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Distribution System Operator Observatory 2020

An in-depth look on distribution grids in Europe

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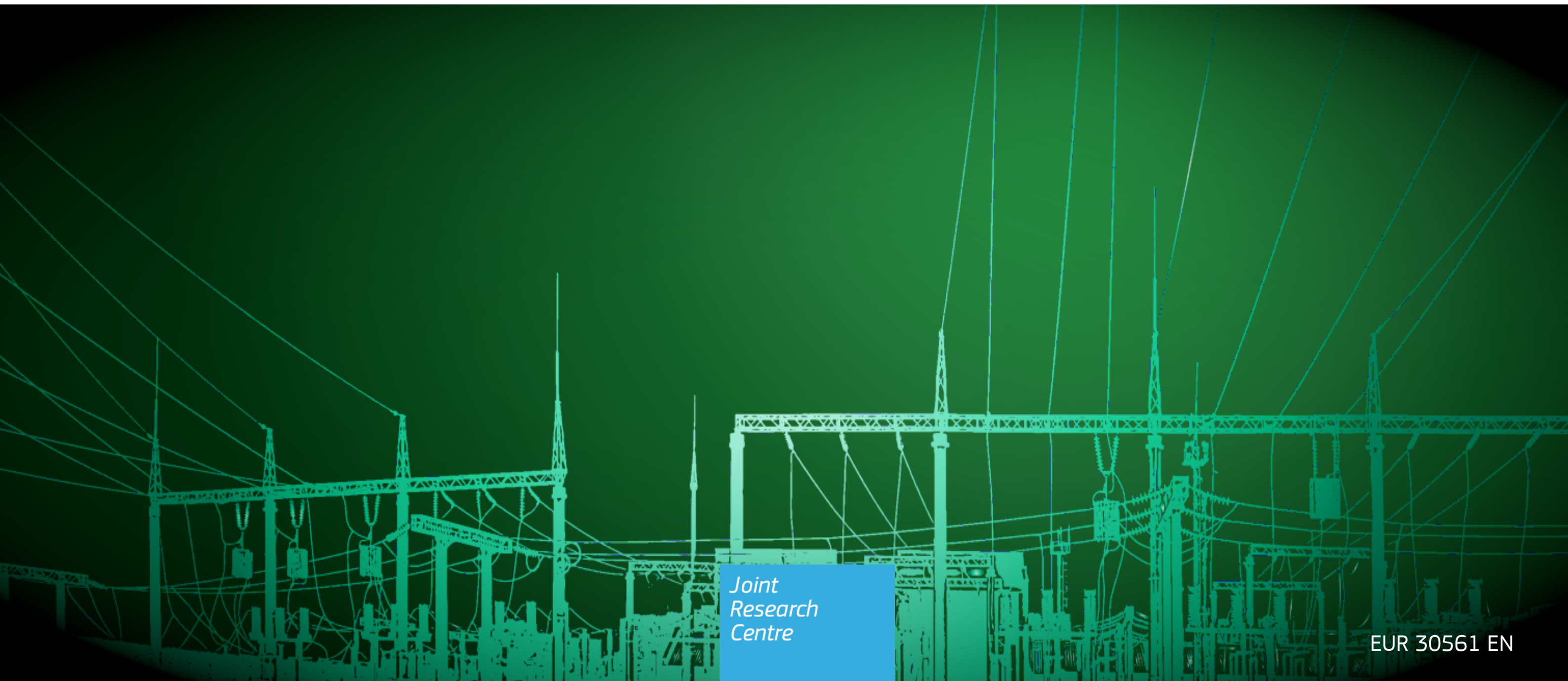

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Abstract

The decarbonisation of our economies and the consequent process towards a more sustainable society are at the core of the set environmental policies. Distribution System Operators (DSOs) as responsible of delivering electricity from High Voltage level to final customers are among the top players in the paved transition. As part of the Clean Energy for All Europeans legislative package, the DSOs have an important role in the European energy market as neutral market facilitators, but also as innovators driving the transition of the energy system towards a more sustainable future. At the same time big differences exist between DSOs operating in different Member States. This report helps shedding some light on them through an extensive data collection. It shows technical data on grid infrastructure, but also analyses the potential of the interviewed DSOs to innovate and to operate their grid more efficiently. Additionally some regulatory aspects and the impact of the Covid-19 pandemic are discussed. Finally, some policy recommendations are given on the basis of the analysis carried out: a key point is to define a common methodology to gather data on distribution systems across Europe, both on technical and regulatory aspects.

Foreword

Smart grid solutions will be mainstreamed in the coming years with the implementation of the EU Clean Energy Package (CEP). The CEP includes the Electricity Directive and the Electricity Regulation with many provisions targeted at Distribution System Operators (DSOs). It is exciting to see that the smart grid research, developments, and demonstrations are going to be rolled out across Europe.

The CEP establishes DSOs as active system operators. DSOs are expected to develop multi-annual network investment plans that consider the trade-off between expanding the distribution grid and procuring flexibility to deal with the local system peaks. Some of the assets that are expected to create new peaks in the distribution grids in the future, such as electric vehicles and heat pumps, can also be part of the solution if they are smartly managed.

By procuring flexibility services (also referred to as non-frequency ancillary services), the DSOs can give incentives to the grid users to smartly heat their homes or smartly charge their cars and home batteries. Following the CEP, the role of DSOs indeed includes location congestion management. The EU DSO Entity will become operational in 2021. This new entity has been mandated to contribute to the drafting of the second generation of network codes that shape the detailed grid connection and market rules in Europe.

However, the devil is in the details of implementation, and there are many open issues that will be debated in the coming years. What methodology will DSOs use when considering the flexibility trade-off. How transparent will DSOs be when they publicly consult their multi-annual investment plans? How will the procurement of flexibility services by DSOs be integrated in the existing sequence of electricity markets in Europe? How will the cooperation between DSOs and TSOs evolve?

The urgency for DSOs to act is also increasing. The EU Green Deal aims for carbon neutrality by 2050 and is revisiting the targets for the 2030 horizon to achieve the 2050 ambition. In most sectors, the decarbonization will be partly achieved via electrification, including the building sector (heat pumps), the transport sector (electric vehicles), and industry (green hydrogen produced with electrolysers). Most of this electrification will take place in distribution grids.

The 2020 edition of the JRC Distribution System Operator Observatory already provides some insights into the readiness of DSOs to face these challenges. Of the 44 DSOs included in the survey:

— 12 have already reached the 80% rollout target for smart meters, for about 63% of the 140 million European customers represented in this survey;

— 54% manage the active customers in their network;

— 56% of DSOs answered they are already considering non-wires alternatives as an alternative to network infrastructure investments.

With the implementation of the CEP, we can expect these numbers to increase. Note finally that the survey for this report reached 44 of the largest DSOs. Hopefully, the thousands of smaller DSOs are equally ready to face this transition.

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Authors

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Executive summary

European DSOs- Distribution System Operators - have a crucial role in the European power system: historically, they have been delivering power from the High Voltage transmission to final customers. Today, their relevance goes much further beyond that: policies at international and European level provide for additional efforts in reaching climate neutrality, and put the DSOs at the centre of this endeavour.

Policy context

Implementing the Paris Agreement, and linking climate efforts to a sought-after economic recovery after the COVID-19 pandemic that hit Europe as the rest of the world, the European Commission committed to climate neutrality of the EU by 2050. The European Green Deal, unveiled at the end of 2019, provides the blueprint for climate, energy and environmental actions for the years to come: it's a comprehensive strategy including not only the reduction to 0 of net CO_2 emissions by 2050, but also decouples economic growth from use of natural resources and aims at having a just transition that is sustainable not only for the environment but also for the society. Clean energy and sustainable mobility are two of the 10 policy areas indicated in the EU Green Deal, and European DSOs are crucial to both. DSOs have been at the center of the new energy market legislation as defined in the revised Directive on Common Rules for the internal market for electricity, part of the Clean Energy for all Europeans legislative package issued in 2019. The directive defines a clear role for the DSOs as the key enablers for innovation in the electricity market: beyond their traditional roles of ensuring the reliability of the electricity distribution, they are also in charge of integrating Renewable Energy Sources, Electric Vehicles and Distributed Energy Resources into the system and therefore appropriate network tariffs should be set up. DSOs should therefore act as neutral market facilitators, and should not own or operate storage or EV charging facilities, unless they are used to ensure network security and reliability or no other company can ensure the provision of such services. The Directive also mandates DSOs to coordinate the streams of information across the energy value chain, taking care downstream of consumers' data management and upstream of sharing balancing resources in the grids with Transmission System Operators. Finally, another important step forward in the policy setting for DSOs is the creation of the so-called DSO entity: an association that will represent and coordinate all DSOs in Europe, along the lines of what has already been established for Transmission System Operators with ENTSO-E.

Key conclusions

This report delves into the details of the implementation of a specific paragraph of the Directive 2019/944: that on Distribution System Operators. In the Clean Energy for All Europeans legislative package the DSOs have an important role in the European energy market as neutral market facilitators, but also as innovators driving the transition of the energy system towards a more sustainable future. The innovative provisions laid down in the Clean Energy for All Europeans package design a completely new role for DSOs and, according to data collected and the JRC analysis presented, they seem ready to take on the challenge. They are already considering advanced technologies to manage their electricity grids, new massive distributed energy resources from renewables, and regulatory experimentations. Policy actions in the near future should therefore mostly focus on monitoring the implementation of the innovative provisions of the Directive, with minor adjustments such as a clarification on the taxonomy of regulatory experimentation, so that experiences across different countries can be compared and best practices for implementation can be identified. Another point of interest in implementing the provisions is the evaluation of costs and benefits of the various steps that DSOs will need to take to make the transition towards a CO_2-neutral energy system: while today the policy priorities have been clearly identified, the alternative options, or possibly lower costs options, are not clearly spelled out and each DSO or each country proceeds at a different pace.

The DSO Observatory, now at its third edition, is still the key document summing up all the major aspects of an industry that is at the core of the European energy transition. The data collected and processed confirm that all the major areas of grid development (use of flexibility sources in the grid, charging infrastructure for EVs, data management, grid investment planning) are currently addressed at EU policy level. Another step forward in understanding how the DSOs world is changing will be the expected creation of the European Interconnection for Research Innovation & Entrepreneurship - EIRIE - platform within the JRC, which will collect, store, and analyse data on smart grids, including at distribution level, that are at the moment only partially treated.

We would recommend to adopt a EU-wide approach on DSO technical data gathering: a need that has been already emerging throughout the years, for example with reliability indicators like SAIDI and SAIFI that are now very widespread. A subset of the JRC's presented indicators can for example serve as an initial basis, allowing to identify the characteristics of all European DSOs, including those serving less than 100,000 customers, and help in defining country-specific characteristics. Accurate information can certainly help European policy-makers but also National Regulatory Authorities in performing their duties, and in particular will help in tracking the progress towards the defined climate targets. Such indicators can also be included in National Energy and Climate Plans, or complement them.

Furthermore, a serious reflection is needed at policy level concerning the use of grid enhancement, like digitalisation, vs. grid expansion, namely investments in increasing the grid capacity. Appropriate policies are those providing incentives to achieve a socially optimal solution: provided the diverse reality of DSOs across Europe a one-size-fits-all solution can hardly be optimal. Nevertheless, DSOs should be incentivised, when drafting their investment plans for example, to evaluate according to specific metrics and indicators the best solution for them to contribute to reaching the European *Fit for 55* targets (reduction of GreenHouse Gases emissions by 55% by 2030): shall they invest in digitalisation, including for example automated control or monitoring of the grid, or rather on increasing their grid capacity in order to allow more RES to be effectively dispatched into the power system? The answer to such questions will be specific to each DSO, but a common methodology can certainly make the task easier for all of them. The JRC has already a years-long experience on such methodologies, as with the Smart Grid Cost Benefit Analysis which is now applied world-wide to evaluate smart grid projects.

Particular attention should be dedicated to the role of DSOs as enablers of innovation in the electricity grid: specific attention should be devoted to their role as DER managers, flexibility providers, and fall-back emergency providers of services, like EV charging, where no other party can provide them. The provision of such services are fundamental for the development and innovation of the European power system and needs to rely on a clear, possibly European-wide, tariff scheme. Such tariff scheme should be designed in a way that ensures a level-playing field for the different technologies and the embracement, instead of discouragement, of various innovations, however complex they might be to handle. Summing up, a regulatory approach that incentivises innovation is needed, and in order to define it a common methodology might be helpful.

Still on the regulatory aspect, the taxonomy mentioned above can be used as a tool to define the map of innovative regulation in Europe, and assess the merits and pitfalls of each approach. Such evaluations can be carried out by the JRC, in cooperation for example with the associations of regulators like CEER - Council of European Energy Regulators and will be able to provide policy makers interesting insights on the innovation taking place in the European distribution grids. Investment plans will also provide interesting information, however a standardised set of minimum content should be defined at EU level, possibly as an exercise within the future DSO-Entity. A possible step forward would be the integration of DSO investment plans with TSOs ten year development plans, in order to provide a clear picture of the whole electricity system, not only of a portion of it. This is also coherent with a more integrated view of the power system.

Finally, another aspect needing attention by policy makers is the response to the COVID-19 pandemic. As mentioned, the long-term effects of the pandemic on the operation of the European power system are still to be seen. However, a coordinated response, involving TSOs and DSOs associations alike, would probably be much welcome. At the moment, in fact, the most common safety measures taken by TSOs and DSOs alike deal with personnel co-presence and rotation, creation of teams that are stable over time, etc. This is certainly important, but very small attention has been given to the implications in terms of long-term stability of the grid, revision of investments in both digitalisation and grid expansion to respond to the falling electricity demand. When the dust settles, the distribution grid and policy makers should reflect together on how the long-term electricity demand will be affected by the present pandemic or other crises, in order to clarify if there are opportunities along the obvious threats and to define an appropriate response.

Main findings

The third edition of the European DSO Observatory aims at capturing all the various directions towards which DSOs are evolving. While the first edition of the report, issued in 2016, presented a picture of DSOs still anchored to mostly traditional tasks of system operation and grid stability, the 2018 report integrated data on more innovative services, like customer data management and data sharing with TSOs, advanced smart metering roll-out, use of flexibility sources, and integration of EVs charging points in the distribution grid. In this report, the evolutionary path taken by European DSOs is even clearer: they are more and more enabler of the energy transition that will take place in the continent over the next decades. Given the vast number of DSOs active in Europe, the mapping effort has been limited once again to the bigger DSOs, namely those which serve more than 100,000 customers and subjected to the unbundling requirements of the EU electricity Directive 2009/72/EC. Also this edition presents data based on a survey directly filled by individual DSOs, collecting new data for 44 DSOs.[1]

Related and future JRC work

The third edition of the DSO Observatory report is a building block of the JRC's activities on distribution grids, which include: the inventory of Smart Grid projects in Europe and of Smart Grid Laboratories worldwide, data visualisation tools with interactive maps and the DiNeMo tool to simulate reference networks within Europe. JRC will continue with this stream of work also hosting the EU platform for electricity grid related information, EIRIE.

Quick guide

This report presents the data collected by the JRC through a dedicated survey among European companies managing the electricity distribution grids. It reports both technical data on the electricity network managed and information about more advanced functionalities implemented by the Distribution System Operators, like: management of Electric Vehicles and Distributed Energy Resources, use of storage and demand response, but also regulatory experimentation and measures put in place to mitigate the impact of COVID-19 pandemic on the European power system.

[1] For clarity, it is worth mentioning that 6 DSOs were aggregated into one reply by a DSOs association, for this reason in the indicators appearing throughout the report there are 39 replies maximum. It is also relevant to say that these 6 DSOs together with another one (corresponding thus to two replies) are non EU DSOs.

1 Introduction

In Europe, operations of electricity grids are distinct into two different realms: electricity transmission, managed by Transmission System Operators, takes care of High Voltage grids, while electricity Distribution (mostly dealing with Medium and Low Voltage, down to the consumers' meters) is managed by Distribution System Operators. Transmission and Distribution activities are subject to unbundling, i.e. the companies carrying out activities where there can be competition, like electricity generators and suppliers, should be separate companies from those doing business within natural monopolies, like transmission and distribution grids (CEER, 2019).
As reported already in (Prettico et al., 2019), the European legislation that imposed unbundling also for Distribution Operators back in 2009 states that "without effective separation of networks from activities of generation and supply (effective unbundling), there is an inherent risk of discrimination not only in the operation of the network but also in the incentives for vertically integrated undertakings to invest adequately in their networks'. However, it should be noted that for power distribution activities unbundling requirements do not create an obligation to separate the ownership of assets of the distribution system operator from the vertically integrated undertaking, but provide for separation at functional and legal level.
A summary on the different type of unbundling can be found in (Florence School of Regulation, 2020). According to functional unbundling, the distribution grid operator is independent in decision making rights and in its organisation. On the other hand, legal unbundling implies that the distribution activities are performed by a separate legal entity. The network company must not necessarily own the network assets but must have "effective decision making rights" in line with the requirements of functional unbundling. Therefore, network operators need the functional unbundling in order to assure their independence in decision making, whereas legal unbundling involves the setting up of a different company (Ropenus et al., 2009).
Today in Europe there are 44 Transmission System Operators and around 2400 Distribution System Operators, of which only 13 percent are subject to unbundling. Table 1 presents the main figures related to the diverse DSO landscape in Europe (Eurelectric, 2020). More in-depth considerations on the different realities of European DSOs (Andreadou et al., 2019) point to a very fragmented landscape, with DSOs clustering around few prominent business models depending on the country of operation, such as one big DSO complemented by a lot of small local DSOs, multiple DSOs of every size, or few big DSOs.

