Policy-adaptation for a smarter and more sustainable EU electricity distribution industry: a foresight analysis

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Rec: 30 August 2017, Accp: 20 February 2018,

Abstract

The European Union (EU) transition to a smarter and more sustainable electricity sector is driven by climate change adaptation and technological developments. For the electricity distribution industry, this has contributed to a growing need to understand how these network monopolies should adapt their role, activities, and responsibilities for a redesigned electricity market, given the growth of distributed generation, and the increased control and monitoring capabilities. Considering this, a foresight study on business model innovation, technological adaptation, and market design policy alternatives is presented. A Policy Delphi method was applied, involving two iterative survey rounds and 207 European experts, which assessed 57 policy alternatives. The results highlight adaptation challenges for implementing new technologies and business practices. Experts support innovation and transition to new roles, and innovative services, ~~whilst~~ while warranting that core electricity distribution activities are secured. This shift in roles is expected to be achieved through research and development (R&D) support policies, innovation friendly regulatory frameworks, and concerted actions at the EU and Member States level. The results contribute to policy-adaptation guidelines for electricity distribution industry stakeholders.

Keywords: Smart grids, Electricity distribution, DSOs, EU, Policy, Market design, Policy Delphi

Introduction

The European Union (EU) aims to shift to an electricity sector that is sustainable, economically competitive, and affordable. This transition has contributed to a growing concern regarding how electricity distribution system operators (DSOs) should be organised and ~~operate~~ operates electricity distribution grids (ACER **2014**). DSOs in the EU operate as natural network monopolies distributing electricity to over 260 Million connected households and businesses (Eurelectric **2013**), and are responsible for the planning, operation, maintenance, and expansion of distribution networks. However, the growing diffusion of innovative technologies connected at the distribution level are changing the way electricity is used and can impact how distribution networks are operated, and, therefore, how DSOs are organised. Technologies being deployed include: distributed generation from small-scale photovoltaic and wind sources; electric vehicles and electric vehicle charging infrastructure; electricity storage; smart metering infrastructure; and smarter appliances. In addition, there is the expanding deployment of a layer of information and communication technologies that increase monitoring, control, automation, and data-related capabilities (Gellings **2009**; Mallet et al. **2014**).

This evolving technological asset base enables grids to become smarter and more sustainable, and potentially increases DSO ability to operate and manage a changing electricity distribution system (Martinot et al. **2015**). However, how DSOs can (or should) adapt their participation in the electricity sector due to these changes is an open topic of discussion. The importance of a more detailed understanding of the DSO role in a smarter and more sustainable electricity sector has gained attention in the policy debate, given its impact on future policies and market design (ACER and CEER **2017b**; CEER **2014**, **2015**).

This study examines potential roles for DSOs and market design alternatives to support the ongoing reform of the EU electricity market, given the changing policies, technologies, and business models. DSO adaptation is particularly challenging due to their regulated activities, legacy technological assets, and traditional business operations. Specifically, there is the potential for conflicts of interest between the natural monopoly characteristics of electricity distribution network activities and competitive opportunities associated with the diffusion of smart grid innovations (Meeus and Hadush **2016**; Oosterkamp et al. **2014**).

We group existing literature contributing to a better understanding on the transition to a smarter and more sustainable distribution sector in three topical areas:

- On technological issues, studying: The impact of integrating electric vehicles (Green et al. **2011**; Mwasilu et al. **2014**; Pieltain Fernandez et al. **2011**; Richardson **2013**). The impact of integrating distributed generation (Al-Muhaini and Heydt **2013**; Bayod-Rújula **2009**; Järventausta et al. **2010**), often focusing on large scale diffusion of solar photovoltaic generation (Braun et al. **2012**). The impact of integrating electricity storage systems (Wade et al. **2010**). The necessary changes in metering, control, and communication technologies (Bouhafs et al. **2012**; Depuru et al. **2011**; Ruiz-Romero et al. **2014**; Usman and Shami **2013**; Zhao et al. **2014**). And, the overall implications of moving ~~toward~~ towards a smart grid scenario (Balta-Ozkan et al. **2014**; Blumsack and Fernandez **2012**; El-hawary **2014**; Galo et al. **2014**; Wissner **2011**; Xenias et al. **2015**).
- On institutional and regulatory aspects, focusing on the need to adapt regulation given growing distributed generation (Cossent et al. **2009**; Joode et al. **2009**; Ropenus et al. **2011**; Ruester et al. **2014**; Scheepers et al. **2007**).
- On business model and organisational topics, which analyse the development of new capabilities (Bergman et al. **2006**; Helms **2016**; Nisar et al. **2013**) and the changes in electricity distribution business models (Meeus and Hadush **2016**; Trygg et al. **2007a**, **b**).

Our research aims to combine these three main areas of analysis. We conducted a foresight study focused on DSOs operating in a smarter EU electricity sector. We apply a Policy Delphi method to obtain expert assessments on business model innovation, technological adaptation, and market design. Our research focuses on the EU, building on the existence of a shared framework of policies and energy transition goals. Through this research, we aim to provide policy-adaptation guidelines on possible pathways for redesigning the electricity distribution industry. This study aims to further advance insights collected in previous expert consultations from the Council of European Energy Regulators and the European Commission on aspects of future market design and the role of DSOs in a changing electricity sector (CEER **2015**; European Commission **2015b**, ~~**2015c**~~ **c**; Tackx and Meeus **2015**). However, now with an updated perspective from European experts on policy alternatives that can contribute to the ongoing market design proposals presented in the Clean Energy for All Europeans policy package (European Commission **2016a**).

The paper is structured as follows. Section **2** reviews the policy-driven changes for electricity distribution in the EU. Section **3** describes the foresight methodology used and research design. Section **4** presents the results and discusses them in relation to recent policy proposals. Section **5** presents policy-adaptation guidelines derived from our findings. Section **6** concludes and highlights the key outcomes of the study.

Policy-driven evolution of electricity distribution

The evolution of electricity distribution activities in the EU has been driven by successive policy packages aimed at achieving structural reforms in the electricity sector. We consider the implementation of policy instruments in terms of two stages of structural change. The first stage comprises all actions taken ~~toward~~ towards market liberalisation, while the second comprises actions taken ~~toward~~ towards a smarter and more sustainable electricity sector (see Fig. **1**).

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Fig. 1 Policy instruments shaping the electricity sector and impacts for electricity distribution

A liberalised electricity sector

The EU electricity sector was gradually liberalised through policy packages intended to create a competitive internal market to deliver better quality and more affordable electricity to European citizens. Prior to EU electricity sector liberalisation, most Member States' electricity sectors were vertically integrated, and consisted largely of publicly owned companies. The realisation that the economic efficiency of the generation and supply segments could be increased through competition motivated the separation of these activities from the network activities of transmission and distribution (Kopsakangas-Savolainen and Svento **2012**). This structural reorganisation of the sector assumed that competitive generation and supply would need to be supported by a well-functioning electricity distribution network infrastructure, which would continue to be regulated as monopolies (Joskow **2008**).

The First Energy Package, Directive 96/92/EC (European Union **1996**) introduced competition for electricity generation, and opened the market for competition at the retail level for large consumers. In addition, non-discriminatory access to networks was established, while generation and retail were unbundled from the monopoly activities of transmission and distribution. This package defined DSO responsibilities as: providing a secure, reliable, and efficient service; acting as a neutral market facilitator by providing non-discriminatory access to electricity networks; and prioritising renewable energy sources when dispatching generating units. DSOs were also made accountable for the privacy of sensitive commercial information collected through their operations.

