adds to the concerns associated with hacking. This adds to the challenges associated with costs, and cost allocation for consumers, Traditional meters have had a lifetime of 16 years. Smart meters have an expected lifetime* *of 8 years, with possibilities to last up to 13 years."* (representative DSO D). Standardization is also an important aspect when it comes to smart meter technologies' adaptation and adoption by DSOs. *"Right now, DSOs are analyzing communication protocols and how these can be standardized."* (representative DSO D).

4.1.5. Legacy technologies

Adapting electricity distribution networks has been generally discussed around the importance of innovative technologies and approaches to network operations. However, legacy technologies are also a relevant element in supporting DSOs adaptation. These represent existing technologies, which have been incrementally improving and are perceived as low-cost and low-risk options. *"In addition to the disruptive technology options there are also low-cost legacy technologies that when implemented result in significant efficiency increases for the DSOs. These include controllable low voltage transformers, and standardized automated controls."* (representative DSO A). An example of the relevance of legacy technologies are the automation systems from the 1980s present in electricity substations. *"Our substations are quite old but the automation present in them from the 1980s works well enough."* (representative DSO C).

Grid expansion is mostly within the scope of legacy technologies and has always been part of DSOs operations. Despite their historical experience, grid expansion is an increasingly challenging task due to location constraints for both transformer stations and lines. *"We have clear plans for grid expansion and we plan to pursue them. These expansion plans are mostly related with building new lines. This brings challenges related to the fact that it is not easy to find places to build new transformer stations, as well as the fact that most of the lines must be planned as underground lines being costlier and less durable."* (representative DSO B).

Despite the challenges, grid expansion is a priority for DSOs. *"At present we are concerned with the building and maintenance of the grid."* (representative DSO B).

4.2. Business model and organizational issues

4.2.1. Existing business model

The business model around which electricity distribution has been structured is no longer adequate. Future legislation should enable the adaptation of the way in which electricity distribution creates and captures value. *"Our current business model is hardly profitable, and we expect legislative changes in the future. Still, we are not taking an active role in contributing to shape these future regulations."* (representative DSO A). Despite the challenges resulting from existing business models, electricity distribution is an interesting business, which can benefit from timely adaptation to the changes in technologies and policies. This adaptation requires understanding the role of DSOs in providing or facilitating new services. *"Being a network company only (unbundled) is a good place to be, there are good chances to do new tasks in the future. What is important is to start these new tasks."* (representative DSO B).

4.2.2. Business restructuring and mergers

Adaptation of the electricity distribution industry is intertwined with an adaptation of the entire electricity sector supply chain. Changes in the electricity sector have resulted in restructuring and mergers across utilities, aimed at increasing economic performance and improving their position to engage in new business lines. *"Due to financial turmoil our mother company is splitting into two companies to capture capital from the markets. One of the companies will keep all the generation and trading related activities. A new company will* *keep the distribution network, renewable energy, and retail-related activities, as the more profitable business areas.”* (representative DSO A).

An example of these restructuring efforts was observed in two German utilities, E.ON and RWE. E.ON restructuring resulted in the creation of a spin-off company, Uniper, covering the unregulated business activities. RWE, following a different approach, retained its unregulated activities, and created a spin-off company for distribution grids, retail, and renewables (see Figure 1) (Zank et al. 2016).