The JRC's Distribution System Observatory provided the first in-depth analysis of a key sector in the European electricity market back in 2016. Since then, 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 is central in the current European policy framework, and new roles with important implications for the whole power system have been emerging. DSOs in fact can be neutral market facilitators (IRENA, 2019), they can procure flexibility sources to the power system (Schittekatte and Meeus, 2020), they can redirect investments in grid reinforcement towards digitalisation (Buvik and Borke, 2017), possibly substituting costly investments in physical infrastructure with smart and innovative solutions. They also have a key role in interacting with end-customers (Vasiljevska et al., 2016), enabling demand response, managing data, and conducting innovative regulatory experimentation. Finally, they are more and more cooperating with the TSOs by sharing experience and expertise, towards the common goal of the energy transition (Vasiljevska and Marinopoulos, 2019).
With respect to the 2018 edition of the Observatory two important changes in European energy policy have taken place: the adoption of the Clean Energy for all Europeans legislative package (European Commission, 2019) and the issuance of the European Green Deal communication (European Commission, 2020). This section aims at presenting their future implications on DSOs. These two landmarks of the European energy and climate policy define new roles for DSOs in the European energy system, providing a vision for their activity in the years to come.
For an overview of traditional tasks of Distribution System Operators in Europe, please refer to (Prettico et al., 2016) and (Prettico et al., 2019). The Clean Energy for all Europeans package includes DSO-specific provisions in the Directive 2019/944 (European Parliament, 2019), which provides for DSOs to ensure a secure, reliable and efficient electricity distribution system and act as neutral market facilitators. We provide below a short description of the main ones.

In the following we present some of the topics from the (European Commission, 2019) touching upon DSOs' activity. They are included in Chapter IV of the Directive. The focus here is on the innovative services and roles that DSOs can play in the future transition towards carbon neutrality, where however the rules laid down aim at limiting the role of DSOs in emerging businesses, so to ensure a level playing field and DSOs cannot enjoy a privileged position from owning the grid. Traditional roles like network planning and network management of course continue to be crucial, and they are not limited but they still constitute the core of DSOs' activity.

— Citizen Energy Communities and Renewable Energy Communities: the Directive 2019/944 provides for CECs, legal entities based upon voluntary and open participation. Such CECs are expected to deliver environmental, economic or social benefits to those who participate. The community, expected to be

Table 1: Number of DSOs in the EU

	Country	Number of DSOs per country	Number of DSOs > 100,000 customers
1	Austria	126	11
2	Belgium	16	12
3	Bulgaria	4	4
4	Croatia	1	1
5	Cyprus	1	1
6	Czech Republic	290	3
7	Denmark	40	10
8	Estonia	34	1
9	Finland	77	9
10	France	144	6
11	Germany	883	80
12	Greece	1	1
13	Hungary	6	6
14	Ireland	1	1
15	Italy	128	8
16	Latvia	11	1
17	Lithuania	6	1
18	Luxembourg	4	1
19	Malta	1	0
20	Netherlands	6	6
21	Poland	184	5
22	Portugal	13	1
23	Romania	51	8
24	Slovakia	3	3
25	Slovenia	1	1
26	Spain	354	5
27	Sweden	170	6
	Total	2556	182

Source: Eurelectric, 2020.

characterised by a relatively small size, can undertake electricity generation, including Distributed Energy Resources, and electricity distribution, supply, consumption, aggregation, storage and operation of Electric Vehicles charging points, or provide any other type of energy-related service. For the purposes of this report the CECs are interesting as they can become either DSO, or closed distribution system operators. DSOs are requested to collaborate with CECs, and it is widely recognised that a fair tariff structure for grid connection and charges should be in place to ensure that CECs are treated fairly by the DSOs, provided that most of them do not intend to disconnect from the grid (Broeckx et al., 2019).

— DSOs as operators of flexibility: the role of DSOs in integrating RES, Electric Vehicles, and Distributed Energy Resources is crucial (Beckstedde et al., 2020), and for these reasons the national regulatory framework should set up network tariffs that encourage the DSO to appropriately manage the flexibility sources in its grid. For example, flexibility can contribute effectively to congestion management, granting to DSOs a fundamental role in making the electricity market work, especially in a context of more and more spread DER (Schittekatte and Meeus, 2020) and (Anaya and Pollitt, 2017).

— DSOs investment plans: just like Transmission System Operators, the DSOs should carefully reflect on the expansion/upgrade of their grid, in order to be able to deliver the transition towards carbon neutrality increased network capacity or more efficient, smart and digitalised grid management (Gomez San Roman, 2017). The plans should be made every two years.

— DSOs, just like TSOs as grid operators, should ensure neutrality and therefore are not allowed to own energy storage facilities, unless these are components of the network and are used to ensure network security and reliability, and shall cooperate with TSOs sharing balancing services across their grids. This particular provision, together with forbidding DSOs to own, operate and manage Electric Vehicles charging points, is one of the main changes introduced by the Clean Energy for All Europeans package. The aim is clear: DSOs are allowed to own and operate storage or EVs charging only in case a market-based process did not identify any company willing to do the same, and in that case the Regulatory authority should revise the decision every few years to ensure that DSOs do not hinder market competition in these emerging sectors of the energy system.

— The creation of a European DSO Entity: 4 DSO associations , i.e. EDSO, CEDEC, Eurelectric and GEODE, presented the draft statutes of this new association to ACER over the summer of 2020, and the DSO Entity should become operational starting in 2021. At the moment it represents already 500 DSOs from all over Europe (EDSO, 2020), and aims at ensuring the coordination of all its member DSOs across Europe. This is certainly a positive innovation that will allow European DSOs to have one single representative where decisions are taken through voting rights granted to each DSO member.

— DSOs also ensure appropriate data management, guaranteeing non-discriminatory access to data. Data can then be shared by DSOs along the electricity value chain both upwards (with TSOs) and downwards (to consumers, suppliers, or other market participants). This specific aspect implies the creation of dedicated Data Management Platforms.

2 The JRC DSO Observatory project

Power systems are perhaps the most complex large-scale engineered systems today and expected to have the highest level of reliability because of the dependence of virtually all human activities on them. Traditionally, power systems are divided into two main levels depending on the voltage value: transmission and distribution networks. Despite that the voltage value which separates the two networks can be different from country to country or even inside the same country, a separation exists between the grid operated by the Transmission System Operator (TSO) and the part(s) of grid operated from the Distribution System Operator (DSO). While for the transmission grid infrastructure a consolidated knowledge is available and high levels of automation are put in place, the distribution grid infrastructure is often lacking both aspects. The presence of this gap for the European DSOs and the networks they operate has motivated in the end of 2014 the birth of the JRC DSO Observatory project. Its aim was mainly to contribute to a better understanding of the challenges that the transition to a new decentralised and decarbonised energy system is currently posing to European distribution system operators and to elaborate sound solutions to address them.

2.1 Previous DSO Observatory exercises

To contribute in closing this knowledge gap, a first data collection exercise was undertaken in 2015. The data collection was made through a survey based on on-line forms directly filled from representatives of the participating DSOs. This exercise resulted in two main outcomes: a JRC Technical Report (Prettico et al., 2016) focused on the collection of technical and structural data from the DSOs, and the building of a set of 13 representative network models publicly available to stakeholders in the power sector([2]). The second data collection exercise took place in 2018 with the same methodology, where also in this case two main outcomes were delivered: a JRC Science for Policy Report (Prettico et al., 2019), this time with a deeper focus on policies, and a distribution network model (DiNeMo) web platform capable of producing distribution grid models *on request*([3]).

2.2 Questionnaire on the current status of EU DSOs

In order to get information directly from the DSOs, JRC prepared a questionnaire that was distributed to virtually all EU DSOs with more than 100,000 customers over the summer of 2020. In this way, we managed to collect valuable and reliable data, which could not be found otherwise in the public domain. The questionnaire contained 10 main 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.

   — The areas that the DSO serves and the total surface of these areas in squared km.

   — The 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. Specifically:

   — The number of total connected customers, as well as the customers connected in LV, MV, and HV.

   — The total km of network lines, as well as the km of LV, MV, and HV lines.

   — The total km of underground cables, as well as the km of LV, MV, and HV underground cables.

   — The total km of overhead lines, as well as the km of LV, MV, and HV overhead lines.

   — The 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.

   — The total number of MV/LV secondary substations, their voltage ratios in kV (e.g. $20/0.4kV$, $10/0.4kV$, etc.), and their total installed capacity in MVA.

([2]) The models are available on: `https://circabc.europa.eu/ui/welcome` by requesting access to the group *JRC Distribution Reference Network Models*.

([3]) DiNeMo is publicly accessible at `https://ses.jrc.ec.europa.eu/dinemo` through an EU login account

- The 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.
- The System Average Interruption Frequency Index (SAIFI), in no. 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, also 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, EV charging, energy storage** This section contains information on DER, electromobility infrastructure (EV charging points), and energy storage connected to the DSO network:

   - Total number of connection points, as well as number of connection points owned and operated by the DSO itself or by third parties.
   - Total number of charging points. A connection point can contain one or more actual charging points (outlets) for EV charging. Regarding the charging points, additional information is provided on how many points are: *a)* connected through a new connection, *b)* connected to a current connection through a separate meter, *c)* connected to a sub-meter behind a smart meter, *d)* connected to a non-metered appliance, *e)* owned by the DSO.
   - Possible specific distribution network charges for EV charging, taking into account their contribution to a more efficient use of the distribution network.
   - Obligation of utilities to communicate installation of new charging infrastructure to the DSO.
   - Energy storage infrastructure owned by the DSO, the type of technologies used, and their total power and/or energy capacity.
   - Access rules for energy storage in the country of the DSO.
   - Installed capacity of photovoltaic (PV) power systems connected to the DSO, in MW, and their total gross electricity generation per year, in GWh.
   - Percentage of PV installations connected at the LV, MV, and HV level.
   - Installed capacity of wind power generation connected to the DSO, in MW, and their total gross electricity generation per year, in GWh.
   - Percentage of wind installations connected at the LV, MV, and HV level.
   - Installed capacity of biomass power generation connected to the DSO, in MW, and their total gross electricity generation per year, in GWh.
   - Percentage of biomass installations connected at the LV, MV, and HV level.
   - Installed capacity of waste power generation connected to the DSO, in MW, and their total gross electricity generation per year, in GWh.
   - Percentage of waste installations connected at the LV, MV, and HV level.
   - Installed capacity of hydro power generation connected to the DSO, in MW, and their total gross electricity generation per year, in GWh.
   - Percentage of hydro installations connected at the LV, MV, and HV level.

5. **Non-frequency ancillary services DR, DSM/DSF and active customers**
   This section contains information on provision of non-frequency ancillary services to the DSO, from various flexibility resources, such as Demand Response (DR), Demand Side Management/Flexibility (DSM/DSF), and active customers. Specifically:

   - DR or DSM/DSF in place in the DSO network.
   - DR or DSM/DSF considered as alternative to investments.
   - Possible estimated savings in CAPEX and/or OPEX from DR, or DSM/DSF.
   - Management of active customers, as well as when (in all cases, in emergency, in pilots, etc.) and how (directly by the DSO, through aggregators, etc.) this is done.
   - In case there is management of active customers the minimum entry level capacity is given, while if there is no management of active customers the DSO provides the main reason for this.

6. **DSO-TSO coordination**
   This section contains information on the data produced and shared by the DSO in the context of DSO-TSO coordination:

   — Mandatory or voluntary sharing of DSO data on demand and generation forecasts with the TSO, and the data's granularity, i.e. yearly, monthly, weekly, daily, hourly, or 15 minutes data.

   — Mandatory or voluntary sharing of DSO data on the network conditions, in specific scheduled data of each power generating facility, and the data's granularity, i.e. yearly, monthly, weekly, daily, hourly, or 15 minutes data.

   — Mandatory or voluntary sharing of DSO real time measurements data from SCADA, and the data's granularity, i.e. yearly, monthly, weekly, daily, hourly, or 15 minutes data.

   — Mandatory or voluntary sharing of DSO metered data on ex-post measurements, and the data's granularity, i.e. yearly, monthly, weekly, daily, hourly, or 15 minutes data.

   — Data on the network conditions received from TSO, either mandatory or obligatory, and the data's granularity, i.e. yearly, monthly, weekly, daily, hourly, or 15 minutes data.

7. **Network monitoring and control**
   This section contains information on various capabilities of monitoring and control of the DSO assets, such as substations, smart metering infrastructure, in particular:

   — Number of remotely controlled HV/MV and MV/LV substations.

   — Percentage of rolled-out smart meters up to now on total end-customers (according to EU Directive 72/2009, 80% of electricity consumers by 2020).

   — Procedure of (active) customers to access and/or control their meter data (e.g. directly, through DSO, through energy provider, etc.)

   — Total number and percentage of Advanced Metering Infrastructure devices installed at the end-users, and reason for being used by the DSO (e.g. obtain consumption data, receive failure notifications, prevent fraud, etc.).

   — Total number and percentage of Advanced Meter Reading devices installed at the end-users, and reason for being used by the DSO (e.g. obtain consumption data, receive failure notifications, prevent fraud, etc.).

   — Use of SCADA system or similar, and type of controls that can be performed at substation, feeder, or end-user level.

8. **Advanced grid management tools**
   This section contains information on various technologies and tools used by the DSO for advanced grid management:

   — Power flow simulations.

   — Data Analytics for asset planning and investment strategies.

   — Sensor Technology for Outage Detection & Prediction.

   — Advanced Load & Storage Management development.

   — DER Visualization and Management tools.

   — Drones technology for infrastructure monitoring.

   — (Micro)-Phasor Measurement Units.

9. **Regulatory aspects**
   This section contains information on some regulatory aspects, stemming from recent developments in EU policies:

   — Are there any Citizen Energy Communities (CECs) in the DSO network and are there special regulatory provisions and/or tariffs for them?

   — Does the DSO participate in any regulatory experimentations (e.g. pilots, innovation projects, regulatory sandboxes)?

   — Does the DSO prepare a 5-10 year investment plan, according to the recast Electricity Directive (EU) 2019/944?

   — Remuneration sources for the DSO activities (e.g. fixed network tariffs, capacity based tariffs, etc.).

10. **COVID-19 pandemic**

This last section contains information on the impact of the COVID-19 pandemic on the DSO demand and the operation of the organisation:

— Percentage of reduction in the total annual energy demand in the DSO served area.

— Strategies to mitigate COVID-19 related risks.

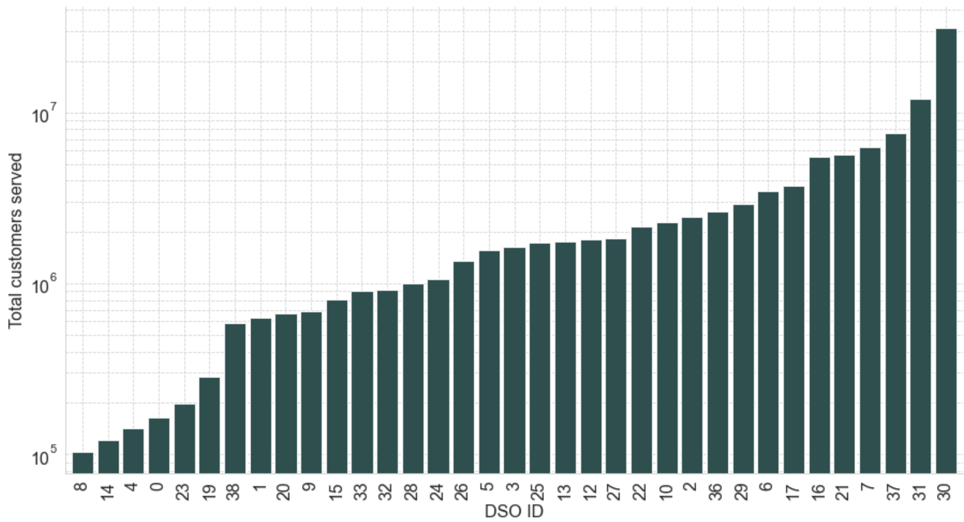
3 DSO technical features

This section contains the most technical part of this report. Its main aim is to provide relevant anonymous data to those stakeholders which are active in the power distribution sector. One main difference with previous DSO Observatory exercises is the fact that the major part of technical data is provided per DSO, by means of a DSO ID. This allows the reader to have detailed information on a DSO, without knowing its identity, but only its technical features. For this reason, we do not provide any information regarding the composition of our DSOs sample: no reference is made throughout the report to particular Member States nor to countries/regions/provinces. We consider this to be a fundamental advantage in comparison with previous exercises. In the following several figures, the main structural data collected from the DSOs are shown, i.e. the number of served clients, their typology (LV, MV, HV), the relation between customers and area of operation, the relation between energy served and area of operation, the length of underground cables and overhead lines, the reliability indexes (SAIDI and SAIFI) and much more. Additionally, for almost each of the mentioned figures, some aggregated statistics is also provided into tables, which shows the number of DSOs that have provided a reply, the average, the first, second and third quartile and the minimum and maximum for the indicator analysed.

3.1 Network Structure Data

A first characterisation of our DSOs can be made by looking at the size of each of them in terms of customers supplied, energy supplied and area of service. Note that from now on every DSO is identified by its *DSO ID* which goes from 0 to 38. In the next figures, the same ID will correspond to the same DSO. Figure 1 shows the number of served customers (LV, MV and HV) sorted in ascending order.

Figure 1: Total customers per each DSOs



Source: JRC, 2020.