The Second Energy Package, Directive 2003/54/EC (European Union **2003**), introduced additional measures: retail market competition was expanded to the household sector, legal unbundling of network activities from competitive activities was mandated, and National Regulatory Authorities (NRAs) for Member States were established. Through this package electricity distribution tasks evolved further: DSOs became responsible for providing the necessary information to system users for efficient access to the networks. They were also required to follow a transparent and non-discriminatory process in their procurement of energy to cover system losses. Furthermore, distribution system expansion planning was required to consider demand-side management and distributed generation as alternatives to upgrading or replacing network capacity.

The Third Energy Package, Directive 2009/72/EC (European Union **2009**), introduced procedures for retail supplier switching, ownership unbundling for transmission system operators, and mandated the development of network codes at the EU-level. This policy package also argued the importance of modernising electricity distribution networks ~~toward~~ towards smart grids to stimulate distributed generation and energy efficiency.

During this stage of structural change ~~toward~~ towards market liberalisation, DSOs assumed growing responsibilities for enabling competition through neutral market facilitation. The need to modernise distribution grids was also raised; however, ~~however~~ no explicit guidance was provided for how this modernisation should unfold, or how and to what extent DSOs should participate in it.

A smarter and more sustainable electricity sector

Following the EU actions ~~toward~~ towards liberalisation, efforts have been pursued to establish a smarter and more sustainable electricity sector, consequently impacting electricity distribution. Recent policies address climate and sustainable development challenges, as well as ongoing technological innovation. Policy-driven efforts for a more sustainable electricity sector are visible in the 2030 goals, which build on the previously set 2020 targets (European Commission **2010**), and support the 2050 strategy for a low carbon economy (European Commission **2011**). These goals target an increase in the share of renewable energy of at least 27%, a reduction of greenhouse gas emissions of minimum 40%, and an increase in energy efficiency of 30% (European Commission **2014a**, **2016a**)~~,~~. The goals are further supported by the Energy Union framework that aims to coordinate efforts to: improve energy security, solidarity and trust; deliver a fully integrated European energy market; increase energy efficiency to moderate demand; decarbonise the economy; and foster research, innovation and competitiveness (European Commission **2015a**). Reaching these climate and energy targets requires the modernisation of distribution grids to accommodate the growing shares of renewable generation, enable energy efficiency measures, and increase system flexibility management capabilities. To support this modernisation, the Integrated Strategic Energy Technology Plan was introduced on the scope of the Energy Union (European Commission **2015d**), as an update from the initial 2007 proposals (European Commission **2007**). The plan's goals include: enabling a smarter energy sector that is more resilient and secure, to be delivered through the demonstration and development of innovative power electronics that enable system flexibility, demand response, and storage capabilities. These broader goals resulted in specific focus areas for DSOs, as proposed through the European Technology and Innovation Platform on Smart Networks for Energy Transition (ETIP-SNET) research and innovation roadmap (ETIP SNET **2016**). The ETIP-SNET roadmap identified the need to focus on:

- Network upgrades, through the introduction of new technologies, methodologies, and tools that improve operations;
- System flexibility, by increasing distributed load management capabilities, such as those from electric vehicles or distributed generation;
- System reliability, through the implementation of network contingencies management procedures;
- Information and communication technologies and digitalisation, to increase the connectivity of DSOs with other stakeholders and their monitoring and control capabilities;
- Market design and regulatory environment, by considering alternative institutional arrangements for electricity distribution and associated governing rules that contribute to convergence between innovation, sustainability, and competitiveness in the internal energy market.

These policy-driven changes ~~toward~~ towards a smarter and more sustainable electricity sector, along with the sector's earlier liberalisation, reflect an ongoing effort to deliver secure and competitive energy to consumers (European Commission **2015d**). With this goal in mind, the Clean Energy for All Europeans package introduced a set of policy proposals for market design adjustments to enable the liberalised electricity sector to adapt (European Commission **2016a**). These proposals result from the revision of the Directive on the internal market for electricity (European Commission **2017a**), of the Regulation on the internal market for electricity (European Commission **2017d**), and of the Regulation establishing the agency for cooperation of energy regulators (European Commission **2017c**). Combined, these policies aim to adapt the market design set by the Third Energy Package, putting more emphasis on the growth on renewable energy, decentralised generation, and technological advancement ~~toward~~ towards smarter grids. This adaptation must be achieved by ensuring renewable energy competes on an equal standing with other energy sources, and by removing existing barriers to the development of system flexibility services, such as demand response (European Commission **2017a**). These recent policy proposals suggest that DSOs procure non-frequency ancillary services in a market-based and non-discriminatory way to include different market participants, such as renewable energy generators, storage owners, aggregators, and demand ~~-~~ response providers. Moreover, the proposals include provisions for the use of system flexibility, integration of electro-mobility in the network, and operation of storage. In the case of flexibility, Member States are encouraged to enable DSOs to procure flexibility services that improve system efficiency. The policy proposals guide Member States to opt for market-based approaches in the deployment, ownership, and operations of electro-mobility charging infrastructure and storage, unless no interest from other parties exists.

The policy-driven evolution of electricity distribution pursued during this stage of structural change builds on the characteristics of a liberalised sector and further expands the participation of DSOs in smart grid related activities. Figure **1** outlines the implemented policy instruments and their implications for DSOs.

However, these recent proposals for policy-adaptation are not yet final. They are currently being discussed by energy regulators (ACER and CEER **2017a**, **b**, CEER **2017a**, ~~**2017c**~~ **c**) and sectoral associations for electricity distribution (CEDEC et al. **2017**), all of which offer perspectives on how electricity distribution should operate in a changing electricity sector, and how DSOs should position themselves in this framework.

Foresight methodology

This research focuses on the ongoing electricity sector policy-adaptation process and aims to contribute with a foresight-based expert assessment of policy alternatives for European DSOs. Our method and research process design follow a Policy Delphi technique, typically used in foresight studies concerning the analysis of policy issues.

Policy Delphi method

The Policy Delphi method is part of the group of Delphi techniques, in which expert knowledge on a topic of interest is systematically gathered through iterative surveys combined with processes for providing structured feedback to participants (Linstone and Turoff **2011**). The knowledge collected is used to discern foresight-based assessments, increasing the accuracy of forecasts on complex issues (Linstone and Turoff **2002**; Woudenberg **1991**). The Policy Delphi was developed specifically to assess policy issues, which are defined as topics where different resolutions are being advocated, or for which guidance is sought (Turoff **1970**). Therefore, the Policy Delphi is used as a decision-facilitation tool, while conventional Delphi studies are used for decision-making (Loe **1995**). This method provides a valuable framework for this research as its approach aims to contribute to the generation of perspectives on policy issues (Loë et al. **2016**). There is no standardised approach for conducting a Policy Delphi study (Gracht **2008**; Loë et al. **2016**). However, the method comprises a set of general characteristics rather than a specific series of steps:

- A group of knowledgeable experts should be engaged;
- The method runs through iterative rounds in which data ~~is~~ are collected, evaluated, and the policy issues under analysis further structured;
- An organised feedback process is established to feed inter-round results back to experts.

