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Distribution System Operator Observatory 2022

Managing innovation and RES grid connection for a carbon-neutral Europe

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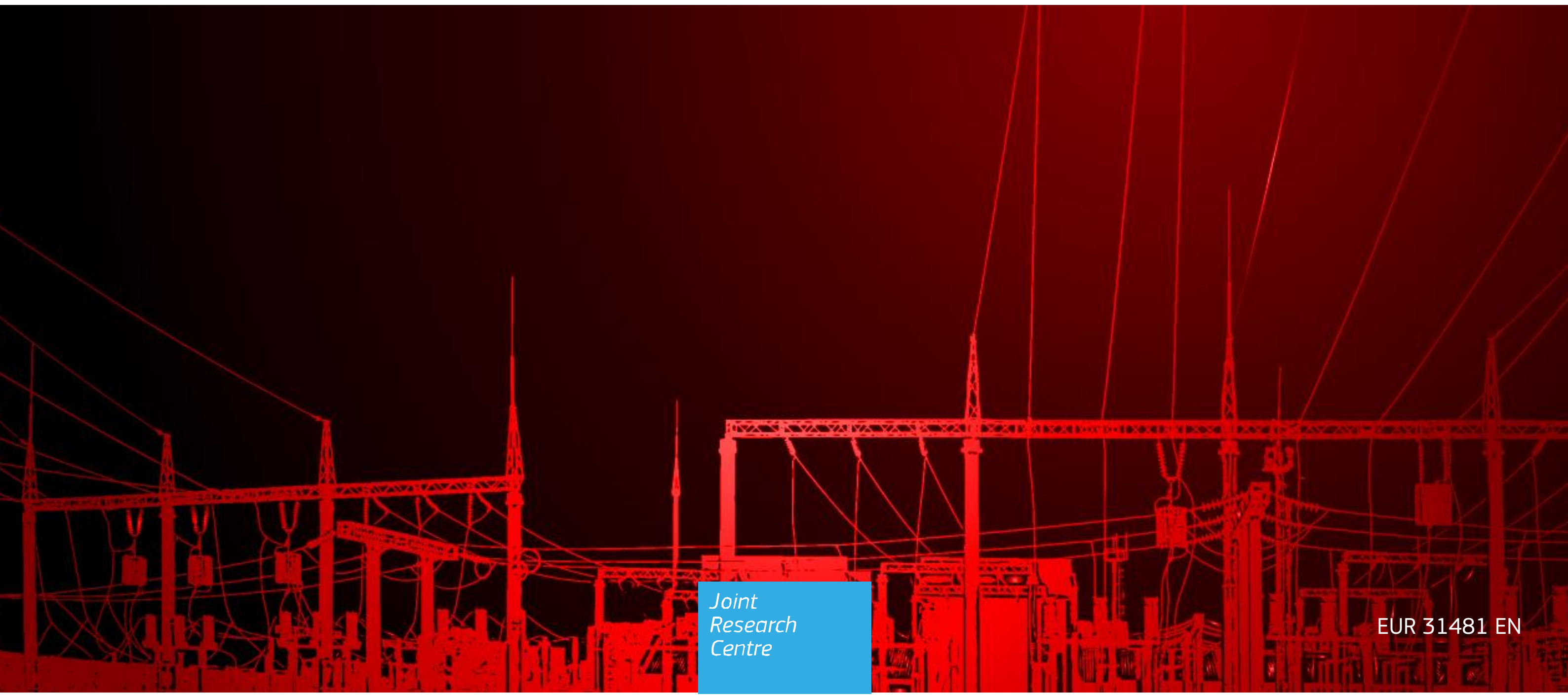

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Abstract

The European energy system is facing unprecedented challenges and the electric power distribution sector is therefore required to move ahead fast with the evolving situation. In 2021, the EU DSO Entity – the association representing the DSOs at European level – has started its operations, placing the sector at the heart of EU energy policy implementation, with new duties and responsibilities. In addition, in 2021, energy market prices have started to soar throughout the continent and the invasion of Ukraine in February 2022 has sparked fire on an already tense situation. The European Union has therefore adopted the REPowerEU plan to reduce the dependency on Russian gas and oil at an accelerated pace. The Distribution System Operators (DSOs) are among the entities impacted by all these different, interrelated dynamics. In view of the above, this new edition of the Distribution System Observatory analyses several emerging tendencies. The urgent request to deploy more and more renewable energy sources at an extraordinary pace to substitute imported hydrocarbons puts pressure on grid operations, while innovative business models and services, like citizen energy communities, and provision of flexibility, start to occupy DSOs' investment plans for the future years. Therefore, both innovation and provision of traditional services like grid connection are put under strain by a tense economic situation for DSO's customers, European consumers and businesses alike. In such fast-evolving situations, regulation cannot focus solely on cost-efficient use of existing infrastructure and investment in grid replacement and reinforcement. To this end, regulatory experimentation has emerged in several EU countries as a novel approach to enable innovation in the energy sector, while protecting consumers and ensuring a fair energy transition for all Europeans.

Foreword

The regulatory approach of the Clean Energy Package has made a significant step towards the shift from the traditional roles of the DSOs in the European Union (EU). The European energy systems are gradually transforming from the «old-fashioned» centric markets into customer-driven digitalised systems with a variety of local electricity markets developed within the operational areas of DSOs.

The Distribution System Operators Observatory 2022 data proves that a vast number of DSOs are already utilizing innovative solutions in their operations, therefore making a substantial contribution, and demonstrating their firm commitment to achieving Fit for 55 targets. For instance, nearly 34% of the DSOs (from 22 countries taking part in this research) procure flexibility services, 45% of DSOs completed and 50% have started to roll out smart meters.

The energy crisis provoked by Russia further accelerated actions taken to reach Fit for 55 targets and reaffirmed the importance and necessity of energy from resources at distribution level. According to the EU action plan on digitalising the energy system[1], EUR 584 billion of investments in the electricity grid will be required between 2020 and 2030 to digitalise and create green and, what is currently more important, resilient energy system. Moreover, the measures proposed by REPowerEU[2] (as one of the EU's first steps to reduce dependency on the Russian gas and accelerate the development of renewables), coupled with the focus on increased distribution grid investments and security of energy supply, will definitely ramp up the development of DSOs` infrastructure. Among others, this will increase the level of smart metering deployment, flexibility procurement mechanisms, use of SCADA and other digital solutions in large and small DSOs across Europe.

Developments of 2022 have also reiterated that DSOs are a real backbone of the energy transition. They may unlock a great potential for renewables in the EU, 70% capacity of which will be connected to the distribution grids by 2030 (Deloitte, E.DSO, and Eurelectric, 2021).

Unfortunately, 2022 has also demonstrated that technological development and smart grid solutions may be negated and threatened by something as unbelievable in the 21st century as the military aggression. The Russian full-scale invasion of Ukraine which started in February 2022 unprecedently impacted, among other things, the energy sector of the whole Europe. Since the beginning of the invasion, Russian troops shelled, damaged, and destroyed about 50% of the critical energy infrastructure of Ukraine worth more than EUR 6.8 billion[4]. Since October 2022, Russia has started frequent and massive missile attacks on Ukrainian major power plants and transmission system operator`s (TSO) substations. In order to keep stability of the system, undermined as a result of the Russian attacks, Ukrainian TSO "Ukrenergo" stopped exporting electricity to the EU and introduced rolling blackouts throughout the country. Some regions were left without electricity, heating, and water supply for up to 30 hours in a row[5]. Ukrainian households could be currently left without electricity supply for 12-20 hours per day. Rapid rebuild and reliability of electricity supply come first in light of these events, and Ukraine is struggling to find necessary materials and equipment.

In reaction to such unforeseen challenges, decentralization of the energy system is essential. It will contribute, among others, to the flexibility and resiliency of the system. Such decentralization is only possible with close cooperation with DSOs, proper regulatory framework, and increased grid investments.

The innovative solutions and tools mentioned in Chapter 4 of this Observatory may prepare EU DSOs for the potential upcoming contingencies. These challenges accelerate the energy transition and DSOs will keep playing essential role in the process. Carbon-neutrality in Europe cannot be reached without a special attention to grid investments and positive dynamics in DSOs' infrastructure digitalisation. I am sure that future editions of the Distribution System Operators Observatories will duly reflect on that.

Oleksandr Fomenko

CEO, DTEK GRIDS LLC

[1] Action Plan on the Digitalisation of the Energy Sector, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0552&qid=1666369684560

[2] REPowerEU, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en

[4] As of November 2022. "The total amount of losses caused to the infrastructure of Ukraine increased to almost $136 billion" — Kyiv school of economics, 2022, https://kse.ua/about-the-school/news/as-of-november-2022-the-total-amount-of-losses-caused-to-the-infrastructure-of-ukraine-increased-to-almost-136-billion/

[5] Temporarily occupied territories and territories close to hostilities may not have access to electricity, heating and water for weeks.

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Authors

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Executive summary

The European Union (EU) is devoted to become a carbon-neutral continent by 2050, in line with its commitment to global climate action under the Paris' Agreement. The European "Green Deal" sets ambitious targets already for 2030 in terms of reduction of Greenhouse Gases Emissions (-55% in comparison to 1990 levels) and use of renewable energy sources (40% of the EU's energy mix).

Policy context

To respond to the recent invasion of Ukraine the EU launched in 2022 the REPowerEU plan, accelerating the energy transition towards carbon-neutral energy sources (mainly RES). The plan calls for energy saving, producing energy from carbon neutral sources, and for diversifying Europe's energy supply. Given that RES are connected to the power system largely through the distribution network, the European Distribution System Operators are called to effectively guide the forthcoming energy transition.

The Distribution System Operator Observatory 2022 presents the results of the JRC's 2022 survey, realised also in cooperation with the newly set up EU DSO Entity, the association of European DSOs established by the Electricity Regulation 2019/243. 56 distribution companies from all over Europe replied to the questionnaire and provided their data about *inter alia* technical characteristics of their networks, level and type of connected distributed energy resources (DERs) as well as regulatory mechanisms in place to incentivise flexibility procurement and provision of other innovative products and services.

Key conclusions

The DSO Observatory provides a unique in-depth view of the energy distribution sector in Europe. Some trends are consolidating with respect to the previous edition in 2020, such as the focus on regulatory innovations like citizen energy communities and the role and value of regulatory experimentation. On the other hand, ensuring a timely and efficient integration of variable renewable energy sources and electrification of other end-use sectors emphasises the critical role of regulation in addressing network challenges associated with the above trends, while enabling a whole range of smart energy technologies and services, including procurement of flexibility services by the DSOs.

The report delivers a nuanced picture of the situation some of the biggest DSOs in Europe face today and highlights the area that might deserve attention at policy level, so that critical aspects are tackled in time to deliver the sought-after energy transition. For instance, regulation for distribution networks needs to be fit for purpose. In other words, regulation cannot be based only on cost-efficiency, but rather promote and facilitate the development of innovative network solutions in light of unprecedented growing rate of renewable energy sources and electrification of other end-use sectors, namely transport and heating. One example in this context is the possibility of DSOs to effectively procure flexibility services from different type of network users, including the ones connected to the LV networks. Also, regulation should allow the best results from regulatory experimentations (regulatory sandboxes, citizen energy communities, etc.) to be replicated at larger scale, while at the same time keep the window open for new experimentations.

In the future such issues (flexibility, grid connection, regulatory innovation) are expected to increase their importance, given the accelerated speed at which recently the European Union has decided to reach its climate and energy goals.

Main findings

The 2022 edition of the Observatory provides an in-depth analysis of the evolving role of the DSOs within the European energy system. We focused on the following aspects of DSOs operations: main electricity network operational data, the ability to connect and effectively manage DERs, the procurement of flexibility in the grid, data management and regulatory experimentation, and the forthcoming first round of Network Development Plans (NDPs) for electricity distribution. Network development will be a crucial activity for the years to come, as moving forward with the energy transition implies replacing a substantial part of the existing distribution grids and equipping them with digital solutions. 80% of the DSOs included in the analysis prepare 5-10 years network development plans, out of which nearly 64% include grid flexibility needs in their plans.

Concerning the connection of DER, the data collected point to an emerging use of flexible connection agreements and flexibility procurement (both market and non-market-based) by the DSOs (mostly wind and solar), though in most of the DSOs included in our analysis, these trends are at an infant stage.

Smart metering, while being already deployed in many of the respondents' network area, is still not adopted in some "pockets", and it seems important that its implementation is encouraged where missing as it provides the basis for a communication layer that will enable a more advanced DSO-customer interaction.

Charging infrastructure for EVs is provided massively throughout Europe: around 1 million charging columns are in the networks of the DSOs included in our analysis, spread among big, medium and small DSOs and pointing to the fact that the dimension of the DSOs does not seem to be so relevant for the deployment of charging infrastructure.

When it comes to regulatory experimentation, around 60% of the respondent DSOs mentioned that they are involved in some type of it, mainly on topics such as smart grids, smart metering and network tariffs. Nearly 40% of the participating DSOs in this study are aware of existing citizen energy communities in their grid.

Another area where appears to be large space for improvement is the procurement of flexibility services: 34% of the DSOs inquired procure flexibility, and they mostly do it thanks to individual arrangement with customers, mainly industrial and commercial and through flexibility tenders/markets, therefore leaving a crucial potential of residential customers mostly untapped at the moment.

Around 60% of the DSOs, exchange real-time measurements SCADA measurements with the TSOs and above 60% of the DSOs included in our analysis perform coordinated operational security analysis with the TSOs. Nearly 50% of the DSOs have above 90% smart metering deployment rate.

Above 70% of the DSOs' businesses are regulated using revenue-cap regulation and close to 60% of the DSOs included in our analysis take part in regulatory experimentation, mainly in the field of smart grids, smart metring, and network tariffs.

Figure 1. Main findings of the DSO Observatory 2022

Number and Size	DER and Flexibility	Data Management	Regulation
56 DSOs from 22 EU Member States	≈ 160 MW of RES connected: PV (45%) wind (39%) hydro (14%)	Almost all DSOs exchange data with the TSO and >60% of them perform coordinated operational security analysis	Above 70% of DSOs' businesses regulated using revenue cap models
25 small DSOs 24 medium DSOs 4 big DSOs 3 urban DSOs	Above 1 mil. EV charging columns reported, nearly all owned and operated by third parties	≈ 60% of DSOs exchange real-time SCADA measurements with the TSO	≈ 45% of DSOs treat R&D costs under specific regulatory mechanism
Nearly 168 mil. of connected customers and above 1600 TWh of avg. distributed annual energy	Above 380 thousand of heat pumps installed (based on the information available to the DSO)	≈ 65% of DSOs share data about generation & demand forecast with the TSO	≈ 60% of DSOs take part in regulatory experimentation on smart grids/metering/tariffs
Close to 6.5 mil. km of network lines	34% of DSOs procure flexibility and ≈ 40% report existence of energy communities in their grids	Nearly 50% of DSOs with >90% of smart metering deployed in their grids	≈ 80% of DSOs prepare 5-10 years investment plan, out of which above 60% include grid flexibility needs

Source: JRC, 2022

Related and future Joint Research Centre work

Joint Research Centre's (JRC) work in the world of electricity distribution takes multiple directions: while the bi-annual DSO Observatory provides the picture of recent developments at distribution level in Europe, additional research work investigates more technical aspects such as the role of adequate grid management and digitalisation in avoiding network reinforcement, creation of typical distribution network model[1] that researchers can use in their investigations, and models for grid planning.

In parallel, the JRC also performs other complementary activities, like the inventories of Smart Grids Projects and Smart Grids Labs and the management of the European Interconnection for Research Innovation & Entrepreneurship (EIRIE) Platform[2] - an interactive multi-functional platform that acts as the meeting point for all actors active in the field of energy research and innovation from all Europe.

Other independent but related research streams are related to Citizens Energy Communities and the role of citizens in the energy transition and the so-called "Living Labs", where regulatory and technical experimentation is put in practice within the JRC sites and laboratories.

Quick guide

The 2022 edition of the DSO Observatory reports on the results of a survey done by the JRC among European companies managing and operating electricity distribution grids. Technical and innovative features are presented, including the use of smart metering, Electric Vehicles infrastructure, regulatory experimentation and the ability to connect an always-increasing number of distributed energy resources (DERs) in the European electricity grid.

[1] See for instance https://ses.jrc.ec.europa.eu/dinemo

[2] Available info on EIRIE Platform at https://ses.jrc.ec.europa.eu/eirie/en/

1. Introduction

1.1. Policy context

The growing integration of renewable generation, the electrification of end-use sectors, such as transport and heat and the digitalisation of the energy sector have led to significant changes in the European energy system over the last decade. Considerable investments in network infrastructure are projected to be required in the next decades to accommodate the above trends (Deloitte, E.DSO, and Eurelectric, 2021) (ENTSO-E, 2021). These investment needs are driven by network upgrades and replacements related to both, integration of variable renewables such as solar and wind, as well as to the progressive electrification of industry, transport and buildings Additionally, modernisation of the grid infrastructure is largely driven by aging EU's grids, where approximately one third of EU's grids is already over 40 years old, trend likely to exceed 50 % by 2030 (Deloitte, E.DSO, and Eurelectric, 2021). On the other hand, diffusion of distributed and variable renewable energy sources, such as wind and solar, of which 70% will be connected at distribution level, digitalisation, as well as policy and regulatory impetus set active customers at the centre of energy transition, which offers significant opportunities for a "smarter" operation and planning of power systems.

These trends place the distribution system operator[3] at the heart of the energy system transformation, thus asking for a more active DSO role in enabling cost-efficient grid utilisation, in view of larger-scale integration of renewable energy into the system and more active customers for EU to be able to deliver on its climate agenda.

In this context, the Electricity Directive 2009/72/EC, Article 25, as part of the 3rd Energy Package[4] adopted in 2009, defines the tasks of the DSOs, among which its role in procuring balancing services while considering energy efficiency, demand-side management measures and distributed generation in the operation and planning of their networks. Furthermore, the Clean Energy for all European package[5] proposal, which came in 2016 and entered into force in 2019, consists of a set of legal acts among which the Renewable Energy Directive (EU) 2018/2001, which in paragraph (24,) calls for 'additional *investments in various sources of flexibility (e.g. demand response and flexible generation) to allow for cost-effective integration of additional renewable energy capacity.* On a similar note, Directive (EU) 2018/2002 on energy efficiency, paragraph (2) endorses that *'energy efficiency and demand-side response can compete on equal terms with generation capacity*'. While this necessitates additional network hosting capacity to accommodate these renewable sources, it also requires smart grid infrastructure to monitor and control growing distribution grid imbalances associated with RES integration and to enable demand-side flexibility.

As part of the same Clean Energy for all European package, Directive (EU) 2019/944 (herewith, also referred as Electricity Directive), Article 31, specifies the obligation of the DSO to "*ensure the long-term ability of the system to meet reasonable demands for the distribution of electricity, for operating, maintaining and developing under economic conditions a secure, reliable and efficient system*". The same Article also identifies the need for close cooperation with relevant TSOs, and definition of products and services to be procured. Furthermore, the Electricity Directive sets the path towards a more active DSO, by defining a set of additional tasks for the DSO, among which the following: (paragraph 5) '*a neutral market facilitator in procuring the energy it uses to cover energy losses in its system in accordance with transparent, non-discriminatory and market-based procedures'*; (paragraph 7) '*the distribution system operator shall procure the non-frequency ancillary services needed for its system in accordance with transparent, non-discriminatory and market-based procedures, unless the regulatory authority has assessed that the market-based provision of non-frequency ancillary services is economically not efficient and has granted a derogation.';* (paragraph 9) *'distribution system operators shall cooperate with transmission system operators for the effective participation of market participants connected to their grid in retail, wholesale and balancing markets.*' Last but not least, Article 32 highlights the importance of development of an adequate regulatory framework '*to allow and provide incentives to distribution system operators to procure flexibility services, including congestion management in their areas, in order to improve efficiencies in the operation and development of the distribution system.*' The same Article calls for DSOs to develop *'a transparent network development plan which shall provide transparency on the medium and long-term flexibility services needed and shall set out the planned investments for the next five-to-ten years, with particular emphasis on the main distribution infrastructure which is required in order to connect new generation capacity*

[3] 'distribution system operator' means a natural or legal person who is 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;

[4] Third energy package (europa.eu)

[5] Clean energy for all Europeans package (europa.eu)

and new loads, including recharging points for electric vehicles. The network development plan shall also include the use of demand response, energy efficiency, energy storage facilities or other resources that the distribution system operator is to use as an alternative to system expansion.'

In parallel, the Electricity Regulation (EU) 2019/943, (article 3) demands adoption of market rules which will '*facilitate the development of more flexible generation, sustainable low carbon generation, and more flexible demand*' and calls for incentives to the DSOs, '*for the most cost-efficient operation and development of their networks including through the procurement of flexibility services'*. Article 53 of the Regulation goes even further by establishing a new entity, the EU DSO with one of its tasks (defined in Article 55) to '*facilitate demand-side flexibility and response and distribution grid users' access to markets'* and '*to facilitate the integration of renewable energy resources, distributed generation and other resources embedded in the distribution network such as energy storage.'*

In December 2019, the European Commission adopted the European Green Deal[6] – an ambitious plan setting up the pathway for EU climate neutrality by 2050, including an intermediate target of '*at least 55% net reduction in greenhouse gas emissions by 2030'.* Actions for decarbonisation of the energy sector to deliver the EU Green Deal include large-scale integration of RES and electrification of the industry, transport, and the building sector. Most of this electrification and growing integration of RES will take place in the distribution grids. To further support the EU decarbonisation goals, in 2020, EU adopted the policy document 'shaping Europe's digital future[7] as part of the EU Digital strategy, which highlights the importance of the twin challenge of green and digital transformation to support the implementation of the EU Green Deal. The most recent Fit for 55 package[8] embraces revision of Europe's climate, energy and transport-related legislation in order to align current laws with the 2030 and 2050 ambitions. As part of this package, both the Renewable Energy Directive and the Energy Efficiency Directive have been proposed for a second revision to align with the EU's increased climate ambition. The proposal for a revised Renewable Energy Directive, reiterates the importance of having national regulatory frameworks, which "*do not discriminate against participation in the electricity markets, including congestion management and the provision of flexibility and balancing services, of small or mobile systems such as domestic batteries and electric vehicles, both directly and through aggregation".* Similarly, the proposal for a revised Energy Efficiency Directive strengthens the value of demand-side flexibility in view of the energy efficiency first principle and calls Member States *'to take into account potential benefits from demand-side flexibility in applying the energy efficiency first principle and where relevant consider demand response, energy storage and smart solutions as part of their efforts to increase efficiency of the integrated energy system.'*

In view of the electrification of the transport sector and as part of the Fit for 55 package, the proposal for Regulation for the Deployment of Alternative Fuels Infrastructure (AFIR) sets mandatory infrastructure targets for the electric vehicle (EV) fleet which will be primarily connected at distribution level – Article 14 (3) of the proposal empowers National Regulatory Authorities to assess the '*contribution of EVs to the flexibility of the energy system'.* On the other hand, DSOs are responsible to assess the flexibility needs, as stated in Article 32 of the Electricity Directive, which sets a requirement for DSOs to conduct a periodical evaluation of flexibility needs in their own network development plans while consulting all interested parties.

The latest European Commission's plan REPowerEU[9] takes a stance on the recent geopolitical and energy market realities and calls on EU Member States to accelerate the clean energy transition and increase Europe's energy independence. Supported by a set of financial and legal measures, REPowerEU commits to massively scale-up deployment of renewable energy sources, as well as accelerate electrification of the end-use sector – both asking for a more active role of the DSOs in the operation and planning of their networks.

Figure 2 summarises the EU energy policies setting the path for the DSO transition into a more active energy player.

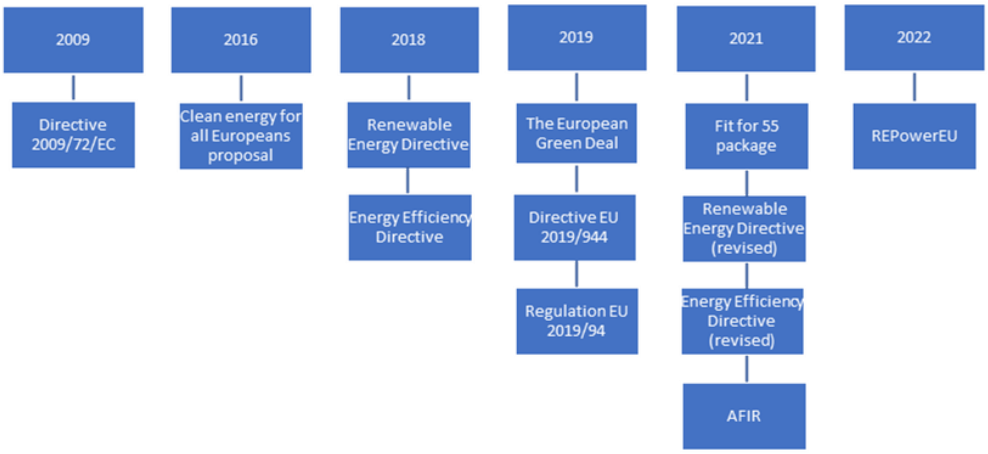
6 European Green Deal (europa.eu)

7 Shaping Europe's digital future | European Commission (europa.eu)

8 Fit for 55 - The EU's plan for a green transition - Consilium (europa.eu)

9 REPowerEU: affordable, secure and sustainable energy for Europe | European Commission (europa.eu)

Figure 2. European energy policies with reference to the DSO transition



Source: JRC, 2022

1.2. Scope of this report

The JRC has since 2015 monitored developments in the distribution systems in Europe and particularly on the state-of-play of distribution networks infrastructure and on the role of distribution system operators. Such developments have been monitored by collecting quantitative and qualitative data about distribution networks in Europe, including number and type of connected users, regulatory frameworks, etc. using a survey approach complemented by an extensive desktop research. The first DSO Observatory was released in 2016 and updated twice, in 2018 and 2020. In 2022, we started a new data collection exercise, with a launch of a revised online questionnaire. Since the release of the first DSO Observatory, the role of European DSOs has evolved significantly – their contribution towards reaching climate-related goals by ensuring a timely and efficient integration of variable Renewable Energy Sources and electrification of other end-use sectors has become central to the European policy framework. As a result, new roles for the DSOs with important implications for the whole power system have been emerging. In this context, and in view of the current energy crisis, the 2022 edition of the DSO Observatory aims to collect and analyse data on both the traditional tasks of the DSOs in Europe, but also on the new possible roles that they will have in the future. To this end, we extend the scope of the study by going beyond purely technical features thereby providing data and insights about more active roles of the DSO, such as procurement of flexibility services, while addressing network challenges arising from the increasing penetration of distributed variable RES and enabling a whole range of smart energy technologies and services.