By looking at a more aggregated level (Table 2), it can be noticed that 50% of the 35 DSOs which have shared this information serves between $100,000$ and $1,6$ million customers. In contrast, only two of the DSOs have more than 10 million customers, with the biggest one supplying electricity to more than 30 million customers. Several DSOs have also shared information about the composition of their customers in terms of voltage level

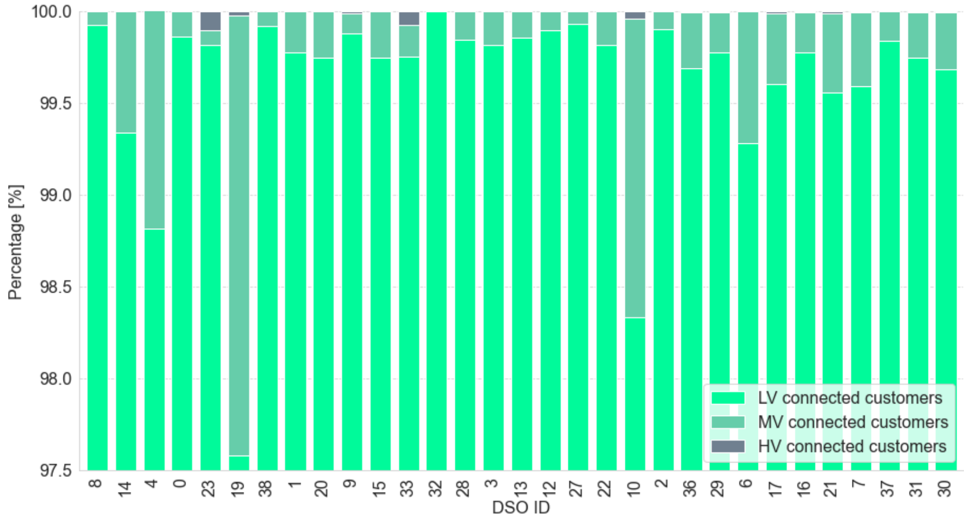
Table 2: Total customers statistics

	Field	Value
0	count	35
1	mean	3,086,960
2	std	5,519,250
3	min	103,086
4	25%	679,490
5	50%	1,635,580
6	75%	2,767,780
7	max	31,324,300

Source: JRC, 2020.

to which they are connected. Figure 2 shows the percentage of customers per voltage level (LV, MV, and HV). As for previous publications of the Observatory, we consider: LV, the grid infrastructure operating with a voltage below or equal to $1kV$; MV, the grid infrastructure operating with a voltage between $1kV$ and $36kV$; HV the grid infrastructure operating with a voltage above $36kV$. As it can be noticed DSOs serve mainly LV customers. All the participant DSOs have in fact more then 95% of their customers connected at the LV level.

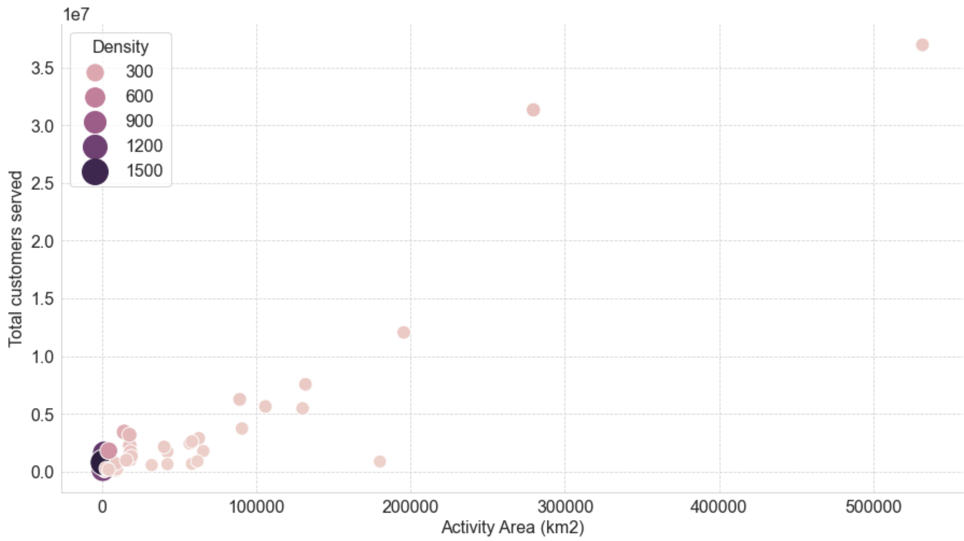
Figure 2: Customers per voltage level



Source: JRC, 2020.

In Figure 3 the relation (scatter plot) between the activity area in which the DSO is operating and the amount of customers served is shown. Note that big dots correspond to DSOs that serve cities, where the customers' density is higher comparing to more mixed areas, composed for instance by urban, semi-urban and rural regions.

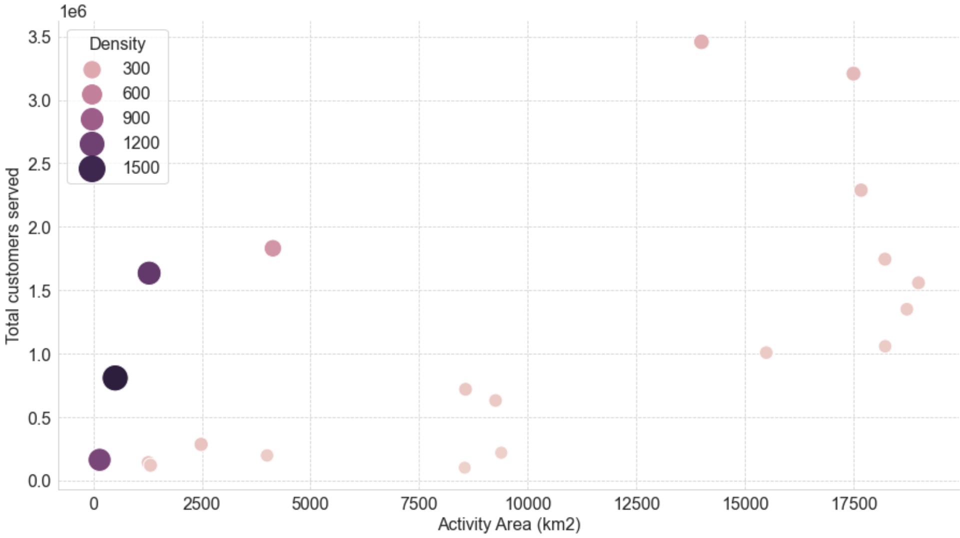
Figure 3: Scatter plot of customers vs area of operation



Source: JRC, 2020.

Despite looking linear in Figure 3, a zoom of this graph closer to the origin (Figure 4) better highlights that this relation for the majority of DSOs cannot be easily identified.

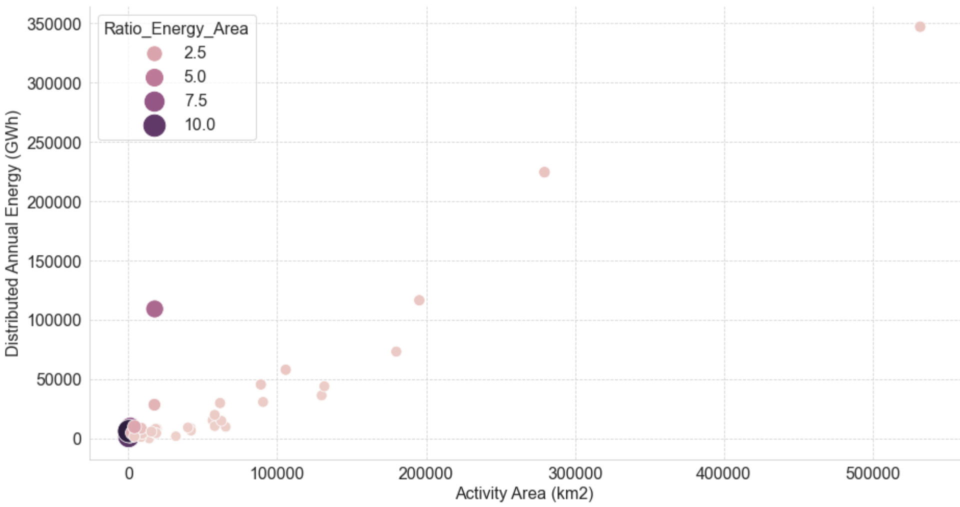
Figure 4: Scatter plot zoom of customers vs area of operation



Source: JRC, 2020.

A slightly different relation between the activity area, in which the DSO is operating, and the amount of energy that the DSO distributes yearly, is shown in Figure 5. Note that once again the big dots identify those DSOs which serve cities.

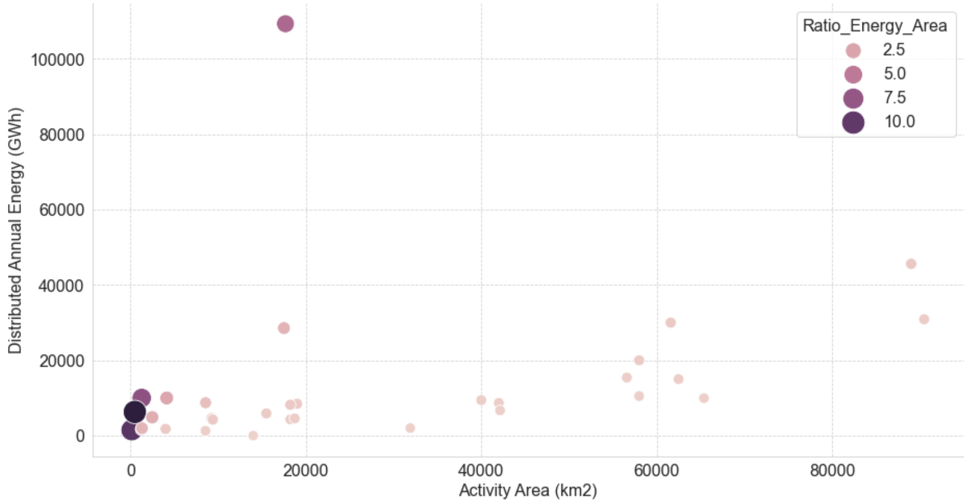
Figure 5: Scatter plot of energy distributed vs area of operation



Source: JRC, 2020.

Also in this case, by considering all the DSOs in our sample the relation energy/area served looks linear, but focusing on the majority of DSOs, e.g. those closer to the origin (Fig. 6) this relation does not seem as linear as thought.

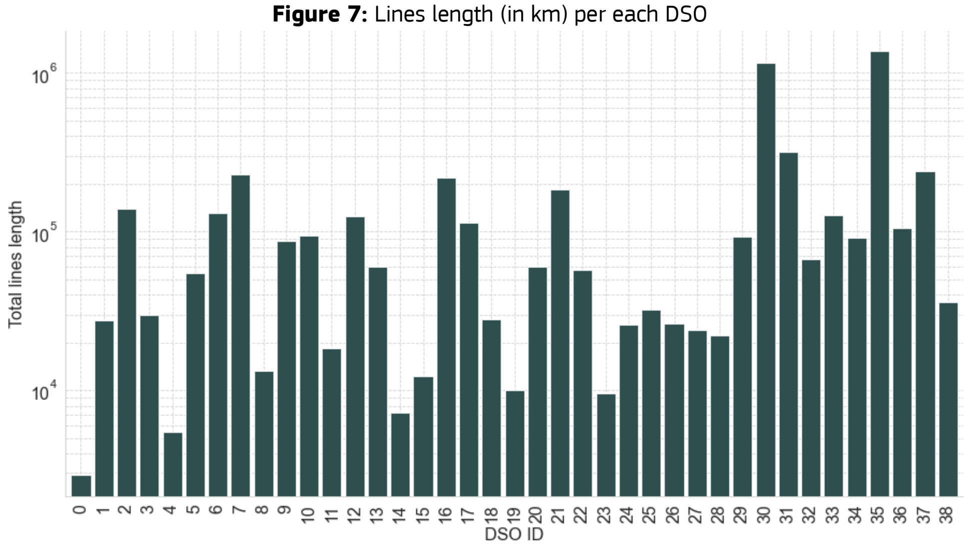
Figure 6: Scatter plot zoom of energy distributed vs area of operation



Source: JRC, 2020.

The total length of the DSO lines is also an important measure of the size and also of the design used by the DSO to serve its customers. Lines length should in practice be correlated with the number of customers and the area in which they are placed. Figure 7 shows the total lines length for each DSO.

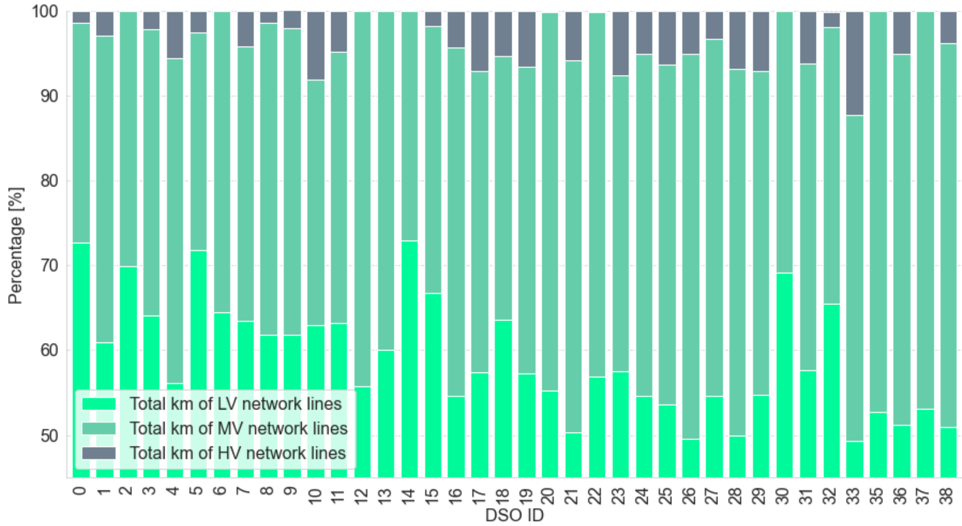
Figure 7: Lines length (in km) per each DSO



Source: JRC, 2020.

To provide an even more in depth look at the used design, lines have been also separated per voltage level. Their percentage with respect to the total is exhibited in Figure 8.

Figure 8: Lines length percentage per voltage level per each DSO



Source: JRC, 2020.

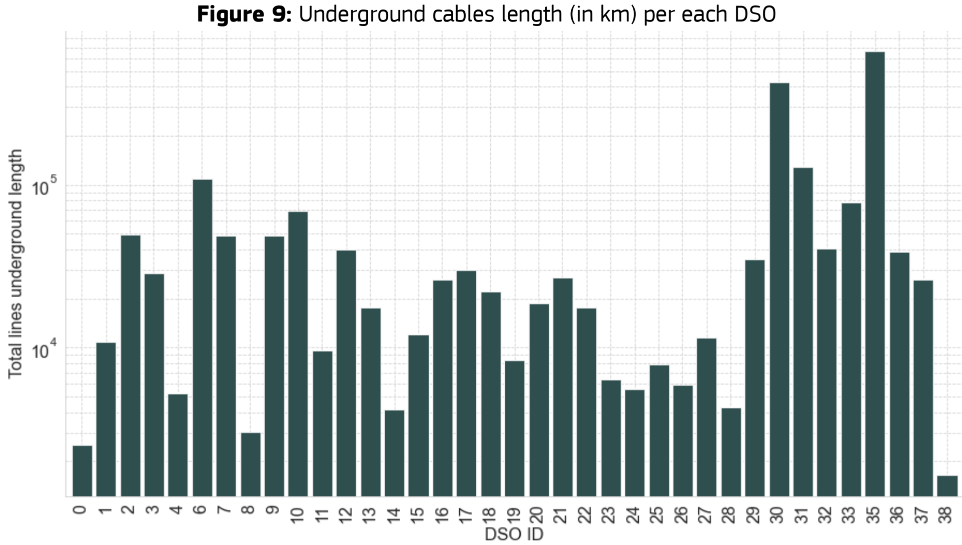
From a more aggregated perspective (Table 3) it can be noticed that 75% of our DSOs' sample has less than about $126,000$ km of lines in place, which is in line with the size of the areas in which they operate (fig. 3 - fig. 6). Still, more information is available on lines. The majority of respondents have shared information on the amount (km) of lines which are underground and those which are overhead. Figure 9 shows these numbers in absolute terms.

Table 3: Total lines length statistics

	Field	Value (km)
0	count	38
1	mean	141,369
2	std	280,662
3	min	2,917
4	25%	24,506
5	50%	58,854
6	75%	126,032
7	max	1,377,270

Source: JRC, 2020.

Figure 9: Underground cables length (in km) per each DSO



Source: JRC, 2020.

From a more general perspective, Table 4 suggests that if we focus on the 75% of our sample, less than a third of the lines are underground cables. From an economic point of view, it is well known that this option is more expensive for a utility, but at the same time it offers the advantages of higher reliability levels, that is, less interruptions for final customers. To complete the picture, underground cables are divided into voltage levels. As

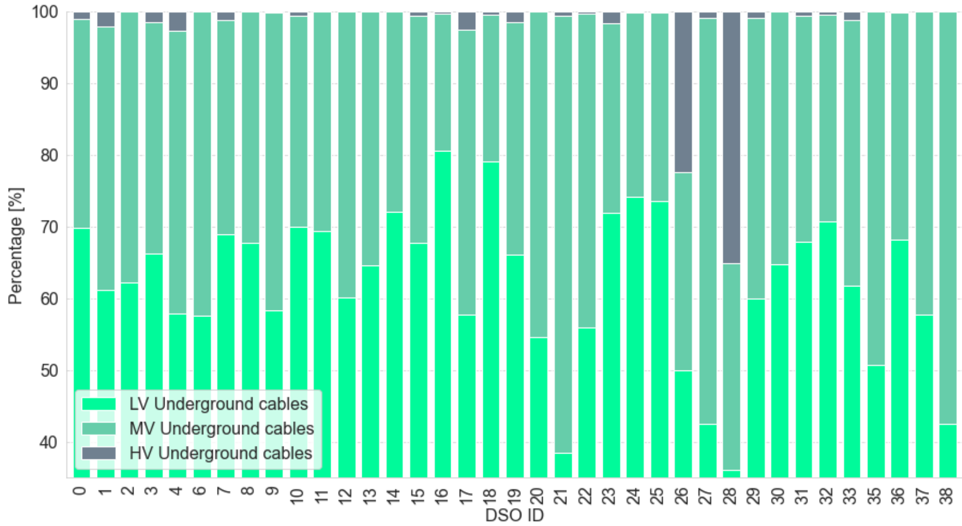
Table 4: Total underground lines length (in km) statistics

	Field	Value
0	count	37
1	mean	56,590
2	std	125,551
3	min	1,640
4	25%	7,865
5	50%	22,250
6	75%	40,440
7	max	665,263

Source: JRC, 2020.

it can be seen (Fig. 10) underground cables are mainly LV and MV. Few DSOs have also HV underground cables.