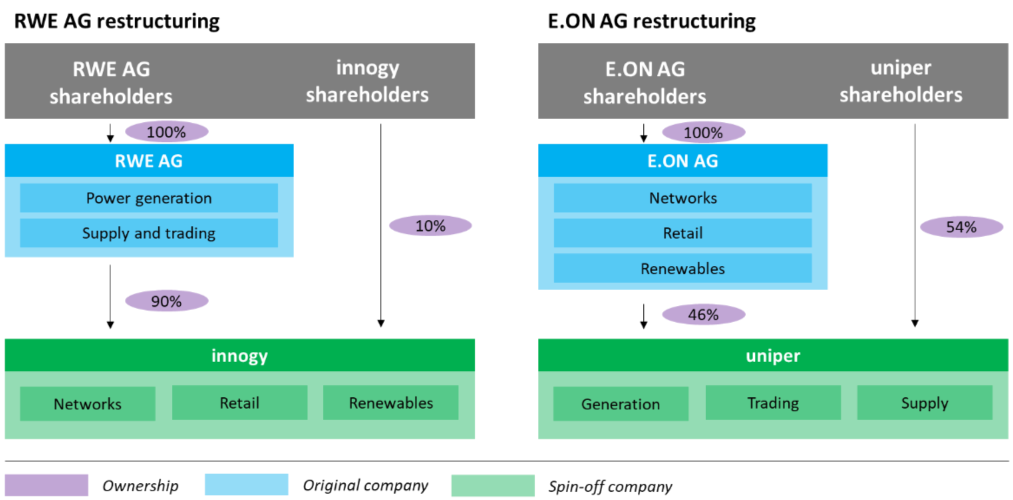

Figure 1. RWE and E.ON restructuring. Adapted from Zank et al. (2016).

Adaptation through mergers is considered as an opportunity by small DSOs, which are looking for ways to reach greater economies of scale. *"Right now, we are considering merging with another DSO. This merger is needed because we are constantly being pushed to reduce our operational costs to improve our efficiency factor. Because of this more than 50% of our employees had to be fired in recent years. In line with this, we estimate the best conditions for medium/big DSO players in the near future"* (representative DSO B). Moreover, collaboration across smaller scale DSOs has been considered as an option to overcome challenges for technology acquisition. *"We joined 7 other DSOs, servicing altogether a consumer population of some 200,000 to achieve greater economies of scale for acquiring technology."* (representative DSO D).

4.2.3. Innovation

Collaborative innovation efforts through Research and Development (R&D) projects are being pursued by DSOs as a source of knowledge and capability development for integrating and operating new technologies. DSOs are engaged in exploring new grid technologies and services. *"We are participating in innovation projects and R&D in partnership with academic institutions. Our projects include advanced usage of smart meters, central battery storage and intelligent control of the systems."* (representative DSO A). In terms of their approach to innovation, DSOs are interested in both exploitation and exploration. Exploration activities are concerned with understanding how new technologies and processes can be part of the electricity distribution industry. These include projects focusing on smart meter integration, storage integration, and intelligent control of systems. Also, through the development of virtual power plants, integration of solar photovoltaic (PV) systems. Exploitation activities focus on more traditional aspects of the electricity distribution operations. These include improvements in asset management, as well as innovations in business processes. *"Complementing our more disruptive applications, we develop internal projects to support the innovation in asset management and business processes."* (representative DSO C).

While being engaged in innovation-driving efforts is an important aspect, it is still challenged by a corporate culture with considerable levels of inertia to changes that embody unfamiliar technologies, processes, and stakeholders. "*As the electricity sector has been to a large extent* *tied to stringent regulations and legacy technologies, certain innovation proposals are hard to pass through. Here having an internal innovation unit enables greater levels of confidence and buy-in from internal decision makers, that external players with disruptive ideas and proposals would not have."* (representative Utility Innovation Unit A).

Concrete examples of the existing inertia to engage in disruptive transformation processes were discussed. For instance, the creation of an innovation hub to mobilize disruptive innovation efforts was considered as unacceptable on the scope of the DSO strategy. *"Our unit proposed the creation of a digital energy disruptor hub outside of the company, which would foster disruptive ideas for the electricity sector. The executive board and internal decision makers annihilated the idea, claiming it would cannibalize our business."* (representative Utility Innovation Unit A). Another example was associated with a proposal to submit the DSOs smart meters to an ethical hacking group, to better understand the extent of the DSOs cybersecurity vulnerabilities. *"We as innovation unit proposed to our DSO that the smart meters being deployed would go through an ethical hacking consulting firm to understand the extent of cybersecurity threats. The board* did not feel comfortable with the idea and rejected it.*"* (representative Utility Innovation Unit A). This gives a sense that there are things that should rather remain unknown, and that maybe research must be conducted outside the companies themselves.

4.2.4. Future business model

The future business model for DSOs is expected to enable value creation and capture through flexibility management services. DSOs are willing to provide new services and integrate new technologies, therefore expanding the scope of their activities and responsibilities. *"The future of our business requires operating flexibility to reduce the network operational costs* *and make the most of distributed energy resources and flexible demand. Moreover, we see a future in which we include new smart elements to operate our networks, such as new transformers, and where we are responsible for the coordination of the ancillary services for the system."* (representative DSO A). Managing electricity storage units is considered as one of the opportunities within flexibility services. *"We want to be able to contract storage to use it for grid balancing. We see a future in which one of our roles is to provide ancillary grid services."* (representative DSO B).