The report includes a compendium of key facts and figures that can be used to inform and support further analysis. In this sense, knowledge sharing is of fundamental importance to see whether (or not) adequate distribution grid infrastructure is in place and developing fast enough to deliver on the European climate agenda, but also to provide a closer look into the DSO's perspective on whether regulation is fit for purpose to support innovative grid solutions.

The report is structured as follows: Chapter 2 provides a detailed description of the methodology followed for data collection and analysis. Chapter 3 discusses the technical features of the distribution networks included in our analysis, such as number of customers, kilometres and type of network lines, number and characteristics of substations and network reliability indices. Chapter 4 sheds light on the evolving role of DSOs. To this end, we look into the role of the DSO as neutral market facilitator and the importance of data collection and sharing and TSO-DSO coordination to enable *inter alia* network access to growing penetration of variable renewable energy sources, provision of charging infrastructure for electric vehicles and facilitate the development of energy communities. In addition, we provide a special focus on the increasing value of distributed flexibility in view of the current energy crisis and the EU decarbonisation targets. Chapter 5 presents the role of distribution network regulation, analysing aspects such as regulatory incentives and barriers for the DSO to adopt more innovative solutions for the operation and planning of their networks. Finally, Chapter 6 sets out the conclusions of the analysis.

2. Methodology

The JRC has since 2015 monitored developments in the distribution grid area, including the evolving role of the Distribution System Operator (DSO) with the aim to contribute to a better understanding of the challenges brought up by the transition to a new decentralised and decarbonised energy system and the way the European DSOs respond to those challenges.

The first data collection exercise started in 2015, and was updated two times since then, in 2018 and 2020 – both times by using a dedicated survey complemented by an in-depth desktop research. The outcome of these exercises resulted in creation of consolidated documents presenting technical and structural data from European DSOs but also shedding light on policy and regulatory implications. In addition, one of the results of the first data collection exercise was a set of 13 representative network models[10] made publicly available to different stakeholders in the electricity sector, including a development of distribution network model (DiNeMo) web platform in 2018 capable of producing distribution grid models on request.[11]

In the most recent exercise, we want to build our narrative on the current energy crisis, also driven by recent EU legislative energy packages. To this end, in this edition of the DSO Observatory we focus the analysis on the evolving role of European DSOs and more specifically, on their contribution towards reaching climate-related goals by ensuring a timely and efficient integration of variable renewable energy sources (RES) and electrification of other end-use sectors – all this having important implications for the whole power system.

To this end, we launched the DSO Observatory 2022 survey, which ran from July until September 2022, targeting European DSOs with more than 100 000 customers with the aim to collect and analyse data on both the traditional tasks of the DSOs in Europe, but also on the possible new roles that they will have in the future.

The questionnaire contained 9 sections, as described in the below paragraphs.

1. **Contact person**

   This section contains the name and contact details, i.e. email address of the contact person from the DSO organisation.

2. **General information of the DSO**

   This section contains some basic data of the DSO:

   - Legal name and the country where the DSO is registered and active.
   - Area that the DSO serves and the total surface of this area in squared kilometres (km^2).
   - Total distributed energy per year, in GWh.

3. **Technical structural data**

   This section contains technical data on the DSO customers, on the distribution network itself, i.e. lines, cables, substations, etc., and on the network's reliability.

   More specifically:

   - Number of total connected customers, as well as customers connected at LV, MV, and HV network levels.
   - Total km of network lines, as well as km of LV, MV, and HV lines.
   - Total km of underground cables, as well as km of LV, MV, and HV underground cables.
   - Total km of overhead lines, as well as km of LV, MV, and HV overhead lines.

[10] The models are available on: https://circabc.europa.eu/ui/welcome by requesting access to the group JRC Distribution Reference Network Models
[11] DiNeMo is publicly accessible at https://ses.jrc.ec.europa.eu/dinemo through an EU login account

- Total number of HV/MV substations, their voltage ratios in kV (e.g. 110/10kV, 220/20kV, etc.), and their total installed capacity in MVA.
- Total number of MV/LV secondary substations, their voltage ratios in kV (e.g. 20/0.4kV, 0/0.4kV, etc.), and their total installed capacity in MVA.
- System Average Interruption Duration Index (SAIDI), in minutes per customer per year for all customers and, in cases when the DSO has available data, also for LV, MV, and HV customers, separately.
- System Average Interruption Frequency Index (SAIFI), in number of interruptions per customer per year for all customers and, in cases when the DSO has available data, also for LV, MV, and HV customers, separately.
- Other possible reliability indices that the DSO might use, as total values and, if available for LV, MV, and HV customers, separately. Such indices could be for example: Customer Average Interruption Duration Index (CAIDI), Average System Interruption Duration Index (ASIDI), etc.

4. DER, electromobility and renewables

This section contains information on DER, electromobility infrastructure (EV charging columns), and energy storage connected to the DSO network. More specifically:

- Total number of charging columns (and possibly plugs), as well as number of charging points owned and operated by the DSO itself or by third parties.
- Installed PV capacity and percentage of PV installations connected to the LV, MV, and HV network levels.
- Installed capacity of wind power generation connected to the distribution grid and percentage of wind installations connected to the LV, MV, and HV network level.
- Installed capacity of biomass power generation connected to the distribution grid and percentage of biomass installations connected to the LV, MV, and HV network level.
- Installed capacity of geothermal generation connected to the distribution grid and percentage of geothermal installations connected to the LV, MV, and HV network level.
- Installed capacity of hydro power generation connected to the distribution grid and percentage of hydro installations connected to the LV, MV, and HV network level.
- Installed capacity of utility-scale power storage connected to the distribution grid and percentage of utility-scale storage installations connected to the LV, MV, and HV network level.
- Total capacity (MW) of DER (including type of generation technology) connected to the distribution grid through flexible (conditional) connection agreements.
- Total number and installed capacity of heat pumps connected to the distribution network.
- Type of customers (residential, commercial, industrial) mostly installing heat pumps.

5. DSO as user of flexibility services

- Type of market players that DSOs mostly procure flexibility from.
- Type of flexibility services DSOs mostly procure.
- Type of network users (residential, commercial, industrial) from which DSOs mostly procure flexibility services.
- The way flexibility is mostly procured (market vs. non-market based).
- Existence of citizen/renewable energy communities or energy cooperatives in the network of the DSO.
- Number and size of such communities (number of consumers and the total energy consumption, as well as percentage of total energy consumption that is self-produced).

6. DSO-TSO coordination

- Demand and generation forecasts data exchanged between DSO and TSO, frequency of sharing such data and whether it is on a voluntary or mandatory basis.
- Scheduled data of each power-generating facility exchanged between DSO and TSO, frequency of sharing such data and whether it is on a voluntary or mandatory basis.
- Real time measurements (SCADA) exchanged between DSO and TSO, frequency of sharing such data and whether it is on a voluntary or mandatory basis.
- Ex-post measurements (metered data) exchanged between DSO and TSO, frequency of sharing such data and whether it is on a voluntary or mandatory basis.

- Type of data about network condition (e.g. performance of generation assets, demand-side response etc.) the DSO receives from other DSOs or the TSO.
- The way DSO exchanges data with other DSOs or the TSO (e.g. using data exchange platform).
- Whether (or not) the DSO performs any coordinated operational security analysis together with the TSO.

7. Smart metering

- Percentage of end-customers equipped with a smart meter to date (according to Dir. 72/2009, 80% of electricity consumers by 2020).
- Whether (or not) the already installed electricity meters are digital and bi-directional.
- Use of smart meters, and more specifically for grid management tasks, grid control tasks, distribution-planning tasks.

8. Data Management System

- Use of SCADA system or similar one.
- Type of control tasks the DSO can perform, and more specifically, substation control, feeder control and end-user load control.

9. Regulatory aspects

- Type of regulatory system in place to regulate DSO business (revenue-cap, price-cap, cost-plus, other).
- Duration (in years) of the current regulatory period.
- The approach used for treating costs (TOTEX vs. non-TOTEX).
- Type of quality incentives included in the calculation of the revenues.
- Whether (or not) efficiency benchmarking is applied to the calculation of the approved cost and if yes, what costs (e.g. TOTEX, controllable OPEX) are subject to efficiency benchmarking.
- The way R&D costs are treated within the adopted regulatory mechanism, including the type of R&D pilot investments incentivised.
- Main DSO innovation priorities in the next 5-10 years.
- Method used for calculation of the Rate of Return (RoR).
- Level of Weighted Average Cost of Capital WACC (%) for 2022.
- Whether (or not) the DSO take part in a regulatory experimentation and if yes, what kind of experimentation (e.g. regulatory sandboxes, pilot projects, etc.).
- Whether (or not) the DSO prepares a distribution network development plan and if yes, what are the national requirements for preparation of such plans.
- Whether (or not) the network development plans consider the medium- and long-term flexibility needs for the next five-to-ten years, according to the electricity Directive, article 32 (3).
- Type of network tariffs used for remuneration of the DSO activities (fixed, capacity-based, volumetric and/or mixed).
- Major barriers, if any, for the DSO to transition into a more active system operator.

We have collected data from 56 DSOs, which represent around half of the EU DSOs with more than 100,000 customers (i.e. those regulated by the EU unbundling rules). The responding DSOs widely differ in terms of number of customers connected, area of distributed activity and distributed annual energy. In this respect, we have categorised the DSOs based on the three criteria above and using the approach proposed in (Prettico et al, 2022). Table 1 shows the criteria for the DSO categorisation. For instance, a DSO is considered small, if it operates in an area higher than 1000 km^2 and distributes annually less than or equal to 10 GWh of electricity per squared kilometre in its area. Based on this classification, we included in our analysis 25 small-size DSOs, 24 medium-size DSOs, 4 big-size DSOs and 3 urban types of DSOs.

Table 1. Categorisation criteria for DSO's size

Type	Area (km^2)	Energy (GWh/ km^2)	Customers (millions)
Small	> 1000	≤ 10	≤ 1
Medium	> 1000	≤ 10	> 1 & ≤ 10
Urban	≤ 1000	> 10	-
Big	> 1000	-	> 10

Source: JRC elaboration based on Prettico et al., 2022

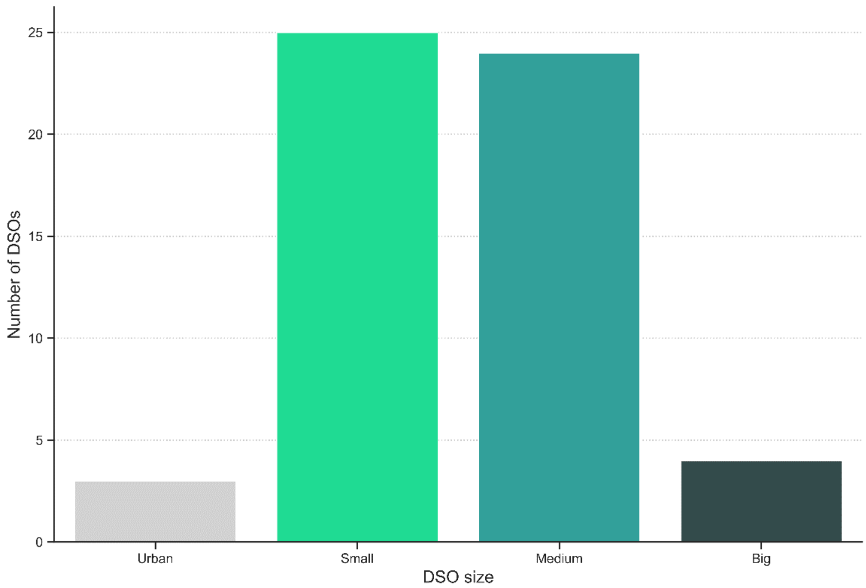
3. DSO technical features

This section presents a first technical perspective emerging from the collected data. Several insights can be obtained by looking at the data from an aggregated point of view. With this aim, the categorisation introduced in section 2 (Table 1) is used to distinguish between different approaches used by the DSOs included in the same category.

3.1. Type of DSOs and number of customers

The majority of the 56 DSOs participating in our study fall in the small and medium category, with 25 and 24 operators, respectively (Figure 3). Only a few DSOs in the sample belong to the urban and big category, 3 and 4 respectively. Additionally, it is worth mentioning that since our survey was conducted on a voluntary basis, it was not always possible to collect all the responses for each one of the technical indicators shown in the following.

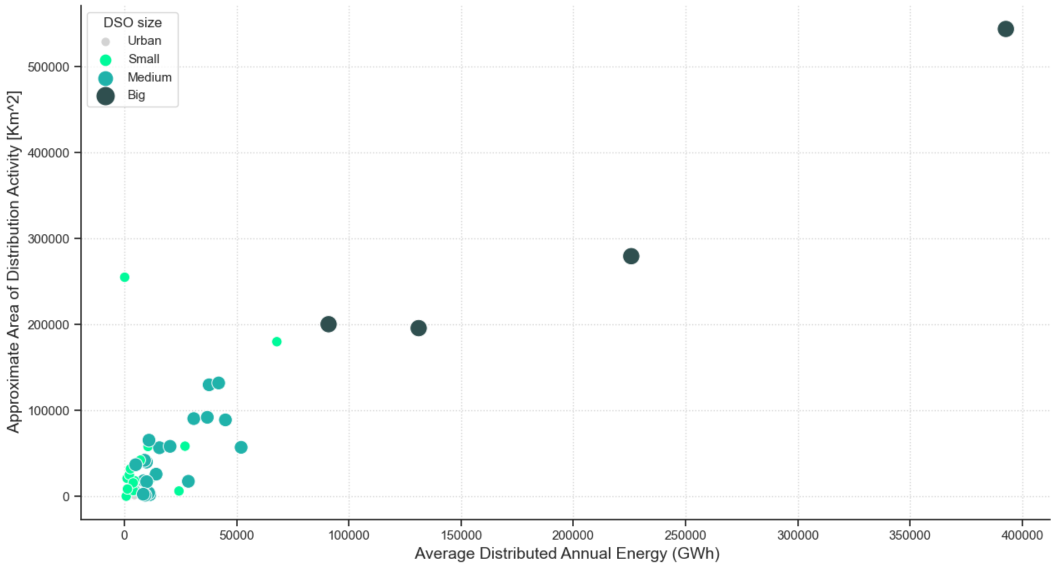
Figure 3. Categorisation of the DSOs included in our analysis



Source: JRC, 2022

Figure 4 provides an overview of the dimension of the DSOs included in this survey, in terms of geographical area of distribution activity and average distributed annual energy. Most of them distribute below 50000 GWh of energy per year, with few notable exceptions (6 DSOs out of 56), most of them being big DSOs. As expected, there is a sort of linear relationship between geographical area size and the amount of energy distributed.

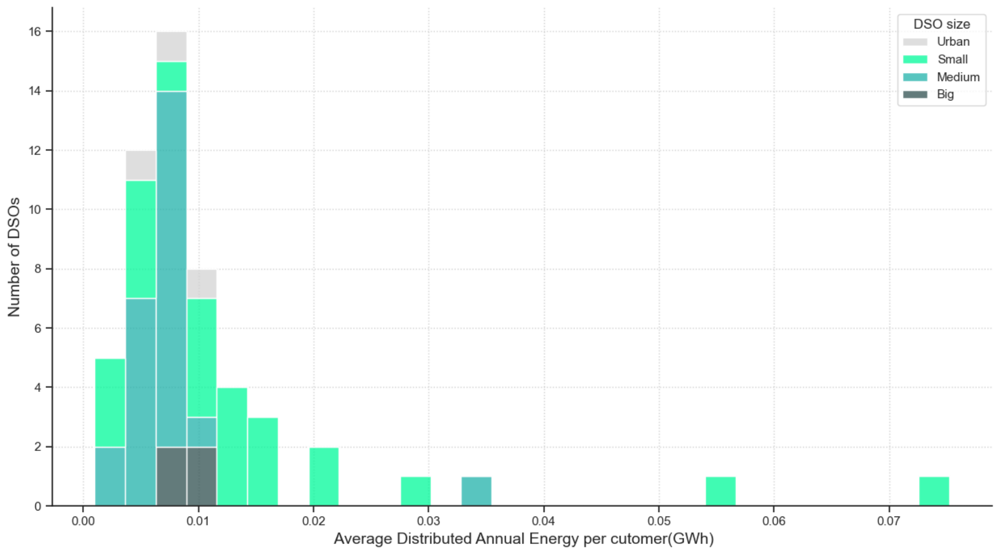
Figure 4. Area supplied vs. distributed energy



Source: JRC, 2022

A more informative picture is offered by Figure 5 where the electricity distributed during the year has been normalised with respect to the total number of customers served by each DSO. Most of the DSOs supply on average less than 15 MWh of electricity per year per customer and a few ones above 15 MWh, thus serving also customers directly connected to the MV and HV network.

Figure 5. Average distributed annual energy per customer

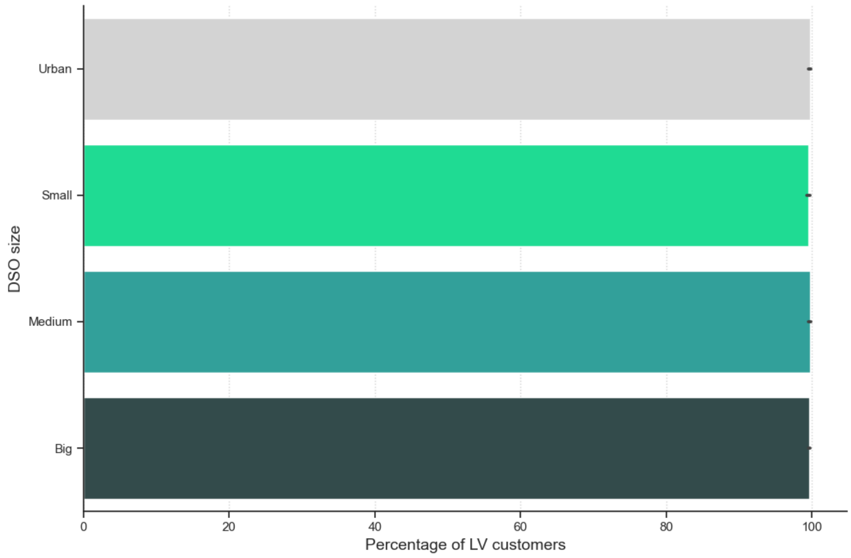


Source: JRC, 2022

Figure 6 and Figure 7 can help us deepen our understanding on the type of customers connected to the different DSOs. Figure 6 illustrates that most DSOs in each cluster have more than 99.5% of LV customers. However, although every cluster has on average 0.3% of the total MV customers, small DSOs can reach up to a 0.7%

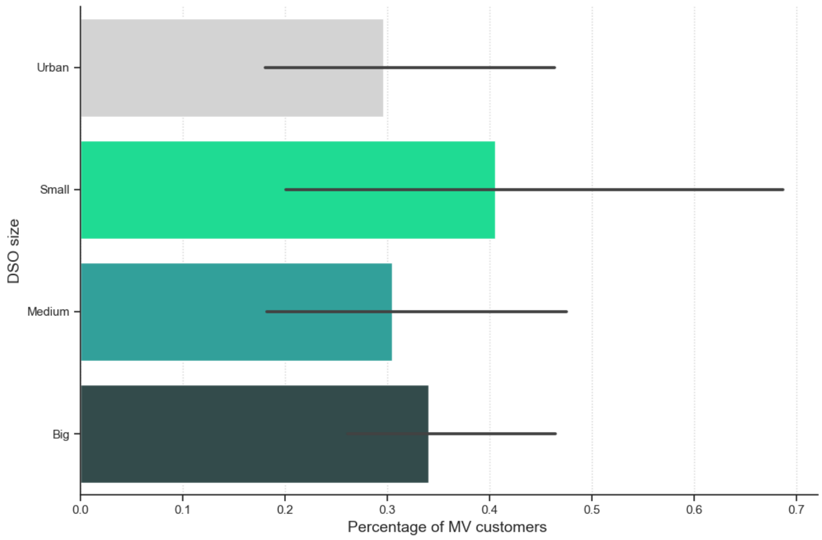
(Figure 7), which could explain the higher energy per customer ratio in Figure 5. The black line on the bars indicates the variation of the indicator with respect to the average value reported. The HV customers figure has not been reported due to the negligible level present in each cluster.

Figure 6. Percentage of LV customers per DSOs cluster



Source: JRC, 2022

Figure 7. Percentage of MV customers per DSOs cluster

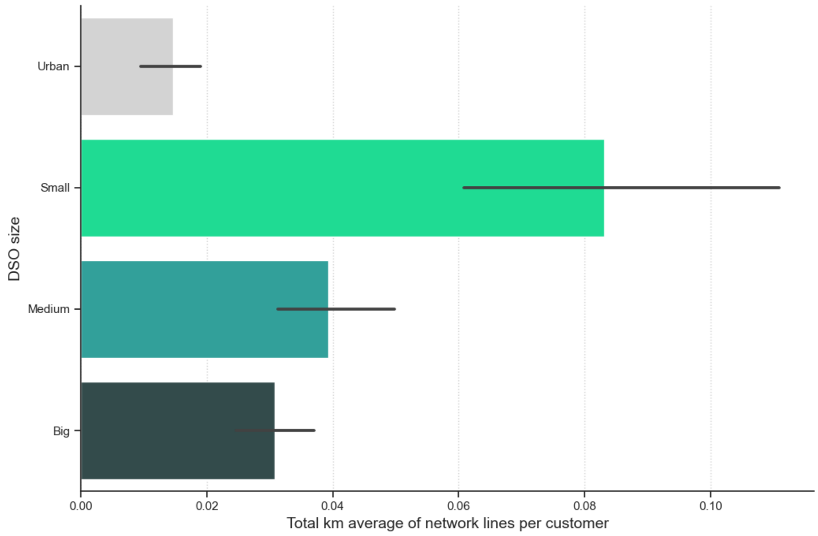


Source: JRC, 2022

3.2. Type and length of network lines

Figure 8 illustrates the relative dimension of the network with respect to the number of customers. Once again, small DSOs show somewhat different figures with respect to the other clusters. Higher average network lines length per customers might imply presence of a more disperse distribution of customers which require longer cables/lines to serve them. This seems to suggest an interesting insight on investment needs of European DSOs: often the biggest share of the investment need is borne by small DSOs, which have lengthier networks in comparison to their size. From a different perspective, it is important to stress that investments are not only related to cabling but also to network digitalisation, for example for network monitoring and control, or better known as non-traditional investments.

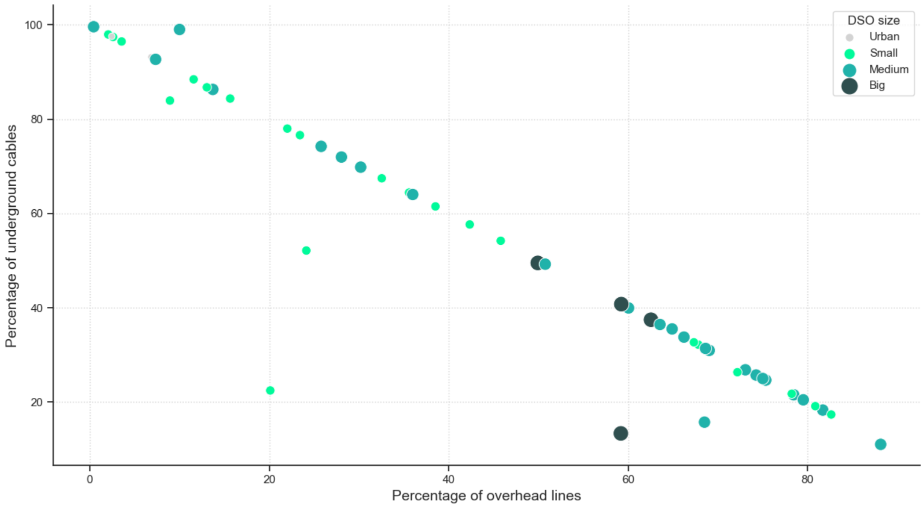
Figure 8. Average km of network line per customer



Source: JRC, 2022

Figure 9 shows the relative size of underground and overhead cables over the total length of each DSO's network. Bigger DSOs have a higher share of overhead lines, in comparison to smaller or urban DSOs. Generally, the ratio between overhead lines and underground cables is geographically related, for example, in the north of Europe, it is more likely to find higher levels of underground cables.