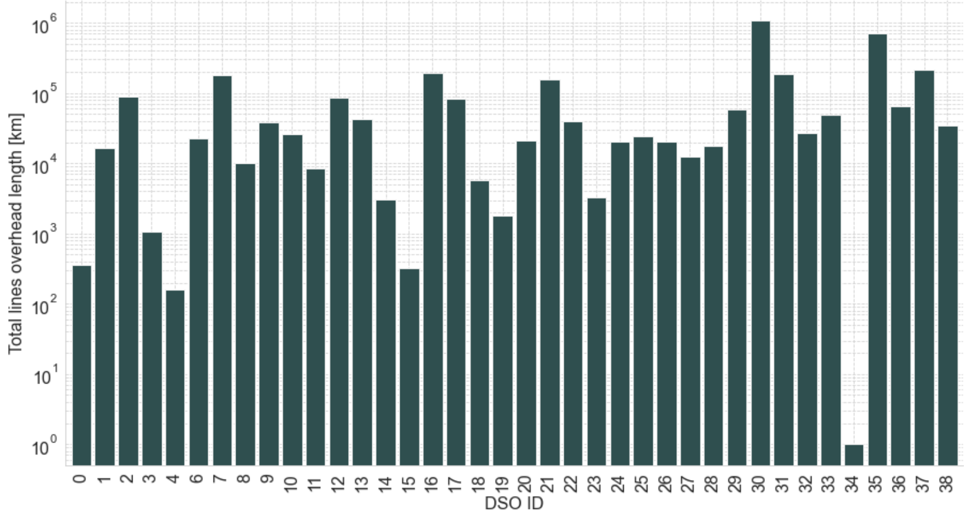
Figure 10: Underground cables percentages per voltage level



Source: JRC, 2020.

Moving to overhead lines, Figure 11 shows their length in absolute terms (km).

Figure 11: Overhead lines length (in km) per each DSO



Source: JRC, 2020.

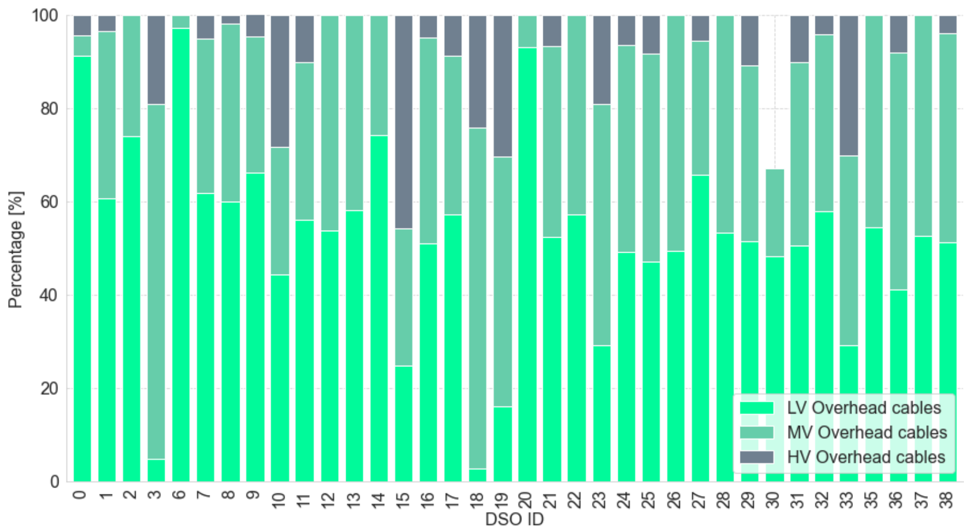
Looking at the 75% of the sample it can be checked from Table 5 that the amount of lines in km is twice that of the underground cables. Overhead lines lengths per voltage level are shown for completeness in Figure 12.

Table 5: Total overhead lines length (in km) statistics

	Field	Value
0	count	36
1	mean	98,837
2	std	21,0421
3	min	317
4	25%	11,883
5	50%	26,287
6	75%	84,883
7	max	1,084,510

Source: JRC, 2020.

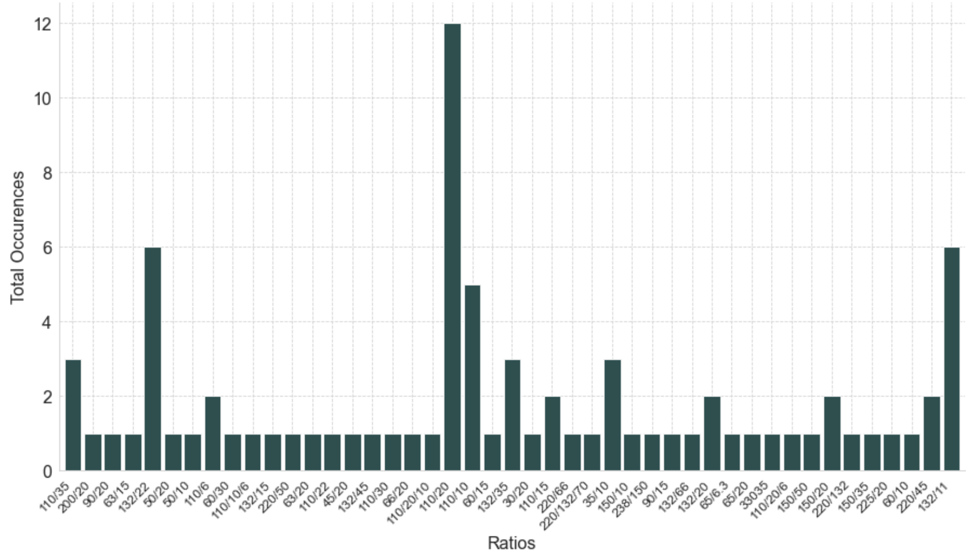
Figure 12: Overhead lines percentages per voltage level



Source: JRC, 2020.

Moving from lines to transformers, Figure 13 shows the diversity existing on the ratio of HV/MV transformers between the interviewed DSOs. Three most common ratios can be highlighted: $110/20kV$, $132/22kV$, $132/11kV$. In terms of top (HV) voltage level, $110kV$ and $132kV$ are indeed the most present ones.

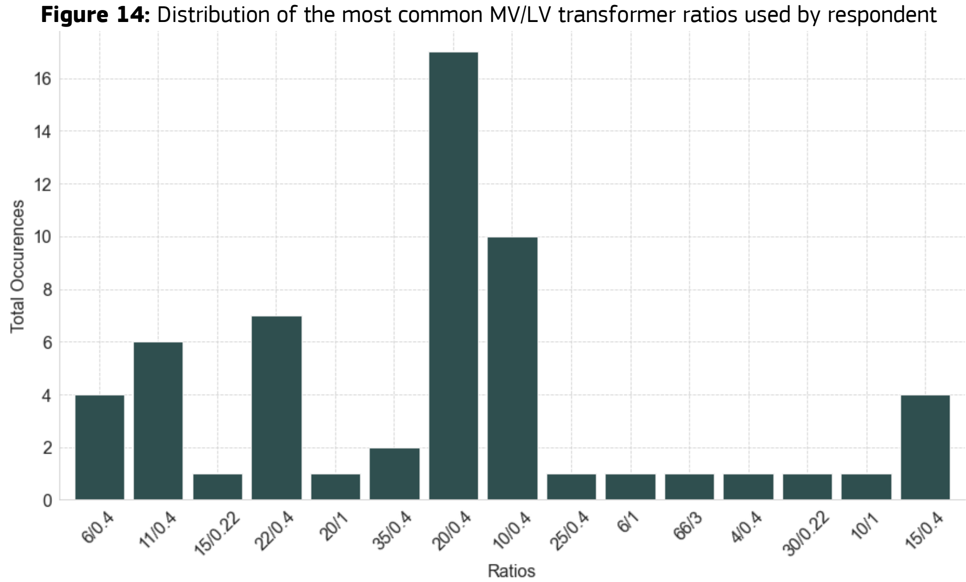
Figure 13: Distribution of the most common HV/MV transformer ratios used by respondent



Source: JRC, 2020.

Moving to MV/LV transformers, the $20/0.4kV$ ratio seems the most common choice done from the DSOs in our sample (fig. 14). For the LV level, $0.4kV$ is indeed the most common value observed.

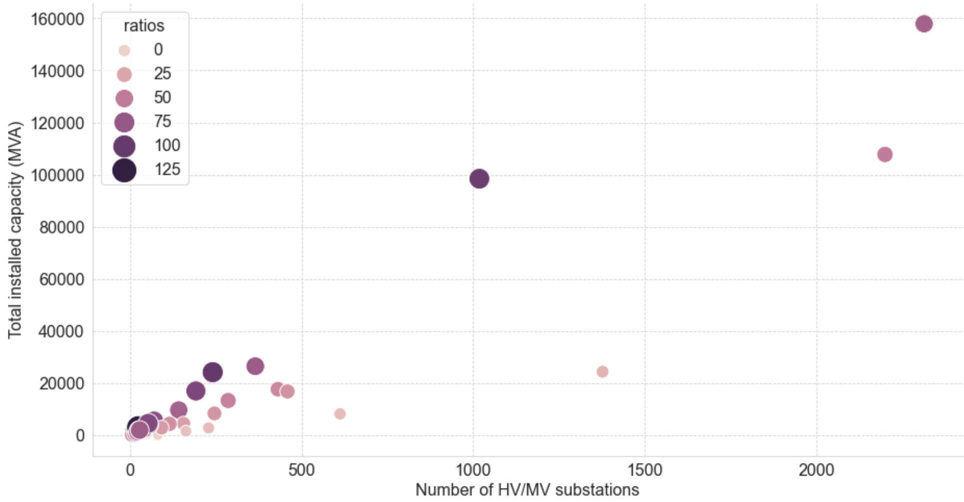
Figure 14: Distribution of the most common MV/LV transformer ratios used by respondent



Source: JRC, 2020.

Figure 15 aims at showing, if any, the relation existing between the number of HV/MV substations and the total installed capacity. The scatterplot highlights that also in this case different choices are done from DSOs on the dimensioning. This might be due to the available set of transformers ratios offered by local markets in every country where the DSO operates or to other design reasons not easy to infer from the previous figures.

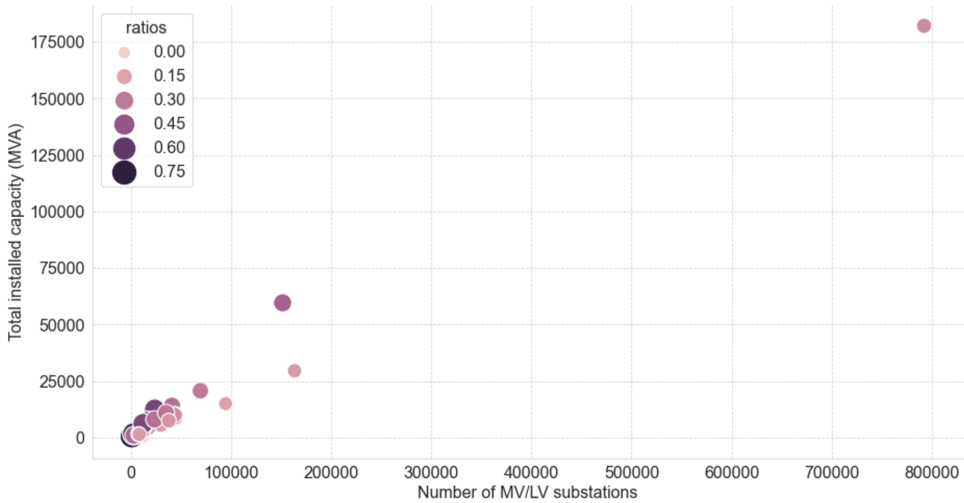
Figure 15: Scatter plot: number of HV/MV susbtations vs. transfromers installed capacity



Source: JRC, 2020.

Differently from the HV/MV substations case, in Figure 16 the MV/LV capacity looks linear with respect to the number of MV/LV substations.

Figure 16: Scatter plot: number of MV/LV susbtations vs. transfromers installed capacity



Source: JRC, 2020.

The continuity of service is a key characteristic that DSOs needs to ensure to their customers and to the system as a whole. It is strictly connected with voltage interruptions which are defined as the decrease in the voltage supply level to $< 10\%$ of nominal for up to 1 min duration (CENELEC, 2011). National authorities usually rely on output-based incentive schemes to improve the continuity of service offered by DSOs based on the measurement of key performance indicators (KPI) related to voltage interruptions. Two of the most commonly used are:

— the System Average Interruption Frequency Index (SAIFI), which is the average number of interruptions that a customer would experience within one year.

— the System Average Interruption Duration Index (SAIDI), which is the average interruption duration within one year for each customer served.

They are defined according to the following formulas:

$$SAIDI = \frac{\sum_{i=1}^{n} U_i}{U_{tot}} \qquad SAIFI = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} U_{i,j} t_{i,j}}{U_{tot}} \tag{1}$$

where n is the number of interruptions in a year; m is the number of customer clusters affected by the same duration of interruption; U_i is the number of customers involved in the i-th interruption; $U_{i,j}$ is the number of customers in the cluster j involved in the i-th interruption; $t_{i,j}$ is the duration of the interruption i for the cluster j and U_{tot} is the total number of customers at the end of the year (Della Giustina et al., 2018). It is worth mentioning, that a technical analysis is in progress in our team to understand more in depth if there is a relation between one of these indexes and some design and structural factor, as for instance the amount of overhead lines or the amount of renewable energy connected to the grid. For example, the two worst performing DSOs in terms of SAIDI, with multiple times higher figures than the others, have 95% and 85% of their total distribution network (in km) equipped with overhead lines, and only 5% and 15% with underground cables. However, there is not always an obvious correlation between different features. Failing to find a meaningful relation might suggest that interruptions are mainly due to external factors which are not under DSO's control, as for instance, the more extreme weather conditions faced in the last years or the ageing and inadequate infrastructure in combination with increasing demand (i.e. EV charging stations), which might lead to increased number of grid faults. Giving a look at the statistics, we see important differences: for SAIDI for instance while the 50% of the DSOs shows values below 64, which almost doubles if we consider 75% of the sample, the maximum value corresponds to almost 1200. It would be interesting to understand the causes behind such a big variation. Similar arguments hold true for the SAIFI which sees the maximum value reaching 5 times more the median one (value of the index at 50$\%$). Figure 17 shows both indexes for each DSO that shared this information.

Table 6: SAIDI statistics

	Field	Value
0	count	35
1	mean	126.3
2	std	217
3	min	2.5
4	25%	31.5
5	50%	64
6	75%	125
7	max	1,188

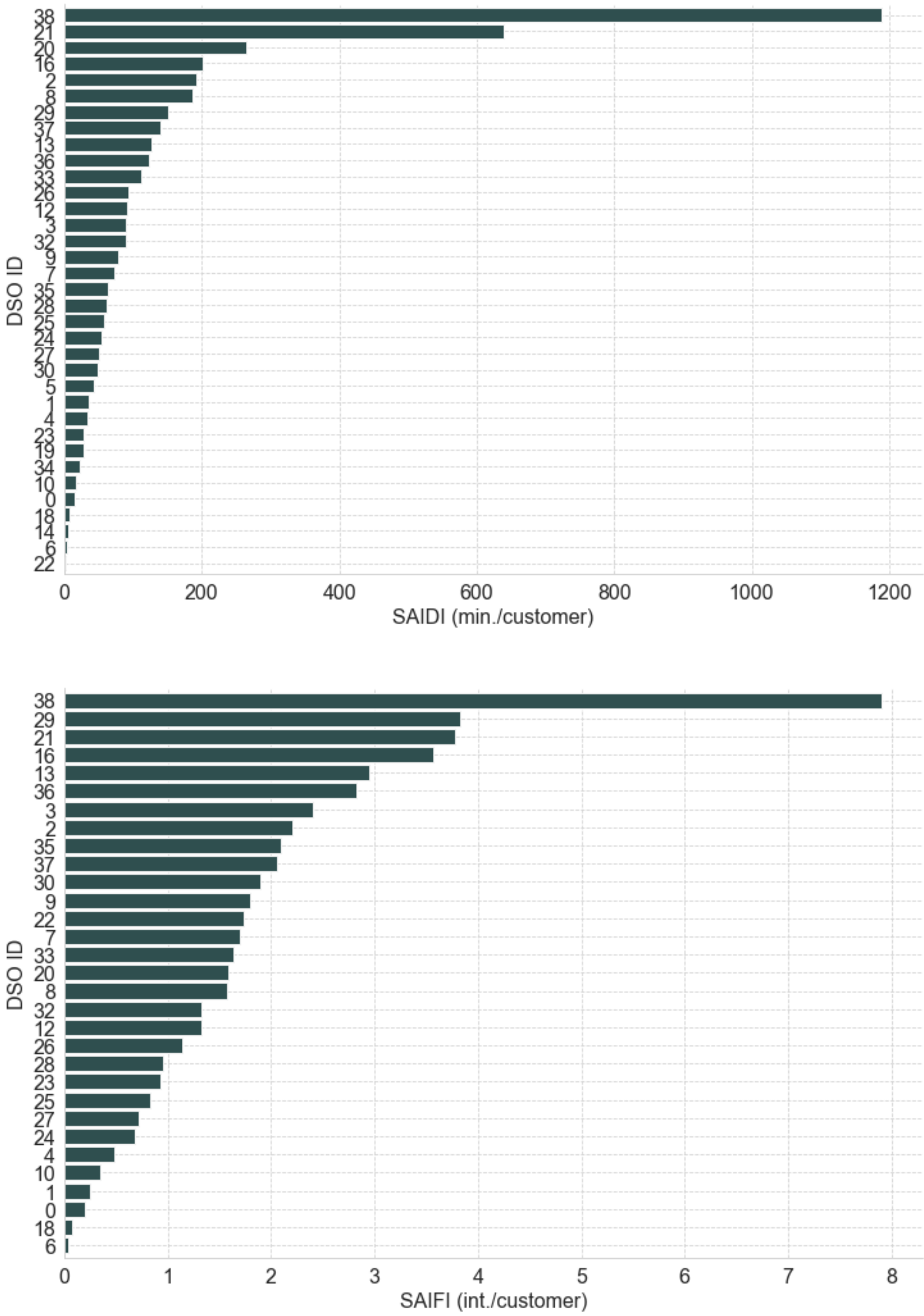
Source: JRC, 2020.