This approach offers a flexible framework for use across industries and policy topics, ranging from public health, security, strategy development, technological forecasting, climate and energy, to name a few (Loë et al. **2016**; Makkonen et al. **2016**). Within the sustainability and energy transition domains, recent applications of this method have contributed to insight on policy issues related to technology, business model, and social aspects. Examples include: community adaptation to climate change (Nguyen et al. **2017**); suitability of indoor environmental quality standards (Alyami et al. **2013**); effectiveness of community-promoted environmental policies (Hsueh **2015**); energy service companies business model viability (Pätäri et al. **2016**; Patari and Sinkkonen **2014**); deployment of smart grids (Balta-Ozkan et al. **2014**; Galo et al. **2014**; Xenias et al. **2015**); solar generation investment risk assessment (Kayser **2016**); applications and use of bioenergy technologies (Billig and Thrän **2016**; Ribeiro and Pereira da Silva **2015**); community acceptance of energy technologies (Carrera and Mack **2010**); energy technology deployment forecasts (Celiktas and Kocar **2010**; Czaplicka-Kolarz et al. **2009**; Liimatainen et al. **2014**; Mayor et al. **2015**; Schuckmann et al. **2012**; Sherriff

2014; Tuominen et al. 2014; Varho et al. 2016). This selection of studies is not an exhaustive list of Policy Delphi applications (see Loë et al. (2016) for a thorough review of Policy Delphi work). Instead, this selection of studies highlights the ability of this method to contribute valuable insights across policy issues. In addition, it highlights recent contributions using a methodology developed in 1970 (Turoff 1970), thus reflecting both the maturity of the Policy Delphi method, and its current relevance for the development of foresight-based policy-adaptation guidance.

Research process

The research process using the Policy Delphi was structured in two stages, as shown in Fig. 2. The first stage focused on study design, while the second stage applied the iterative rounds method to obtain experts' feedback on selected DSOs policy issues. For a detailed description, see Appendix Tables 14 and 15.

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Fig. 2 Policy Delphi research process

In this study, we refer to the Policy Delphi statements as policy alternatives, given their ability to provide guidance for policy-adaptation actions. Policy-adaptation is considered in a broad sense here, encompassing actions from different stakeholders to facilitate the transition of the electricity distribution industry. These stakeholders include: policy ~~-~~ makers, DSOs, industry analysts, regulators, researchers, sectoral associations, to name a few.

The surveys used in this study were designed for experts to evaluate policy alternatives using ordinal scales measuring agreement, difficulty, importance, or priority. The policy alternatives used in this analysis resulted from a literature review, complemented with insights from industry experts~~,~~; see Appendix Table 14 for detailed information. Furthermore, Appendix Table 16 presents the structure of the survey, number of statements across topics, measurement scale type, and the scale conversions used for data analysis. We converted the measurement scales to provide clearer policy relevant results.

Results and discussion

This section describes the panel of experts and presents their assessments of the policy alternatives regarding business model innovation, technological adaptation, market design, and electricity distribution industry transition.

Expert demographics

In terms of region of origin, the experts represented 26 countries in the ~~1st~~ First round, and 21 countries in the ~~2nd~~ second round, see Table 1. This broad regional representation provided confidence that survey responses reflected consideration of the different electricity sector contexts across Europe.

Table 1 Region of origin of participating experts

Country	~~1st~~ First round	~~2nd~~ Second round
Austria	14	7
Belgium	6	4
Bosnia and Herzegovina	1	1
Bulgaria	1	–
Croatia	5	4
Cyprus	1	–
Czech Republic	3	2
Denmark	2	–
Finland	8	6
France	6	–
Germany	14	3
Greece	4	3
Ireland	3	2
Italy	20	13
Latvia	1	1
Netherlands	13	4
Norway	5	1
Portugal	39	19
Romania	1	1
Slovenia	2	–
Spain	9	5
Sweden	12	5
Switzerland	3	1
Turkey	2	1~~United~~
~~Kingdom~~UK	11	6
Not indicated	21	14
Total	207	103

Experts were also categorised according to their role in the electricity sector (see Table 2). Furthermore, the area of expertise was obtained from the experts participating in the second survey (*n* = 103) as an additional categorisation measure. Participants backgrounds included: business and economics (*n* = 19); engineering and sciences (*n* = 79); engineering, business, and economics (*n* = 1), law (*n* = 2), and other (*n* = 2).

Table 2 Role in the electricity sector of participating experts

Role	~~1st~~ First round	%	~~2nd~~ Second round	%
Distribution system operator	85	41.10	38	36.90
Electricity generation companies	9	4.30	3	2.90
Electricity retail companies	3	1.40	–	–
Electricity sector associations	3	1.40	–	–
Industry analysts and consultants	27	13.00	10	9.70

Policy maker	2	1.00	–	–
Regulator	3	1.40	1	1.00
Researchers and academics	57	27.50	32	31.10
Transmission system operator	6	2.90	3	2.90
Other	12	5.80	16	15.50
Total	207	100.00	103	100.00

The next section shows the results from the Policy Delphi survey rounds. When a statement was included in both rounds, we present the final assessment from the second round, and the overall variation (*Δ*). Despite the change in sample size from the first survey (*n* = 207) to the second survey (*n* = 103), no substantial differences in the results were identified after considering both the experts assessments from the total number of participants for the first survey, and when only considering the returning experts. Also, no noteworthy responses differences across stakeholder role subgroups were found. We present the results for all policy alternatives, highlighting the dominant consensus position of our experts.

The results are based on the converted scales as shown in Appendix Table **16**. The mean (\(\bar{x} \)) and median (\(\tilde{x} \)) from the original scale are also presented for each statement, providing measures of central tendency for each policy alternative (Loë et al. **2016**).

Business model innovation

The business model innovation policy alternatives included in the study were intended to provide a more detailed understanding on the evolution of electricity distribution from an organisational perspective.

Adaptation challenges

These statements focused on DSO adaptation difficulties (see Table **3**). The results indicate that most difficulties in DSO adaptation are expected with their integration of new technologies supporting smarter grids, their integration of new business and managerial processes, and the timeliness of their adaption. Experts were less certain about the effect of regulation on DSO adaptation.

Table 3 How do you perceive the difficulty of DSOs adaptation to a changing electricity sector?

Policy alternative	Difficult (%)	Uncertain (%)	Easy (%)	\(\bar{x} \)	\(\tilde{x} \)
DSOs will be able to adapt to a changing electricity sector only with adapted regulation[a]	24.~~3%~~3 *(Δ − 10.~~0%~~0)*	**42.~~7%~~7 *(Δ 14.~~2%~~2)***	33.~~0%~~0 *(Δ − 4.~~2%~~2)*	4.1 *(Δ 0.1)*	4.0 *(Δ 0.0)*
DSOs will be able to integrate new technologies to support the transition to smarter distribution grids[a]	**62.~~1%~~1 *(Δ 10.~~4%~~4)***	19.~~4%~~4 *(Δ 3.~~0%~~0)*	18.~~4%~~4 *(Δ − 13.~~4%~~4)*	3.5 *(Δ − 0.3)*	3.0 *(Δ 0.0)*
DSOs will be able to integrate new business processes and management practices[a]	**62.~~1%~~1 *(Δ 10.~~9%~~9)***	20.~~4%~~4 *(Δ 1.~~1%~~1)*	17.~~5%~~5 *(Δ − 12.~~0%~~0)*	3.4 *(Δ − 0.2)*	3.0 *(Δ 0.0)*
DSOs will be able to adapt their role in a timely manner[a]	**83.~~5%~~5 *(Δ 17.~~8%~~8)***	12.~~6%~~6 *(Δ − 4.~~8%~~8)*	3.~~9%~~9 *(Δ − 13.~~0%~~0)*	2.9 *(Δ − 0.4)*	3.0 *(Δ 0.0)*

[a]Statement included in the first and second round

These results emphasize the importance of developing a DSO transition framework to ease existing difficulties. Moreover, it is relevant to note that, despite the agreement amongst policy makers on the importance of improving the existing regulatory framework to facilitate DSOs adaptation (CEER **2015**; EDSO for Smart Grids **2015**; Ruester et al. **2014**), a significant share of experts question the role of regulation in facilitating this transition process.