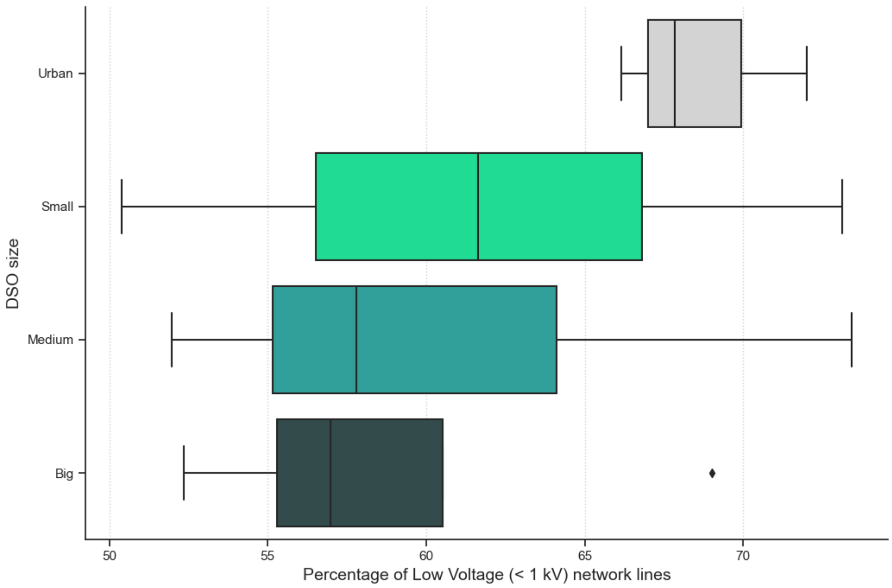
Figure 9. Overhead and underground lines as a share of total network lines



Source: JRC, 2022

Figure 10 presents the percentages of LV lines (over the total lines length) per each DSOs cluster. Urban DSOs show higher share of LV network lines, with percentages between 66% and 70% (mean value around 68%), whereas for the other clusters, these values are slightly lower ranging from 55% to 66%.

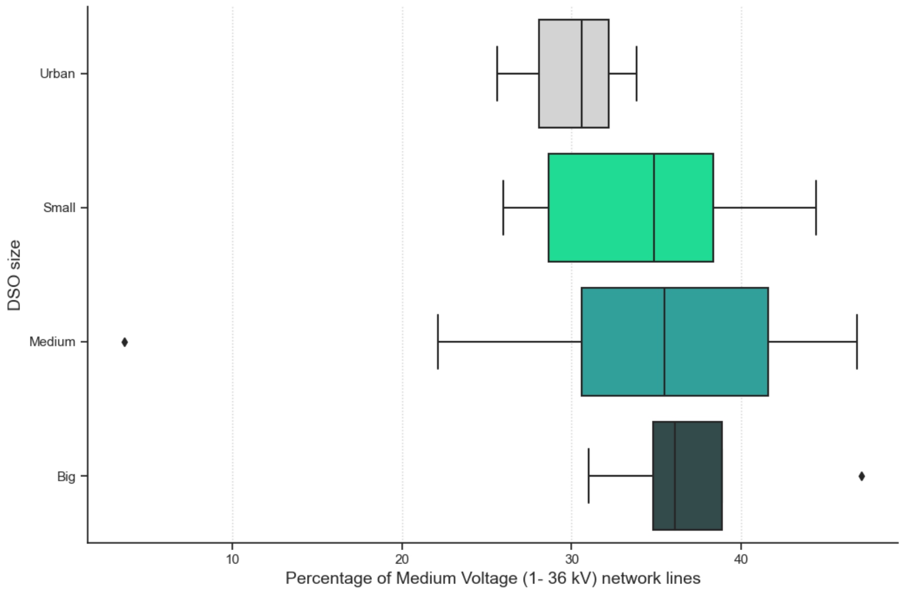
Figure 10. Share of LV network lines over total network lines per DSO cluster



Source: JRC, 2022

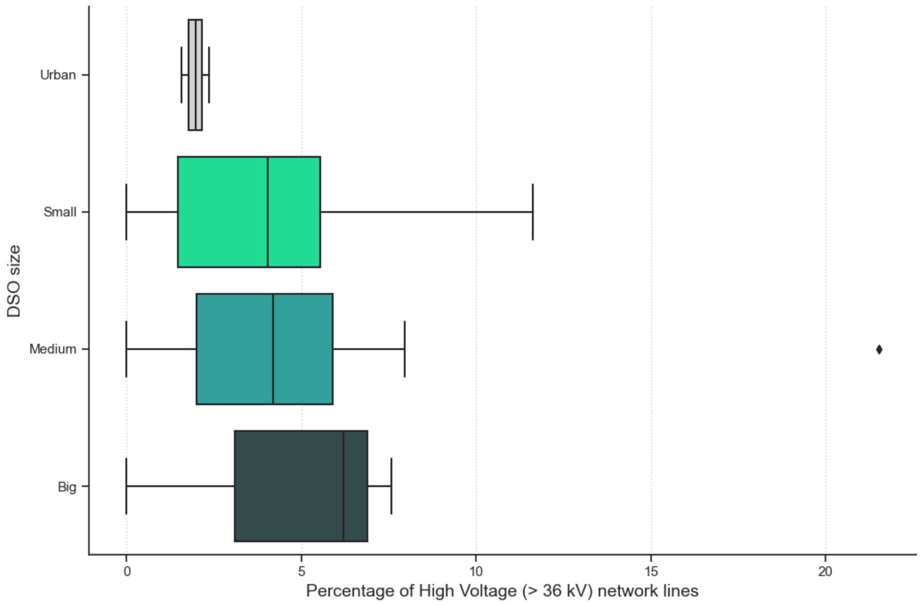
Figure 11 presents the percentages of MV lines (over the total lines length) per each DSOs cluster. In this case, while urban DSOs are more concentrated (with a mean around 30%), the remaining DSOs are generally above 35% and present larger distribution intervals. Figure 12 presents the percentages of HV lines (over the total lines length) per each DSOs cluster. Also in this case, while urban DSOs are very concentrated (with a mean around 2%), the other clusters are more spread (with a mean around 5%).

Figure 11. Share of MV network lines over total network lines per DSO cluster



Source: JRC, 2022

Figure 12. Share of HV network lines over total network lines per DSO cluster



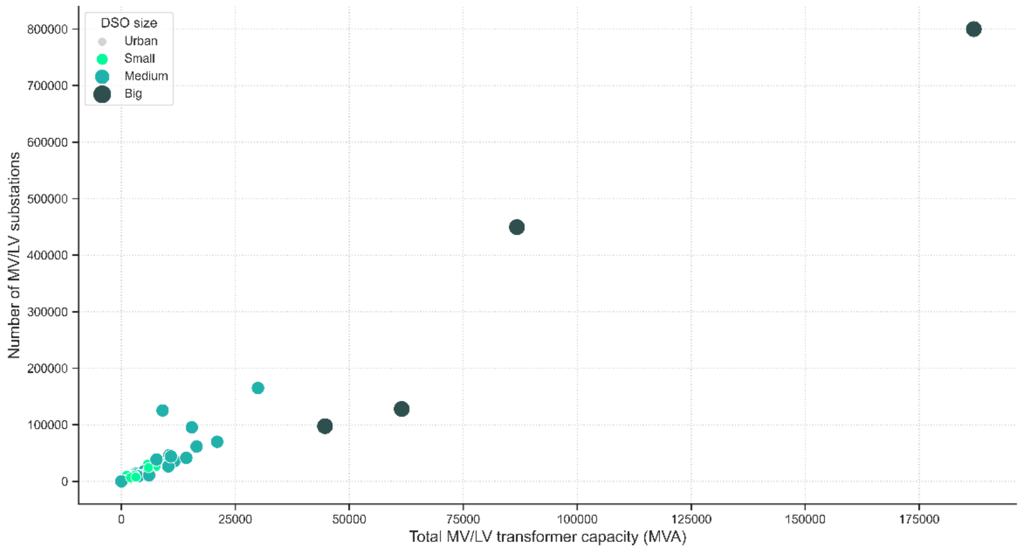
Source: JRC, 2022

3.3. Number of substations, voltage levels and installed capacity

In this section the focus is on technical characteristics of the distribution networks such as capacity of transformers and their relationship with substations and voltage levels. Figure 13 and Figure 14 show that the bigger DSOs have by far the highest transformer capacity available, both at MV/LV level and at HV/MV level.

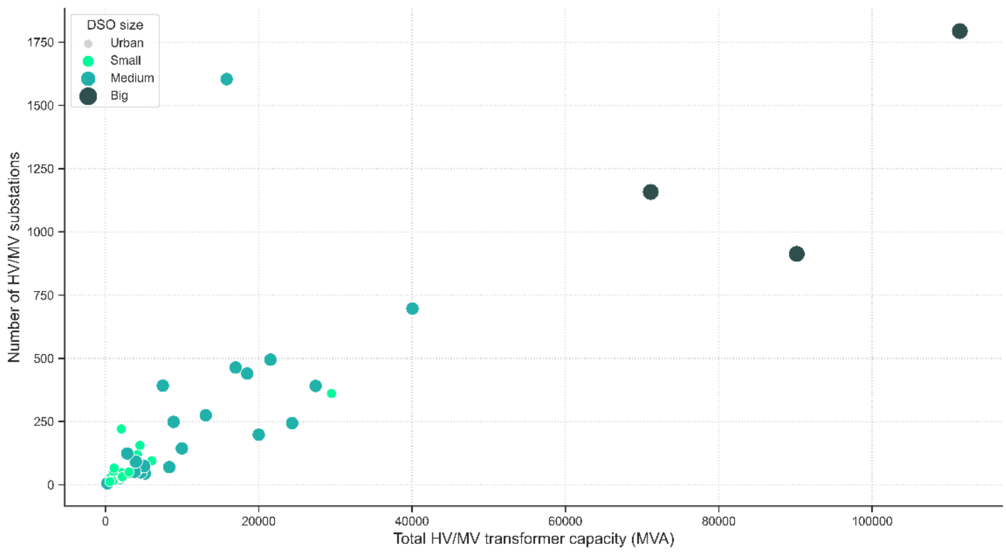
These figures have important implications in terms of ability of the DSO to integrate higher level of RES energy in their system. As expected, both figures show a sort of linear relation between the number of substations and the total installed capacity.

Figure 13. Total MV/LV transformer capacity by number of MV/LV substations



Source: JRC, 2022

Figure 14. Total HV/MV transformer capacity by number of HV/MV substations



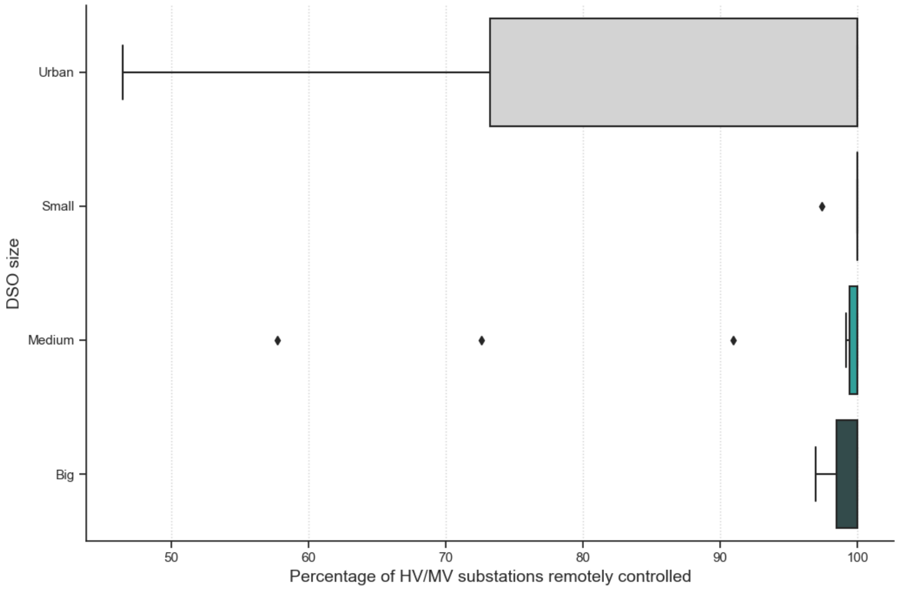
Source: JRC, 2022

3.4. Remotely controlled substations and reliability indexes

This section presents the state-of-art about remote control of substations. Looking at Figure 15 it is evident that nearly all DSOs in the surveyed sample have almost 100% of the HV/MV substations remotely controlled.

This fact ensures that DSOs can reliably operate the network by acting promptly whenever outages are due to the malfunctioning of the HV/MV transformers.

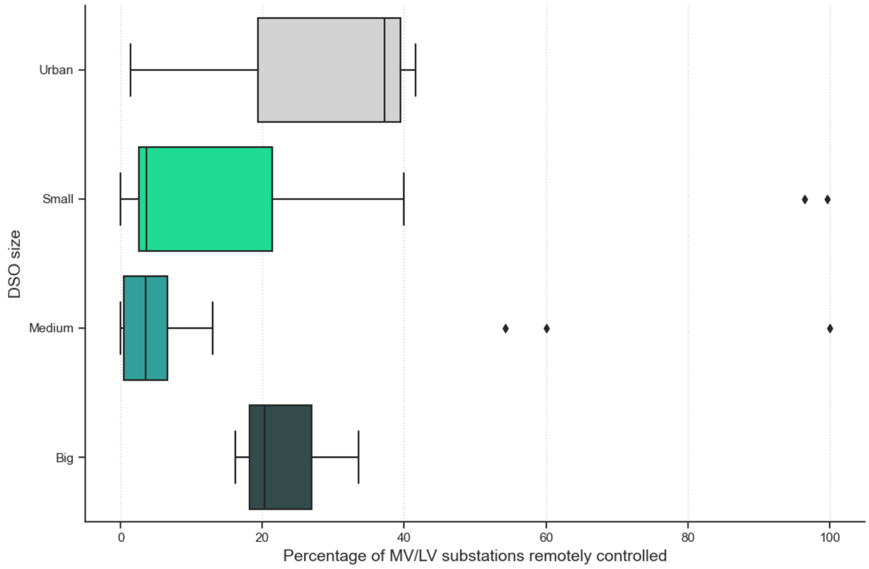
Figure 15. Percentage of remotely controlled HV/MV substations per DSOs cluster



Source: JRC, 2022

The situation is quite different when moving to MV/LV substations. As highlighted in Figure 16, apart from urban DSOs which have between 20% and 40% of their MV/LV substation remotely controlled, the remaining clusters have very low percentages of MV/LV substation remotely controllable, thus having an implication on the network operation performances and on reliability levels. It is important to foster investments on technologies which could help better control MV/LV transformers to improve the quality of supply of MV and LV network connected customers.

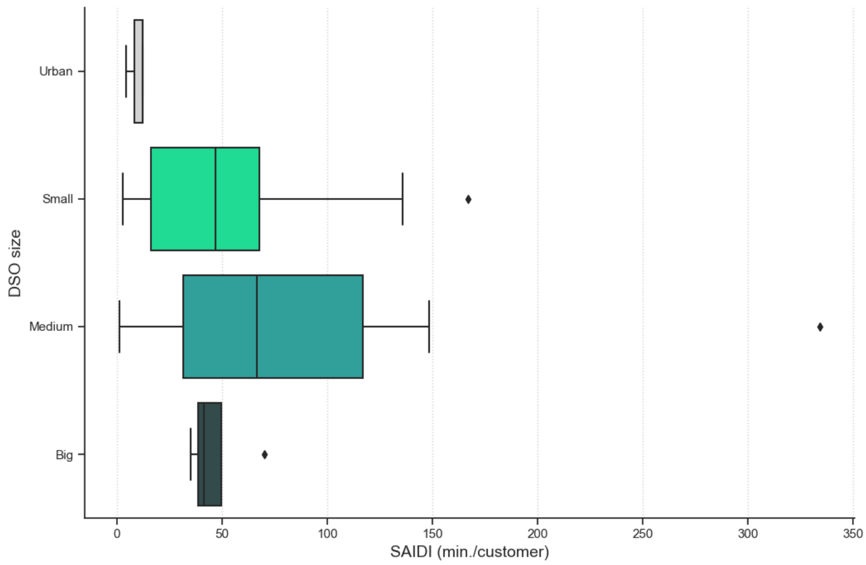
Figure 16. Percentage of remotely controlled MV/LV substations per DSOs cluster



Source: JRC, 2022

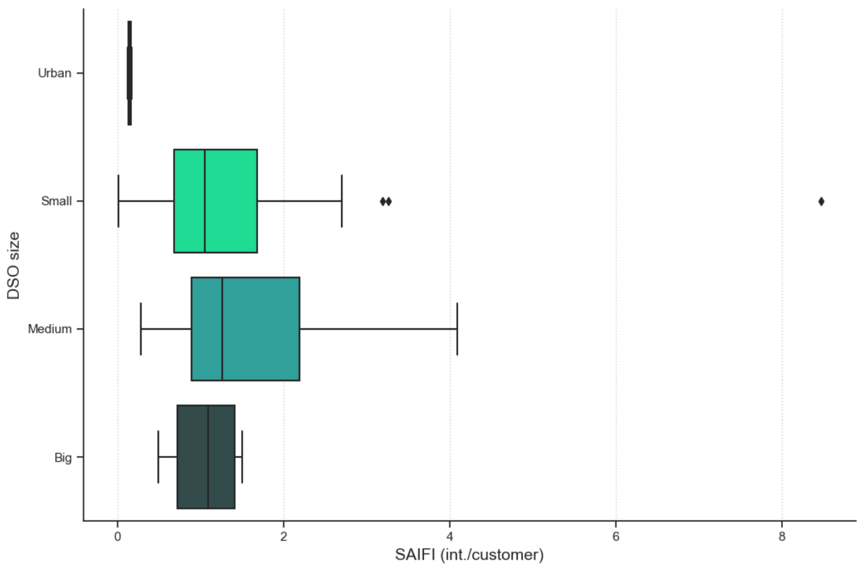
Regarding the reliability figures (Figure 17 and Figure 18), the most common indicators used at European level are the SAIDI (System Average Interruption Duration Index) and the SAIFI (System Average Interruption Frequency Index). In a nutshell, these indicators indicate for every year the average duration and number of supply interruptions that customers face. Urban DSOs normally face shorter interruptions duration and less frequent ones. This could be attributed to the network size (smaller and better-connected portion of area) and the meshed topology of networks which can make use of alternative paths through substations to supply clients affected by an outage. Big DSOs having a mixed set of topologies to be operated (urban, semi-urban, rural) generally face higher levels of SAIDI and SAIFI when compared with urban DSOs. The same happens for small and medium sized DSOs which register on average higher levels of interruptions and higher distribution intervals when compared with big DSOs. This might be due to the topology of the networks they operate which are more widespread and typically have a radial topology.

Figure 17. SAIDI per DSOs cluster



Source: JRC, 2022

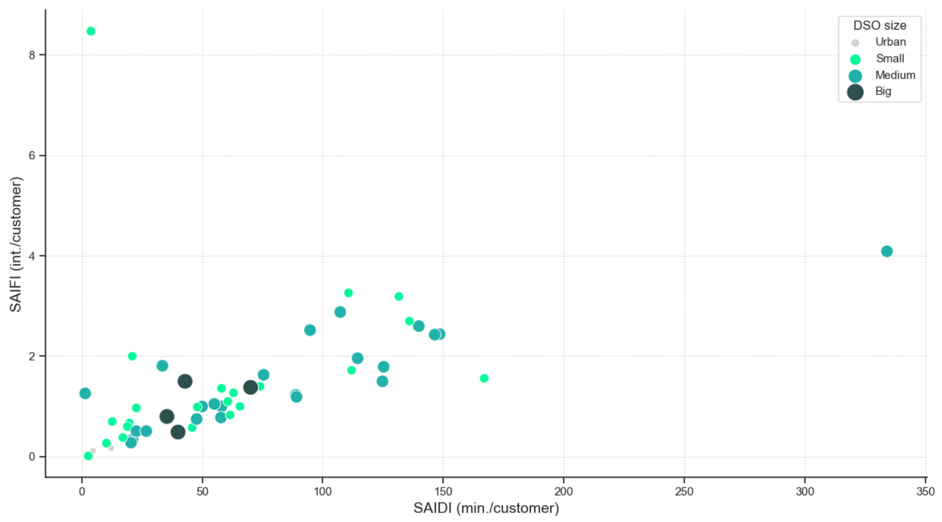
Figure 18. SAIFI per DSOs cluster



Source: JRC, 2022

By plotting a scatterplot of the SAIDI (x-axis) and SAIFI (y-axis) levels (Figure 19), we can see that certain DSOs face the same number of interruptions (same SAIFI value) though the duration of the interruption is considerably longer (higher values of SAIDI). This might be due to a more efficient management of the interruptions (better monitoring, faster time of crew intervention, etc.).

Figure 19. SAIFI vs SAIDI



Source: JRC, 2022

Finally, 24% of the DSOs included in our survey do not monitor SAIDI and SAIFI per voltage level, which can be consider as a barrier to better network monitoring and as a result prevent the deployment of a more targeted set of investments in the company assets.

4. Evolving role of the DSO

Over 7 million km of electricity networks in the EU needs to be renewed until 2050, which corresponds to two-thirds of those networks in place today (IEA, WEO, 2022). Lines, cables, and transformer capacity will present the main strain of electricity networks, however digital technologies will also play a significant part of the investment. The distribution sector accounts for around 75% of all investment in digital infrastructure (IEA, Smart Grids, 2022) – with rollout of smart meters, automation of substations, feeders, lines, and transformers via the deployment of sensors and monitoring devices being one of the main areas of digitalisation. Digital investment in distribution also includes network digital twins and non-wire alternatives, such as flexibility services and distributed storage systems. Furthermore, growing penetration levels of variable renewable energy sources (RES) – as main technological option for decarbonising the energy system – together with electrification of other end-use sector, such as heating and transport, is already exerting stress on transmission and distribution networks.

Digital technologies are critical in responding to those challenges, by enabling grid access to different renewable technologies and empowering customers to accelerate the clean energy transition. To this end, the process of scaling-up renewable generation needs to be closely coordinated with and integrated across multiple energy carriers *to 'unlock additional flexibility for the overall management of the energy system and in turn help to integrate increased shares of variable renewable energy production.'*[12]

To accommodate these trends significant investments in distribution network infrastructure will be required in the next decades, between 50%-70% compared to today (Deloitte, E.DSO, and Eurelectric, 2021) (ENTSO-E, 2021). In addition, the current practices of the distribution network operation, management and planning need to be revisited, thereby calling up for more active role of the DSOs – from neutral market facilitator to actively procuring flexibility services to be able to effectively respond to network constraints or as an alternative to traditional network reinforcements.

To this end, in this edition of the DSO Observatory we look deeper into roles of the DSOs beyond the traditional ones, by also highlighting the importance of adequate regulatory and market incentives to facilitate the transition into a more active and engaged DSO. Figure 20 provides an overview of the main findings, including 4 (four) core areas of research interest: 1) number and size of DSOs, 2) level and type of DER capacity installed, together with procurement of flexibility services, 3) data management and 4) regulation of the DSO's businesses.

We have collected data from 56 DSOs coming from 22 different EU Member States, widely differing, in terms of number of customers connected, area of distributed activity and distributed annual energy. To this end, and using the methodology described in Chapter 2, we have categorised the 56 DSOs into small (25) and medium (24), big DSOs (4) and urban DSOs (3), together comprising close to 6.5 km of network lines. The total number of customers connected to the distribution networks of all DSOs included in our analysis account to nearly 168 million with a total average distributed energy above 1600 TWh. The total installed capacity of distributed renewable energy sources sums to nearly 160 MW, out of which mainly PV, wind and hydro. Above 1 million of EV charging columns were reported by the DSOs, mainly operated by third parties. 16 out of 56 DSOs included in our analysis indicated the number and possibly installed capacity of heat pumps in their networks, adding up to a total of above 380 thousand heat pumps. However, as most of the heat pumps are installed at residential customers' premises, most of the DSOs do not have information about the number of installed heat pumps in their grids.

As for the use of flexibility services, 34% of the DSOs procure flexibility for various services and close to 40% report existence of energy communities in their grids. The need for a DSO-TSO data exchange emerges clearly: DSOs need to exchange data on a number of topics and large part of them (above 60%) perform coordinated operational security analysis[13] together with the TSO. 11% of the DSOs included in our analysis exchange data at least every 15 min about demand and generation forecast and about 16 % of the DSOs about scheduled data of each power generating facility. Nearly 50% of the DSOs report deployment rate of smart metering above 90%.