Table 7: SAIFI statistics

	Field	Value
0	count	31
1	mean	1.8
2	std	1.5
3	min	0.0
4	25%	0.8
5	50%	1.6
6	75%	2.2
7	max	7.9

Source: JRC, 2020.

Figure 17: SAIDI and SAIFI indicators for each DSO



Source: JRC, 2020.

4 The Smart Grid Dimension of distribution grids

The energy transition is based on the well-know 3 D's, i.e. Decarbonisation, Decentralisation, and Digitalisation. In each of these aspects, the impact on the DSO business, but also the role of the DSO as facilitator for the transformation towards a smart grid is prominent. Decarbonisation requires massive integration of renewable energy sources, which are already changing drastically the distribution network through the introduction of bi-directional power flows, requirement for better monitoring and control, need for flexibility, etc. Decentralisation is bound to increase the role of the DSOs, who will need to integrate various DER, e.g. roof-top PV, EVs, home battery systems, smart heat pumps, etc., to their distribution network. Finally, digitalisation gives the final boost for the overall system optimisation by integrating different energy sectors, enabling consumers to actively participate in the energy markets, and allowing better TSO-DSO coordination.
In this chapter, we try to better understand the current status of the European DSOs regarding the smart grid dimension of their network. We investigate if and how much do they use new technologies and tools to manage their network and how do they collaborate with the TSO, through data exchanges. We also take a look into some regulatory issues and finally we make an attempt to briefly assess the impact of and the resilience to COVID-19 pandemic. This chapter is structured as follows: section 4.1 analyses the use of non-frequency ancillary services by the DSOs, in section 4.2 the DSO management of DER, EVs, and energy storage is presented, section 4.3 focuses on the assets monitoring and control capabilities of the DSOs, section 4.4 investigates the use of advanced technologies, section 4.5 is dedicated to the DSO-TSO coordination, section 4.6 deals with some issues of the DSO regulatory framework, and finally section 4.6 mentions some implications of the COVID-19 pandemic on DSOs' business.

4.1 DSOs as users of non-frequency ancillary services

In this section we analyse the use of non-frequency ancillary services by the DSOs. We specifically investigate the participation of the DSOs in demand flexibility programs, which in the current survey refer only to demand side management (DSM) and demand response (DR), and the management of active customers. Demand side management aims to improve flexibility on the consumer side: it ranges from improving energy efficiency (e.g. better insulation materials) to having fully autonomous energy systems that automatically respond by shifting the planned demand. On the other hand, demand response refers to programs that encourage participants to make short-term changes in the energy demand, either by reducing their consumption (e.g. turning off or dimming lighting, shutting down a non-critical manufacturing process) or by shifting the load to a different time in the day (e.g. shifting the operation of a device for a later time following a lower price signal). Demand Response can be either implicit (price-based) or explicit (incentive-based). In implicit DR, consumers choose to be exposed to time-varying electricity prices, reflecting the value and cost of electricity in different time periods and alter their behaviour accordingly. In explicit DR, consumers or DR aggregators participate in specific programs and provide DR resources on the wholesale energy, reserves/balancing, and/or capacity markets (COWI CONSORTIUM, 2016).

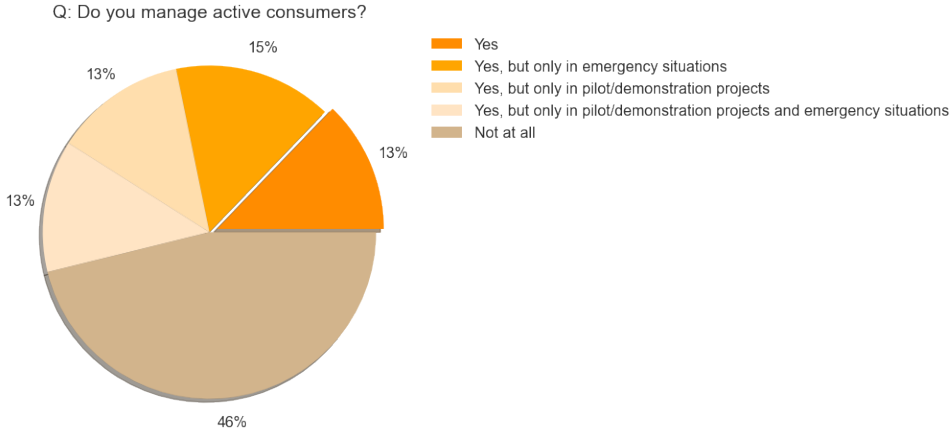
4.1.1 Demand response

According to our latest survey results, 38.5% of the participating DSOs have some kind of DSM or DR program in place. A question related to the above was if the DSO is using DR/DSM/DSF as an alternative to network infrastructure investments, also known as *non-wires* alternatives. The results to this question were non-intuitive, as slightly more than 56% of the DSOs answered positively, even though 61.5% of them do not use DR or DSM. In other words, DSOs consider DR/DSM as non-wires alternative, obviously for their future plans, even if they do not currently have any such programs in place, showing a clear potential for these programs. On the other hand, not all of the DSOs that do have such programs in place consider those as non-wires alternative. Finally, only a third of all DSOs has reported estimated savings in their CAPEX and OPEX resulting from the use of DR/DSM/DSF. Once more, not all DSOs that have such programs in place have reported savings, but also not all DSOs that have estimated some sort of savings have actual DR/DSM programs currently in place, which could be considered as a sign of future potential for DR/DSM.

4.1.2 Active customers

Another group of questionnaire inquiries regarding DR/DSM investigated if the DSOs have active consumers in their network, i.e. customers who might consume or store electricity, sell self-generated electricity, or participate in flexibility or energy efficiency schemes, provided that those activities do not constitute their primary commercial or professional activity (European Parliament, 2019). As shown in Figure 18, almost half of the DSOs answered that they do not manage any active consumers in their network, at all. Only about 13% has answered clearly that they manage active consumers, while about 40% have answered that they do manage active consumers but only in pilot/demonstration projects and/or in emergency situations.

Figure 18: Management of active consumers



Source: JRC, 2020.

In a following question the DSOs were called to answer on how active consumers are managed. In this question, DSOs could choose more than one answers, thus the total sum in Figure 19 is higher than 100%. As we can see in the same figure, one-third of the DSOs are managing the active consumers directly themselves, while 15% prefer to manage them through independent aggregators and even less (about 8%) through energy suppliers/retailers. Surprisingly, in that question almost two-thirds of the DSOs have used the answer 'Other'. However, when we analysed further their answers, we noticed that almost half of the DSOs that have answered 'Other' (12/25) are actually not managing any active customers at all. Some others haven't defined what they meant by 'other', while some have specified the following:

— Active consumers are managed based on the grid management constrains instructions: during critical situations, automatically or by issuing appropriate decisions.

— Only heat pumps of some consumers are managed.

— The way to manage active consumers depends on the pilot.

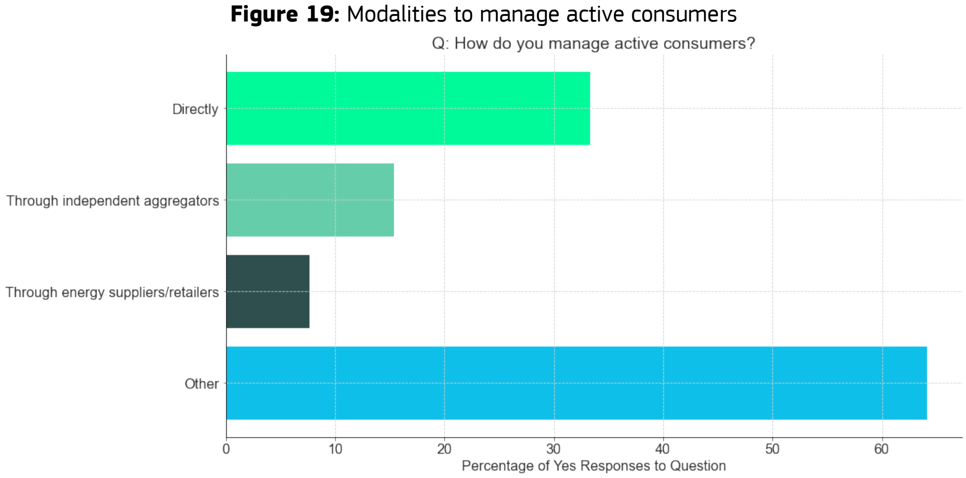
— Active consumers are managed only in pilot projects, either directly or through market parties.

— Active consumers are managed either through an aggregator or bilaterally .

— Directly for emergency situations. Through aggregators (or case being, single large customers for flexibility contract capable to fully provide the desired service) Smart/conditional connection serving individual customers on a case by case.

— In a MS, the DSO has answered that active consumers is still a new concept, nevertheless the intent is to increase to number of active consumers and to facilitate the integration of such consumers in the network.

Figure 19: Modalities to manage active consumers



Source: JRC, 2020.

In the next question the DSOs were asked to specify if there is a minimum entry-level capacity for accepting active consumers in their network. As shown in Figure 20, a third of all DSOs said that all kind of resources, independently of their power capacity, are accepted, whereas 15% of the DSOs only accept active consumers with resources capacity larger than $100kW$. The rest of the DSOs, about 50%, have used the answer 'Other', which when analysed further revealed the following:

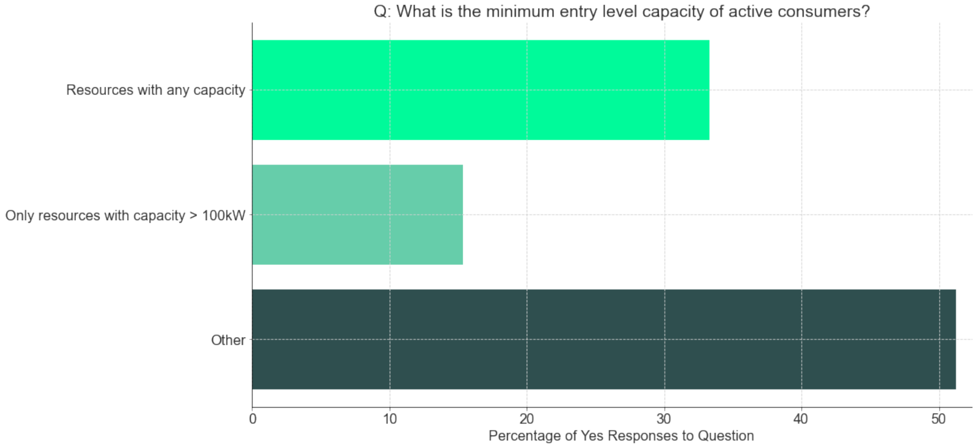
— The DSO does not manage active consumers (9 DSOs)

— The minimum entry-level depends on the pilot (2 DSOs)

— Active customers need 15-minute meter reading (smart meter or telemetry). The required capacity depends on the specific situation, although usually there is a minimum value of $100kW$. Sometimes it can be higher.

— For smart/conditional connections: no minimum size but the CBA and feedbacks received led one DSO to test the products on MV customers of more than $100kW$

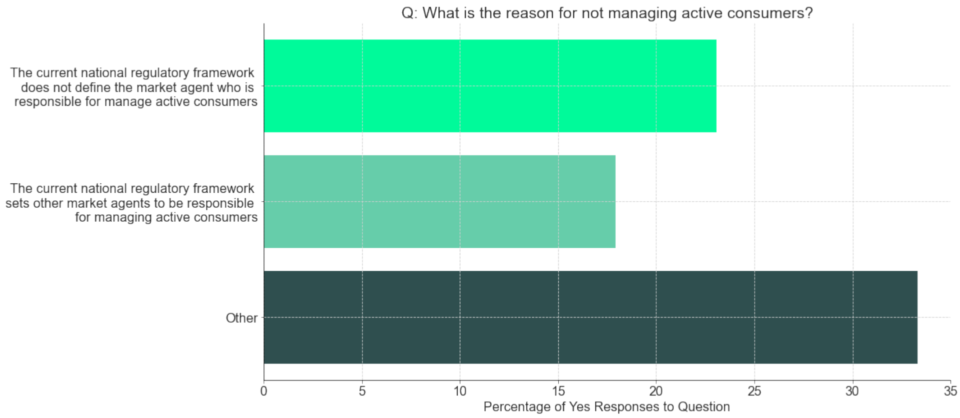
Figure 20: Minimum entry level capacity of active consumers



Source: JRC, 2020.

Finally, we asked the DSOs what was the reason for not managing active consumers in their network. As shown in Figure 21, almost one in every four DSOs do not manage active consumers because the current national regulatory framework does not define the market agent responsible for that. On the other hand, almost one in every five DSOs does not manage active consumers because the current national regulatory framework sets other market agents as responsible for managing active consumers, thus the DSO is practically not allowed to do so. In these cases, the other market agents might be the TSO, BSPs, energy suppliers, and aggregators. Finally, one-third of the DSOs answered 'Other', which when further analysed includes:

Figure 21: Main reasons for not managing active consumers



Source: JRC, 2020.

— One DSO is not managing active consumers, but it is currently in the process of developing a digital platform for managing all active (flexible) distribution network users.

— One DSO said that it does not manage active consumers due to the national TSO rules

— In one case the DSO is currently implementing the systems necessary for this and will be starting in 2021 with demand and distributed energy resource management. In parallel, work is done on the regulatory and legal framework for this that will be also updated by 2021.

— In the case of a specific MS, no DSO is managing active consumers, as the whole regulation is currently under development.

4.2 DSOs management of DER, EVs and storage systems

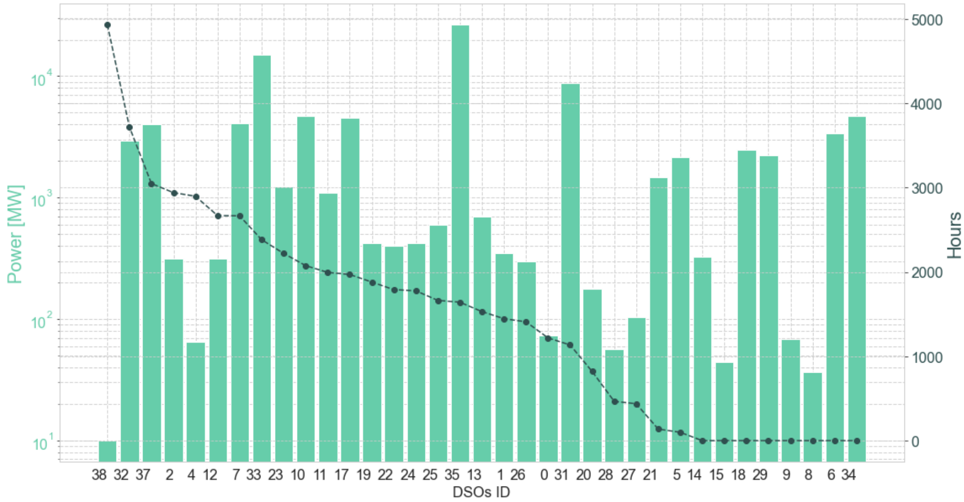
The ongoing transformation of the power system has brought the emergence of decentralised resources that produce, consume or store energy and are connected to the distribution network. The emergence of solar PV systems, driven by the declining costs and beneficial policies has boosted the installation of more and more rooftop PV systems connected directly at residential or commercial level. In some countries, combined heat and power (CHP) units are also a very economical way for producing heat and power for the house needs. Following a similar pattern with PV in terms of declining cost, batteries are becoming cheaper and cheaper, mostly due to the EV industry. This results in more affordable EVs, which in their turn lead to increasing numbers of EV charging points connected to the distribution network, either at the residential level or stand-alone directly to the distribution network in street charging poles or (high power) charging stations. Such increasing EV charging infrastructure puts more pressure to the distribution network and any potential grid restrictions will need to be tackled through infrastructure investments in smart grids and/or grid reinforcements and upgrades. On the other hand, digitalisation could enable EVs to act as flexible loads and a decentralised storage resource that could minimise or avoid grid reinforcement. Additionally, EVs could bring even greater flexibility to the system by supplying power back to the grid or home in a vehicle-to-grid or vehicle-to-building scenario (Alonso Raposo et al., 2019). Besides the increase in EVs on the roads, the declining battery costs lead also to more affordable battery energy storage systems (BESS), used to optimise the self-consumption of rooftop PV produced energy. Larger BESS are also used for other services in the commercial sector, or can be even directly connected to the distribution network with the sole purpose of providing ancillary services to the DSO. All of the above create new types of resources, which are (or will be) seen as potential flexibility providers for the DSO. Thus, in this section we further investigate the management of these new types of resources by the DSO, i.e. DER, EVs and energy storage systems.

4.2.1 Distributed Energy Resources

The growing complexity brought about by DER makes it increasingly difficult for DSOs to meet the needed quality of service standards. Therefore the only sustainable way for DSOs to cope with such emerging trends and keep their economic model in balance is to enhance the technological level of the grid and the efficiency of their operations, moving toward the smart grid. To make this process efficient it is of utmost importance to monitor DER presence in distribution grids in order to assess their impact on the quality of service. To help with that, in this section a fundamental picture of the penetration of DER connected to the distribution grids is provided. Figure 22 shows through the turquoise bars the total DER power installed connected to the DSOs grids (left y-axis). On the same figure, the dark dots represent the equivalent hours (right y-axis) in which DER have been injecting power into the grid([4]). DSOs with zero hours correspond to those which have not shared this information.

([4]) The number of equivalent hours has been obtained by dividing the total amount of electricity generated throughout the year by the nominal installed power.

Figure 22: Installed power and equivalent hours of DER working for each DSO



Source: JRC, 2020.

From a general perspective, in terms of equivalent hours (Table 8), it can be observed that only 25% of our respondents has DER generating for more than 2000 equivalent full hours.