Strategy, operations, and organisational adaptation

Statements included in this topic aimed at shedding light on how DSOs should reconfigure their business strategy, and operations (see Table **4**). Strong policy alternatives include adapting DSO organisational structures to take advantage of the opportunities arising from a smarter grid scenario. Such adaptation can include efforts to improve skills, create or restructure teams, redefine responsibilities and create new internal roles, as well as ensuring that existing departments, strategy, and resource allocation practices are aligned with the challenges and opportunities of the energy transition (Eurelectric **2016**). Our Delphi experts also agreed on the need for innovative system services that contribute to the creation of new sources of revenue, and the need to test new business models and strategies that challenge the current industry framework. The importance of exploring new business models is evident from the cases of Uber, Airbnb, Lyft, eBay, Amazon, Tesla, Google, which have transformed traditional industry practices in transportation, accommodation, communication, and commerce, often by overriding market rules and conventional mindsets. More limited DSO adaptation, such as focusing only on grid operation and maintenance, and limiting business strategy to the possibilities created by current regulations, were considered weak alternatives by our Delphi experts.

Table 4 How should DSOs position themselves regarding business model and organizational innovation?

Policy alternative	Weak policy alternative (%)	Uncertain policy alternative (%)	Strong policy alternative (%)	\(\bar{x} \)	\(\tilde{x} \)
DSOs should focus on adapting their organisational structure to be ready for the opportunities resulting from a fully deployed smart grid	3.~~9%~~9	2.~~4%~~4	**93.~~7%~~7**	6.2	6.0
DSOs should provide innovative system services allowing for new sources of revenue	9.~~7%~~7	3.~~9%~~9	**86.~~5%~~5**	5.7	6.0
DSOs should test business models and strategies that challenge the current regulation and disrupt the market	22.~~2%~~2	7.~~7%~~7	**70.~~0%~~0**	5.0	6.0
DSOs should focus only on grid operation and maintenance, planning and expansion, and quality of service	**70.~~5%~~5**	6.~~3%~~3	23.~~2%~~2	3.1	3.0
DSOs should limit their business strategy to the possibilities allowed by existing	**81.~~6%~~6 *(Δ***	1.~~0%~~0 *(Δ − 3.~~4%~~4)*	17.~~5%~~5 *(Δ*	2.6 *(Δ − 0.5)*	2.0 *(Δ − 1.0)*

regulations[a]	***14.~~4%~~4)***		*− 11.~~0%~~0)*		

[a]Statement included in the first and second round

These expert assessments emphasize the need for DSOs to expand their operations beyond core electricity distribution services, and explore new possibilities. This could be accomplished through internal changes, such as business strategy reconfiguration, and innovative service experimentation.

Activities and responsibilities

This topic examined current and potential DSO responsibilities. Unsurprisingly, most experts advocated for DSOs to continue performing core electricity distribution functions of grid management and planning. However, they also considered smart ~~meter~~ metre deployment, data collection, and the integration of distributed generation technologies into electricity distribution operations as a good fit for DSOs. On the contrary, they did not recommend DSO involvement in Electricity retail. See Table **5** for detailed results.

Table 5 In the future DSOs should be involved in the following activities?

Policy alternative	Weak policy alternative (%)	Uncertain policy alternative (%)	Strong policy alternative (%)	$\bar{x}$	$\tilde{x}$
Grid management (i.e. operation and maintenance)~~.~~	1.~~9%~~9	1.~~0%~~0	**97.~~1%~~1**	6.5	7.0
Grid planning (i.e. expansion and reinforcement)~~.~~	1.~~4%~~4	0.~~5%~~5	**98.~~1%~~1**	6.5	7.0
Smart ~~meter~~ metre deployment~~.~~	6.~~3%~~3	5.~~3%~~3	**88.~~4%~~4**	6.1	6.0
Data gathering~~.~~	6.~~3%~~3	9.~~2%~~2	**84.~~5%~~5**	5.9	6.0
Integration of distributed generation technologies~~.~~	7.~~7%~~7	3.~~4%~~4	**88.~~9%~~9**	5.7	6.0
Smart ~~meter~~ metre ownership[a]	10.~~7%~~ 7 *(Δ − 1.~~9%~~9)*	18.~~4%~~ 4 *(Δ − 2.~~3%~~3)*	**70.~~9%~~9** ***(Δ 4.~~2%~~2)***	5.6 *(Δ 0.2)*	6.0 *(Δ 0.0)*
Neutral market facilitation (i.e. avoiding interference with competitive market activities)~~.~~	9.~~2%~~2	14.~~0%~~0	**76.~~8%~~8**	5.6	6.0
Integration of electricity storage technologies.	8.~~7%~~7	6.~~8%~~8	**84.~~5%~~5**	5.6	6.0
Data storage and management	12.~~6%~~6	12.~~6%~~6	**74.~~9%~~9**	5.5	6.0
Providing flexibility services to end-users (i.e. demand response, flexible consumption, flexible production, flexible storage)	14.~~0%~~0	7.~~7%~~7	**78.~~3%~~3**	5.4	6.0
Managing a data marketplace (i.e. to enable the development of added value services by other market players)[a]	12.~~6%~~ 6 *(Δ − 5.~~7%~~7)*	11.~~7%~~ 7 *(Δ − 5.~~3%~~3)*	**75.~~7%~~7** ***(Δ 11.~~0%~~0)***	5.4 *(Δ 0.4)*	6.0 *(Δ 0.0)*
Electric vehicle infrastructure deployment.	13.~~5%~~5	10.~~6%~~6	**75.~~8%~~8**	5.3	6.0
Indirect grid balancing (i.e. through price signals to other relevant market players, therefore participating in procuring flexibility)~~.~~	13.~~0%~~0	9.~~2%~~2	**77.~~8%~~8**	5.3	6.0
Direct grid balancing (i.e. connecting and disconnecting consumers from the grid)~~.~~	17.~~4%~~4	8.~~2%~~2	**74.~~4%~~4**	5.3	6.0
Management of electricity storage technologies~~.~~	16.~~4%~~4	7.~~7%~~7	**75.~~8%~~8**	5.2	6.0
Management of distributed generation technologies[a]	16.~~5%~~ 5 *(Δ − 7.~~6%~~6)*	9.~~7%~~ 7 *(Δ − 0.~~9%~~9)*	**73.~~8%~~8** ***(Δ 8.~~6%~~6)***	5.2 *(Δ 0.3)*	6.0 *(Δ 1.0)*
Provide energy efficiency and energy savings advise to end-users[a]	18.~~4%~~ 4 *(Δ 1.~~1%~~1)*	14.~~6%~~ 6 *(Δ − 0.~~4%~~4)*	**67.~~0%~~0** ***(Δ − 0.~~6%~~6)***	5.1 *(Δ 0.1)*	6.0 *(Δ 1.0)*
Electric vehicle infrastructure ownership[a]	35.~~0%~~ 0 *(Δ 6.~~0%~~0)*	19.~~4%~~ 4 *(Δ − 7.~~6%~~6)*	**45.~~6%~~6** ***(Δ 1.~~7%~~7)***	4.2 *(Δ 0.0)*	4.0 *(Δ 0.0)*
Electricity retail[a]	**81.~~6%~~6** ***(Δ 21.~~7%~~7)***	10.~~7%~~ 7 *(Δ − 2.~~4%~~4)*	7.~~8%~~ 8 *(Δ − 19.~~3%~~3)*	2.0 *(Δ − 1.1)*	1.0 *(Δ − 1.0)*