[12] EU strategy on energy system integration (europa.eu)
[13] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32017R1485

Regulation that is fit-for-purpose plays a major role in incentivising DSOs to cost-efficiently manage, operate and plan their networks. For most of the DSOs included in our analysis, incentive regulation (revenue-cap) is used for regulating their businesses, both by using TOTEX[14] and non-TOTEX approach.

Nearly 45% of the DSOs use specific regulatory mechanism for treating R&D costs and close to 60% take part in regulatory experimentation on various topics related to smart grids, smart metering, and network tariffs.

A considerable number of DSOs (80%) prepare five-to-ten years network development plan, in accordance with the Electricity directive, article 32 (3), out of which above 60% include flexibility needs of their grids and services acquired, as part of their network development plans.

Figure 20. Main findings of the DSO Observatory 2022

Number and Size	DER and Flexibility	Data Management	Regulation
56 DSOs from 22 EU Member States	≈ 160 MW of RES connected: PV (45%) wind (39%) hydro (14%)	Almost all DSOs exchange data with the TSO and >60% of them perform coordinated operational security analysis	Above 70% of DSOs' businesses regulated using revenue cap models
25 small DSOs 24 medium DSOs 4 big DSOs 3 urban DSOs	Above 1 mil. EV charging columns reported, nearly all owned and operated by third parties	≈ 60% of DSOs exchange real-time SCADA measurements with the TSO	≈ 45% of DSOs treat R&D costs under specific regulatory mechanism
Nearly 168 mil. of connected customers and above 1600 TWh of avg. distributed annual energy	Above 380 thousand of heat pumps installed (based on the information available to the DSO)	≈ 65% of DSOs share data about generation & demand forecast with the TSO	≈ 60% of DSOs take part in regulatory experimentation on smart grids/metering/tariffs
Close to 6.5 mil. km of network lines	34% of DSOs procure flexibility and ≈ 40% report existence of energy communities in their grids	Nearly 50% of DSOs with >90% of smart metering deployed in their grids	≈ 80% of DSOs prepare 5-10 years investment plan, out of which above 60% include grid flexibility needs

Source: JRC, 2022

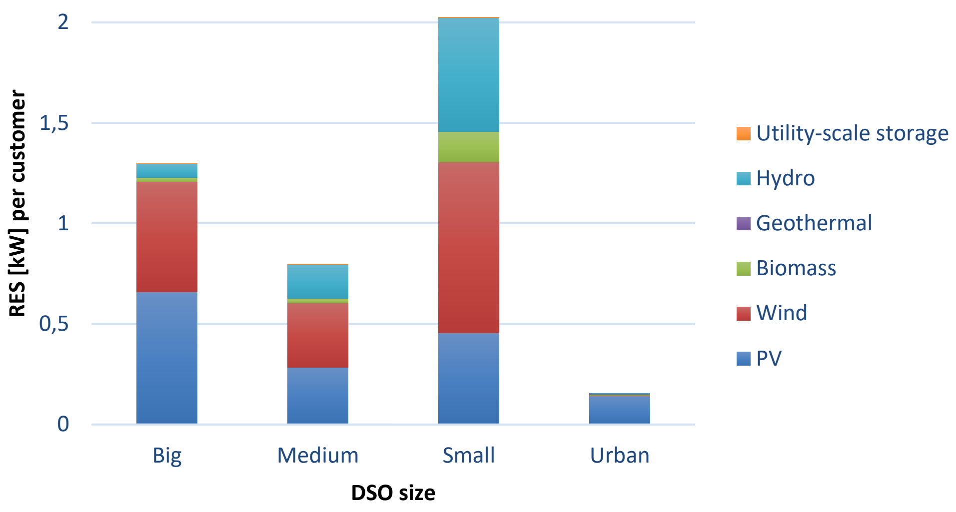
4.1. Connections of DER assets

Figure 21 depicts the average RES capacity per cluster (DSO size) normalised by the total number of customers for each DSO. PV, wind and hydro are the three RES technologies largely present across all clusters, except for the urban type of DSOs, which mainly have solar PV installed in their networks. Highest PV installed capacity per customer is evident in both big and urban type of DSOs, closely followed by wind (in the case of big DSOs). DSOs belonging to the 'small' cluster type include highest wind capacity per customer, followed by hydro and PV. Also, biomass is mainly evident in this cluster and the installed capacity of utility-scale storage per customer is rather negligible (compared to the rest of the technologies) and mainly present in the grids of the big and medium DSOs. This is largely owing to regulation in place and unbundling requirements in most of the EU countries that prevents DSOs to own and operate energy storage. Similarly, to the utility-scale storage, geothermal installed capacity per customer is negligible and mainly evident in the urban type of DSOs.

Figure 22 illustrates the share (in %) of RES capacity per cluster. PV technology shows the largest share in the total RES capacity for the urban (84%), medium (44%) and big (53%) cluster of DSOs, closely followed by wind capacity for the medium and big clusters of DSOs. Wind capacity shows largest share in the total RES for the small-size DSOs (42%), closely followed by hydro capacity (34%). Biomass technology is evident though with small share in all types of DSOs, whereas geothermal is mainly present in the urban type of DSOs (8%).

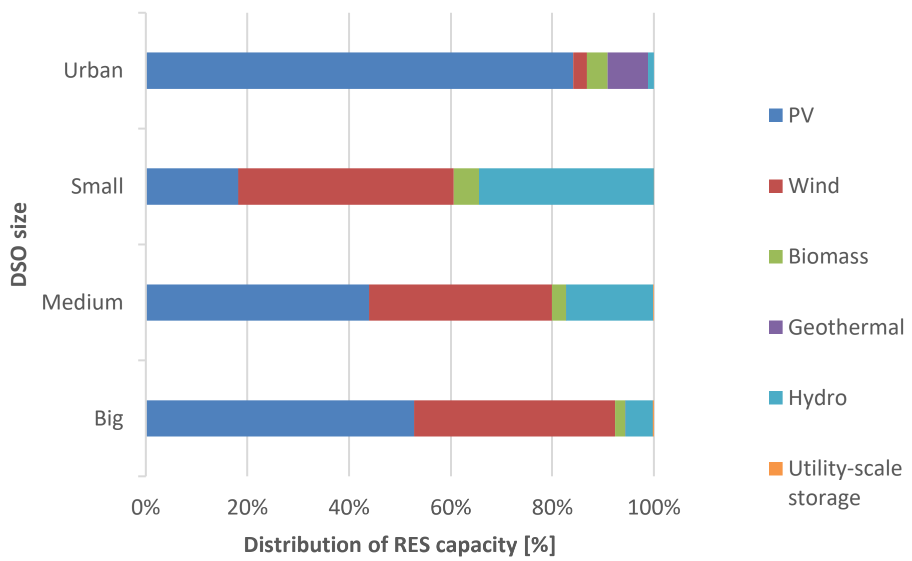
[14] A TOTEX approach (total expenditure = capital + operational expenditure) provides regulated companies with the freedom to deliver set of outputs as they see fit, subject to living within an overall total expenditure allowance, thereby without making a distinction between operating expenditure and capital expenditure.

Figure 21. Average RES capacity per cluster normalised by total number of connected customers



Source: JRC, 2022

Figure 22. Share of RES capacity per DSO size

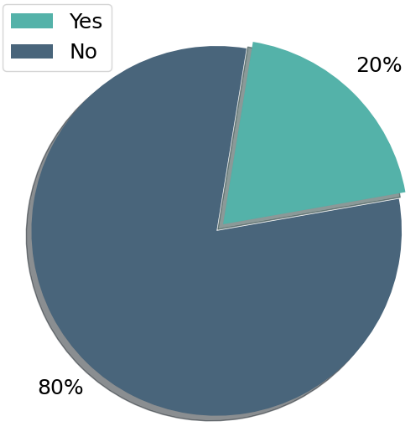


Source: JRC, 2022

4.1.1. Type of connection agreements

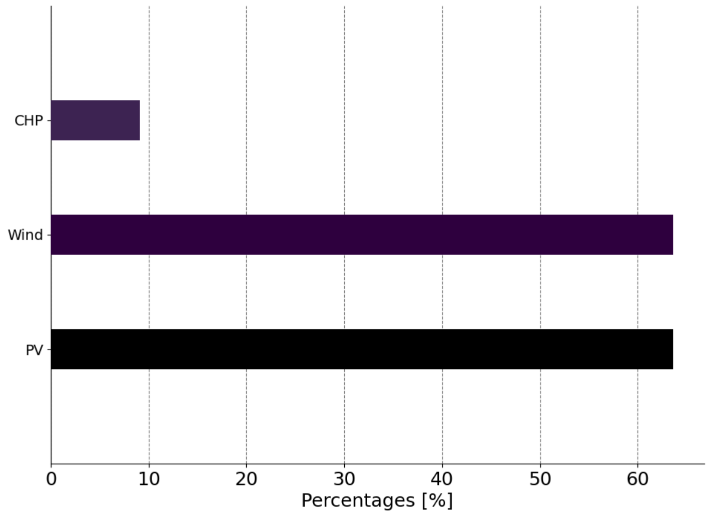
Most of the DSOs report no DER connected using flexible connection agreement and only 20% of the DSOs make use of such conditional connection possibility (Figure 23), mainly for PV and wind (Figure 24). Such possibility gives the customers the option of not investing into increasing the capacity of the grid in return for reduction of their generation capacity in periods of network overload.

Figure 23. Flexible vs. firm generation connection agreements



Source: JRC, 2022

Figure 24. Percentage of generation technology connected using flexible connection agreements



Source: JRC, 2022

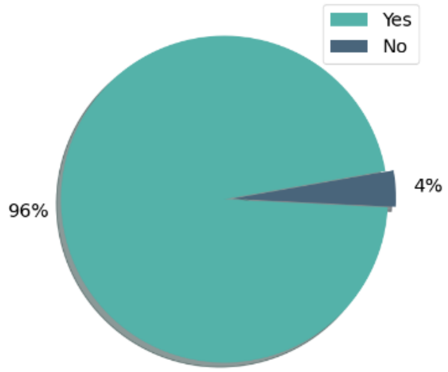
4.2. Use of SCADA

SCADA (Supervisory Control and Data Acquisition) systems are used in power systems to monitor, operate, and control generation; transformer, switching and load stations (Hamoud et al., 2003). Such control can be manually or automatic initiated by operator commands. Having advanced data collection capabilities, SCADA system plays a significant role in the operation of the system. Typically, at distribution side SCADA can automate entire distribution network and facilitate remote monitoring, coordination, control and operation of distribution components. A typical SCADA system consists of three main components, namely, remote terminal unit, master control and telecommunication network. All the European DSOs that have participated in our survey use a SCADA system or a similar one for at least one of the following purposes: substation control, feeder control and load control of end-users.

4.2.1. Substation control

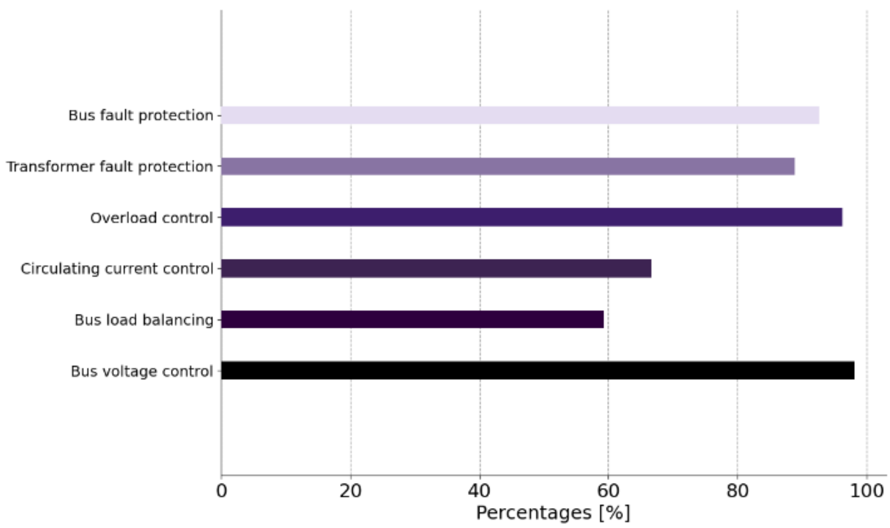
SCADA system continuously monitors the status of various equipment components of the substation and accordingly sends control signals to the remote-control equipment. Additionally, it collects the historical data of the substation and generates the alarms in the event of electrical accidents or faults (Electrical Technology 2022). As Figure 25a shows, out of the 56 DSOs that participated in the Survey, 96% use a SCADA system or similar one for substation control. More specifically, 98% of these DSOs use SCADA to perform bus voltage control, 59% for bus load balancing, 67% performs circulating current control, 96% use it for overload control, 89% for transformer fault protection and 93% for bus fault protection (Figure 25b).

Figure 25a. Percentage of DSOs using a SCADA system or similar one for substation control



Source: JRC, 2022

Figure 25b. Percentage of specific type of controls performed using a SCADA system

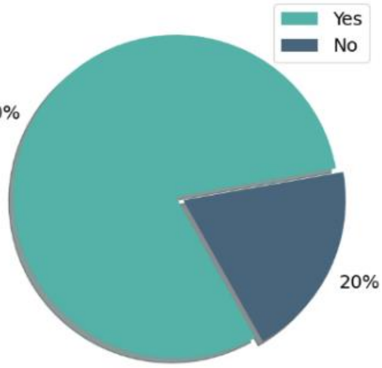


Source: JRC, 2022

4.2.2. Feeder control

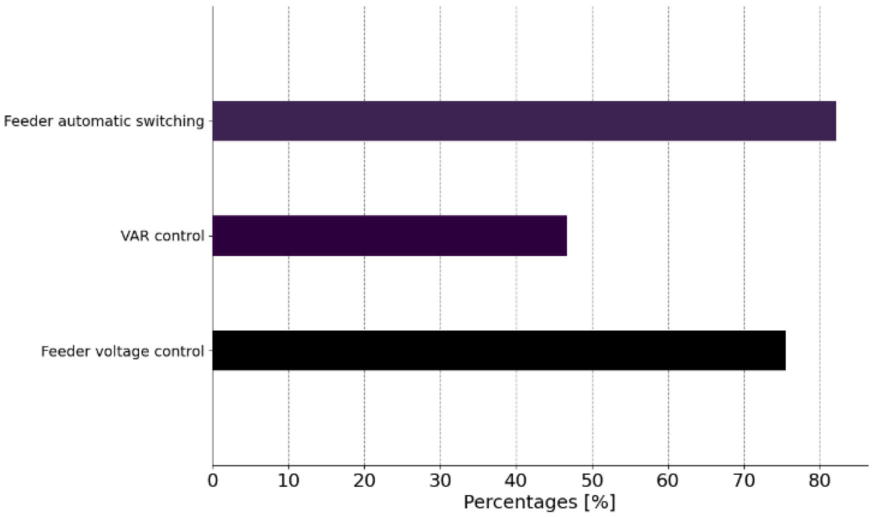
Automated feeder switching systems utilise controls, sophisticated algorithms, and data communications to go beyond the reliability benefits of more traditional reclosers and automatic sectionalisers. Out of the 56 DSOs that participated in the Survey 80% (45 DSOs) use a SCADA system or similar one for feeder control (Figure 26a). Out of these 45 DSOs, more than 80% reported that they use SCADA system for feeder automatic switching, followed by feeder voltage control and VAR control (Figure 26b). Automated switching of distribution feeder circuits provides significant improvements in reliability, enhances operational flexibility, and increases productivity of both utility personnel and distribution lines (The Teche, 2021).

Figure 26a. Percentage of DSOs using a SCADA system or similar one for feeder control



Source: JRC, 2022

Figure 26b. Percentage of type of specific controls performed using a SCADA system



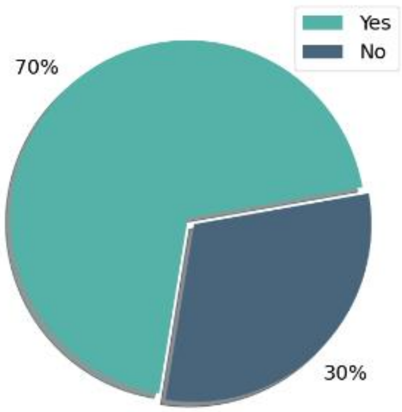
Source: JRC, 2022

4.2.3. End-user load control

This type of automation at user end side implements functions like remote load control, automatic meter reading and billing generation. The main objective is to manage residential, commercial or industrial consumption, by reducing or curtailing load to keep the power consumption in or below a specified set point, based on generation availability and according to the customer preferences (Kshirsagar et al., 2012). In addition, this type of automation is able to detect theft and energy meter tampering and accordingly disconnect the remote service and reconnect it once the problem is resolved.

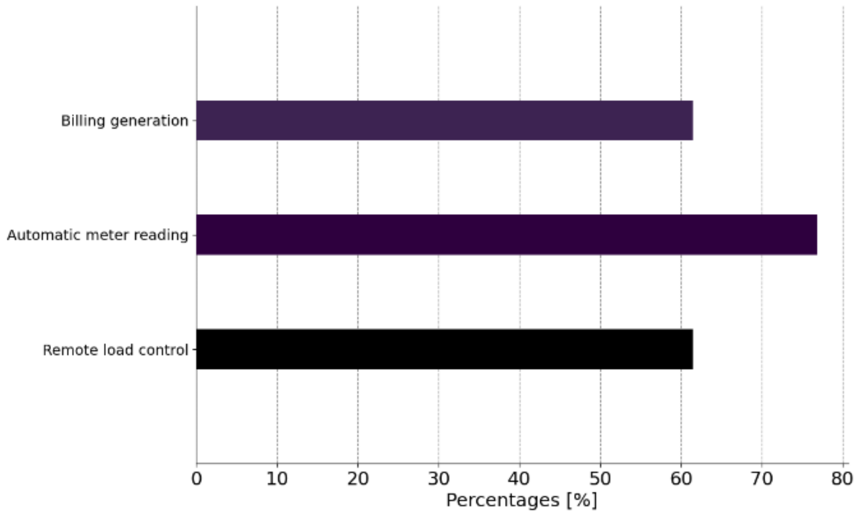
70% out of the 56 DSOs that participated in our Survey use a SCADA system or similar one for end-user load control (Figure 27a) – out of which 62% use SCADA system for remote load control, 76% for automatic meter reading and 62% for generating bills (Figure 27b).

Figure 27a. Percentage of DSOs using a SCADA system or similar one for end-user load control



Source: JRC, 2022

Figure 27b. Percentage of type of specific controls performed using a SCADA system



Source: JRC, 2022

4.3. Use of smart metering infrastructure

The introduction of smart metering is one of the core elements in the European policies targeting competitiveness and environmental sustainability of energy markets. For more than a decade, EU Directives have been progressively setting the policy agenda for smart metering rollouts. Already since 2009[15], in accordance with the provisions set out in the Third Energy Package, EU Member States were requested to ensure the implementation of intelligent metering systems that shall assist the active participation of consumers in the gas and electricity markets (EC, 2009a, 2009b). More specifically, Member States were requested to proceed with the roll-out for a minimum of 80% of the electricity end-users by the year 2020, provided that the respective Cost-Benefit Analysis (CBA) turns a positive result. Although not legally binding, the target was set to be an aspirational benchmark. In recent years, the EC has issued several guidance documents. For instance, after 2009, a Communication by the EC also reiterated specific targets for the smart metering roll-out and has provided guidance on how to perform the CBA.

In 2019, the new legislation “Clean Energy for all Europeans” has been introduced. The package, in line with the European Green Deal objectives is shaping the smart metering roll-out in the coming years for the countries,

[15] Directive 2009/72/EC adopted on 13 July 2009

which had not completed the roll-out yet (Vitiello et. al 2022). Smart meters are a fundamental component of the grid since they empower consumers to be active members of this energy transition by monitoring and controlling their consumption. Smart metering has been addressed in the Directive on common rules for the internal market in electricity (Directive (EU) 2019/944), revising the 2009 Directive. In Directive 2019/944, for the first time, it is underlined that the smart meter is a powerful tool, which however needs to be coupled with consumer energy management systems to deliver its benefits. Some new crucial aspects are also introduced; the smart metering should be interoperable, and its operation should respect the rules on data protection (Art. 19 of Directive (EU) 2019/944). In Article 19, in paragraph 2, it is also reiterated that the responsibility to roll out smart meters stays with the governments of the EU Member States, i.e. they shall ensure that the roll-out takes place[16].

Concerning the costs and benefits of the roll-out of smart meters, the directive states some important principles: first, part of the smart meter roll-out costs is attributed to the consumers (but such contribution should be transparent and non-discriminatory). The benefits stemming from the smart metering roll-out should be considered along the whole value chain, therefore accruing for the positive impacts on all types of involved stakeholders (electricity companies, consumers, energy services providers, national regulatory bodies, etc.).

4.3.1. Smart metering deployment

The results of our analysis confirm that the adoption of both Directives (2009, 2019) has been a great stimulus to the deployment of smart metering systems since the vast majority (95%) of the DSO that participated in the survey have already started implementing a smart meter roll-out program. Only three DSOs have not yet introduced any smart meter roll-out program. Despite the high number of smart metering initiatives that have been undertaken by the DSOs included in our analysis, the level of smart meter coverage (or smart meter deployment rate) varies significantly between them.

For the scope of our analysis, we collected data on the level of coverage that each DSO has achieved by installing smart meters at the premises of their customers. The coverage rate is expressed as the number of end-customers equipped with a smart meter, relative to the total number of end-consumers in the DSO area served. Based on these data we distinguish five different levels of coverage: (1) Completed roll-out, (2) About to complete roll-out, (3) Roll-out in progress, (4) Early-stage roll-out (smart meter pilot project) and (5) No roll-out. On the one hand, DSOs, which have achieved full coverage across their serving area, are those that have completed a roll-out program, achieving an average of 97% coverage. These DSOs are assigned to group (1). On the other hand, DSOs, which have installed smart meters to less than 20% of their customers, achieving an average of 10% customer coverage, are assigned to group (4). Table 2 provides more details regarding the ranges of coverage, and the mean value of coverage for all the related groups.

Table 2. Smart metering coverage ranges values and the mean value of coverage for all the related groups.

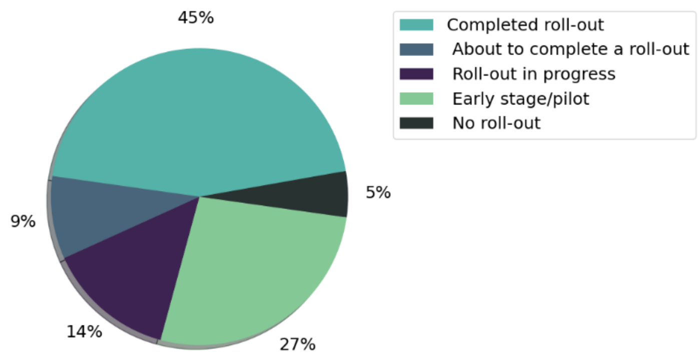
	Completed roll-out	About to complete	In progress	Early stage/pilot	No roll-out
Ranges	>97%	97%-70%	70%-20%	<20%	0%
Number of DSOs	25	5	8	15	3
Average Coverage	98%	85%	35%	10%	0%

Source: JRC, 2022

Figure 28 shows that, out of the total number of DSOs surveyed, 45% have already completed a roll-out. Another 9% of the DSOs are about to complete the deployment of the smart meter roll-out, having already on average 85% of their total number of consumers equipped with smart meters. Another 14% of the DSOs surveyed, have started a roll out program but they will still need time to complete it, as the average coverage of customers equipped with smart meter in this group equals 35%. Finally, there is still a significant number of DSOs, which are implementing smart metering installations, but these installations are either at an early stage or in a pilot phase.

[16] Member States shall ensure the deployment in their territories of smart metering systems that assist the active participation of customers in the electricity market. Such deployment may be subject to a cost-benefit assessment which shall be undertaken in accordance with the principles laid down in Annex II

Figure 28. Percentage of DSOs allocated to clusters based on smart meter deployment rate (coverage)



Source: JRC, 2022

The national strategy for a smart-meter roll-out is driven by the results of the CBA. If the CBA generates a positive result, the next steps for a roll-out can be prepared and a national strategy can be derived. In what concerns our analysis, the level of coverage that individual DSOs have achieved is very much dependent on the results of the CBAs that have been carried out at national level and on the associated decisions regarding national rollouts. This explains why for some Member States the smart metering rollouts have been completed while for others the smart meter rollouts have started later or have not started yet (EC, 2019).

Overall, according to latest available information, 21 Member States have decided to go ahead with a national roll-out or have already completed it. In four countries, however (Belgium, the Czech Republic, Germany and Slovakia) the CBAs turned either negative or inconclusive, thus giving a red light for a smart meter roll-out. Nevertheless, the German government has recently adopted a draft law[17] – to enter into force in spring 2023 – which enables large-scale smart metering rollout to start immediately before becoming mandatory from 2025 and provides a roadmap to achieve a full rollout by 2030.

Finally, two Member States, Bulgaria and Hungary have not completed or have not been able to communicate their CBA results yet (EC, 2019).

As of 2022, several EU countries have surpassed the Directive requirements (80% coverage by 2020) while others are trailing behind with some having abandoned the commitment altogether. As expected, DSOs operating in Member States where a national roll-out has been completed, the level of smart meter coverage is close to 100%, thus the DSOs were clustered together in group (1). Italy, Sweden, Finland, Spain, Denmark and Estonia are some of the leading EU countries for smart meter deployment.