Table 8: Equivalent hours of DER production statistics

	Field	Value
0	count	35
1	mean	1,455
2	std	1,247
3	min	0
4	25%	118
5	50%	1,529
6	75%	2,147
7	100%	4,931

Source: JRC, 2020.

In terms of installed DC power there is a big gap between the minimum and the maximum value which goes from 10 MW up to 26 GW. Being absolute values these number per sé do not provide that much information which instead can be obtained by normalising the power by the number of served customers. This is done in

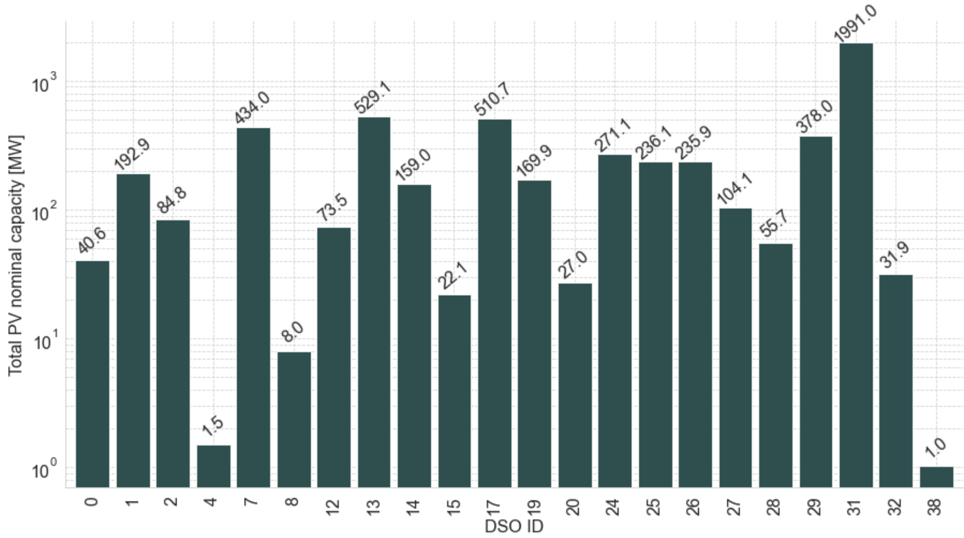
Table 9: DER installed power (in MW)statistics

	Field	Value
0	count	35
1	mean	2,694
2	std	5,137
3	min	10
4	25%	237
5	50%	599
6	75%	3,176
7	max	26,579

Source: JRC, 2020.

the following where a more in-depth view per DER technology is provided. After showing the installed power per each technology (PV, Wind, Biomass, Waste and Hydro), their composition per voltage level (LV, MV, and HV) is shown as well. These figures are really important especially for modelling and for network analysis. In previous DSO observatory exercises, we decided not to share the percentages related to voltage levels due to the scarce number of collected cases. In this new edition, thanks to the collaboration of the DSOs which have participated to it, we have collected data on this specific aspect from around 22 DSOs which already helped us to have a clearer view on this aspect. Figure 23 shows the PV installed power per each DSO.

Figure 23: Total photovoltaic power installed per DSO



Source: JRC, 2020.

Table 10 shows the statistics for the PV power installed per customer. This helps to have a more general view of the level of PV penetration in our DSOs' sample. It can be seen that also by considering normalised values the gap remains quite broad. It goes from a minimum of $1.7W$ to a maximum of $2kW$ per customer, with 75% of the sample being below $300W$ per customer.

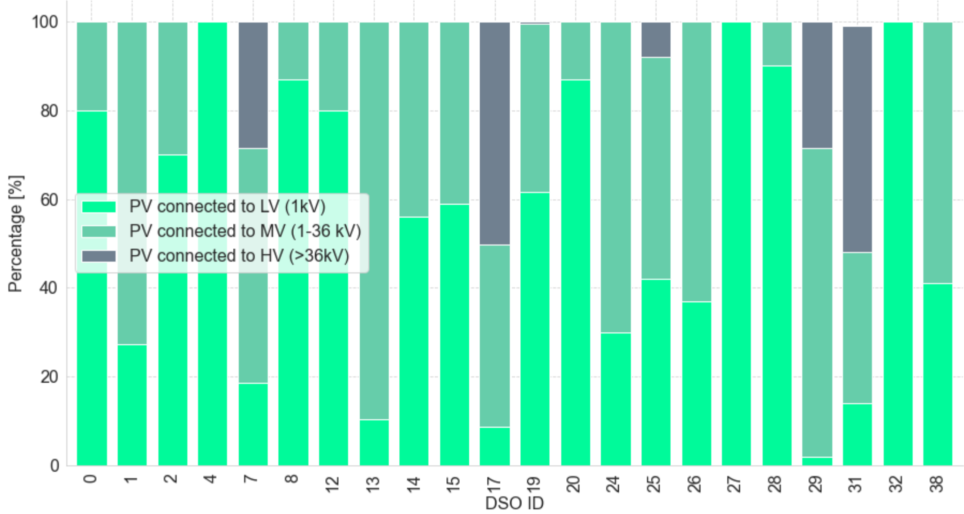
Table 10: Nominal PV power installed (Watt per customer) statistics

	Field	Value
0	count	35
1	mean	324
2	std	451
3	min	1.7
4	25%	56
5	50%	165
6	75%	305
7	max	2,035

Source: JRC, 2020.

As it can be seen in Figure 24, only in few cases PVs are connected to the high voltage level ($> 36kV$). The majority of PVs is in fact connected to a voltage level below $36kV$ which often in Europe indicates the Medium and Low voltage ($< 1kV$) levels.

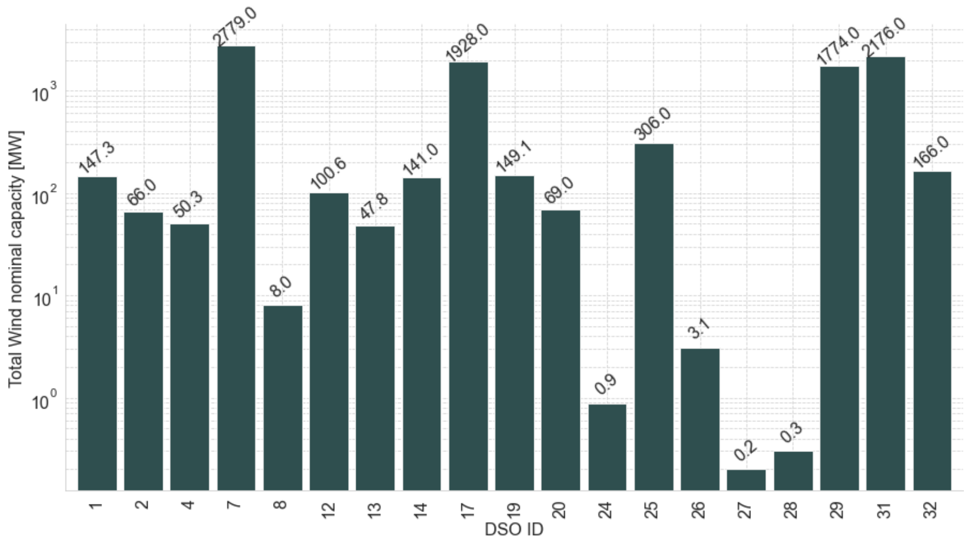
Figure 24: Photovoltaic power installed share per voltage level per DSO



Source: JRC, 2020.

Figure 25 shows the nominal Wind installed capacity per DSO. If compared with PV it can be seen that capacity levels are considerably higher. This can be confirmed once normalised values are considered.

Figure 25: Total wind power installed per DSO



Source: JRC, 2020.

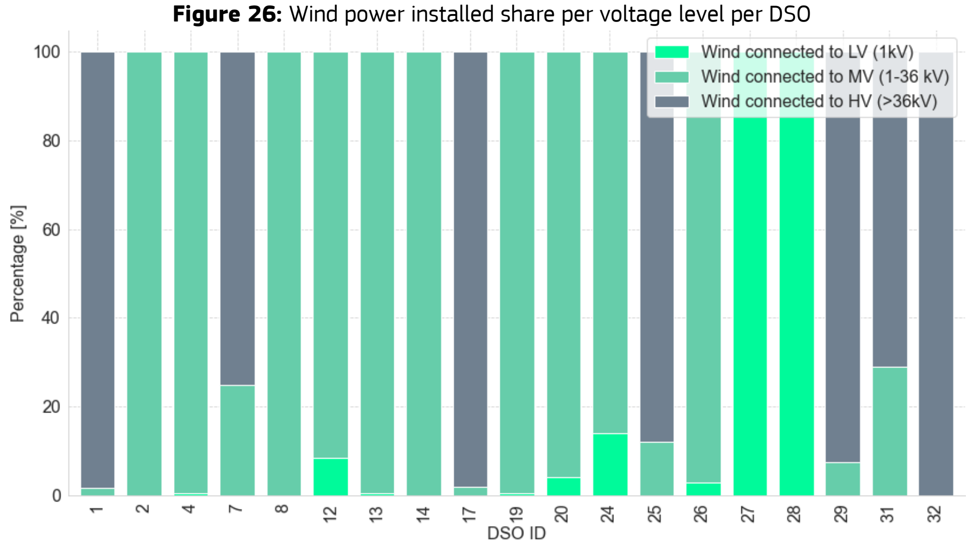
Table 11 highlights this fact. By focusing on the upper part of the aggregated figure (e.g. values above 50%), the 75% value and the maximum value are in fact definitely higher when compared with PV. The maximum in this case corresponds to more than $5.5kW$ of installed power per client which is definitely very high if compared with other operators.
A different situation emerges when we look at the voltage levels to which turbines are connected (Figure 26). Focusing on DSOs with more than $1MW$ of wind capacity installed and connected to their grid, the situation looks quite different if compared with the PV case. Wind turbines in fact are mainly connected to the MV grid or even to the HV ($> 36kV$). Also this aspect can be relevant for modelling and network analysis scopes.

Table 11: Nominal Wind power installed (Watt per customer) statistics

	Field	Value
0	count	30
1	mean	582.5
2	std	1184
3	min	0.1
4	25%	26
5	50%	180
6	75%	504
7	max	5,662

Source: JRC, 2020.

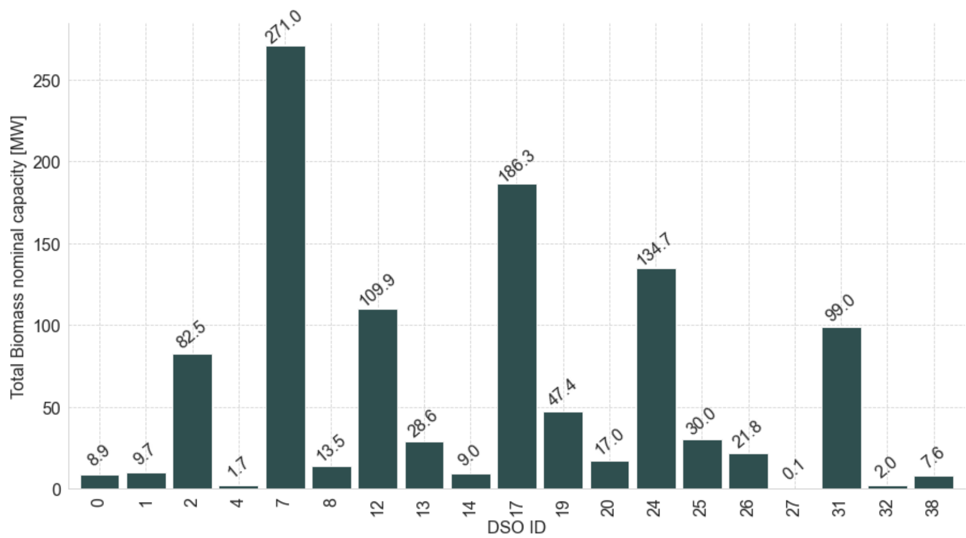
Figure 26: Wind power installed share per voltage level per DSO



Source: JRC, 2020.

Biomass is also among those green generation technologies connected at the distribution level as well. In the case in question, despite being less than wind production in terms of capacity, it is considered fundamental due to the fact that it is not intermittent as other distributed resources. However it may suffer from some seasonality effect.

Figure 27: Total biomass power installed per DSO



Source: JRC, 2020.

Looking at the normalised power levels (Table 12), it can be seen that as expected the watts per customer are considerably lower when compared with PV and wind sources. As for wind turbines, it is quite common to

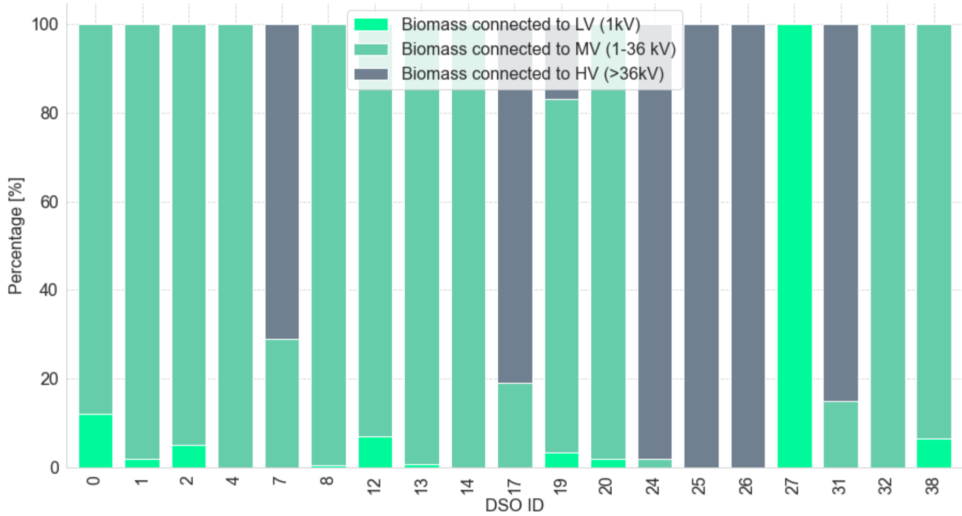
Table 12: Nominal Biomass power installed (Watt per customer) statistics

	Field	Value
0	count	30
1	mean	79
2	std	106
3	min	0.1
4	25%	12
5	50%	32
6	75%	114
7	max	407

Source: JRC, 2020.

find biomass units connected at MV and HV levels, as shown in Figure 28.

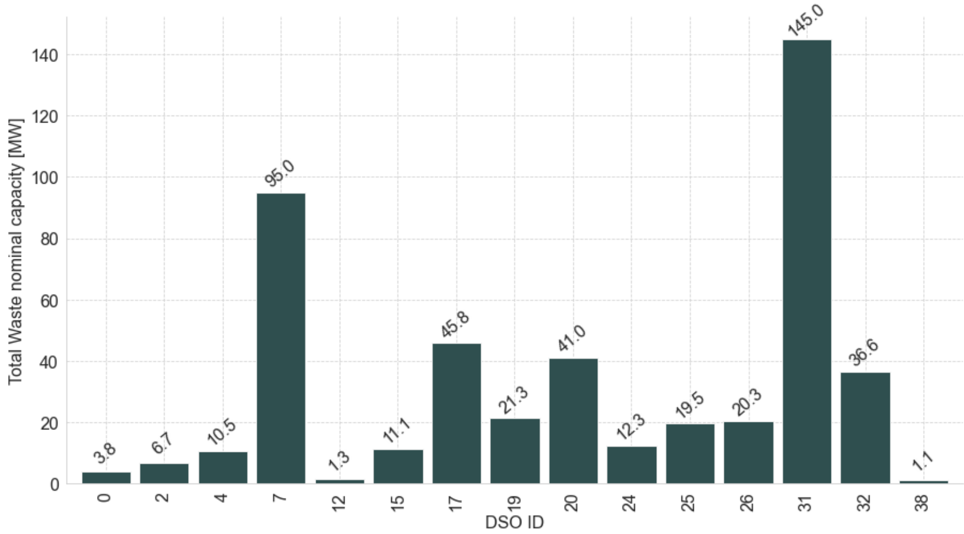
Figure 28: Biomass power installed share per voltage level per DSO



Source: JRC, 2020.

Energy production from waste is still not very widespread in Europe being often fostered or impeded from diverse national policies. From our sample it seems that this is the smaller contributor to electricity production among the considered distributed energy resources connected at the distribution level. Figure 29 shows the total waste capacity installed and connected to the grids of our respondent DSOs.

Figure 29: Total waste power installed per DSO



Source: JRC, 2020.

By taking the normalised aggregated values (Table 13) it becomes clearer that the production of electricity coming from waste incineration is considerably lower than that coming from other previously introduced sources. Looking at the shares per voltage level, it is evident that waste plants are mainly connected to MV and HV levels

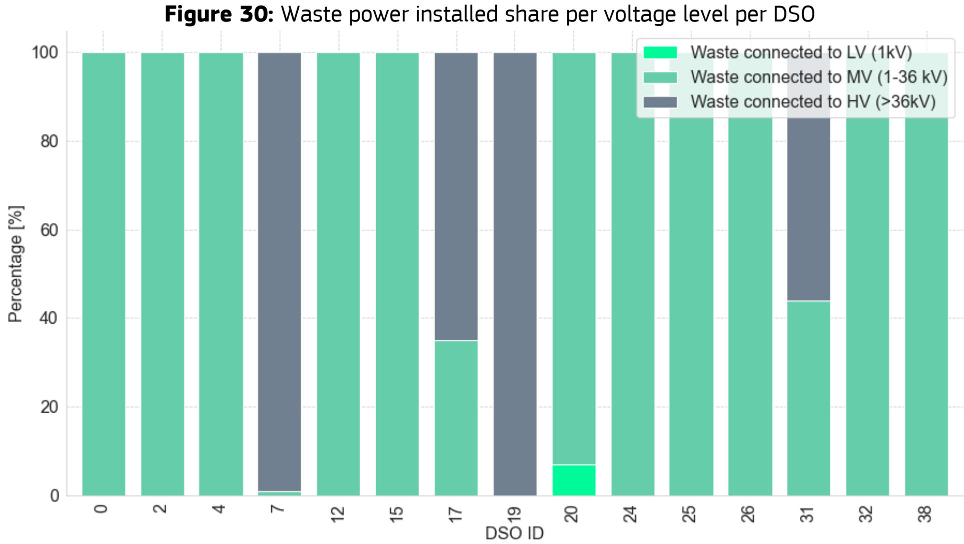
Table 13: Nominal Waste power installed (Watt per customer) statistics

	Field	Value
0	count	19
1	mean	25
2	std	30
3	min	0.7
4	25%	5.7
5	50%	12
6	75%	31
7	max	100

Source: JRC, 2020.