[a]Statement included in the first and second round

The expert perspectives match the current market structure in which DSOs are expected to operate as neutral market facilitators, supporting competitive market players, but without actively participating in the competitive segments of retail and generation (ACER and CEER **2017b**~~,~~; CEER **2014**, **2015**). Nonetheless, the expert assessments also offer insight on the importance of pursuing new activities and increasing smart grid related responsibilities for DSOs. For instance, they recommend that DSOs take responsibility for the integration and management of electricity storage facilities. This differs from the recent proposals, in the Clean Energy for All policy package (ACER and CEER **2017b**; European Commission **2017a**), that DSOs should only engage in storage ownership, development, management, or operation, when no other parties are interested.

Technological adaptation

Given the technical intensity of electricity distribution operations, it is important to understand technological adaptation needed to combine legacy technologies with smart grid innovations. Our experts assessed the appropriateness of different R&D activities and digital capabilities for DSOs.

Engagement and approach to R&D activities

Our examination of DSO engagement in R&D activities (see Table **6**) aimed at understanding which technology readiness level should be the priority for DSOs in a changing electricity sector (EARTO **2014**; European Commission **2014b**). The results indicate that nearly 40% of our experts ~~prioritized~~ prioritised DSO engagement in piloting and demonstrating emerging technologies. Just over a third ~~prioritized~~ prioritised DSO exploitation of tested and proven technologies, while nearly a quarter recommended that DSOs engage first in exploratory R&D. The different policy alternatives have similar levels of expert support, however, highlighting the importance of DSOs being engaged at all stages of technology R&D.

Table 6 How should DSOs position themselves for technological innovation and research and development (R&D) activities?

Level of technological development	Policy alternative	~~1st~~ First priority (%)	Rank	$\bar{x}$	$\tilde{x}$
Basic technology research Research to prove feasibility	DSOs should conduct exploratory R&D activities for new technologies and innovative applications[a]	23.~~3%~~ 3 *(Δ − 3.~~3%~~3)*	3	2.2 *(Δ 0.0)*	2.0 *(Δ 0.0)*
Technology development Technology demonstration	DSOs should pilot and demonstrate the potential and impact of emerging technologies[a]	39.~~8%~~ 8 *(Δ 1.~~2%~~2)*	1	1.7 *(Δ − 0.1)*	2.0 *(Δ 0.0)*
System commissioning System operations	DSOs should exploit proven technologies, deploying external R&D results from universities, ICT firms, and other DSOs[a]	36.~~9%~~ 9 *(Δ 0.~~2%~~2)*	2	2.1 *(Δ 0.1)*	2.0 *(Δ 0.0)*

[a]Statement included in the first and second round

The results suggest expert preference for DSOs engaging in R&D activities that are closer to deployment versus early exploratory developments. The former can contribute to faster results, and possibility more rapid delivery of benefits, ~~whilst~~ while also bearing fewer risks than exploratory research. Experts also strongly favoured a research approach in which DSOs develop R&D in cooperation with external entities (see Table **7**).

Table 7 How should DSOs develop R&D activities?

Policy alternative	Weak policy alternative	Uncertain policy alternative	Strong policy alternative	$\bar{x}$	$\tilde{x}$
DSOs should explore technological innovation in partnership with external entities such as universities, ICT firms, and other DSOs	1.0%	1.9%	**97.1%**	6.4	7.0

Jointly, these expert assessments suggest that DSOs can best manage and minimise technological adaptation risks by developing R&D in collaboration with entities providing complementary capabilities.

These expert assessments of R&D approaches offer additional insight into how the research and innovation roadmap, as described in ETIP-SNET, could be implemented (ETIP SNET **2016**; European Commission **2016b**).

Electricity distribution digital capabilities

Electricity distribution operations are becoming increasingly digitised (EDSO **2016**; ETIP SNET **2016**; European Commission **2016a**). Our analysis examined the relative importance of different digital capabilities to deal with growing quantities of data (see Table **8**). Experts were almost unanimous in their assessment that DSOs should be capable of data collection from all connected distribution networks and devices, such as distributed generation, smart ~~meters~~metres, electric vehicle infrastructure, network monitoring points, substation monitoring. They also agreed that most other digital activities, such as data validation, analysis and interpretation will be important capabilities needed by DSOs. Data analysis and interpretation can directly contribute to increasing the efficiency and quality of service by supporting the definition of flexibility schedules, and forecasting network expansion and reinforcement needs.

Table 8 What is the importance of the following digital capabilities for DSOs new roles?

Policy alternative	Weak policy alternative (%)	Uncertain policy alternative (%)	Strong policy alternative (%)	$\bar{x}$	$\tilde{x}$
Collection of data	3.4	3.4	93.2	6.1	6.0
Validation and quality certification of data	3.9	5.3	90.8	6.0	6.0
Analysis and interpretation of data	5.8	4.3	89.9	6.0	6.0
Aggregation of data (e.g. from a diversity of sources to obtain meaningful decision-support information)~~.~~	4.3	4.3	91.3	5.9	6.0
Automation	7.7	7.2	85.0	5.8	6.0
Communication of data to other market participants~~.~~	8.2	14.5	77.3	5.4	6.0

These assessments underline the need for digital capabilities at the DSO level. Only after data is appropriately collected, validated, analysed, and aggregated, should DSOs use it to increase automation or share data with other market participants. Nevertheless, digital automation is expected to become a critical DSO capability, in which previously gathered data supports the design and implementation of distributed generation, flexibility management algorithms, and automatic storage coordination algorithms.

These results foresee a central role for DSOs in data management and support the Clean Energy for All Europeans policy package, which recommends that DSOs should enable data access in a non-discriminatory way to all eligible parties (European Commission **2017b**).

Market design

In addition to business model innovation, and technological adaptation, market design issues are also paramount in a changing electricity sector due to the policy-driven nature of the electricity distribution industry. We examine topics and policy alternatives addressing both EU and Member States level policy actions, as well as R&D and innovation policies.

EU-level policy actions

We asked experts to assess the importance of various EU-level market design policies (see Table **9**). There was strong expert consensus favouring the definition of a common vision for DSO role. Experts also largely agreed on the importance of defining common rules for DSO-TSO data management and exchange standards, which aligns with the proposals presented by the European Commission (~~European Commission~~ **2017d**). Moreover, experts agreed on the need for the Digital Single Market strategy to provide guidance on the roles of DSOs as these become increasingly interconnected and data ~~-~~ driven. Our experts also supported the development of a specific electricity distribution EU-directive and the development of a regulatory body facilitating DSO transition. EU-level actions in line with these policy alternatives are currently being pursued. The proposals for the new electricity directive released with the Clean Energy for All Europeans package establish a framework for DSOs operations in a smarter electricity sector, providing guidance on electricity storage, data handling, electric vehicle charging infrastructure, and system flexibility issues (European Commission **2017a**). Moreover, the European Commission has also proposed the creation of a EU-level DSO Entity to provide support for the adaptation of the electricity distribution industry (Eurelectric **2017**; European Commission **2017d**).