Italy pioneered a large-scale roll-out of smart meters in the early 2000s, deploying some 36.7 million meters between 2001 and 2011 (Stagnaro, 2019). Similarly, Sweden has also reached 100% coverage with the early deployment of automated 'smart' meters beginning as far back as 2003. Although these meters did not adhere to the same functionality regulations that were introduced in 2014, their rollout happened at a rapid pace. Spain was also among the first countries to reach 100% installation in 2018 following a government mandate (Tripica, 2022). According to a recent review, Estonia had already met its target achieving a 98% rollout coverage.

In the survey there are some respondent DSOs which are coming from countries where a national roll-out (positive CBA) is still in progress, yet about to be completed. These DSOs were sorted into group (2). Probably the most well-known cases are those of France, Portugal, Austria and the Netherlands.

Like other EU Member States, France conducted a CBA to allow the national regulator to determine whether to proceed with a national rollout or not. Although France began a trial rollout of the Linky smart meters in 2010, and again between 2013 and 2015, the official launch of the country's nationwide rollout began in 2018 (Tripica, 2022). At the moment, France has achieved the Directive requirements (80% coverage by 2020), reaching 92% coverage.

[17] BMWK

The full rollout of smart metering is also at the heart of Portugal's smart grid strategy. Portugal was a late starter to the rollout, with installations beginning in 2019, however, the country is expecting to reach full coverage with 2.5 million smart meters installed by 2025 (Tripica, 2022).

Despite the many deployment success stories, some EU countries are still behind target in 2022. According to the European Commission's benchmarking report of 2018, 34% of all electricity metering points were equipped with a smart meter (EC, 2019). In countries where there are negative decisions regarding a national roll-out (based on a negative CBA) or where they have recently decided to proceed with a smart meter roll out, the DSOs were assigned either to group (3) or to group (4). For example, Germany, decided against[18] a national smart meter rollout. The data confirm the correlation between national decisions for roll out and smart meter coverage rate. Only one out of the four German DSOs, which participated in the survey, reported coverage of 40% while the rest three reported a coverage of less than 10%. Other countries that decided against a roll-out, include the Czech Republic and Belgium. One DSO from Belgium reported a coverage of 5%, while none of the DSOs from Czech Republic participated in the survey, thus leaving us with no available data for this country.

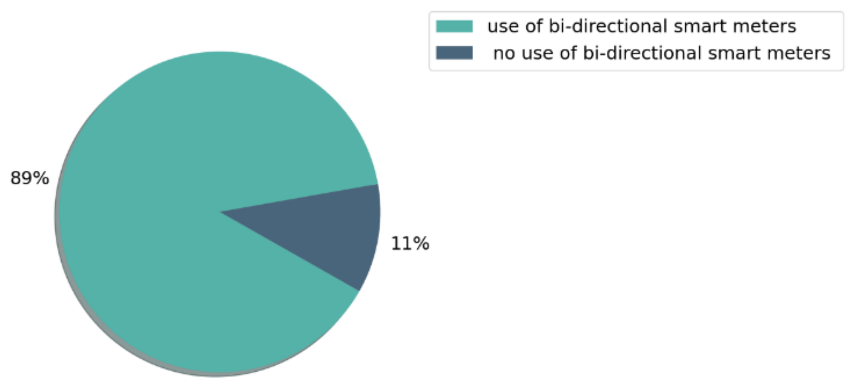
It should be noted that the Directive 2019/944 provides for a specific commitment in case the CBA supporting a government's decision on whether to roll out smart meters or not is negative: in this case, a re-assessment is required at least every four years, or even more recently if significant changes in the conditions considered in the CBA occurred. This provision, therefore, maintains the roll-out option substantially open to all countries, also to those ones that at this stage decided against it.

4.3.2. Smart meter functionalities and data use

The trends of decentralisation and digitalisation are at the core of the energy transition. To achieve the asset monitoring at the customers' premises, installation of smart metering infrastructure is necessary. It is worth mentioning, that all the respondents who are involved in smart metering rollout programs, have installed digital smart meters at their customers' premises. However, an interesting question is to what extent the installed digital meters can serve bi-directional energy flow measurements and to what extent they can be used for grid management tasks, grid control tasks and for distribution planning tasks by the DSOs. In order to formulate our questionnaire and to analyse for which purpose DSOs are using the smart metering data we used the taxonomy provided in a recently published report by CIRED (Cired, 2022).

Bi-directional meters are electronic energy meters used to measure the energy flow in two directions. This makes them ideal for renewable energy applications, such as solar power, which can generate electricity when connected to the grid. This type of smart meters is particularly useful for net metering design as the energy consumption and generation are measured separately. This is confirmed by the fact that most of the DSOs participating in the survey have installed bi-directional meters to enable simultaneously measurements of the electricity consumption and power generation. Figure 29 shows that 89% of the DSOs have installed a bi-directional smart meter while only 11% have not installed this type of smart meters yet.

Figure 29. Percentage of DSOs with installed bi-directional smart meters at customers premises



[18] The Higher Administrative Court of North Rhine-Westphalia provisionally halted a rollout due to an action being brought by a company in Aachen. The reason being that legal requirements would likely not be met.

Source: JRC, 2022

4.3.2.1. Use of smart meters for grid management tasks

The distribution grid assets and its hosting capacity require effective management. Any system collecting data regarding outages and voltage quality, or imbalance provides views on the grids about critical nodes. Such systems can support optimising the grid and the decision-making with respect to asset management. From a technical point of view, smart meters with enhanced functions could be a step towards higher visibility of the grids. The way the generated data can be implemented to manage distribution grids more efficiently depends on the provided information and the communication technology used. According to the survey results, 73% of the DSOs are using smart meters for grid management tasks (Figure 30a). This way DSOs can increase the visibility of their networks for the monitoring of voltage, grid capacity and power quality. The specific use cases include the following: a) Network state analysis & topology assignment, b) Outages/disturbances detection and prevention, c) State estimation and d) Costumer monitoring.

a) Network state analysis - topology assignment

Synchronous distributed measurements are planned using the power snapshot analysis method that helps realistic grid model planning and accounting for the uncertainties arising in a weak grid (Abart et.al., 2011). As Figure 30b shows 61% of the DSOs, use smart meters for collecting data regarding network state analysis and topology assignment.

b) Outages / disturbances detection and prevention

Prevention and management of outages and disturbances can take place at different network states, i.e. at normal operation state, at critical network sate and during outages. As Figure 30b shows 54% of the DSOs, use smart meters for detecting and preventing outages and disturbances.

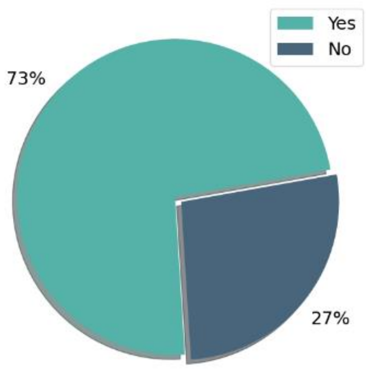
c) State estimation

Most of the management and control activities needed to significantly operate electricity networks are based on correct information of operating circumstances. The instrument of choice for achieving the required situational awareness is state estimation (Alassery, 2022). State estimation supported by smart metering data can contribute to several use cases by providing or compensating missing data or supporting different forecasting approaches for predictive management and control. As Figure 30b shows 32% of the DSOs, use smart meters for state estimation.

d) Customer monitoring

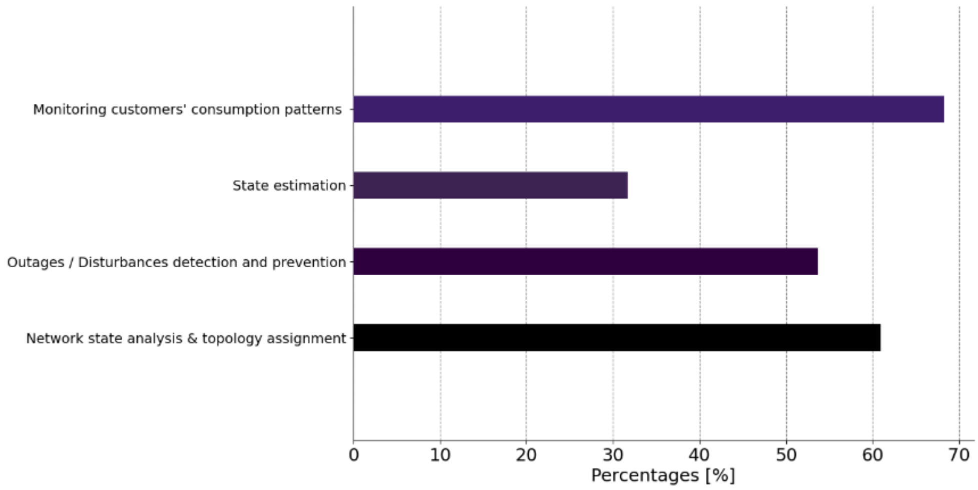
DSOs and retailers are able to improve the load models of their customers, when handling data about consumption behaviour. In this context, the consumption patterns of customers are clustered in common groups, and this allows DSOs and retailers to design electricity rates that facilitate demand response applications. Consumption patterns and other characteristics from smart meters can also be used to preselect suspected customers to be inspected on-site for abnormalities, billing errors or potential fraud (Liu et.al., 2011). As Figure 30b shows 68% of the DSOs, are using smart meters for customer monitoring.

Figure 30a. Percentage of DSOs using smart meters for grid management tasks



Source: JRC, 2022

Figure 30b. Percentage of DSOs using smart meters for specific type of grid management control



Source: JRC, 2022

4.3.2.2. Use of smart meters for grid control tasks

Using smart metering data for grid control tasks can reap significant benefits like the automation of LV/MV grid operation and the automation of customer's systems. Unfortunately, according to the survey results, only 34% of the DSOs use smart metering data for grid control tasks (Figure 31a).

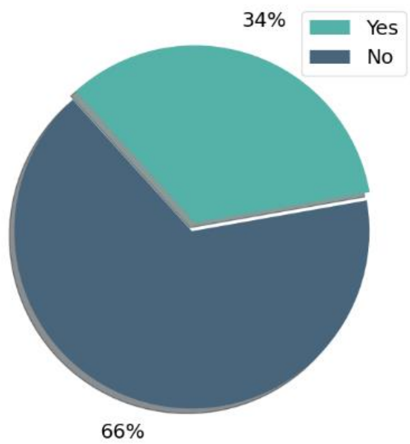
a) Automation of LV/MV grid operation

Distribution grid automation solutions provide DSOs the tools to monitor, manage and automate processes across a wide range of distribution grid applications. In this context, the automation of the LV/MV grid may involve solutions for switching in case of disturbances or in case of planned outages (scheduled maintenance and replacement of distribution grid assets). Smart meters can assist outage detection and isolation. However, our analysis shows that only 79% of the DSOs use smart meters for automation of distribution grid operation (Figure 31b).

b) Automation of customers' systems

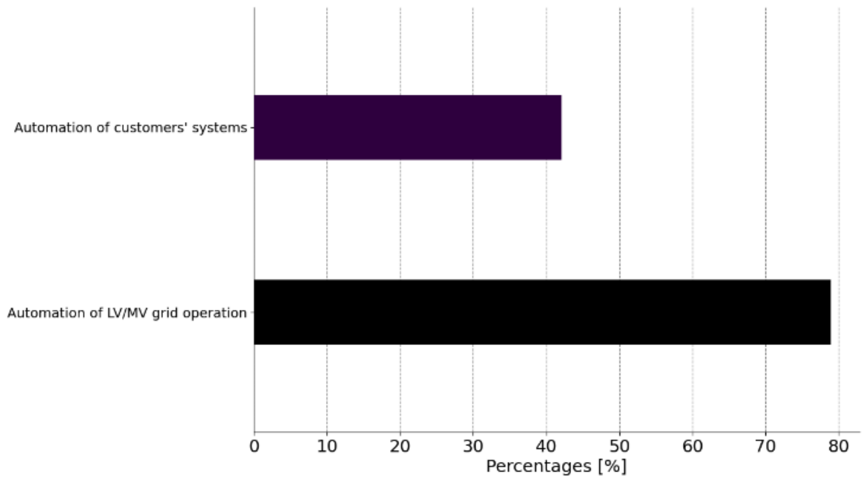
Smart meters have the potential to improve the level of service provided to the consumers. Smart metering technologies may also enable new dynamic tariff and demand-response designs to support network operators manage grid constraints and renewables integration. In particular, the DSO can manage demand side during peak load crisis and decrease the risk of blackouts. In this context, smart meters may facilitate demand-side response through different load control features (load control services, time of use tariffs or power-based tariffs (Lummi et.al., 2015). As Figure 31b shows 42% of the DSOs, use smart meters for automation of the customers' systems.

Figure 31a. Percentage of DSOs using smart meters for grid control tasks



Source: JRC, 2022

Figure 31b. Percentage of DSOs using smart metering for specific type of grid control



Source: JRC analysis, 2022

4.3.2.3. Use of smart meters for distribution grid planning tasks

Electric distribution system planning supports investment decisions and operations strategies. It is a broad subject with many facets. The increasing number of DERs and smart meters connected to the grid is changing how utilities perform their distribution planning process.

Smart metering data allow new network analysis methods for LV networks. Precise voltage and power measurement data in the four-wire system enable improved use of LV networks for consumers and easier integration of decentralised generation systems and e-mobility. In addition to measuring consumption data, smart meters may also be used for remote control of loads and generation systems. According to the survey results, 52% of the DSOs use smart meters for distribution planning tasks (Figure 32a).

a) Grid planning based on real data

Future customer loads and feed-in forecasts are fundamental to distribution system planning and necessary to evaluate future system constraints and investment alternatives.

With the use of smart meters, measurement data from users and, for each phase of the network line may become available to the DSO. As a result, scenarios that are more realistic can be built for power flow calculation. With improved network calculations, peak loading, as an important planning criterion, can be estimated more accurately at each point of the LV network. In addition, the losses can be evaluated more precisely, and trends in peak loading can be indicated (CIRED, 2022). In this context, the true individual load curves and phase connections will be known and this is of paramount importance for LV networks where constraints are often due to unbalanced loads, whose presence leads to additional losses and voltage drops (Antoine et.al., 2011).

In rural areas, the planning of MV and LV network grids could focus on voltage rise and drop. In existing grids, assessing customers' requests for connection of decentralized generation or load requires an estimation of loads and generation to calculate voltage levels. In this context, smart meters can provide real voltage levels from wide-area measurements and voltage rise and drop caused by the requested connection can be used for a more realistic modelling in planning of LV grids. As shown in Figure 32b, , 93%[34] of the DSO which use smart meters for grid planning tasks perform these tasks based on a real data.

b) Revising design standards and strategies of distribution facilities

Based on the current methods for MV or LV grid planning, use of detailed data provided by smart meters and other sensors is a challenging task with respect to the currently available grid planning tools. For operating a large number of different technologies and flexibilities, like voltage controllers and demand response schemes, automated management and a verification system are needed - especially for devices that are part of a system installed at customer premises. In such cases, smart meters could be implemented as a simple and robust interface to customers' equipment and a surveillance (monitoring) module. As shown in Figure 32b, 38%[34] of the DSOs deploying smart meters for grid planning tasks use them for revising design standards and strategies of distribution facilities.

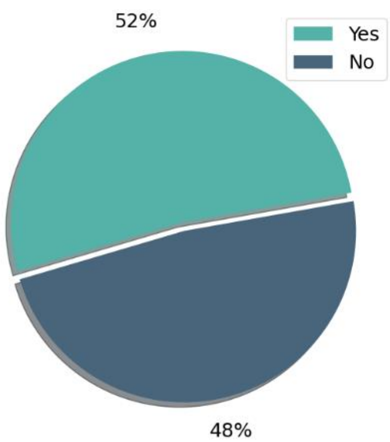
c) Grid asset planning

The ultimate objective of asset management is to help reduce/minimise/asset lifecycle costs across all phases, from asset investment planning, network design, procurement, installation and commissioning, operation and maintenance through decommissioning and disposal/replacement. Optimising the costs associated with each of these lifecycle phases remains among the key objectives of an asset-intensive utility organisation.

To facilitate grid asset planning, smart meters can provide useful data like distribution transformer loading, load factor, voltage unbalance factor, harmonics, overload due to short circuit currents, etc.,

As shown in Figure 32b, 55%[19] of the DSOs are using smart meters for grid asset planning.

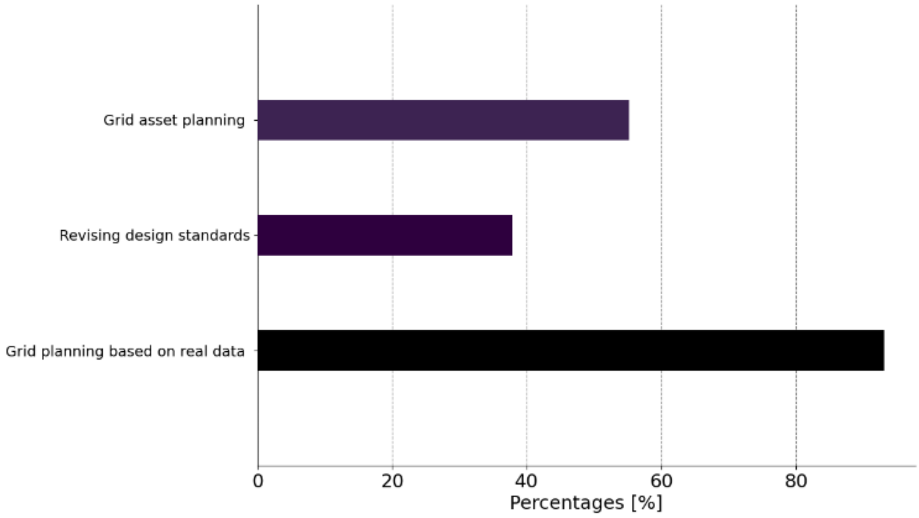
Figure 32a. Percentage of DSOs using smart meters for distribution grid planning tasks



Source: JRC, 2022

[19] Regarding the overall sample of the respondent DSOs (56 respondents) the respective percentage of DSOs using smart meters for: a) grid planning tasks based on real data is equal to 48%, b) revising design standards and strategies of distribution facilities is equal to 19% and c) grid asset planning is equal to 28%.

Figure 32b. Percentage of DSOs using smart meters for specific controls regarding distribution grid planning



Source: JRC, 2022

4.4. Provision of Electric Vehicle charging infrastructure and heat pumps

In view of the current energy and geopolitical crisis and EU decarbonisation ambitions, there is an ever-increasing need to electrify other end-use sectors, such as transport and heating. The Electric Vehicle (EV) market is seen as one of the most dynamic, with global shares of EV sales doubling from 2021 and Europe witnessing a robust growth up to 65% compared to 2020 and increase of 25% for the first quarter of 2022, compared to the first quarter of 2021[20]. To this end, the distribution system is facing new consumption patterns and congestions at the same time as vast amounts of new renewable and DERs are to be integrated into the grids. These trends place the DSO at the forefront of the e-mobility development, but at the same time present a largely unused resource to improve grid operation and increase efficiency using smart charging infrastructure. Recent study from Regulatory Assistance Project[21] shows that with growing incentives for EV drivers to use smart charging, the number of tariffs and services continue to grow too. However, only few smart charging services and tariffs use data from local grid operators that reflects the actual system conditions, such as time-varying network tariffs or market-based aggregated residential flexibility. On the other hand, the EU Electricity Market Directive[22] requires DSOs to use market-based flexibility wherever possible to avoid or defer grid reinforcements or extensions. In addition, the proposal for Regulation for the Deployment of Alternative Fuels Infrastructure[23], as part of the Fit-for-55 package[24] recognises the value of electric vehicles in providing flexibility to the energy system. As a result, it sets mandatory infrastructure targets for the electric vehicle fleet which will be primarily connected at distribution level, but also it empowers National Regulatory Authorities to assess the '*contribution of EVs to the flexibility of the energy system*'. Furthermore, DSOs are responsible to assess the flexibility needs in preparation of their network development plans, while consulting all interested parties.

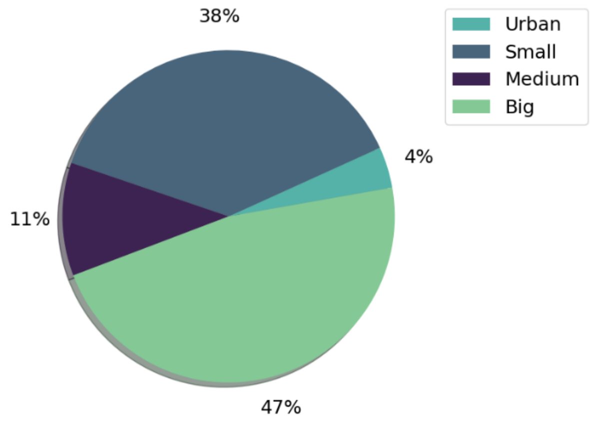
However, regulatory and market incentives are still missing in different Member States, and without proper regulatory framework the flexibility potential of EV for grid operation and management will remain largely untapped.

Above 1 millions of EV charging columns were reported by the DSOs included in our analysis, out of which only 6400 owned and operated by the DSOs themselves. This is in line with Article 33 of the EU Electricity Directive, indicating that *'DSO shall not own, develop, manage or operate recharging points for electric vehicles, except where distribution system operators own private recharging points solely for their own use.'*

Figure 33 depicts the average distribution of EV charging columns per connected customer for each DSO cluster, where DSOs belonging to the big and small cluster hold the largest share of EV charging columns.

[20] https://www.iea.org/reports/global-ev-outlook-2022/executive-summary
[21] https://www.raponline.org/wp-content/uploads/2022/04/rap-jb-jh-smart-charging-europe-2022-april-26.pdf
[22] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32019L0944
[23] https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A52021PC0559
[24] https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/

Figure 33. Percentage of EV charging columns per connected customer

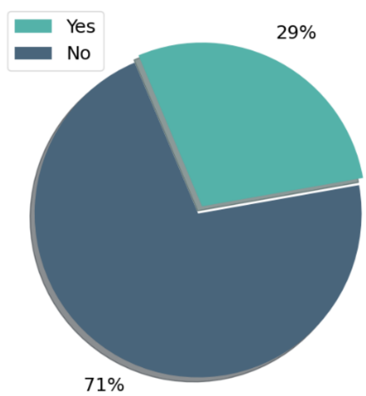


Source: JRC, 2022

Along with the electrification of the transport, heating is one of the end-use sectors where electrification is seen as an effective decarbonisation option. European households, on average, can save up to 39% on their bills when replacing fossil fuel-powered heating systems to electric heating pumps and up to 400% efficiency gain over comparable gas boilers when installed in properly insulated homes and often equipped with an intelligent energy management system and smart meters[25]. This way heating systems can respond to grid conditions and respective CO_2 levels and price signals by matching demand with renewable energy when available, thus avoiding peak load hours.

Only 16 out of 56 DSOs included in our analysis reported data about the number or capacity of heat pumps installed in their networks. The total number of heat pumps, mainly installed at residential customers exceeds 380 thousand. Nevertheless, this number is much higher as heat pumps are installed at the customer premises and most of the DSOs do not have information about the number nor capacity of the heat pumps installed. Figure 34 illustrates the percentage of DSOs having information about the number and/or capacity of heat pumps installed at their networks.

Figure 34. Percentage of DSOs having information about the number and/or installed capacity of heat pumps connected to their networks



Source: JRC, 2022

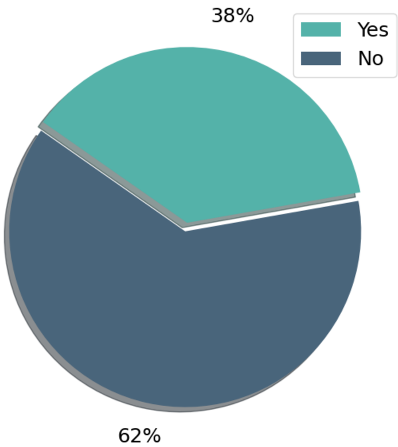
[25] https://www.eurelectric.org/publications/power2people-follow-up-report-heat-pumps/

4.5. Collective action of energy consumers

Technological innovation and decreasing cost of technology have made new forms of consumer participation in energy production and management more accessible. The Clean energy for all Europeans package[26], adopted in 2019, reinforces the role of collective action of energy consumers by introducing the concept of energy communities in its legislation, notably as citizen energy communities and renewable energy communities. More specifically, the electricity Directive (EU) 2019/944 [27] includes new rules that enable active consumer participation, individually or through citizen energy communities, in all markets, either by generating, consuming, sharing, or selling electricity, or by providing flexibility services through demand-response and storage. In addition, the revised renewable energy Directive (EU) 2018/2001[28] aims to strengthen the role of renewables self-consumers and renewable energy communities, thus ensuring that they can participate in different markets, on equal footing with large participants.

Energy supply uncertainty, current energy prices and urgent climate targets provide strong incentives to accelerate the deployment of energy communities, providing the right regulatory and market signals are in place. 38% of the DSOs included in our analysis (Figure 35) report existence of energy communities in their electricity networks, though most of them still in an infant stage – number of energy communities do not exceed 50 in the case of more than half of these DSOs. Regarding the size of these communities – in terms of number of customers and total annual energy consumption, responses were rather scarce and largely differing.