In addition to the emphasis on system flexibility management, creating value from data is one of the opportunities considered promising in a more digital electricity system. These opportunities result from the direct access to new data that DSOs benefit when integrating smart meters and sensors as part of grid modernization actions. Moreover, access to data from third parties can contribute for creating data-driven services. However, delivering these benefits from data will only be possible through a shift in DSOs conservative culture regarding data access and sharing. *"However, while data represents significant opportunities for new service development, it is still difficult to get buy in from decision-makers on matters that involve sharing data or using it in new ways. Previous attempts to implement ideas that require data sharing from the DSO to other partners resulted in reactions such as: 'That is not what we do', 'We are a regulated business, we are not supposed to share data', and 'That is not part of our operations'.* (representative Electricity Utility Innovation Unit A). The possible business model changes around data do not necessarily indicate that DSOs will become actively engaged in delivering new services for electricity consumers. This may be a more suitable role for other market players. Nonetheless, DSOs can play an important role in facilitating those market players that have the capabilities to deliver innovative services.

Future business models around data and digitalization can benefit from blockchain technology (Aitzhan and Svetinovic, 2016; Knirsch et al., 2018; Mengelkamp et al., 2017a), similar to the approach being followed by LO3Energy in Brooklyn, New York (Mengelkamp et al., 2017b). However, its energy- and time-intensive characteristics are considerable barriers. *"Blockchain applications for smart grids appear to be interesting in some cases. However, these can rapidly become an oxymoron. We calculated that 55 kWh are necessary to clear a transaction through blockchain, which makes little sense if the transactions are about energy, and if the energy being traded is below this amount."* (representative Electricity Utility Innovation Unit A). While blockchain and the possibilities for introducing smart contracts seem attractive, it is possible to do similar things without any blockchain technology. However, at least both big DSOs (A and C) indicated that they would like to be perceived as pro-actively considering innovative and potentially disruptive technologies such as blockchain in their future operations.

Beyond the complexities of technological adaptation, introducing new services in electricity distribution requires additional resources and capabilities that are not part of the DSOs existing operations. DSOs are assessing their future needs to better understand how to adapt. *"From a capability perspective, we are now looking at the resources we have available and how these can support the challenges brought by the energy transition. Soon, we expect to have a clearer idea if our technical and human resources are adequate for the digitalization of electricity distribution."* (representative DSO D)

Moving toward new business models requires detailed planning and consideration for the necessary investments and changes to be implemented. However, these plans are challenged by the need for DSOs to react to changes in the distribution network, such as the growth of connected distributed generation units. *"The choice to pursue new business opportunities, and associated investments, faces a barrier related with the limited planning horizon. Plans are basically made as a reaction to new surges in connected distributed generation units."* (representative DSO B). The need to continuously improve operational efficiency contributes also to the challenges of implementing strategic changes in the business model. This often results in preference being given to reactive measures such as outsourcing of activities and staff reductions. *"Considering our challenging operational framework, we see outsourcing of business activities and staff reduction as options for the future."* (representative DSO B). The characteristics of future business models can also be understood by considering the possible changes across core electricity distribution activities (see Table 5).

Table 5. DSO activities evolution (DSO A). (DSO A, 2016)

Activity	Traditional	Today	Future
Electricity management	Load management	Grid stability control with increasing shared of distributed generation	Flexibility management
Operation	Static load flow calculation	Monitoring and control based on additional measurements	Automated operational control
Asset management	Standardized equipment	Integration of novel technologies	Operation and control of smart equipment
Communication	Exchange of aggregated values, mostly for billing	Immediate, transparent, and non-discriminatory data transfer	Operation of a data platform
System reliability	Local voltage quality	Introduction of ancillary services	Provision of ancillary services via distribution system

Understanding DSOs' adaptation to future business models benefits from contributions from European sector associations such as Eurelectric and its plans for the realization of smart grids toward 2020 (Eurelectric, 2011). This plan established a framework in which the necessary technologies, policies, and practices for smart grid deployment are implemented (see Figure 2). The aim is to create awareness for policy makers and industry on the necessary actions to facilitate the transition to smart grids in the EU.