Table 9 How important are the following EU-level policy-oriented actions in the ongoing DSOs transition?

Policy alternative	Weak policy alternative (%)	Uncertain policy alternative (%)	Strong policy alternative (%)	$\bar{x}$	$\tilde{x}$
DSOs should follow a common ~~-~~ vision of their most effective role in the electricity value chain, to support and strengthen the development of the EU internal electricity market	7.~~2%~~2	9.~~2%~~2	**83.~~6%~~6**	5.4	6.0
The DSOs and Transmission System Operators (TSOs) data management and exchange standards should be defined at the EU-level	11.~~6%~~6	18.~~4%~~4	**70.~~0%~~0**	5.2	6.0
The EU strategy ~~toward~~ towards a Digital Single Market should provide guidance on the role of DSOs as these become more interconnected and data driven	12.~~1%~~1	15.~~5%~~5	**72.~~5%~~5**	5.2	6.0
DSOs should have a specific EU-level directive, focusing on the operation of the distribution network in a smarter grid framework	12.~~1%~~1	13.~~5%~~5	**74.~~4%~~4**	5.1	5.0
The DSOs and TSOs congestion management and balancing responsibilities should be defined at the EU-level[a]	10.~~7%~~ 7 *(Δ − 3.~~3%~~3)*	19.~~4%~~ 4 *(Δ − 0.~~4%~~4)*	**69.~~9%~~9 *(Δ 3.~~7%~~7)***	5.0 *(Δ − 0.4)*	5.0 *(Δ − 1.0)*
A new regulatory body should be established focusing on the transition to a smarter grid framework, with a strategy and incentives for DSOs to innovate[a]	28.~~2%~~ 2 *(Δ 0.~~6%~~6)*	9.~~7%~~ 7 *(Δ − 2.~~4%~~4)*	**62.~~1%~~1 *(Δ 1.~~7%~~7)***	4.5 *(Δ − 1.1)*	5.0 *(Δ − 1.0)*
The unbundling threshold, currently set to DSOs with 100 000 connected consumers should be re-considered as it can challenge the adaptation and innovation potential of DSOs[a]	12.~~6%~~ 6 *(Δ − 3.~~8%~~8)*	**49.~~5%~~5 *(Δ 17.~~6%~~6)***	37.~~9%~~ 9 *(Δ − 13.~~8%~~8)*	4.3 *(Δ 0.3)*	4.0 *(Δ 0.0)*

[a]Statement included in the first and second round

Our experts were divided on the value of redefining the 100 000 connected consumers unbundling rule. In line with this, recent policy proposals maintain this threshold (European Commission **2017b**).

Member ~~State~~ state level policy actions

We also asked experts to assess policy alternatives at the Member State level (see Table **10**). Experts largely agreed on the importance of having Member States encourage DSO experimentation with new technologies and services. Experts also favoured developing national strategies for smart grid deployment in the form of National Smart Grid Action Plans. They disagreed on whether the role of DSOs should be solely defined at the Member State level; over 40% of the experts indicated this was important while nearly 40% indicated the opposite.

Table 10 How important are the following Member State level policy-oriented actions in the ongoing DSOs transition?

Policy alternative	Weak policy alternative (%)	Uncertain policy alternative (%)	Strong policy alternative (%)	$\bar{x}$	$\tilde{x}$
Member States should encourage DSOs to experiment with new services, technologies, business models and market designs, even if it requires overriding current regulations	11.~~6%~~6	11.~~1%~~1	**77.~~3%~~3**	6.0	6.0
Member States should develop a National Smart Grid Action Plan to provide a deployment roadmap and the roles of actors in this context	7.~~2%~~2	13.~~0%~~0	**79.~~7%~~7**	4.6	5.0
The role of the DSOs should only be specified at the Member State level, allowing each country to establish its role to fit the specific context[a]	36.~~9%~~ 9 *(Δ − 5.~~1%~~1)*	20.~~4%~~ 4 *(Δ 4.~~9%~~9)*	**42.~~7%~~7 *(Δ 0.~~2%~~2)***	4.0 *(Δ − 0.5)*	4.0 *(Δ − 1.0)*

[a]Statement included in the first and second round

These results can inform Member State efforts supporting the electricity distribution industry transition, and complement the ongoing EU-level restructuring efforts.

R&D and innovation policy action

Finally, we examined R&D and innovation policies that affect market design (see Table **11**). The redesign of the electricity market calls for a coordinated R&D and innovation policy framework facilitating the introduction of new technologies, processes, and practices underpinning innovative roles and services. Our experts strongly supported the existence of specific support programmes for technological innovation at the DSO level. They also favoured developing a flexibility market governance model and programmes to support DSO business model innovation. Such programmes could facilitate the establishment of new departments for smart grid operations, the integration of new processes for asset management, or new skills development. Our experts overwhelmingly agreed on the importance of having a regulatory framework supportive of innovation and investment in smart grids.

Table 11 How important are the following R&D and innovation policy-oriented actions in the ongoing DSOs transition?

Policy alternative	Weak policy alternative (%)	Uncertain policy alternative (%)	Strong policy alternative (%)	$\bar{x}$	$\tilde{x}$
There should be specific support programmes for technological innovation at the DSOs level	7.7	9.7	82.6	5.4	6.0
A flexibility market governance model should be implemented to ensure the adequate intervention of different actors	6.3	15.0	78.7	5.4	6.0
There should be specific support programmes for business model innovation at the DSOs level	11.1	9.2	79.7	5.2	5.0
DSOs regulation should be designed to facilitate innovation and investments in smart grid technologies	3.4	2.4	94.2	5.0	5.0

These assessments align with recent policy efforts to support DSO innovations. Such efforts include the recent Smart Networks for Energy Innovation R&D and innovation roadmap with a specific set of objectives for electricity distribution, estimating the need for 1 475 Million Euros to develop the proposed activities (ETIP SNET **2016**). European regulators and DSOs are also exploring ways to encourage innovation at the distribution level by adapting regulatory frameworks (CEER **2017b**; Eurelectric **2016**).

Electricity distribution industry transition

The extent to which the electricity distribution industry shifts ~~toward~~ towards new roles and activities can impact the overall diffusion of smart grid related technologies, and the pace at which potential benefits are transferred to connected grid users. We asked experts to predict future roles for DSOs as well as the timeframe for this transition.

Role of the DSOs in the electricity sector

We presented DSO roles in the electricity sector within three archetypes: passive network managers, active network managers, or reactive network managers (Martinot et al. **2015**; Oosterkamp et al. **2014**). Our experts suggest that DSOs will become active network managers (see Table **12**) or, alternatively, become reactive network managers. Conversely, most experts did not foresee DSOs acting as passive network managers in the future, a pattern consistent with more traditional electricity distribution designs.

Table 12 What's the future of DSOs in the electricity sector?