Figure 35. Percentage of DSOs having information about citizen/renewable energy communities in their distribution networks



Source: JRC, 2022

4.6. DSO procuring flexibility services

The legal framework for use of flexibility by DSOs has been established by Directive (EU) 2019/944[29]. Flexibility should be procured and used in a coordinated way[30] with TSOs, and other market parties where relevant, to ensure that the activation of one resource to address issues in one part of the system does not create network issues elsewhere. Article 3 of the Electricity Regulation (EU) 2019/943[31], demands adoption of market rules which will '*facilitate the development of more flexible generation, sustainable low carbon generation, and more flexible demand*' and calls for incentives to the DSOs, '*for the most cost-efficient operation and development of their networks including through the procurement of flexibility services*'. More specifically, Article 32 of the Electricity Directive (EU) 2019/944 highlights the importance of development of an adequate regulatory framework '*to allow and provide incentives to distribution system operators to procure flexibility services, including congestion management in their areas, in order to improve efficiencies in the operation and development of the distribution system*.' Furthermore, Article 13 of the Electricity Regulation (EU) 2019/943

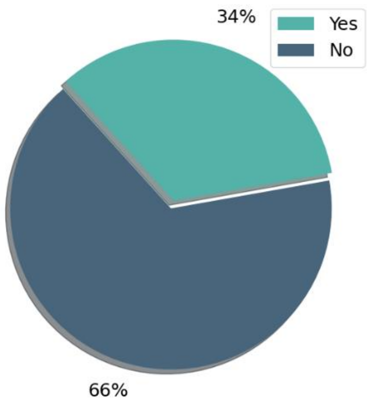
[26] https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en
[27] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32019L0944
[28] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG
[29] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32019L0944
[30] https://www.edsoforsmartgrids.eu/wp-content/uploads/2019/04/TSO-DSO_ASM_2019_190304.pdf
[31] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019R0943

indicates that the re-dispatched resources shall be selected among generation, storage or demand facilities using market-based mechanisms. This will empower customers and allow for active market participation, where DSOs will act accordingly within their role as neutral market facilitators.

Markets for distributed flexibility have emerged in some Member States even before the adoption of Directive (EU) 2019/944. Following the Directive transposition deadline (December 2020), no Member state has fully transposed provisions related to DSOs' flexibility procurement, though in the last 2 years significant progress has been made in some EU countries (Chondrogiannis et al., 2022). Closely related to this is the development of the network code on demand-side flexibility – framework guidelines submitted by ACER to the EC in December 2022[32] – which may bring further rules on DSOs' flexibility procurement.

In view of the current energy crisis, power system flexibility procurement is seen as key to electricity security and at the same time enabler and catalyst for integrating larger amount of renewable generation and electrifying other end-use sectors, such as transport and heating. Still, 34 % of DSOs included in our analysis use flexibility (Figure 36a), mainly offered by individual customers – mostly industrial and commercial and generation units or a combination of both (Figure 36b) – thus leaving the potential of the residential sector largely untapped. One of the major barriers in this regard remain the lack of regulatory incentives in some Member States for market access of smaller residential customers, including new market actors, such as independent aggregators and virtual power plants (VPPs) (Chondrogiannis et al., 2022).

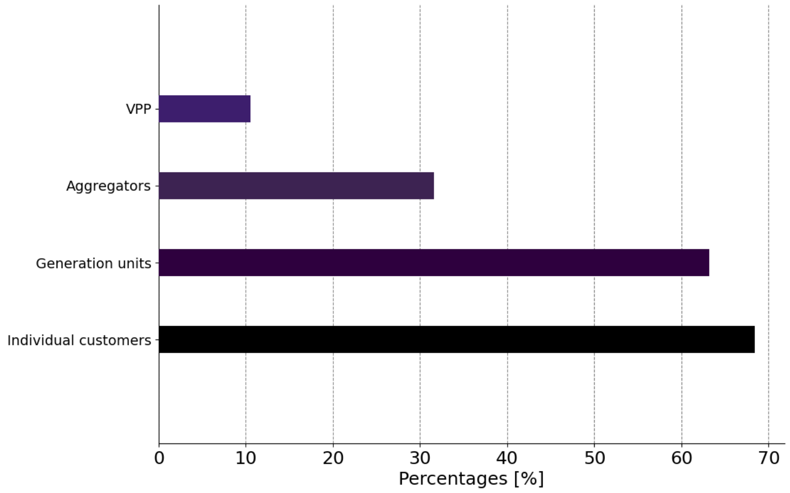
Figure 36a. Percentage of DSOs procuring flexibility and type of flexibility providers



Source: JRC, 2022

[32] https://documents.acer.europa.eu/Official_documents/Public_consultations/Pages/PC_2022_E_05.aspx

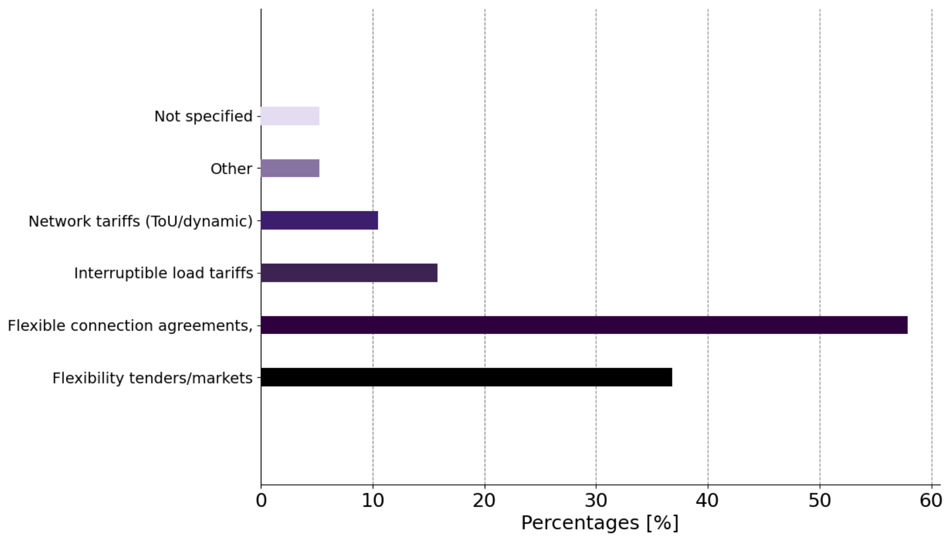
Figure 36b. Type of flexibility providers DSOs mostly procure flexibility form



Source: JRC, 2022

With respect to the way the DSOs access flexibility, both market-based and non-market-based approach has been reported, namely flexibility tenders/markets, flexible generation connection agreements, interruptible load tariffs and dynamic network tariffs or a combination of these four options. Most of the DSOs use flexible connection agreements to procure flexibility (Figure 37), followed by market-based approach (flexibility tenders/markets), interruptible tariffs and dynamic network tariffs. One DSO indicated flexibility procurement through individual contracts with some generation units activated in specific occasions (option 'other') in Figure 37.

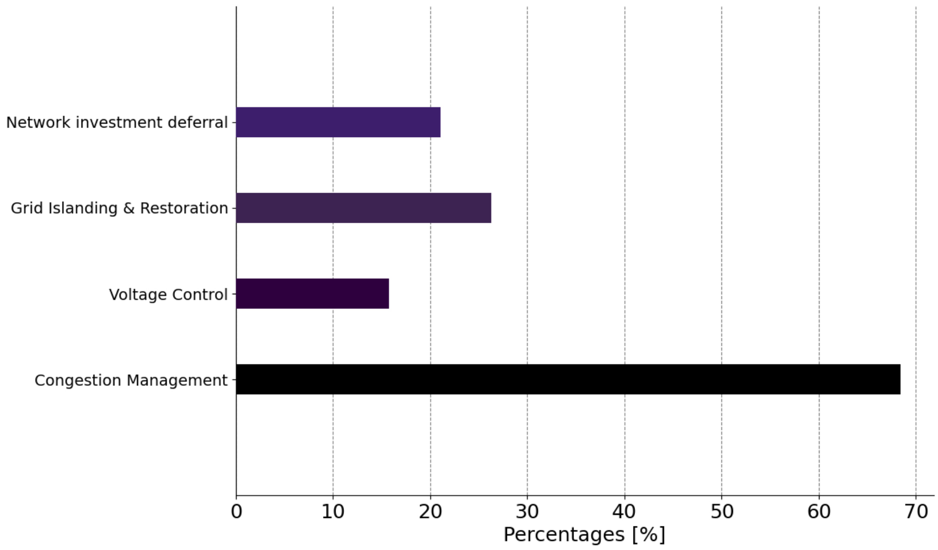
Figure 37. DSO options to access flexibility



Source: JRC, 2022

The main flexibility services DSOs procure are for congestion management, grid islanding and restoration, voltage control and postponement of network reinforcements/upgrades or a combination of the four. Most of the DSOs procure flexibility to solve congestion management, followed by grid islanding and restoration (Figure 38).

Figure 38. Type of flexibility services procured by the DSOs



Source: JRC, 2022

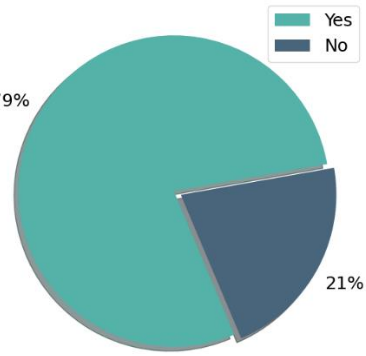
4.7. Investment planning according to the Electricity Directive (EU) 2019/944

According to Article 32, paragraph 3 of Directive 2019/944, the development of a distribution system shall be based on a transparent network development plan that the DSOs shall publish at least every two years and submit to the energy regulatory authorities. The network development plan shall provide transparency on the medium and long-term flexibility services needed and shall set out the planned investments for the next five-to-ten years, with particular emphasis on the main distribution infrastructure, which is required in order to connect new generation capacity and new loads, including recharging points for electric vehicles.

As Figure 39 shows most of the DSOs (79%) are preparing a five-to-ten-year investment plan. Out of these DSOs, 64% include in their investment plans the medium- and long-term network flexibility services needed, according to Article 32(3) of Directive 2019/944.

A first challenge for DSOs resulting from the Directive (EU) 2019/944 is to assure a better integration of the HV and MV network with the LV network development planning, allowing to assume that the network development plan represents an integrated distribution networks development and investment plan, recasting the national laws in line with these recent European legislative developments. In most of the country cases, the national requirements reflect the Electricity Directive (EU) 2019/944. For instance, in Bulgaria, according to the requirements of Art. 13, paragraph 7 of Ordinance No. 3 on licensing of activities in the energy sector, operators of distribution networks have the obligation to submit to the Regulator a 5-year business plan no later than three months before the expiration of the previous business plan. In Estonia, the DSO consults with network connection users and the TSO when preparing the network development plan, publishes the results of the consultation together with the network development plan on its website before submitting it to the Competition Authority.

Figure 39. Percentage of DSOs preparing a five-to-ten-year investment plan



Source: JRC, 2022

4.8. DSO-TSO coordination

The security and stability of the electricity grid will increasingly rely on the contribution of assets connected to the distribution grid. Sound coordination schemes between TSOs and DSOs are thus critical to avoid harmful interferences across voltage levels and competition for accessing resources.

As a principle, DSOs and TSOs are responsible for ensuring secure operation of their grids. However, coordination between system operators is vital for the safe operation of the whole electricity system (ENTSO-E et al., 2019). TSOs and DSOs have adopted this principle in order to avoid mutual harmful interference when invoking balancing and/or congestion management actions. Each network operator is responsible for forecasting restrictions, including voltage problems, in their network and for, at least, initiating a coordinated – as applicable – solution.

4.8.1. Data exchange on demand, generation forecasts and power generation facilities

Information exchange between TSOs and DSOs for the purposes of long-term and operational network planning[33] should be based on a structured approach in the form of demand and generation forecasts and dynamic data models. Both long-term network development planning and operational planning require cooperation and exchange of data between TSOs and DSOs (ENTSOE, 2016).

On the one hand, information exchange between TSOs and DSOs for supporting long-term network development process could include annual demand/generation forecasts per physical TSO–DSO interface. On the other hand, information exchange between TSOs and DSOs for supporting operational planning process could include periodically demand/generation forecasts on the TSO–DSO interface. These forecasts could be exchanged and/or published and could facilitate integration of RES and new customer connections. The periodicity of these forecasts' exchanges could evolve over time. Additionally, when TSOs obtain more precise demand forecasts they are able to optimize the generation resources used by the electrical system, which also indirectly reduces emissions due to the more efficient programming of thermal generation in the system and the maximisation of the use of renewable energy sources.

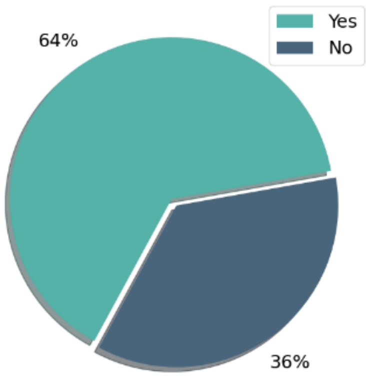
From the policy perspective, Article 50(4) of the Electricity Regulation obligates TSOs to '*publish relevant data on aggregated forecast and actual demand, on availability and actual use of generation and load assets, on availability and use of the networks and interconnections, on balancing power and reserve capacity and on the availability of flexibility […]*'.

To gather more information regarding the exchange of data between TSO-DSO on demand and generation forecasts and on exchange of scheduled data of each power generating facility we asked relevant questions to the participants of the survey. Overall, 64% of the DSOs share data with the TSOs regarding demand and generation facilities (Figure 40a). Out of these DSOs, 38% share these data on annual basis, while others do it

[33] Network planning comprises both long-term network development (from one year ahead and onwards) and operational planning (from hour ahead to year ahead).

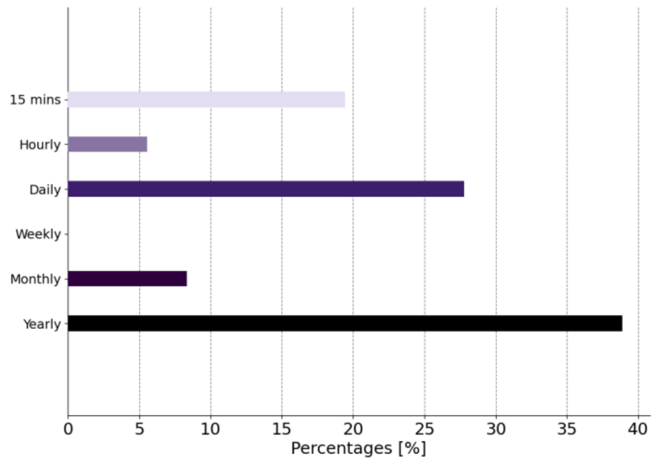
with lower granularity: around 27% of the DSOs share this type of data on daily basis, slightly above 5% on hourly basis and 18% of the DSOs share data on 15-minute granularity (Figure 40b).

Figure 40a. Percentage of DSO respondents sharing data with the TSOs regarding demand and generation forecasts



Source: JRC, 2022

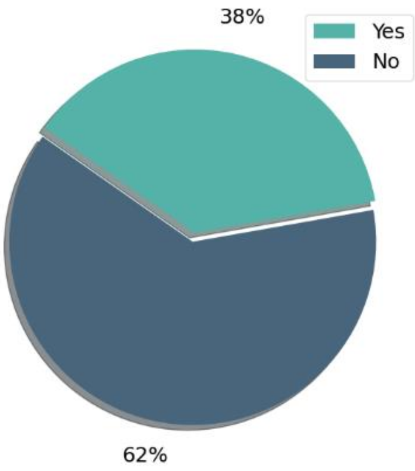
Figure 40b. Minimum granularity of data sharing between DSOs and TSOs regarding demand and generation forecasts



Source: JRC, 2022

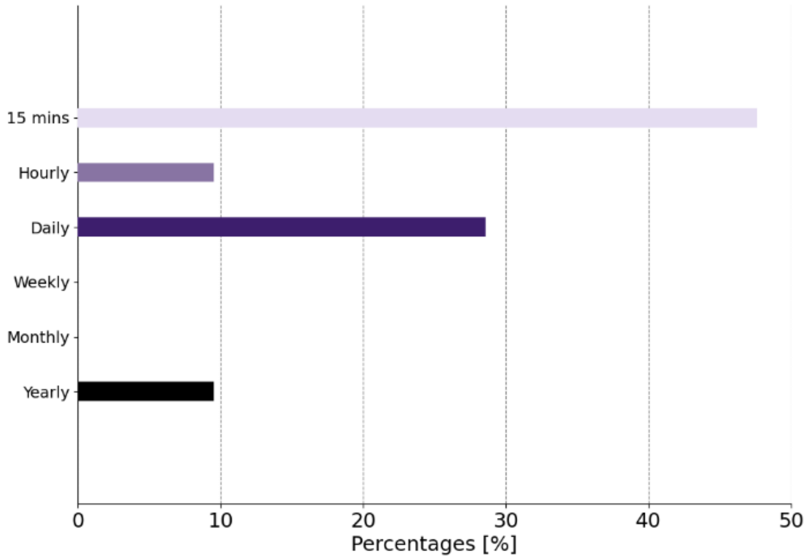
In total 38% of the DSOs, share data with the TSOs regarding power-generating facilities (Figure 41a). Out of these DSOs, almost 10% share these data on annual basis, while the rest do it with lower granularity: around 28% of the DSOs share data on daily basis, close to 10% on hourly basis and nearly 50% of the DSOs share data with 15-minute time granularity (Figure 41b).

Figure 41a. Percentage of DSO respondents sharing data with the TSOs regarding power-generating facilities



Source: JRC, 2022

Figure 41b. Minimum granularity of data sharing between DSOs and TSOs regarding power-generating facilities



Source: JRC, 2022

In a few cases, DSOs reported what type of data they share with the TSO regarding power-generating facilities. For instance, in Lithuania the DSO reported that they share data with the TSOs regarding wind plants that have a capacity greater than 5 MW as well as data regarding real time P-power (MW), V-voltage (kV) measurements from PV. In Greece, the DSO sends to the TSO data regarding load and DG forecasting on an annual basis and load projections at every TSO/DSO connection point and DER installed capacity on a monthly basis. Additionally, in Greece the TSO is cooperating with the DSO regarding the planning of new interconnections with the non-interconnected islands of Greece.

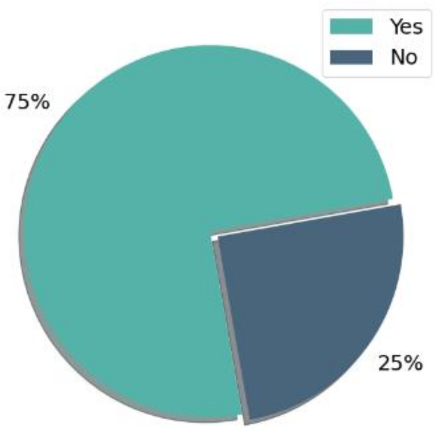
4.8.2. Exchange of real time and ex-post measurements

Generally, under normal grid operating conditions, the TSO is responsible for balancing the grid and the DSO is not involved in this kind of activities. However, distribution customers can already take part in the balancing process, as is the case for some countries. For those cases, the DSOs are involved in the prequalification process and communicate metering data to the TSO either in the form of real time measurements (SCADA) or in the form of ex-post measurements.

DSOs need to know when they are allowed to use smart metering data for system operation purposes based on a prior consent of all concerned users. Therefore, to be able to solve, among others, voltage problems, it is important for the DSO to be allowed to use smart meter readings to their full extent.

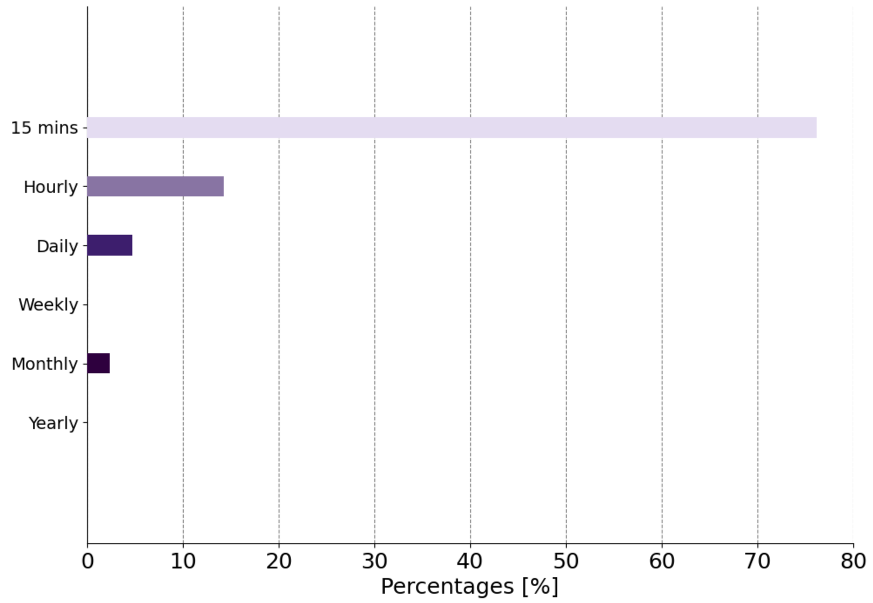
Figure 42a shows that the great majority of the DSOs (75%) share data with the TSOs regarding real-time measurements. Out of these DSOs, 78% share this type of data with very low time granularity of 15 minutes, 13% on hourly basis and only 5% on daily basis (Figure 42b). Accordingly, Figure 43a shows that a high number of DSOs (86%), share data with the TSOs regarding ex-post measurements. Out of these DSOs, 34% is using ex-post measurements with low-time granularity of 15 minutes (Figure 43b).

Figure 42a. Percentage of DSO respondents sharing data with the TSOs regarding real-time measurements



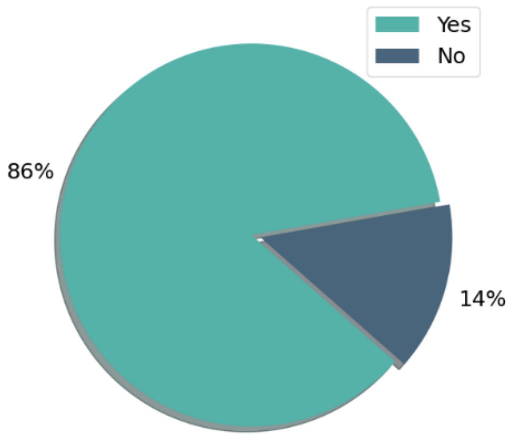
Source: JRC, 2022

Figure 42b. Minimum granularity of data sharing between DSOs and TSOs regarding real-time measurements



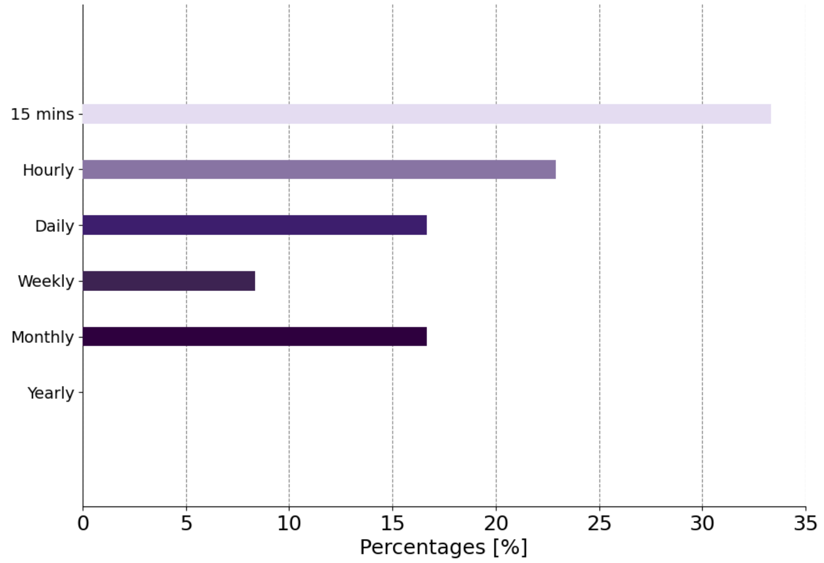
Source: JRC, 2022

Figure 43a. Percentage of DSO respondents sharing data with the TSOs regarding ex-post measurements



Source: JRC, 2022

Figure 43b. Minimum granularity of data sharing between DSOs and TSOs regarding ex-post measurements



Source: JRC, 2022

5. DSO's Regulatory Aspects

5.1. Regulatory Schemes

For regulating the DSO entities which operate over a country (whenever this is the case), the national regulatory authorities apply common approaches and methodologies in what concerns the calculation of required revenues and tariffs. Thus, for the scope of the current analysis the collected data are presented at country level rather than at DSO level.

To group European countries according to the applied regulatory schemes, different criteria can be used. For the scope of current analysis, following Cambini et al. (2016) and Meletiou et al. (2018), we investigate whether or not regulatory schemes are in place to induce cost efficiency or productivity by providing relevant incentives to DSOs. This study identifies four broad categories of models: a) price-cap models, b) revenue-cap models, c) cost-plus models, and d) hybrid models.