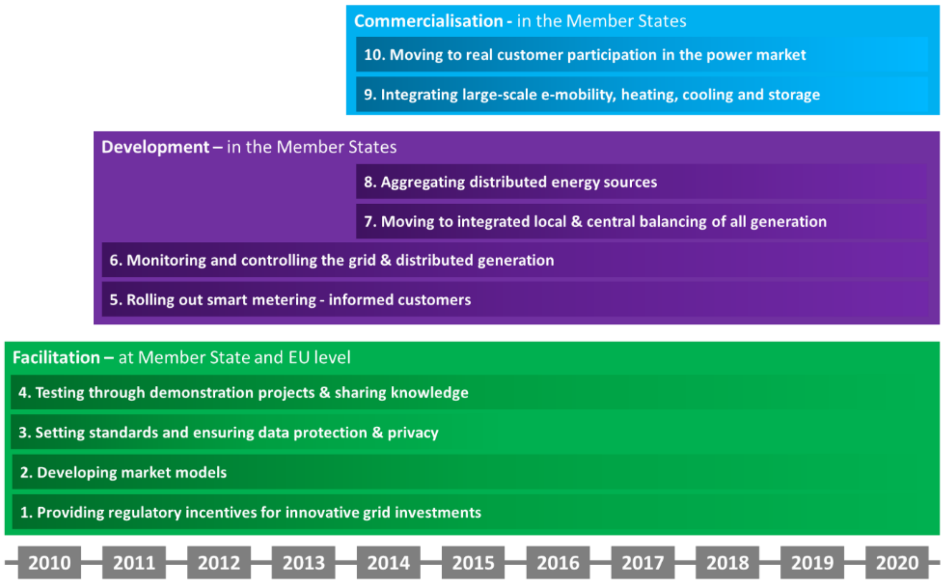

Figure 2. Smart grid roadmap. Adapted from Eurelectric (2011)

4.3. Market design and regulation

4.3.1. Market structure

Market structure is a relevant aspect when considering adapting market designs and existing regulatory frameworks. The electricity distribution industry across the EU presents a heterogeneous concentration, which is mostly the result of the historical and cultural perception of the interaction between communities and their electricity infrastructure. *"DSO market concentration is mostly related to the fact that local communities wanted to have some control over their energy infrastructure. Therefore, patchy structures are a result of every community wanting to own their grid."* (representative DSO A).

The attractiveness of electricity distribution as a business creates possibilities for changes in market structure. Municipalities are becoming increasingly interested in operating their local electricity distribution grids. This can result in a shift in ownership from larger, integrated DSOs that operate distribution grids through concessions with municipalities, to ownership by municipalities. *"For instance, we have contracts with the municipalities for 20 years regarding the operation of their local grid, however we note that increasingly municipalities want to operate their grid by themselves, given that grid operation is a good business."* (representative DSO A). This shift was observed in Germany when the incumbent utility Vattenfall lost the grid operation concession to a municipality (representative Research Centre A). This structural change was the result of a referendum for the re-municipalization of energy networks held in 2013 (Wagner and Berlo, 2015).

Changes in market structure can also result from different adaptation capabilities across different DSOs scales. In this context, larger DSOs seem to be better prepared to adapt to technological changes, given their ability to capture greater economies of scale because of their larger consumer base. *"Larger DSOs companies have an easier time rolling out smart meter, and other smart grid related technology."* (representative DSO D).

Electricity sector reforms impact also the distribution market structure. Market liberalization was introduced as a driver for more affordable, higher quality electricity services. However, having an integrated view of the electricity supply chain, which was a possibility in vertically integrated utilities, can also be beneficial in times of disruptive change in the electricity sector. When pushing for innovation it does help to look at the entire electricity supply chain.

4.3.2. Regulatory aspects

A market design focused on driving operational efficiency improvements is a sensible regulatory approach for a traditional electricity distribution industry. However, this is not compatible with a changing electricity sector in which new technologies are being integrated across the electricity supply chain, which impact electricity distribution. This hinders the engagement of DSOs in smart grid developments. *"This is bad news for smart gird related* *projects that often reduce the operational efficiency and harm revenue collection capability. This regulatory approach creates barriers on the business strategy DSOs pursue. This results in a preference for grid expansion instead of smart grid investments, since a smart grid would increase the operational costs, where a grid expansion increases the capital costs and thus increase the efficiency factor."* (representative DSO A)

Regarding the investment needs to adapt to a changing electricity sector it is important to highlight that financial resources are not a significant barrier; the real barrier is obtaining business plan approval. *"For all these future activities we need to be able to get the money, but this is not difficult; what is difficult is obtaining an approved business model by the regulator for these investments."* (representative DSO B). Efforts to adjust existing market design and regulations have benefited from the growing resources dedicated to advancing the energy transition. *"The energy transition is supporting an increased attention into topics related to the changing role of DSOs."* (representative DSO A).