Policy alternative	Weak policy alternative (%)	Uncertain policy alternative (%)	Strong policy alternative (%)	$\bar{x}$	$\tilde{x}$
DSOs as active network managers DSOs will incorporate the full spectrum of smart grid capabilities, managing system flexibility as part of its operations, operating as active network managers	9.~~2%~~2	6.~~3%~~3	**84.~~5%~~5**	5.7	6.0
DSOs as reactive network managers DSOs will incorporate some additional coordination capabilities, handling congestions and other grid related issues at the operation stage, by restricting load and generation, operating as reactive network managers	18.~~4%~~4	9.~~2%~~2	**72.~~5%~~5**	5.1	6.0
DSOs as passive network managers DSOs will continue with their traditional activities, solving most of the grid related issues at the planning stage, operating as passive network managers[a]	***77.~~7%~~7 (Δ 21.~~6%~~6)***	2.~~9%~~9 *(Δ − 3.~~9%~~9)*	19.~~4%~~4 *(Δ − 17.~~8%~~8)*	2.7 *(Δ − 0.8)*	2.0 *(Δ − 1.0)*

[a]Statement included in the first and second round

These expert assessments reinforce current policy actions to support the establishment of smarter and more sustainable electricity networks, which will require new capabilities and more active system management (ACER and CEER **2017a**).

Transition trajectories

The ongoing advances in policy and technology ~~toward~~ towards a smarter and more sustainable electricity sector enable DSOs to assume more responsibility in facilitating system flexibility, consistent with more active network management. Expert consensus suggests that most DSOs will be operating as active network managers by 2021–2031 (see Table **13**).

Table 13 When will DSOs fully evolve ~~toward~~ towards active network managers, procuring flexibility services?

Policy alternative	DSOs become active network managers…				DSOs will not become active network managers (%)	$\bar{x}$	$\tilde{x}$
	Between 2017–2020 (%)	Between 2021–2030 (%)	Between 2031–2040 (%)	Between 2041–2050 (%)			
Small DSOs (Less than 100 000 connected consumers)[a]	3.~~9%~~9 *(Δ − 6.~~3%~~3)*	***76.~~7%~~7 (Δ 24.~~0%~~0)***	16.~~5%~~5 *(Δ − 6.~~2%~~2)*	0.~~0%~~0 *(Δ − 2.~~9%~~9)*	2.~~9%~~9 *(Δ − 8.~~7%~~7)*	2.2 *(Δ − 0.3)*	2.0 *(Δ 0.0)*
Large DSOs (Unbundled, with 100,000 or more connected consumers)[a]	10.~~7%~~7 *(Δ − 3.~~8%~~8)*	***76.~~7%~~7 (Δ 14.~~9%~~9)***	10.~~7%~~7 *(Δ − 6.~~2%~~2)*	1.~~9%~~9 *(Δ − 1.~~0%~~0)*	0.~~0%~~0 *(Δ − 3.~~9%~~9)*	2.0 *(Δ − 0.2)*	2.0 *(Δ 0.0)*

[a]Statement included in the first and second round

Because the electricity distribution industry in the EU consists of a significant number of DSOs of varying sizes (Eurelectric **2013**), we wanted to understand the possible impact of DSO size on adaptation patterns. The results indicate that size is not perceived as differentiating factor, as both large and small DSOs are expected to become more active network managers within the same time period.

Policy-adaptation guidelines

We offer a set of policy-adaptation guidelines, aimed at supporting the electricity distribution industry transition. These result from the consideration of our study findings, in combination with ongoing policy debates, as discussed in the previous section.

Regarding business model innovation:

- The European Commission and European energy regulators should consider the strong support for policy alternatives associated with evolution and exploration of new possibilities in electricity distribution business models, and the provision of innovative services. While the ongoing transition to a smarter and more sustainable electricity sector strives to build on a liberalised market structure, the analysis of future roles, activities, and responsibilities, should consider disruptive approaches that include all possible future scenarios. This "open-mind" approach to electricity sector restructuring could contribute to the identification of alternatives that might go unnoticed in focusing only on options adjacent to the present market structure.
- Policy – makers and DSOs alike should reconsider the allocation of responsibilities, considering expert support for integration, ownership, and management of electricity storage by DSOs, which differs from the recent proposals in the Clean Energy for All Europeans package.

Regarding technological adaptation:

- The European Commission and the European Technology and Innovation Platform on Smart Networks for Energy Transition (ETIP-SNET) should consider the assessments on R&D engagement and reflect on whether DSOs should be encouraged to achieve specific technology readiness levels. Such decisions might affect the Integrated Strategic Energy Technology Plan, as well as the ETIP-SNET Research and Innovation roadmap for electricity distribution, and the more recent implementation plan being discussed for the period between 2017 and 2020 (ETIP SNET **2017**).
- DSOs should consider the importance of data-related capabilities underpinning industry digitalisation, and assess whether they meet the demands of a data intensive smart grid framework. While DSOs have been largely responsible for data management in the past, significant growth in data volumes and data sources may require new data governance models, new operational capabilities, and new market participants in the industry.

Regarding market design:

- The European Commission, European regulators and National Regulatory Authorities should consider assessments pointing to the relevance of R&D and innovation support policies and define how these can be fostered at the levels of both the EU and individual Member States. In addition, they should focus on how regulatory frameworks, innovation incentives and market design can be combined into an effective policy package.
- The European Commission should consider how it could implement a flexibility market governance model for DSOs.
- Member States governments, and National Regulatory Authorities should consider developing National Smart Grid Actions Plans (i.e.: comparable to the previously mandated National Energy Efficiency Actions Plans, and Renewable Energy Action Plans) to guide the development of new roles, markets, and the delivery of smart grid related societal benefits.

Conclusions

The adaptation of the electricity distribution industry to a smarter and more sustainable electricity sector requires organisational, technological, and institutional changes, which will influence the role and operations of DSOs. We developed a foresight study focused on these aspects to inform the ongoing policy-adaptation process underway in the EU.

We identified challenges for both technological and business model adaptation by DSOs. These are intensified by uncertainty about the role of regulation in facilitating change. However, the experts confirm the importance of expanding DSO strategy, from a focus on core electricity distribution activities, ~~toward~~ towards the introduction of innovative system services. Such a shift in strategy must be supported by disruptive business models and underpinned by changes in current organisational structures, skills, capabilities, and internal processes.

We validate the importance of DSO engagement in all stages of R&D, with a slight preference for piloting and demonstrating proven technologies. We also note the value of collaborative R&D approaches. In addition, the expert assessments emphasize the value of DSO data management capabilities as the distribution industry becomes more digital. Specifically, experts expect benefits from DSOs developing capabilities in data collection, validation, analysis, aggregation, and dissemination to other market participants.

We confirm the importance of a EU vision for DSOs, as well as common rules for TSO-DSO interaction. In addition, to the need for a specific EU-level policy and support body. These EU-level elements are complemented by the relevance of policy actions at the Member State level that support planning (i.e. ~~,~~ through the development of National Smart Grid Action Plans) and experimentation of new approaches (i.e. ~~,~~ services, technologies, business models, and market designs). Furthermore, underpinning both the EU and Member States policy options, the R&D and innovation policy alternatives highlight the importance of support for technological and business model innovation, as well as the need of a market governance model for flexibility.

This paper described the results of a foresight assessment on the future of the electricity distribution industry in the EU, and consequently on the role of DSOs. The size and demographics of the Policy Delphi expert panel are a key strength of this study. The ~~1st~~ First round included 207 experts, while 103 returned in the ~~2nd~~ second round. Additionally, these experts represented a diversity of regions, educational backgrounds, and sector roles, contributing diverse perspectives on DSO-related policy-adaptation. Future work might focus on adapting this EU-level foresight study for the national level. While the recent market redesign proposals evolve into final policies at the EU-level, further information will be needed to inform policy making at the level of Member States.