Out of the 22 countries in our sample, 59% apply revenue-cap schemes, 14% price-cap scheme, 14% hybrid schemes, and the remaining 14% cost-plus schemes. Figure 44 shows the applicable regulatory scheme at the country level.

Price-cap regulation has typically been regarded as the initial incentive-based regulation model, since it was introduced in the UK during the privatisation and liberalization era to motivate cost minimization by regulated utilities (Cambini et. al 2016). Under the price-cap framework, a CPI-X mechanism is applied where revenue needs are adjusted by inflation minus an annual efficiency factor (X) (Mahoney et. al 2011).

One often sited example is the Dutch price-cap regulatory model. In the Netherlands, price-cap regulation has been applied since the first price control in 2002. Under this regime, the revenues that DSOs are allowed to earn within a regulatory period are fixed and determined using a mathematical formula. This model incentivises network operators to lower their costs to maintain or increase profits (CEER, 2022). Similarly, in Slovakia the basic principle of the regulation of prices applies a price-cap as a method, which guarantees profit only under real efficient business operation and incentivises network operators to reduce their own losses. Interestingly, in Slovakia, the price-cap is set for each voltage level[34] separately (CEER, 2022).

In the past, cost-based regulation approaches (rate-of-return regulation or cost-plus regulation) were widely used for tariff regulation purposes. The cost-plus approach determines an allowed rate of return on investment for the company, and every price review rates are adjusted so as to ensure the firm earns the authorized return (Armstrong and Sappington, 2006). Traditional rate-of-return regulation encourages capital investments if the rate of return exceeds the cost of capital, and favours capital over operating expenses (Averch-Johnson effect), which in turn may not promote cost efficiency (Tahvanainen et al., 2012).

In our sample, only three countries (Belgium, Croatia and Estonia) implement cost-based regulatory schemes. Usually, in countries where cost-plus regulatory schemes are applied, these are combined with strong quality of service or other type of incentives. For instance, in Belgium35, the regulator applies an advanced cost-plus model, which combines a profit-sharing (PS) and a quality-of-service (QoS) mechanism. PS is a cost reduction mechanism where the operator is incentivised to maintain its actual spending under budget as it retrieves 50% of the actual-budget difference (within a limit set at 10% of the budget). QoS is a Key Performance Indicator based mechanism, where the operator is incentivised to reach certain thresholds for a selection of parameters like SAIDI, SAIFI, complaint handling, etc. (CEER, 2022).

The revenue-cap regulation is the one that seeks to control the amount of revenues that DSOs can earn. This type of regulation permits firms in the distribution industry to change their prices, in so far it will not cause the revenue generated to exceed the revenue-cap. Revenue-cap regulation is quite alike to the price-cap regulation but there is one main difference: a price-cap model is linking DSO profits to the amount of electricity distributed and this could work as an obstacle to the energy efficiency while revenue-cap models decouple sales from revenues (Dubash, 2004). As the revenue-cap regulation models focus on the overall revenues of the DSOs, it could also enable them to set their own electricity tariffs, individually.

Figure 44 shows that the revenue-cap regulation is widely used in European Union. Out of the 22 countries represented in our analysis, more than half of them use a revenue-cap model. In Germany, the regulatory

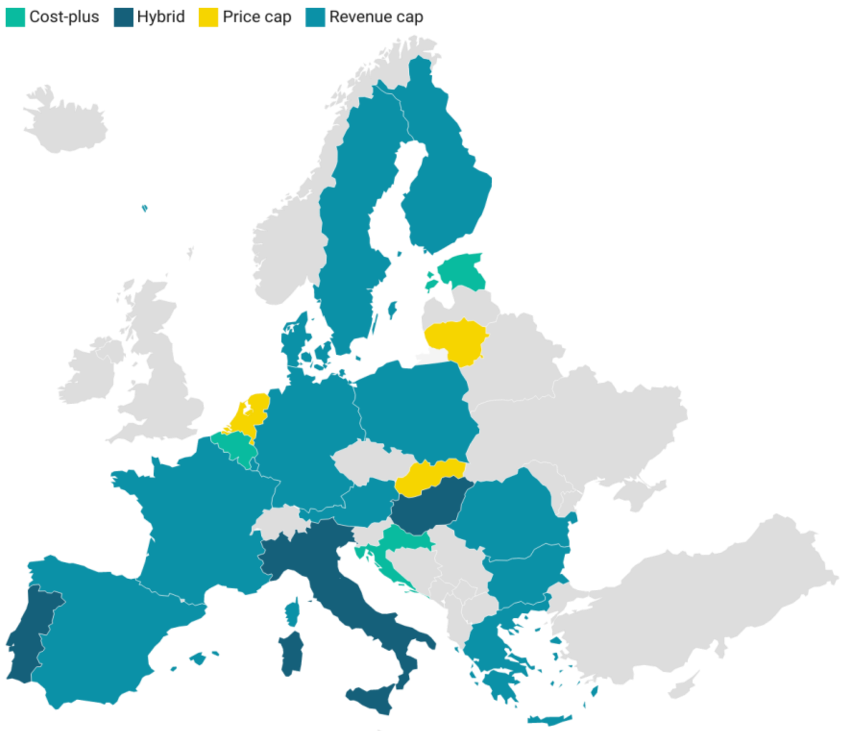
[34] There are the following voltage levels: EHV being 110 kV, HV 22 kV and LV 0.4 kV.
[35] In the Brussels capital region, a single DSO is operating both gas and electricity networks.

authority applied a cost-based regulation from 2001 to 2008, before switching to a revenue-cap scheme in 2009 (Frontier-Economics, 2012). By comparison, other countries have introduced reforms more recently. For instance, Greece has switched from cost-plus approach to revenue-cap methodology in 2020[36] (RAE, 2020). The new methodology for the calculation of required revenue provides for quality-adjusted revenue-caps. In Denmark, revenue-caps set a ceiling on the operating revenues of DSOs and they consist of three main components: a cap on costs, allowed returns and efficiency requirements (CEER, 2022). The cap on costs is based on an average of actual costs in the previous regulatory period.

Some European regulators have developed and implemented hybrid models that combine rate-of-return and/or price-cap and/or revenue-cap regulatory models. Figure shows that Italy, Portugal and Hungary are among the countries that use hybrid regulatory schemes.

In practice, many hybrid models follow a cost-based approach for the treatment of capital expenses (CAPEX) and an incentive-based approach for the treatment of OPEX. In Portugal, the hybrid scheme is using a price-cap model for the treatment of the OPEX and a Rate-of-Return for the treatment of the CAPEX for medium voltage network level activities. Another example is the Italian regulatory model, where the Italian regulator (AEEG) has prompted DSOs to trim down OPEX costs by a factor (X) year-on-year, while the invested capital is remunerated at a rate that is fixed for four-year period. Finally, the Hungarian incentive regulation is a price-cap-like system but in practice it combines a mixture of price-cap, revenue-cap, and quality regulation.

Figure 44. Snapshot of the applied regulatory schemes of the European DSOs included in our analysis



Source: JRC, 2022[37]

5.2. Treatment of costs (TOTEX vs. non-TOTEX)

DSOs incur expenditures for operation and maintenance (OPEX) and capital investment (CAPEX) in order to provide distribution of electricity under service quality standards (Meletiou et al., 2018). OPEX refers to expenses incurred in the course of the ordinary business, they are fully deducted in the accounting period they were incurred and are not subject to depreciation. In contrast, an investment in a long-lived asset, which requires a

[36] The new methodology was issued in October 2020.
[37] The map was created using the online tool Datawrapper.

certain CAPEX, will take a long time before the investment is paid back. Thus, in contrast to OPEX, CAPEX requires binding capital for a longer period (Brunekreeft et al., 2021).

Regulation is provided to remunerate OPEX and CAPEX after defining which costs are eligible to enter the pricing scheme. TOTEX framework authorises an overall total expenditure allowance rather than individual CAPEX and OPEX allowances. In this context, it is of paramount importance to understand if the regulatory authorities treat differently the CAPEX and OPEX parts of the revenues and to explore to what extent there is a common X-factor/efficiency [38] requirement applied on both the CAPEX and OPEX or otherwise called an efficiency benchmarking on TOTEX.

Following the literature on economic regulation of utilities, we can distinguish and formulate two different cases for OPEX & CAPEX treatment and benchmarking (ACCC/AER, 2012):

A) A common approach for the treatment of OPEX & CAPEX (TOTEX)

- The investment plans (CAPEX) are evaluated in advance of the regulatory period. The regulator then decides what revenue can be collected to cover the cost of these plans. This implies that CAPEX is treated on a cost-plus basis, with settlements for differences between approved and realised expenditure carried out at the end of the regulatory period. Similarly, a cost-plus approach is followed for the treatment of the OPEX allowance, which are fully adjusted, based on actual figures.
- The investment plans (CAPEX) are evaluated in advance of the regulatory period, but a common efficiency requirement is applied on both OPEX and CAPEX, or otherwise on TOTEX.

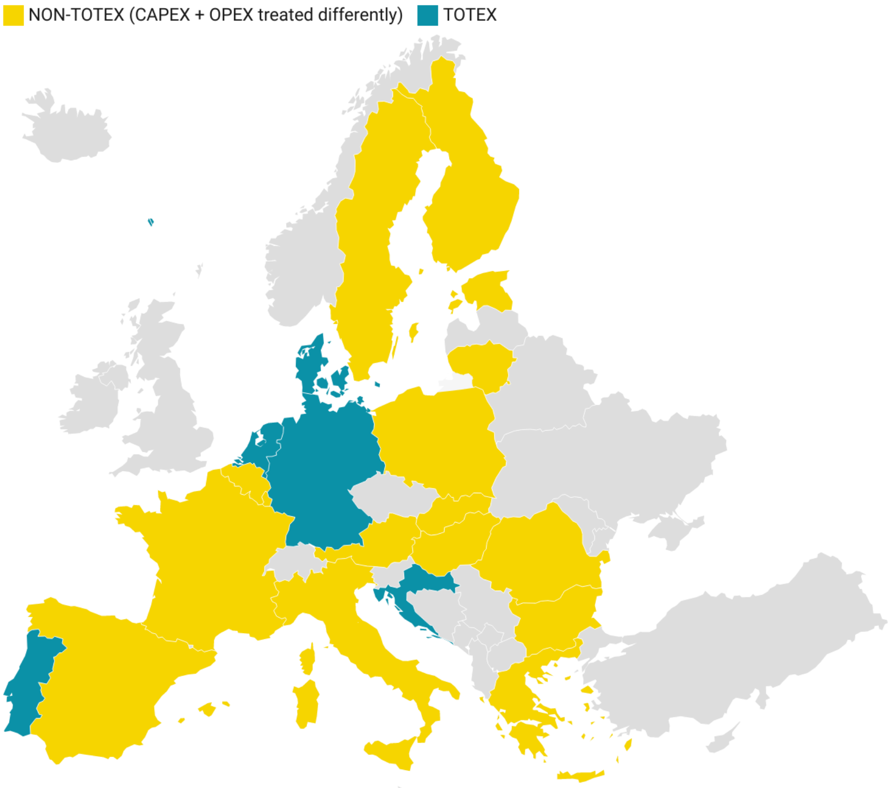
B) A different approach for the treatment of OPEX & CAPEX

- A cost-plus approach is followed for the treatment of the CAPEX while an efficiency benchmarking model is used to estimate firm-specific potential for efficiency improvements on OPEX. In this case, an efficiency factor is applied to the treatment of the OPEX.
- An efficiency factor is applied to the treatment of the CAPEX and accordingly a separate efficient factor is applied to the treatment of the OPEX. While both CAPEX and OPEX are treated using an efficiency factor, the level of this factor differs.

In order to shed light on the mechanisms which regulators employ to treat the DSO costs we have asked the respondents to indicate the costs treatment approaches which are applied in their business. In most of the European countries, the regulatory authorities apply a non-TOTEX approach, treating CAPEX and OPEX differently. As Figure 45 shows, most of the EU countries (77%) follow a non-TOTEX approach, which corresponds to 80% of the DSOs included in our analysis. Only in a few countries (Netherlands, Portugal, Germany, Croatia, Denmark) the regulator follows common approach for the treatment of OPEX and CAPEX. For instance, in Denmark the regulator applies an efficiency requirement on both the OPEX and CAPEX, utilising a comparative benchmarking technique. Similarly, in Portugal the X-factor applied on TOTEX is equal to 2% but only for the low voltage networks.

[38] X factor is intended to be a proxy for a competitive market, in industries, which are natural monopolies. X factor is a productivity adjustment in a price/revenue-cap formula, used to adjust price in line with a firm's expected productivity improvements.

Figure 45. Cost treatment approaches in the European regulatory frameworks for DSOs



Source: JRC, 2022[39]

5.3. Efficiency benchmarking applied to the calculation of approved costs

Efficiency benchmarking involves assessing the operators' individual costs against the services they provide and determining each operator's cost efficiency compared to the other operators or against their own potential/historical costs.

When the cost of one operator is compared to those of others, the aim of cost benchmarking is to assess the efficiency of the different operators and to determine the justified level of operating costs. Since efficiency benchmarking is a comparative method, the results for the individual network operators have a mutual influence on each other (CEER, 2021) A network operator that provides the same type and quality of services as another operator but has higher costs (than another operator with 100% efficiency score) will have an efficiency score lower than 100%. The efficiency scores are then applied to the costs. Common methods which are used for comparative benchmarking include data envelopment analysis (DEA) and stochastic frontier analyses (SFA) to the defined parameter groups.

When the calculation of efficiency improvement is based on historical costs, the efficiency reference level is based merely on the operators' own historical costs (e.g. the costs of the previous year). Likewise, in the calculation of efficiency improvement potential, the network operator's realised OPEX are benchmarked against the operator's own reference[40] operative costs.

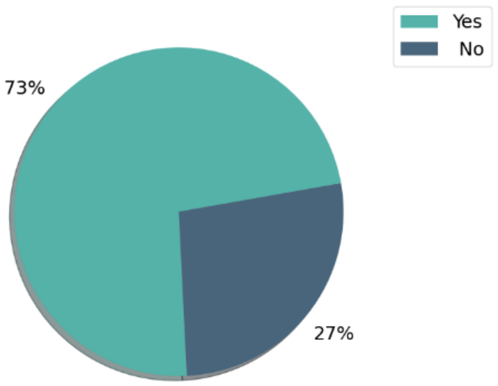
Recently in Europe the efficiency benchmarking has been increasingly applied in the regulatory schemes. To be able to better understand how regulators treat the DSO costs, we have asked the respondents to indicate, first, if there is an efficiency benchmarking applied to the calculation of the approved costs and second what type of costs are subject to an efficiency benchmark. As it can be seen from Figure 46a, in most European countries 73%, the regulatory authorities apply a form of benchmarking (86% of the DSOs included in our analysis). Figure 46b illustrates that out of these countries, 63% apply an efficiency factor on total OPEX (denoted as

[39] The map was created using the online tool Datawrapper.

[40] For instance in Spain, the network operators receive an allowance for operation and maintenance (OPEX) that is calculated by multiplying the number of assets of each type by the OPEX reference values. Therefore, operators has an incentive to operate and maintain the grid below the OPEX reference values set for each regulatory period, as they retain the difference.

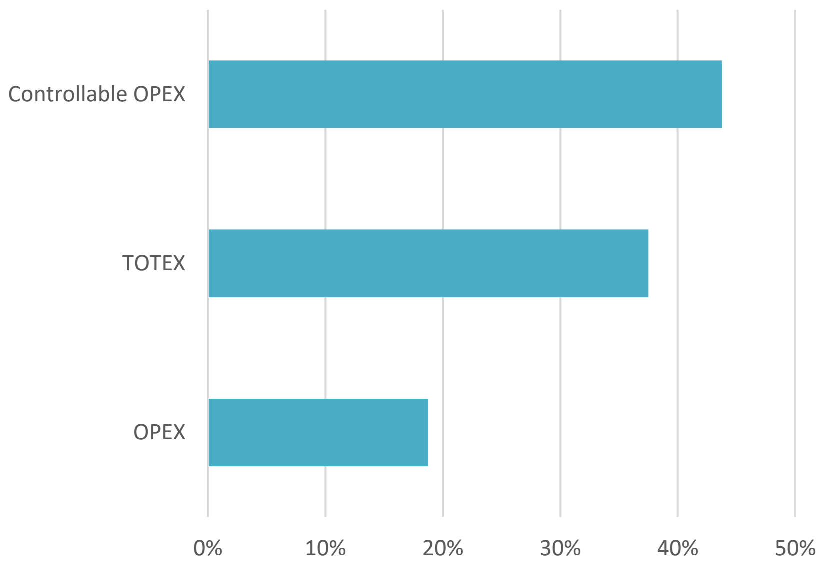
simply OPEX in Figure 46b) and controllable OPEX (60% of the DSOs) and 37% on TOTEX (40% of the DSOs). When efficiency benchmarking is applied on OPEX this could be made in various forms. For instance, Slovenia, France, Hungary, Bulgaria Sweden, Romania and Finland apply efficiency benchmarking on controllable OPEX, however, there are significant differences on the type of costs that can be defined as controllable OPEX and thus can be considered as such. In principle, costs like operation and maintenance of distribution assets are frequently considered as controllable. Nevertheless, disturbances, outages, safety level of maintenance and equipment failure are not controllable but can be also considered as part of the OPEX. In addition, in some other countries customer-specific costs, such as measurement, calculation and reporting costs can be defined as controllable OPEX.

Figure 46a. Percentage of EU countries applying an efficiency benchmarking in distribution network regulation



Source: JRC, 2022

Figure 46b. Type of DSO expenses subject to an efficiency benchmarking



Source: JRC, 2022

When designing benchmarking methodologies regulatory authorities should take into consideration many different factors. Probably the most important one is the level of efficiency factor. The second one is the benchmark values and the way they are calculated. Some other important factors, which should be considered in the design of a successful efficiency benchmarking mechanism, include the time span which is granted to the operators for eliminating individual inefficiencies or the methodology that each DSO applies for eliminating the inefficiencies (CEER, 2021).

5.4. Weighted Average Costs of Capital in energy distribution tariff regulation

A very important aspect of the applied regulatory methodologies is the calculation of the Weighted Average Cost of Capital (WACC). In regulated environments, such as the energy distribution sector, sectoral regulators set the WACC and the DSOs are compensated for the opportunity costs of capital through the WACC. The WACC gives allowance for both the cost of debt and the cost of equity. When the WACC is set above the future opportunity costs of capital, consumers will pay too much, while when the WACC is below that level, network operators may be unable to finance investments affecting quality of network services (Romeijnders and Mulder, 2022). A reasonable profit within the regulatory period is calculated by multiplying the WACC and the Regulated Asset Base (RAB) values. It shall take into account the scope of the investments required to ensure a long-term, reliable, safe and efficient system operation, an adequate return on operating assets, and the stimulation of stable long-term business. A very important point, looking at the current WACC levels in the EU, is that currently WACCs are often set at levels that are well below inflation. This creates a negative incentive towards innovation and upgrade of European distribution grids, and therefore should be a priority in the regulators' agenda for the next regulatory period.

Since the implementation of the ex-ante regulation with price and revenue-caps, the question of how to determinate a reasonable return on revenues for DSOs has been widely discussed in many European countries. The determination of the appropriate level for the WACC could be a major challenge for the regulators, as most of the parameters used to calculate the WACC are unobservable and must be estimated. The energy regulators have to deal with great uncertainty about the future conditions in capital markets and make relevant estimations based on assumptions and judgements. One of the main uncertainties of capital markets may concern the level of inflation as well as the fluctuations of bond yields. In this context, the regulatory methods for estimating inflation expectations may not always be able to produce accurate outcomes.

In the EU, inflation has recently surged to levels, which have not been seen in more than 20 years[41]. When DSOs borrow in nominal terms, they bear a risk if the inflation expectation is different to actual inflation (CIE, 2020). This risk is greater the higher is the uncertainty about actual inflation outcomes. With surging inflation, DSOs will be faced with increasing interest rates leading to increased cost of capital, which in turn can hinder their ability to invest in network assets and grid modernization.

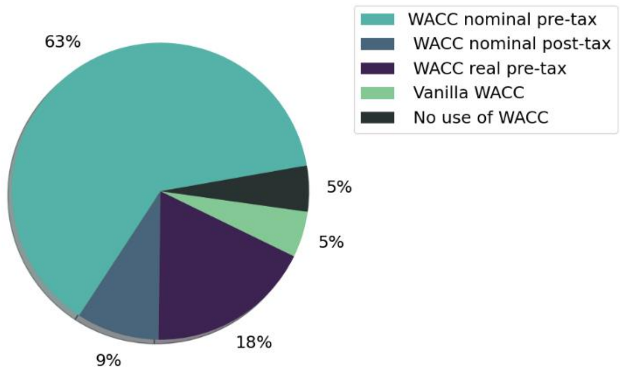
Based on the survey data, all the European regulators apply WACC for the calculation of distribution network tariffs, with the only exception being Germany where there is no use of WACC. In general, WACC could be in two different forms: a nominal WACC and a real WACC. A nominal WACC is measured in current terms, while a real WACC is expressed in constant terms. Hence, the real WACC shows the WACC excluding the impact of inflation and is therefore lower than a nominal WACC, all other things being equal. The WACC should be consistent with the choice of price base. Therefore, if prices are regulated in real/nominal terms, the cost of capital should be expressed respectively in real/nominal terms (IRG, 2007).

For the European DSOs participating in the survey, the most popular approach is the use of nominal WACC before taxation (pre-tax). As shown in Figure 47, in 63% of the countries (57% of the DSOs included in our analysis) the regulatory authorities use a nominal pre-tax WACC for the calculation of the rate of return. The second most popular approach followed by the energy regulators in 18% of the EU countries is real pre-tax WACC (29% of the DSOs included in our analysis). Finally, the use of nominal post tax WACC and Vanilla WACC[42] are the least popular approaches followed by only 9% and 5% of the countries, accordingly (5% and 2% of the DSOs, accordingly).

[41] Euro area annual inflation is equal to 9.2% in December 2022, according to a flash estimate from Eurostat, the statistical office of the European Union: https://ec.europa.eu/eurostat/documents/2995521/15725146/2-06012023-AP-EN.pdf/885ac2bb-b676-0f0d-b8b1-dc78f2b34735#:~:text=Euro%20area%20annual%20inflation%20is,office%20of%20the%20European%20Union .

[42] Vanilla WACC is defined as the weighted average cost of capital using a pre-tax cost of debt and a post-tax cost of equity.

Figure 47. Distribution of different types of WACC in distribution network tariff regulation among the 22 European countries from where the 56 DSOs, survey respondents, come from

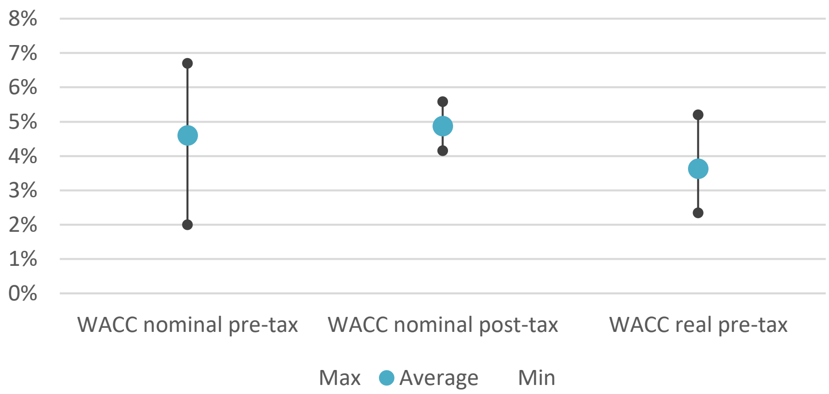


Source: JRC, 2022

In some countries, the regulation provides for different values of the WACC between the DSOs in the electricity distribution activity. Although these differences are minor, for these countries an average WACC value was calculated. For example, in Austria, the WACC is efficiency dependent[43] and for this reason, the country's WACC value was calculated as the mean of the WACC values of the five Austrian DSOs, which participated in the Survey. This average value is equal to 4.93%. Similarly, for Slovakia an average WACC price of 5% is applied for the two DSOs, participating in the survey. Finally, in Poland, the average WACC is 5.4%. Interestingly in Poland the risk-free rate is updated every three months for electricity network companies, thus affecting the level of WACC.

Figure 48 illustrates that when a nominal pre-tax WACC is used the average value for the European countries included in our analysis equals to 4.61%. The figure also shows that on average a nominal post-tax WACC equals 4.87%. Finally, the average value for real pre-tax WACC is equal to 3.64%. Vanilla WACC was not included in Figure 48, since there is only one country (Belgium) applying this type of WACC in the calculation of distribution energy tariffs.

Figure 48. Average, maximum/minimum (Max/Min) WACC values by type of applied (regulated) WACC in the 22 EU countries, based on the survey data from 56 DSO respondents.