30.

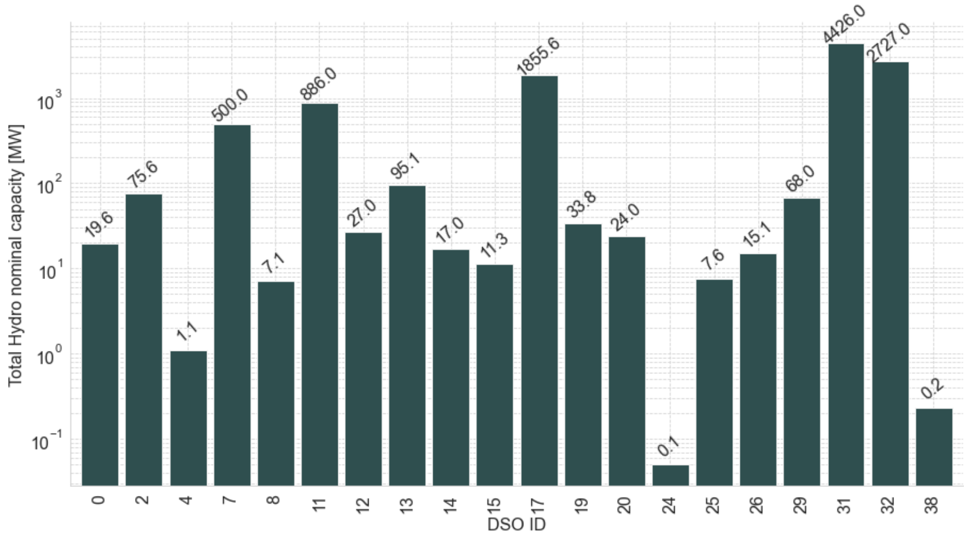
Figure 30: Waste power installed share per voltage level per DSO



Source: JRC, 2020.

Moving to hydro power production, it is well known that it is a zonal resource, meaning that it depends on

Figure 31: Total hydro power installed per DSO



Source: JRC, 2020.

the zone in which the DSO is operating. In our sample (Fig. 31) only 3 DSOs have more than $1GW$ of hydro power connected to their grids. But it is only by looking at the normalised values (Table 14) that emerges a curious fact: one DSO has almost $13kW$ of hydro power installed per customers which is definitely far from a median value equal to $47W$ or from the third quarter equal to $118W$ per customer.

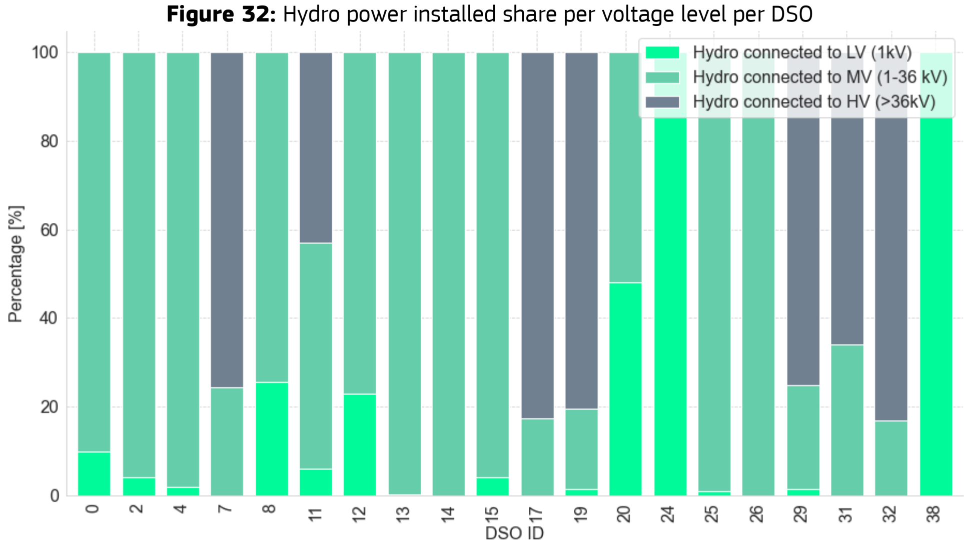
Table 14: Nominal Hydro power installed (Watt per customer) statistics

	Field	Value
0	count	28
1	mean	781
2	std	2,557
3	min	0.1
4	25%	13
5	50%	47
6	75%	118
7	max	12,976

Source: JRC, 2020.

Looking at the shares per voltage level, it seems that hydro plants are mainly connected to MV and in minor part to HV and LV levels (Fig. 32).

Figure 32: Hydro power installed share per voltage level per DSO

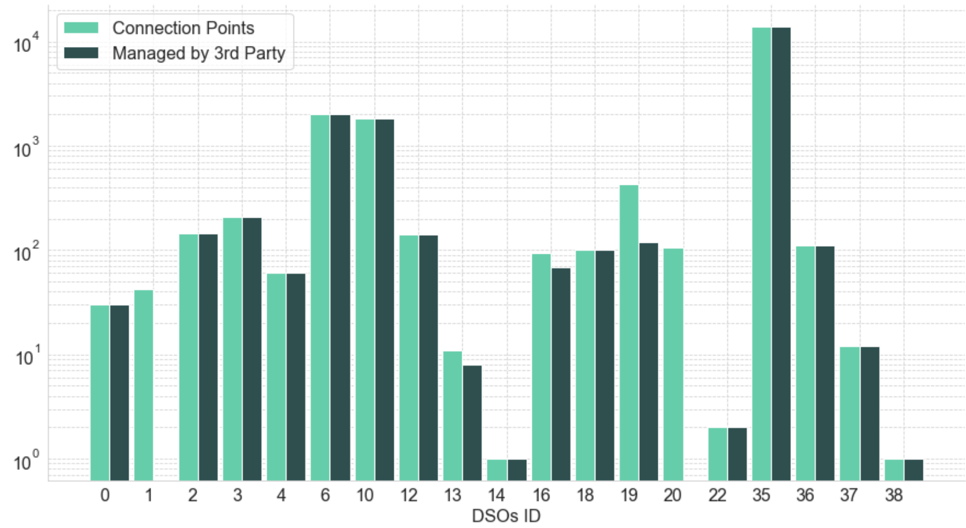


Source: JRC, 2020.

4.2.2 Electromobility

Figure 33 shows the number of EV connection points per DSO (turquoise bars) together with the number of connection points managed by third party operators (dark grey bars). As it can be seen, the majority of them are managed by third parties in line with the (European Parliament, 2019) which stresses the fact that ownership and operation should be precluded to network operators. From the dataset, in the majority of cases charging points are almost twice the number of connection points (not shown in the figure), which means that there are in the majority of cases two plugs per charging column: two EVs can be charged simultaneously from the same connection point.

Figure 33: Number of EVs connection points per DSO



Source: JRC, 2020.

From a more general view, the number of connection points seems still quite low (Table 15): this is confirmed from the fact that three-quarters of the DSOs in our sample can count less than 176 connection points connected to their grids. It is worth mentioning that very likely these numbers do not take into account all the connection points. This is mainly due to the fact that, connection points and charging stations are connected behind the meter of large trading centres, shops, hotels, administrative and business districts. Generally DSOs seem to lack the complete picture due to the fact that clients can ask for connection without the obligation to specify that it will connect charging infrastructure. With respect to *ad-hoc* distribution network charges for EVs, the situation

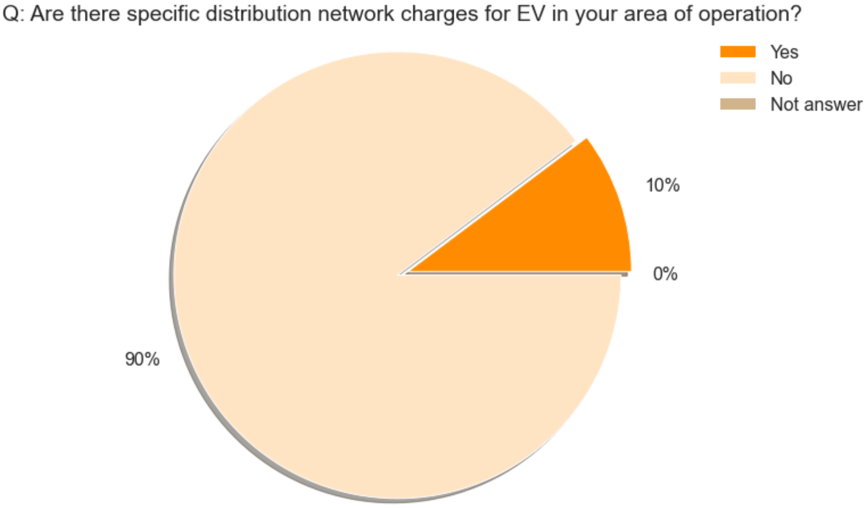
Table 15: EVs charging points statistics

	Field	Value
0	count	19
1	mean	1,017
2	std	3,197
3	min	1
4	25%	21
5	50%	100
6	75%	176
7	max	14,000

Source: JRC, 2020.

can be defined to be still at an embryonic stage. Only 10% of the DSOs have mentioned some form of dedicated charges (Figure 34).

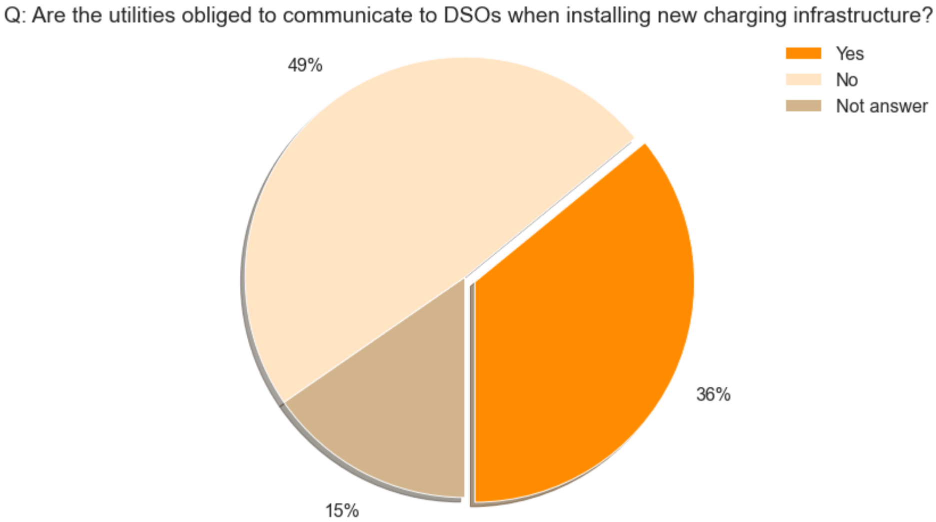
Figure 34: Percentage of respondents to the question on EV distribution charges



Source: JRC, 2020.

An important point which deserves due attention is the fact that close to 50% of our sample has declared that in their area of operation utilities are not obliged to communicate when new EV charging infrastructure is installed (Figure 35). In the long term this lack of information could hinder the optimal operation of the distribution grid especially where smart charging is not in place. Failing to opportunely tackle this issue could lead to unexpected peak loads which can definitely increase the cost of supplying electricity to final users.

Figure 35: Percentage of respondents to the question on new EV charging infrastructure

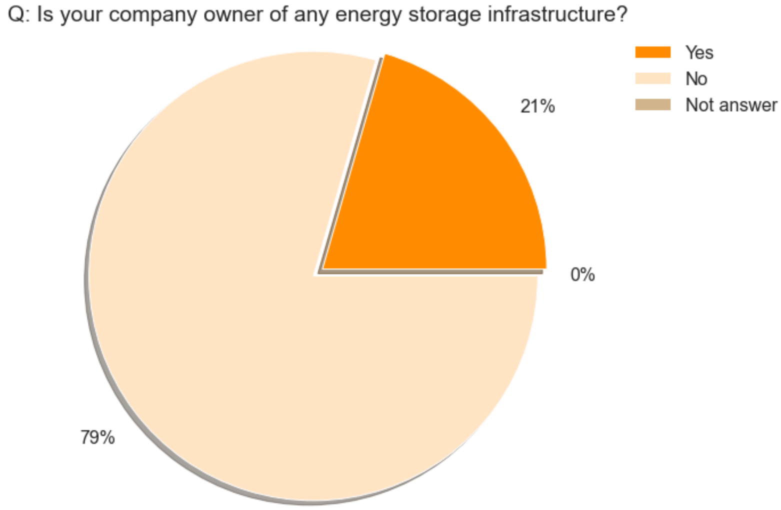


Source: JRC, 2020.

4.2.3 Storage

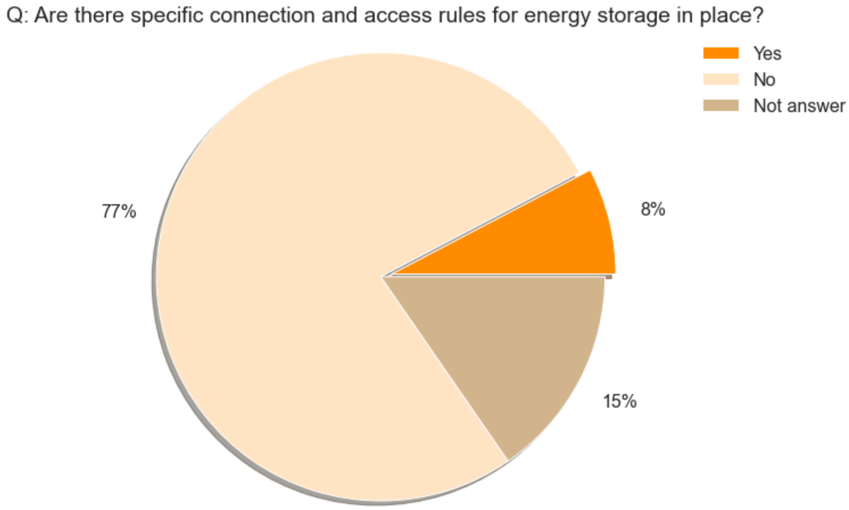
In our survey, eight out of thirty-nine DSOs have mentioned about the ownership of a storage system as shown in Figure 36. The major technology being used is lithium-ion batteries. In terms of size of these systems, apart from some systems which have been installed during pilot projects in which the DSO was involved ($500kW$, $2MW$, $2.5MW$) DSOs which have a storage system in place indicate a capacity size below $100kWh$ and usually distributed through substations for powering transformers equipment during outages or for customer powering during critical situations. Note that this is in line with the provisions specified in the EU Directive 2019/944 (European Parliament, 2019). Additionally, in the majority of cases (77%) no specific connection and access rules are in place for energy storage systems (Fig. 37): both generators' and consumers' rules are applied for energy storage facilities.

Figure 36: Percentage of respondents to the question on storage ownership



Source: JRC, 2020.

Figure 37: Percentage of respondents to the question on storage connection rules



Source: JRC, 2020.

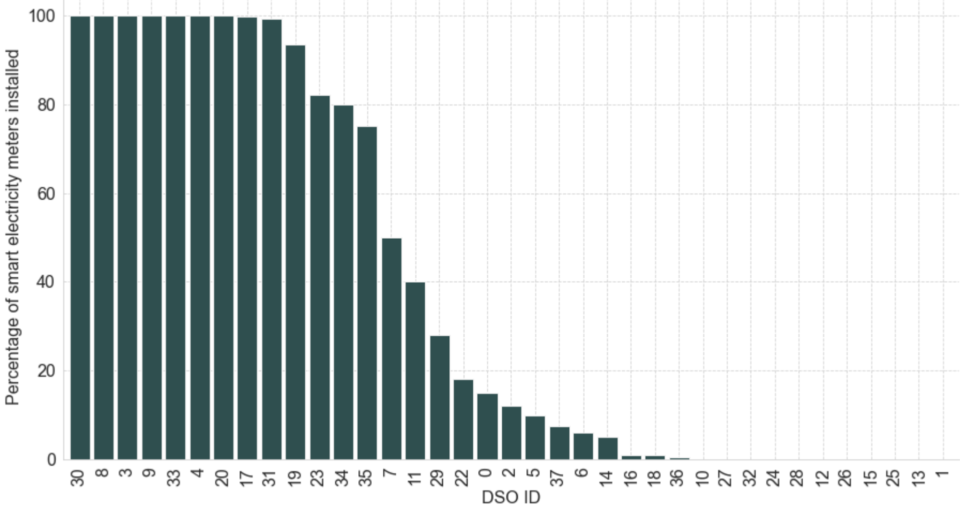
4.3 DSOs monitoring and control of assets

As mentioned in the beginning of this chapter, the trends of decentralisation and digitalisation are at the core of the energy transition. The DSO networks, which were traditionally simpler in their operation, due to unidirectional power flows and minimum controllability, are transforming into a smart grid with multiple assets, including besides loads also DER, storage, etc. The operation of such network requires much more monitoring and controllability than the traditional DSO network, at least in the same level as a TSO network. To achieve the asset monitoring at the customers' premises, installation of smart metering infrastructure is necessary. Moreover, to timely tackle issues of congestions, voltage control, stability, etc., the possibility of remote control of the distribution network substations is crucial. The classic SCADA systems are widely used by the DSOs, and now even more for additional types of control at substations, feeders, and end-user loads. The above three aspects of monitoring and control, i.e. smart metering, remote control of substations, and use of SCADA system control are the focus of this section.