5. Synopsis of challenges and opportunities

We classify the insights obtained from the multi-stakeholder workshops into challenges and opportunities for electricity distribution (companies' and system's/technologies') adaptation needs. This provides an updated perspective on what is hindering the adaptation of electricity distribution, as well as on which future opportunities are being considered. In terms of operations, technology, and asset management (see Table 6) challenges are perceived when it comes to both smart grid, and smart meter technologies, as well as legacy technologies. Future opportunities include flexibility management from distributed energy resources, and more access to data as a new source of added value.

Table 6. Operations, technology, and asset management

Topic	Challenges	Opportunities
Integration of distributed energy resources/distributed generation	• Operations at the medium and low voltage segments of the grid. • Surge of distributed generation in rural areas. • Time and capital-intensive investments required. • Network stability.	• Increase system flexibility on low-voltage levels.
Operation and maintenance	• Peak loads, both in consumption and production.	• Flexibility management.
Smart grid technologies	• Identify the best approach to integrate electric mobility in electricity distribution grids ("*Will there be charging stations at home? Are charging stations stranded capital? Should there be a subsidy for charging stations?"*). • Regulatory framework and incentives for electricity storage. • Standardization of technologies for seamless integration.	• Electric mobility. • Electricity storage. • Smart metering. • Distribution automation. • Data-driven innovations. • Partnerships with external data providers.
Smart meter technologies	• One-tariff system that hinders smart meters potential to send economic signals. • Uncertainty if smart meters are the best technology for DSOs data needs. • Increased complexity in data collection • Cybersecurity and hacking concerns. • Investment and cost allocation. • Shorter life span of the technology. • Standardization of communication protocols.	• More information about the grid. • Fault location capabilities. • Observability. • Network congestion management.
Legacy technologies	• Finding new places to build new transformer stations. • Obtaining permits for underground lines.	• Low-cost legacy technologies that increase efficiency (Low voltage transformers, standardized automated control devices)

Business models and organizational challenges (see Table 7) include strategic restructuring, which has been pursued through demergers and creation of new companies to support reallocation of assets and operations. While innovation is being pursued and is considered a source of knowledge for expanding service offering, the inertia associated with DSOs traditional business culture challenges the adoption of innovative technologies and hinders the possibilities for disruptive ideas to be considered. Opportunities encompass integration and adaptation of distributed energy resources, and the facilitation of data-intensive services.

Table 7. Business model and organizational issues.

Topic	Challenges	Opportunities
Business restructuring and mergers	• Separating the more profitable from the less profitable segments of the value chain.	• Use mergers to boost scale-effects • Use partnerships to share development costs and risks
Innovation	• Electricity sector historically tied to regulations and legacy technologies. • Innovation proposals are hard to pass through. • Decision-makers adversity to disruptive ideas from external stakeholders (e.g. from start-ups).	• Advanced use of smart metering. • Battery storage. • Intelligent systems control. • Virtual power plants. • Integration of solar PV. • Participation in R&D projects with universities and external partners at National and European level. • Technology exploration and exploitation. • Improve asset management. • Business process improvement. • Internal innovation initiatives.
Future business model	• Decision-makers adversity to using data for service innovation. • Understanding the technical and human resources needed. • Difficult to establish future plans, which are mostly driven by distributed generation diffusion.	• Expand service offering. • Integrate new technologies. • Develop new capabilities. • Operate system flexibility. • Provide ancillary services. • Data-driven business models. • Increase data collection through more sensors. • Partner with external data provider for new service offerings. • Outsourcing business activities. • Staff reductions.

Regarding market design and regulation (see Table 8) challenges are associated with the possible limitations of a liberalized market structure when considering disruptive changes. Moreover, pursuing operational efficiency can act as a barrier on smart grid investments, as well as result in job losses in the industry.

Table 8. Market design and regulation

Topic	Challenges	Opportunities
Market structure	• Liberalized market structure can result in a siloed view of the different segments of the supply chain. • Focus on operational efficiency compromises smart grid investments.	• Considering the entire electricity sector supply chain, and how innovation can improve it, beyond current market structures.
Regulatory aspects	• Continuous efficiency improvements • Obtain regulatory approval for new business models.	