FundingThe authors acknowledge the Portuguese National Foundation for Science and Technology (FCT) for supporting this work through the Doctoral Grant PD/BD/105841/2014, awarded under the framework of the MIT

Portugal Program funded through the POPH/FSE. Additionally, this work has been partially supported by FCT under Project Grant: UID/MULTI/00308/2013, and SAICTPAC/0004/2015-POCI-01-0145-FEDER-016434, as well as by the Energy for Sustainability Initiative of the University of Coimbra.

Compliance with ethical standards

~~Conflicts~~ Conflict of interest

The authors declare that they have no conflict of interest.

Appendix

See Tables 14, 15 and 16.

Table 14 Research process description

Study stage	Activity	Description
~~1st~~ First stage	Literature review	An initial literature review evaluated the adequacy and impact of different areas of consideration previously deemed relevant to policy-adaptation options and the future of electricity distribution (Pereira and Silva 2016). These areas included organisational, technological, and institutional aspects (Dubois and Saplacan 2010; Kiesling 2016; Kossahl et al. 2012; Markard 2011; Persideanu and Rascanu 2011; Praetorius et al. 2009; Trygg et al. 2007a, b; Tsoukas and Papoulias 2005)~~.~~
	Industry insight collection	We collected industry insight in drafting the initial scope of topics for the Policy Delphi survey. This process involved four interviews with six representatives from three DSO companies, and one interview with one representative from a NRA, see ~~the annex~~ Appendix Table ~~A 2~~ 15 for details~~.~~
	Policy Delphi survey development	Based on the perspectives gathered, the organisational dimension was further structured to focus on business model innovation. The technological dimension was developed to target technological adaptation. The institutional dimension was further specified to consider market design and policy-making. In addition, topics concerned with the role of the DSO and associated transition trajectories were identified as relevant for the study~~.~~
	Survey piloting and validation	The initial draft of the survey was revised by a group of academic researchers and DSO representatives~~.~~
~~2nd~~ Second stage	Expert selection and invitation	The guiding principles for expert selection included:
		Experience in smart grids development, electricity sector, or energy policy development;Interest in the energy transition, and impacts for electricity distribution and DSOs~~.~~
		Based on these criteria, the following communities were identified as relevant sources of experts for the study: the smart grid plus ERA-Net knowledge community (Smart Grids Plus 2017); the European electricity grid initiative (Grid Plus 2017); the European Commission's smart grids task force (European Commission 2017e), national and regional smart grid initiatives in Europe (ETIP Smart Grids 2016); and the International Conference on Electricity Distribution participants community (CIRED 2017)~~.~~
	Iterative Delphi rounds (~~1st~~ First and ~~2nd~~ second round)	The iterative rounds approach in this study was based on two consecutive surveys to experts, distributed through email and using Enuvo GmbH's online survey platform eSurvey Creator for expert data collection (Enuvo 2017)Expert recruitment resulted in 207 participants for the ~~1st~~ First Policy Delphi survey round, of which 103 participated in the ~~2nd~~ second Policy Delphi survey round. The ~~1st~~ First survey included the initial 57 policy alternatives, while the second survey included only the statements where the expert aggregated assessment was below 70% in any of the scales used for data analysis (i.e.: a statement on Business Model ~~Innovation — Strategy~~Innovation—Strategy, operations, and organisational adaptation, for which aggregated expert's rating on the first-round survey is below 70% on any of the data analysis scales, would be included in the second-round survey). The use of a percentage threshold for inter-round statement selection is a commonly used technique in Policy Delphi applications (Loë et al. 2016; Ribeiro and da Silva 2015). Additionally, at the end of each round a customised report was provided to each participating expert, in which the individual assessment was presented as well as the aggregate distribution from the assessments of all the participating experts. The study was conducted between March 2016 and April 2017~~.~~

Table 15 Industry experts consulted for Policy Delphi study design

Entity	Number of interviews	Number of representatives consulted	Interview date	Region of action
National Regulatory Authority	1	1	March 2016	Southern Europe
Distribution System Operator 1	2	3	April 2016September 2016	
Distribution System Operator 2	1	1	May 2016	Northern Europe
Distribution System Operator 3	1	2	June 2016	

Table 16 Survey structure and measurement scales ~~1 to 71 to 71 to 3 1st 2nd 3rd 1 to 71 to 71 to 71 to 71 to 5~~

Topic	Number of policy alternatives				Assessment scale	
	Experts survey					Data analysis
	~~1st~~ First round	~~2nd~~ Second round	Measure of	Type	Label	Scale conversion
Business model innovation						
Adaptation challenges	4	4	Difficulty[a]	1–7	1: Very difficult 7: Very easy	1–3: Difficult 4: Uncertain 5–7: Easy

Strategy, operations, and organisational adaptation	5	1	Agreement[b]	1–7	1: Strongly disagree 7: Strongly agree	1–3: Weak policy alternative 4: Uncertain policy alternative 5–7: Strong policy alternative			
Activities, and responsibilities	19	6							
Technological Adaptation									
Engagement in R&D activities	3	3	Priority[c]	1–3	1:	First priority 2:	Second priority 3:	Third priority	No scale conversion
R&D approach	1	0	Agreement[b]	1–7	1: Strongly disagree 7: Strongly agree	1–3: Weak policy alternative 4: Uncertain policy alternative 5–7: Strong policy alternative			
Electricity distribution digital capabilities	6	0	Importance[d]	1–7	1: Not at all important 7: Extremely important				
Market design									
European Union level policy action	7	3	Importance[d]	1–7	1: Not at all important 7: Extremely important	1–3: Weak policy alternative 4: Uncertain policy alternative 5–7: Strong policy alternative			
Member State level policy action	3	1							
R&D and innovation policy action	4	0							
Electricity distribution industry transition									
Role of the DSOs in the electricity sector	3	1	Agreement[b]	1–7	1: Strongly disagree 7: Strongly agree	1–3: Weak policy alternative 4: Uncertain policy alternative 5–7: Strong policy alternative			
Electricity distribution transition trajectories	2	2	Yearly evolution[e]	1–5	1: DSOs become active network managers by 2017–2020 2: […] by 2021–2030 3: […] by 2031–2040 4: […] by 2041–2050 5: DSOs will not become active network managers	No scale conversion			
Total policy Delphi statements	57	21							

[a]Difficulty scale: 1, Very difficult; 2, Difficult; 3, Somewhat difficult; 4, Neither difficult or easy; 5, Somewhat easy; 6, Easy; and 7, Very easy

[b]Agreement scale: 1, Strongly disagree; 2, Disagree; 3, Somewhat disagree; 4, Neither agree or disagree; 5, Somewhat agree; 6, Agree; and 7, Strongly agree

[c]Priority scale: 1, ~~1st~~ First priority; 2, ~~2nd~~ Second priority; and 3, ~~3rd~~ Third priority

[d]Importance scale: 1, Not at all important; 2, Low importance; 3, Slightly important; 4, Neutral; 5, Moderately important; 6, Very important; and 7, Extremely important

[e]Yearly evolution scale: 1, DSOs become active network managers between 2017–2020; 2, DSOs become

active network managers between 2021–2030; 3, DSOs become active network managers between 2031–2040; 4, DSOs become active network managers between 2041–2050; and 5, DSOs will not become active network managers

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