[43] Efficiency dependent WACC includes adjustment factors for each individual DSO. For example in Austria, it exists an adjustment of cost parameters k1 and k2 (i.e. the "weights" for each type of capital employed by each DSO) in a cost-neutral manner as well as an increase in the general productivity requirement (slight increase from 0.67 to 0.83% p.a.). Due to such settlement the bandwidth of the efficiency dependent WACC is further narrowed and spans between 4.55% for the minimum efficient DSO to 5.05% for the efficient DSO (CEER, 2021).

Source: JRC, 2022

5.5. Incentive regulation – quality of service and energy network losses

Over the last years, apart from incentives for cost efficiency, regulators have introduced incentives related to Quality-of-Service (QoS) and the technical operational quality. QoS regulation has become a topical issue, particularly in the context of large-scale disturbances and adverse weather phenomena (Tahvanainen et al., 2012). Additionally, the energy regulators needs to ensure a sufficient level of operational quality and an efficient use of the networks. For this reason, they have introduced incentives that will allow DSOs to reduce the electricity losses in their networks.

The overall goal of QoS regulation is to guarantee a good level of continuity and quality of supply for the energy consumers. To address the major aspect of quality of supply for electricity, we focus on the major topic of the availability of electricity, otherwise known as continuity of supply. Network users expect a high continuity of supply level at an affordable price (CEER, 2016). The fewer the interruptions and the shorter these interruptions are, the better the continuity is from the viewpoint of the network user. Therefore, one of the roles of DSOs is to optimise the continuity performance of their distribution network in a cost-effective manner.

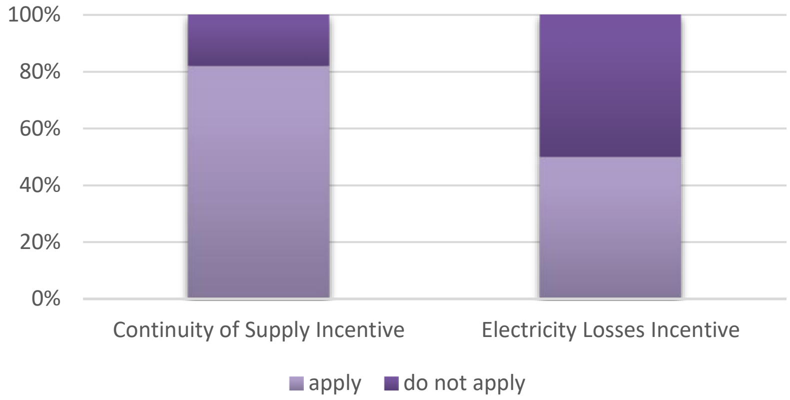
Today, it is fairly common that DSOs measure the duration and number of interruptions in electricity distribution. For this purpose, they use international standards, like SAIDI and SAIFI which serve as valuable indices for comparing electrical utilities performance reliability. In this context, SAIDI and SAIFI are used to measure the quality and reliability of supply or otherwise called continuity of supply.

The continuity of supply incentive scheme sets the DSOs interruption cost against a target that is based on the average interruption cost during a period of time for each DSO. If the company's performance is under the target, it is allowed to earn extra return, and should it fail the target, the allowed return is reduced.

As shown in Figure 49, continuity of supply incentive is used in most European countries (82%) included in our analysis, which corresponds to 88% of the DSOs from where the survey respondents come from. In these countries, the energy regulators are mainly using the SAIDI and SAIFI indicators in order to impose penalties and rewards. For instance, in France, the DSO can earn a maximum bonus of 83€ million but can also receive a penalty of 125 € million per year. In Poland, the regulation provides for incentives and penalties for achieving the objectives of quality regulation. The quality regulation model is based on indicators that are monitored and evaluated such as the duration of interruptions (equivalent to SAIDI), the frequency of interruptions (equivalent to SAIFI) and the customer connection lead-time. In the Netherlands, the regulation introduces a q factor as QoS incentive mechanism. By way of the q-factor, the regulator provides an incentive to the electricity DSOs to maintain an optimal quality standard. If a DSO has fewer or shorter outages than the norm, it will gain extra revenue through a positive q-factor. If it has more or longer outages than the norm, it will lose a share of his revenues through a negative q-factor.

Although electricity losses constitute an important, but inevitable, amount of wasted resources, they remain one of the least known components of an electricity system. Over the last years, the European energy regulators have chosen to use network losses as an indicator for an efficient utilisation of the power grid, employing dedicated incentive mechanisms for the mitigation of network losses. As shown in Figure 49, in half of the EU countries from where the DSO respondents come from, (43% of the DSOs included in our analysis) the energy regulators apply electricity losses incentives. Usually, these incentives are in the form of a penalty/reward mechanism. DSOs can benefit if they manage to reach a level of losses, which is lower than the reference value of losses that is set by the regulator (maximum level of network losses allowed per year).

Figure 49. Use of continuity of supply and electricity losses incentive regulation mechanisms in the 22 EU countries, based on the survey data from 56 DSO respondents



Source: JRC, 2022

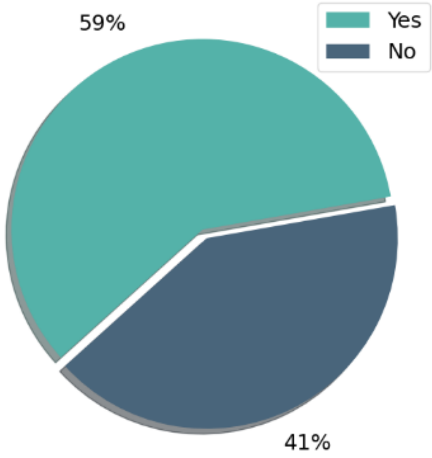
In general, the features of the incentive mechanism like the reference price of energy losses may vary significantly between European countries. The decisions for setting an accurate reference price of the energy losses and for determining the allocation of energy losses costs between consumers and producers is always a challenging task for the energy regulators. However, the calculation method of the incentive is common in the EU countries (CEER, 2020). Usually, the award/penalty is calculated as the product of a reference price [€/MWh] and the difference between the level of reference and the actual losses [MWh]. As reference price of the energy losses could be considered the unit cost of energy lost at the day-ahead or balancing market in a specific hour of the day or the average price during the regulatory period. To limit the financial risk for DSOs linked to the implementation of the aforementioned incentive, the overall ceiling/floor of the financial incentives borne by the operator is maintained at certain level (upper/lower ceiling) to offset the impact of extreme performance. For instance, in France, for a given year N, the annual incentive for loss compensation corresponds to 20% of the difference between the annual reference amount and the actual expenses (incentive on 20% of deviations from a reference trajectory) and the DSO can earn/receive a maximum bonus/penalty of 40€ million per year. In this context, the regulation provides that, when a DSOs actual performance is much better or worse than the performance targets to the extent that the financial reward/penalty under the regulation exceeds the revenue at risk cap[44] under the scheme, its actual performance must be adjusted accordingly.

5.6. Innovation incentives

European energy regulators have also developed dedicated incentive mechanisms to stimulate innovation in the electricity distribution sector. Often targeted at different technologies or commercial arrangements, these mechanisms are designed to support innovation that DSOs are unlikely to undertake in the absence of incentives. In this context, regulatory experimentations could be in one of the following forms: a) pilot smart grid (SG) projects, b) regulatory sandboxes, c) regulatory experiments for innovative technologies and d) regulatory pilots (CEER, 2022). Overall, 59% of the DSOs (33 DSOs) included in our analysis reported that they take part into regulatory experimentations (Figure 50a).

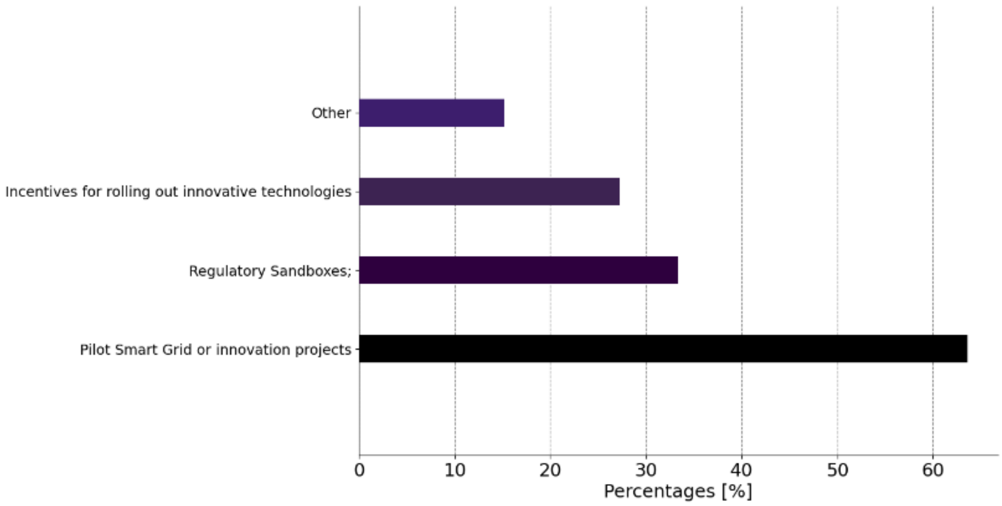
[44] Revenue at risk caps the potential rewards and penalties for the DSO for each year of the regulatory control period.

Figure 50a. Percentage of DSOs participating in regulatory experimentations



Source: JRC, 2022

Figure 50b. Type of regulatory experimentations DSOs take part in



Source: JRC, 2022

Pilot smart grid projects are small-scale, preliminary in-field trials conducted to evaluate the feasibility, benefits, costs, and risks of an innovative approach/functionality/technology. These pilots involve grid operators (DSOs and/or TSOs) and regulatory approval is necessary. Regulators sometimes contribute funding to pilots through a levy on network tariffs (extremely limited impact due to the small scale of the pilot), and in such a case full transparency on the results is required. The results indicate that out of the 33 DSOs, which participate in regulatory experimentations, 64%[61] of them are involved in pilot SG projects (Figure 50b).

Regulatory sandboxes are general frameworks that innovators can apply to test their innovative products, services, and methodologies (including new business models) for a certain period of time. In most cases, the sandbox involves a specific derogation (waiver or exception) from standard regulations, subject to conditions imposed by the regulator. Figure 50b shows that out of the 33 DSOs which participate in regulatory experimentations, 33%[45] are involved in regulatory sandboxes while 16% are involved in other type of regulatory experimentations (e.g. pilot tariffs for a small group of customers, pilot smart meters etc.).

[45] When considering the overall sample of 56 DSOs, survey respondents, the respective numbers of DSOs, which are involved in pilot SG projects, regulatory sandboxes and innovative technologies, are 37%, 19% and 16% respectively.

Innovative technologies: “large-scale” and “policy-driven” experiments in which derogations are awarded to grid operators (only) to test changes in regulation combined with new grid technology. This kind of experiments is commissioned, coordinated, and overseen by the regulator (or another public institution). Figure 50b shows that 27%[61] of the DSOs are incentivised for rolling out innovative technologies through regulatory experiments while

In addition to the regulatory experimentation, we also looked into other possible regulatory mechanisms in place for treatment of the R&D costs. Based on the results of our survey, in most European countries R&D and demonstration expenses are treated like any other cost; i.e. there is no specific compensation for the risks involved in testing new technologies and processes. Additionally, 45% of the DSOs included in our analysis reported existence of specific regulatory mechanism for adjusting revenues within the regulatory period, either in form of higher rates of return (i.e., adding an extra or bonus component to the regulatory WACC), or adjustment of revenues (i.e., providing an extra allowance or specific rewards due to performance targets).

5.7. Network Tariffs

A properly designed tariff structure is essential for the optimal promotion of short-term system usage and for providing appropriate signals for the efficient long-term grid development. It is also important to note that, although operators' costs are recovered mainly by network use tariffs, they are also recovered through other mechanisms, such as connection charges, regulated services or contractual arrangements with industrial customers and generators for the provision of flexibility services. Therefore, tariff design should reflect the link between these mechanisms and use of system charges.

The current legislation at the EU level provides some principles about the elements that national regulators should consider when deciding on the tariff structure for the allocation of costs on different network users. These principles include (AF Mercados, 2015): economic sustainability, allocative efficiency, cost-reflectiveness, non-discrimination and transparency. Establishing a trade-off between the above often competing objectives is a major regulatory challenge. As stated in (CEER, 2017), each country will have to make different trade-offs regarding tariff principles to better reflect on the specificities of their market structure, and the pace of change and the development of their retail market.

As mentioned before, tariffs for use of the electricity network cover the costs of building, maintaining and operating the networks. The costs are generally allocated among demand users and generators based on various cost-reflectivity criteria. Traditionally, costs have been recovered from users to reflect network usage, however costs are increasingly driven by new factors such as the growth of distributed generation, the digitalisation and electrification of the whole energy system, as well as the management of intermittency – all factors imposing new regulatory challenges.

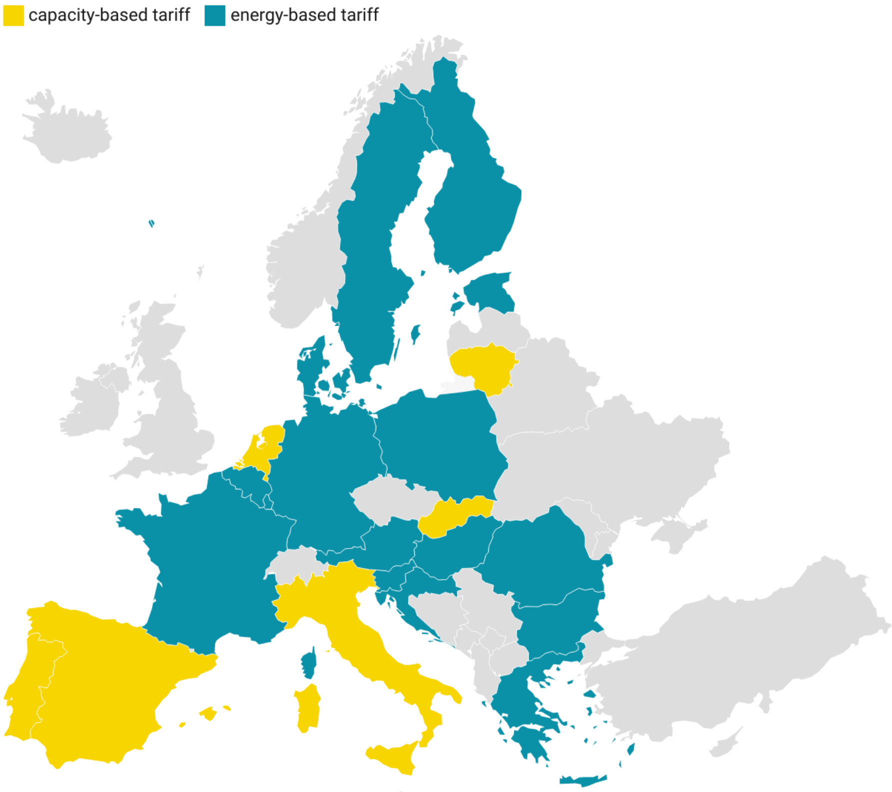
In this section, we analyse the main elements and alternatives about network pricing. When considering the components of the tariff structures, they are generally reduced to one, or a combination, of the following basic alternatives:

- Fixed charge: it refers to a fortiori lump-sum (€/connection) which is not linked to the contracted, measured or installed capacity of the connection. A fixed tariff is typically charged for services such as metering and other administrative costs.
- Power or capacity-based tariffs: billing scheme based on capacity or power charging (€/kVA or €/kW) in two forms: a) Ex-ante contracted capacity tariffs which, are based on the subscribed or installed capacity or b) retrospective capacity usage based tariffs, which are based on the actual power used (measured capacity).
- Volumetric or energy-based tariffs: is a billing scheme based on consumed energy (€/kWh). Energy usage network tariffs charge consumers for the energy they take from the grid, using a flat rate or on a time varying pricing basis.

In practice, in many European countries hybrid tariff schemes are used. Hybrid tariff schemes combine either volumetric and capacity charging (two-component tariff) or volumetric, capacity and fixed charging methods (three-component tariff). The two-component tariff refers to charges based on a customer's (measured or contracted) maximum capacity (€/kVA or €/kW) and consumed energy (kWh), while the three-component tariff also includes a fixed fee for the connection itself. Different weigh factors are assigned to each one of the three components of the tariff. Based on the component of the tariff which has the greatest weighting factor in the tariff structure we distinguish between[46] capacity-based tariffs and energy-based tariffs.

For the scope of the tariff analysis, the data are presented at country level rather than at DSO level. When multiple DSO entities operate over a country, the national regulatory authorities usually apply common approaches and methodologies in the design of the tariffs. However, in some countries the regulatory models provide more flexibility to DSOs to decide on the tariff structure. For instance, in Finland, the energy authority does not regulate the actual charges and tariffs, as TSOs and DSOs set them independently (CEER, 2021). For these countries where the DSOs apply different tariff schemes we calculated an average for each component included in the tariff. As Figure 51 shows only 6 countries (21% of the DSOs included in our analysis) use a capacity-based tariff structure while the rest use energy-based tariffs.

Figure 51. Use of capacity-based and energy-based electricity network tariffs in Europe, based on the survey responses of 56 DSO from 22 EU countries



Source: JRC, 2022[47]

In the past, three-component tariffs were mostly applied to industrial and large commercial consumers (CEDEC, 2014). However, the data from our analysis demonstrate that in 60% of the countries included in our analysis, the electricity distribution grid tariff for household customers consists of three components: a fixed component (€ / point of delivery), a component billing the contracted connection capacity (€/kW), and an energy or volume component (€/kWh). Interestingly enough in Romania, energy-based component weights 100% on the tariff structure, thus it is considered as a pure volumetric tariff scheme. Table 3 summarizes the tariff structure components along the basic descriptive statistics. The typical tariff structure as formulated by the data responses of the DSOs from the 22 European countries participating in the survey is as follows (mean values): 11% of fixed component, 33% capacity-based component and 56% of volumetric. In other words, this means that the average European DSO recovers 56% of their costs through energy consumption, 33% of their costs through utilized power and only 11% through a fixed tariff. Interestingly in the Netherlands, one DSO reported

[46] Fixed component of the tariff is the one that has always the lowest weight in all the applicable tariff structures.
[47] This map was created using the online tool Datawrapper.

that the tariff is 90% capacity-based and 10% energy-based. Similarly, in Italy the surveyed DSOs reported that they get on average 80% of their remuneration from the power component of the tariff.

Table 3. Descriptive statistics: mean, maximum/minimum values (Max/Min) for the three components of the network tariffs for all the DSOs included in our analysis

Statistics	**Fixed**	**Capacity-based tariff**	**Energy-based tariff**
Max	52%	90%	100%
Mean	11%	33%	56%
Min	0%	0%	3%

Source: JRC, 2022

5.8. Major barriers for DSOs to transition into a more active system operator

The DSOs that participated in the Survey have identified three major barriers for becoming a more active and engaged DSO. These barriers are summarised as follows:

a. **Regulation does not provide appropriate incentives for innovation.** More specifically, current regulatory mechanisms do not promote or even, in some cases, hinders innovation. On the same note, cost-efficiency cannot be the only criterion based on which regulation is designed. For example, annual costs for procuring flexibility services in absence of a liquid flexibility market can be higher than reinforcing/upgrading the grid, though customers can get a connection faster. Furthermore, some DSOs indicated the barrier of having overly regulated DSO business or in other words having stringent regulation in place. One example in this regard is the possibility of DSOs to own and operate storage (art. 36 of EU Directive 2019/944), being strictly limited to fully integrated network components and upon NRA's approval. This prevents deployment of storage as essential grid management tool for network management purposes and according to the view of these DSOs, pre-conditions for DSO's use of storage in such cases, should be re-assessed and requirements revisited. Finally, there needs to be a favourable environment for regulatory experimentation to allow for development and testing of new innovative technologies and practices, notably for the benefit of a more adjusted and balanced energy transition. In addition, R&D costs were reported to be hardly compensated by network tariffs, thus calling for special regulatory mechanisms to treat R&D costs.

b. **Lack of qualified personnel** presents one of the major barriers for the adoption of digital transformation of the energy sector in general and more specifically for the DSO's business and practices. With this in mind, there is a strong urgency to close skills gap to be able to accelerate the digitalisation of the electricity system since some DSOs reported slow progress on this front, lacking, as a result, observability of the distribution grids at different network voltage levels.

c. **Regulatory uncertainty and instability** (too slow or constantly changing regulations)**, including political instability.** For instance, with surging inflation, DSOs can potentially be faced with increasing interest rates leading to increased cost of capital, which in turn can hinder their ability to invest in network assets and grid modernisation. In many cases, the regulation is adapting too slow to the new needs while in other cases the regulation is constantly changing, creating cash flow uncertainty and investment instability.

6. Conclusions

The 2022 edition of the DSO Observatory provides an in-depth analysis of the evolving role of the Distribution System Operators within the European energy system. We focused on the following aspects of DSOs operations: main network operational DSO data, the ability to connect and effectively manage DERs and procure flexibility in the grid, data management and regulatory experimentation, and the forthcoming first round of Network Development Plans for electricity distribution. Network development will be a crucial activity for the years to come, as moving forward with the energy transition implies replacing a substantial part of the existing distribution grids and equipping them with digital solutions.

Concerning the connection of DERs, the data collected point to an emerging use of flexible connection agreements (mainly solar and wind) and procurement of flexibility services. This latter uses both market and non-market-based approaches) by DSOs to respond to an unprecedented need to timely integrate growing amount of RES into the European distribution grids and electrify other end-use sectors, such as transport and heating.

Smart metering, while being already deployed in many of the respondents' network area, is still not adopted in some "pockets", and it seems important that its implementation is encouraged where missing as it provides the basis communication layer to a more advanced DSO-customer interaction.

Charging infrastructure for EVs is provided massively throughout Europe: around 1 million charging columns are in the networks of the DSOs included in this analysis, spread among big, medium and small DSOs and pointing to the fact that the dimension of the DSOs does not seem to be so relevant for the deployment of EV charging infrastructure.

When it comes to regulatory experimentation, around 60% of the respondent DSOs mentioned that they are involved in some type of it, mainly on topics such as smart grids, smart metering and network tariffs. Above 40% of the participating DSOs in this study are aware of existing citizen energy communities in their grid.

Another area where appears to be large space for improvement is the procurement of flexibility services: 34% of the DSOs inquired have agreements to source it from their network, and they mostly do it thanks to individual arrangement with customers, mainly industrial and commercial and through flexibility tenders/markets, therefore leaving a crucial potential of residential customers mostly untapped at the moment.

To conclude, the 2022 Observatory provides once again a unique in-depth view of the energy distribution sector in Europe. Some trends are consolidating with respect to the previous edition in 2020, as the focus on regulatory innovations like citizen energy communities and the role and value of regulatory experimentation. On the other hand, ensuring a timely and efficient integration of variable renewable energy sources and electrification of other end-use sectors emphasises the critical role of regulation in addressing network challenges associated with the above trends, while enabling a whole range of smart energy technologies and services, including procurement of flexibility services by the DSOs.

The report delivers a nuanced picture of the situation some of the biggest Distribution System Operators in Europe face today and highlights the area that might deserve attention at policy level, so that critical aspects are tackled in time to deliver the sought-after energy transition. For instance, regulation for distribution networks needs to be fit for purpose. In other words, regulation cannot be based only on cost-efficiency, but rather promote and facilitate the development of innovative network solutions in light of unprecedented growing rate of renewable energy sources and electrification of other end-use sectors, namely transport and heating. One example in this context is the possibility of DSOs to effectively procure flexibility services from different type of network users, including the ones connected to the LV networks. Also, regulation should allow the best results from regulatory experimentations (regulatory sandboxes, citizen energy communities, etc.) to be replicated at larger scale, while at the same time keep the window open for new experimentations.

Another clear example of the missed opportunities coming from the current most common regulatory frameworks is the level of regulatory incentives vs. the level of inflation, which topped at 10.6% in October 2022[48]. If regulatory incentives for innovative distribution grid solutions are lower than the level of inflation, as happened in various countries during 2022, the incentives for DSOs to innovate need to be revised to guarantee an effective decarbonisation of the EU over the long term.

[48] Eurostat, "Euro area annual inflation rate and its main components".

In the future such issues (flexibility, grid connection, regulatory innovation) are expected to increase their importance, given the accelerated speed at which recently the European Union has decided to reach its climate and energy goals.

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List of abbreviations and definitions

ACER	Agency for the Cooperation of Energy Regulators
ASIDI	Average System Interruption Duration Index
CAIDI	Customer Average Interruption Duration Index
CAPEX	Capital expenditure
CBA	Cost Benefit Analysis
DERs	Distributed Energy Resources
DSO	Distribution System Operator
EIRIE	European Interconnection for Research Innovation & Entrepreneurship
EU	European Union
EV	Electric Vehicles
GWh	Gigawatt hours
HV	High Voltage
JRC	Joint Research Centre
KPI	Key Performance Indicator
LV	Low Voltage
MV	Medium Voltage
MVA	Megavolt-Amperes
MW	Megawatt
OPEX	Operational expenditure
PS	Profit-Sharing
PV	Photovoltaic
QoS	Quality-of-Service
RES	Renewable Energy Sources
R&D	Research and Development
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition
SFA	Stochastic frontier analysis
TOTEX	Total expenditure
TSO	Transmission System Operator
TWh	Terawatt-hour
VPP	Virtual Power Plant
WACC	Weighted Average Cost of Capital

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