Moreover, we identified adaptation challenges that are perceived to impact DSOs differently, depending on their scale (see Figure 3).

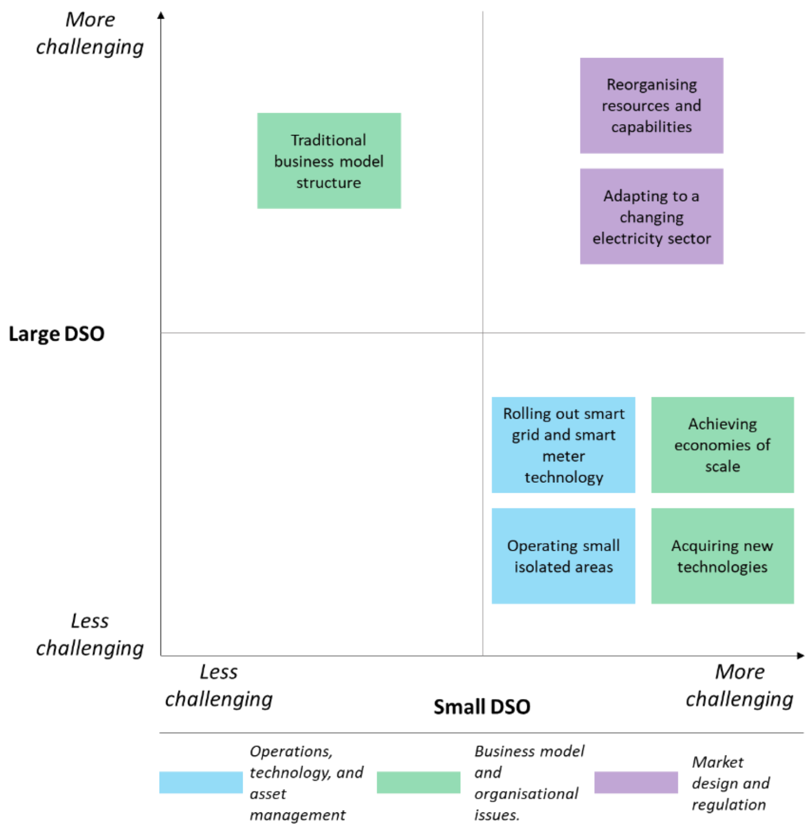

Figure 3. DSOs scale and associated challenges.

6. Conclusions and policy implications

This study provides insights on challenges and opportunities for DSOs regarding technology, business models, and market design in the EU. Through a series of nine multi-stakeholder workshops in two representative EU Member States, Germany, and Portugal, we collected qualitative up-to-date perspectives on how DSOs are facing and accommodating the shift to a smarter, more decentralized, and sustainable electricity sector. As the discussion on the digitalization of the electricity system increases we highlight the fact that our findings reveal some uncertainty regarding the value of full-scale rollouts of smart meters by DSOs. Policy makers should consider how this influences future expectations regarding large-scale diffusion of smart metering technology.

Adapting operations for the provision or facilitation of new value-added services, such as flexibility management, is considered a future opportunity. However, we observe a corporate culture with high levels of inertia to changes. Future policies should consider the impacts of inertia to change in the deployment of innovative technologies and adoption of new business processes. Evolving toward smart grid technologies and processes can be challenging with a regulatory framework focused on continuous improvement of operational efficiency. Our insights also indicate that while operational efficiency is important, it may result in job losses in the quest for cost reductions, as well as motivate outsourcing of core business activities, leading to loss of internal knowledge and technical capabilities. Policy makers should consider these impacts when designing regulation to support smart grid investments and capability development by DSOs.

The broad applicability of these findings is somewhat limited in the sense that only stakeholders from Germany and Portugal participated in the multi-stakeholder workshops. However, these stakeholders and Member States are in representative of the EU context and shed light on a rather neglected, but nonetheless essential part of the energy transition, related to the adaptation dynamic of DSOs to smart grids. Our results provide a recent guiding reference on what are the challenges and opportunities impacting the electricity distribution industry in the EU, helping to pave the way for future research and considerations. Given the exposure of the engaged stakeholders to the European context the results presented can be considered in the broader context of the EU transition of DSO roles. Future work includes collecting more insights to understand how existing policies contribute to more adaptable DSOs across the EU.

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