4.3.1 Smart Metering

To enable consumer-centric electricity markets consumers should be equipped at least with a smart meter, as provided in the Directive (European Parliament, 2019). Despite the roll-out target of 80% of consumers equipped with a smart meter by 2020, its achievement seems still a bit far (Tractebel, 2019). Figure 38 shows the percentage of smart meters installed by each European DSO that replied to our survey in their respective control areas, including both AMI (Automated Metering Infrastructure) and AMR (Automatic Meter Reading). Of the 37 European DSOs who have replied to our survey, 34 declared that there is currently some action concerning smart metering installation taking place in their control area, regardless of official national plans adopted.

Figure 38: Smart electricity meters installed per each DSO (% of total metering points per DSO)



Source: JRC, 2020.

Interestingly, smart Metering roll-out is taking place also outside Europe: the 7 Non-EU DSOs in our sample also provided data about their roll-out status, ranging from a minimum of 3% to a maximum of 16% of their total customers. This is a positive signal, provided that no official target has been adopted in this Non-EU country yet, showing that smart metering roll-out is seen as beneficial also where no legislative requirements provide for it. Of almost 140 million metering points managed by the European DSOs replying to this survey, around 88 million have already been replaced with smart meters, equivalent to 63% of their total metering points. Looking at the distribution in table 16 the mean value of smart metering roll-out is of 38.5%(5) in our DSOs sample.

The distribution shows how the installation of smart metering solutions is polarized: the top 25% of our sample (9 DSOs) has equipped with smart meters more than 99% of its customers. The median value shows instead a much lower achievement: half of our sample has installed only 12% of smart meters over its total metering points. The last 25% of our DSOs sample practically has not started any wide scale roll-out yet. In order to achieve at least the 80% target in the control areas of each DSO who replied to this survey, additional 23 million smart meters should be installed. Assuming an average cost of EURO 200 to equip each metering point with a smart meter, this would correspond to additional investments for roughly EURO 4.6 billion in the very next few years. There are two facts that are worth mentioning here: first, the 80% target refers to each single EU country, while here we have considered 80% of the total customers served by the European DSOs

(5) Note that this number refers to the average of the percentages per each DSO.

Table 16: Smart meters (AMI and AMR) installed (% per DSO) statistics

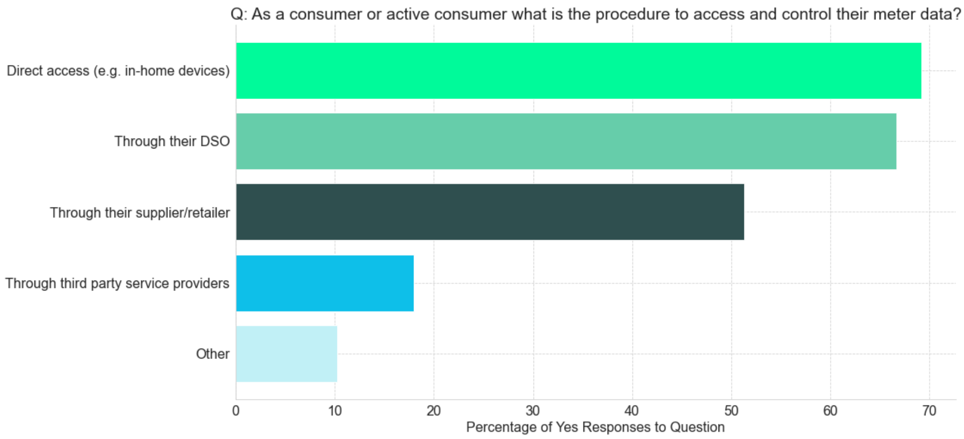
	Field	Value
0	count	37
1	mean	38.5
2	std	43.6
3	min	0
4	25%	0
5	50%	12
6	75%	93.4
7	max	100

Source: JRC, 2020.

in our sample; second, having 260 million electricity customers in Europe (Eurelectric, 2020) the investment need calculated still represents a lower bound of the needed investments in smart meters, provided that the customers served by the DSOs who replied to the survey are around 140 million (53%).

We have asked to our respondents which have some kind of smart meter installed (both AMI and AMR) through which procedure consumers can access their consumption data (Fig. 39). Almost 70% have mentioned the option *direct access*, that is by using in-home devices, 66% have mentioned the possibility to get them through the DSO, a slightly more than 50% mentioned that the supplier/retailer is in charge of this task and 18% mentioned that data are provided by third party service providers.

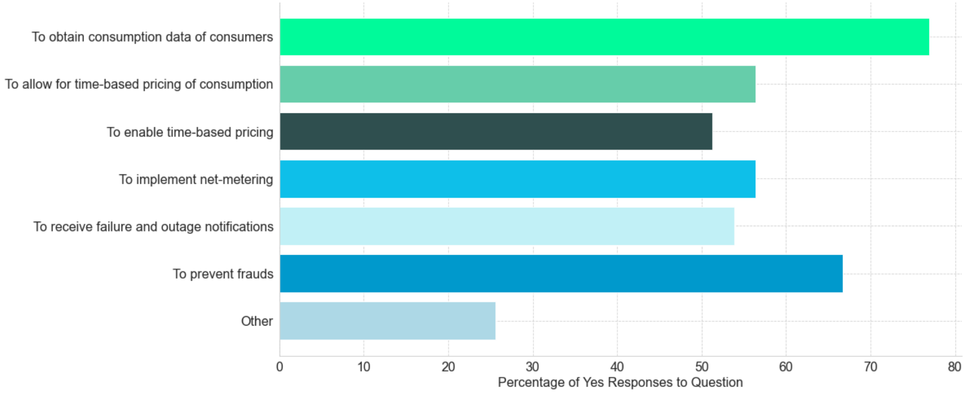
Figure 39: Options to retrieve data for final consumers



Source: JRC, 2020.

In terms of AMI utilisation (shown in Figure 40), the majority (66%) of the interviewed utilities uses them to obtain consumption data of their consumers, but also to prevent frauds, which are easier to implement with old conventional ones. A 55% uses also AMI to allow for time-based pricing of consumption and also to implement net metering for those consumers that are also producers (prosumers). Finally, a 53% uses them for failures and outages notifications, which are fundamental for DSOs to react to unplanned events.

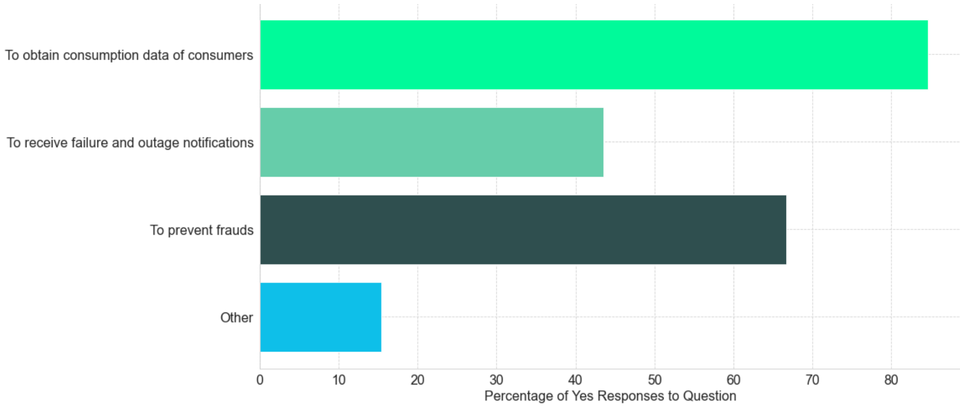
Figure 40: Options for the usage of AMI



Source: JRC, 2020.

In terms of AMR, their utilisation (shown in Figure 41) is mainly for obtaining consumption data of consumers (84%), but also to prevent frauds (67%). Only a 43% uses AMR for notifications on outages and failures.

Figure 41: Options for the usage of AMR



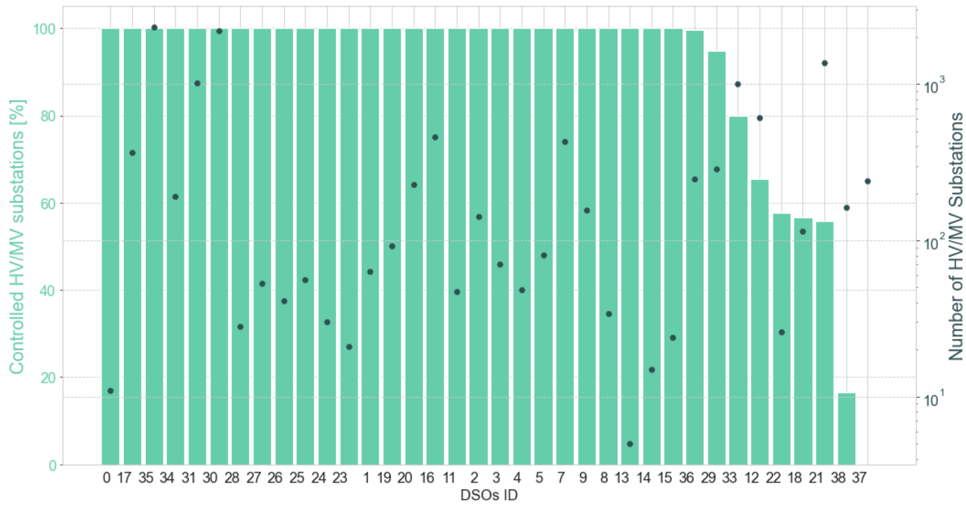
Source: JRC, 2020.

Some DSOs mentioned also the use of AMI and AMR to check power quality, thus voltage quality, and also for remote connection and disconnection of loads connected to them.

4.3.2 Remotely controlled substations

Moving to asset control, we have inquired about the capabilities that DSOs have currently to remotely control HV/MV and MV/LV substations. Two facts have emerged: first, remote control is quite a common practice at the HV/MV level, second, this is not instead very common at MV level. More in detail, Figure 42 shows per each DSO, on the left y-axis the percentage of HV/MV substations remotely controlled (turquoise bars), on the right y-axis the total number of HV/MV substations (dark dots).

Figure 42: Remotely controlled HV/MV substations per DSO



Source: JRC, 2020.

As mentioned, it is quite common for DSOs to have remote control capabilities over their HV/MV substations. Table 17 highlights that 75% of the DSOs in our dataset has more than 99.9% of their HV/MV substations remotely controllable and that on average 90% of them has this capability.

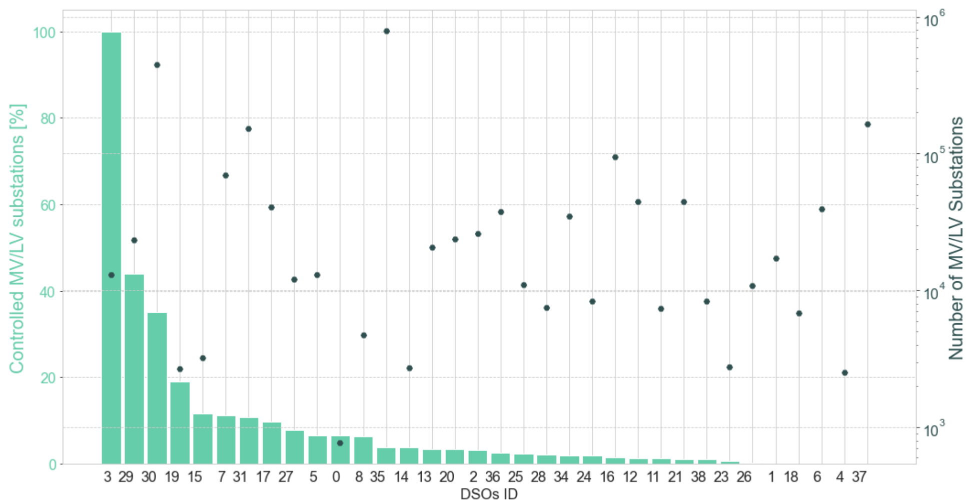
Table 17: Percentage of HV/MV controlled substations statistics

	Field	Value
0	count	36
1	mean	90
2	std	24
3	min	0
4	25%	99.9
5	50%	100
6	75%	100
7	max	100

Source: JRC, 2020.

At the MV level, the situation is rather different. From Figure 43 it can be seen that only one DSO out of the 34 who have shared this information has 100% of its MV substations remotely controllable.

Figure 43: Remotely controlled MV/LV substations per DSO



Source: JRC, 2020.

Table 18 helps us look at this point from a broader perspective. By looking at the sixth parameters in the table we learn that 75% of the respondents have less than 7.5% of their MV substations remotely controllable. This fact might represent a barrier to the deployment of DER connected at MV and LV level. The intermittency of renewable sources might be definitely tackled more effectively if higher levels of controllability are present at the MV level.

Table 18: Percentage of MV/LV controlled substations statistics

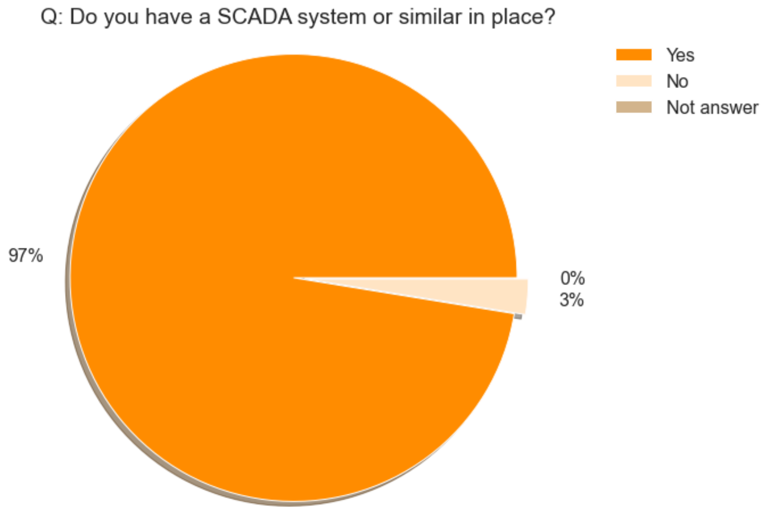
	Field	Value
0	count	34
1	mean	9
2	std	19
3	min	0
4	25%	1.1
5	50%	2.8
6	75%	7.4
7	max	100

Source: JRC, 2020.

4.3.3 SCADA system control

SCADA systems are well known tools used in power systems. SCADA stands for Supervisory Control And Data Acquisition and can be thought of as a system of different hardware and software elements that together enable an operator to supervise and control processes for a correct functioning of assets. We have asked to the DSOs in our sample (Fig. 44) if they have a SCADA system or similar in place to control and monitor their assets. 97% of our respondents replied positively to this question.

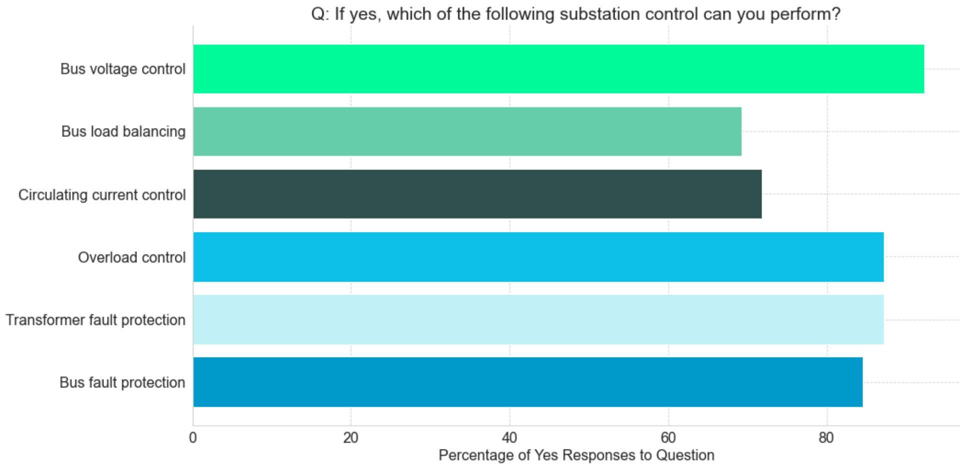
Figure 44: Percentage of SCADA system or similar used by DSOs



Source: JRC, 2020.

Thereafter, we have asked them more in detail about three main types of control: on substations, on feeders and on end-user loads. With respect to substation control, four main capabilities can be considered to be key for more than 83% of the respondents: voltage control at the bus level, overload control and transformers and buses fault protection. Additionally, 66% of them can also control load balancing at the buses level and the circulating current (Fig. 45).

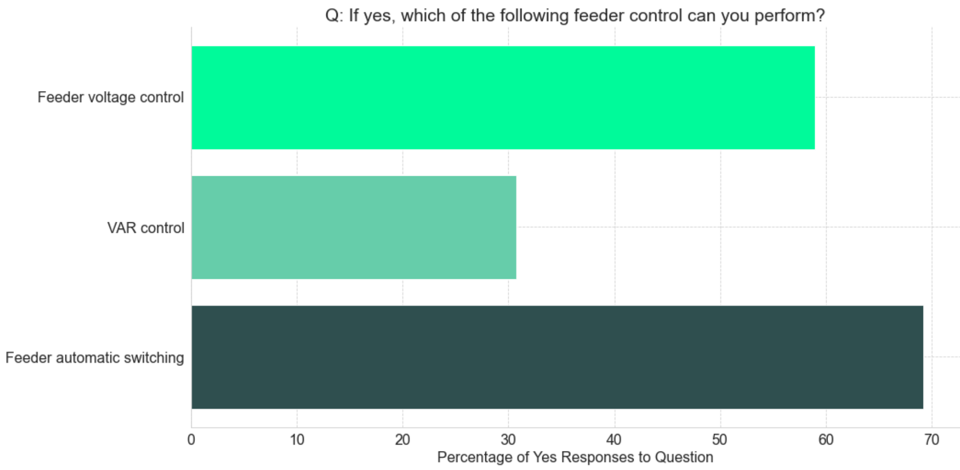
Figure 45: Substation control activities performed by DSOs



Source: JRC, 2020.

Moving to feeder control, automatic switching for network reconfiguration can be performed from almost 70% of the DSOs having a SCADA system in place. Voltage control on feeders can be performed from 58% of the respondents and a slightly more than 30% can also control reactive power on feeders (Fig. 46).

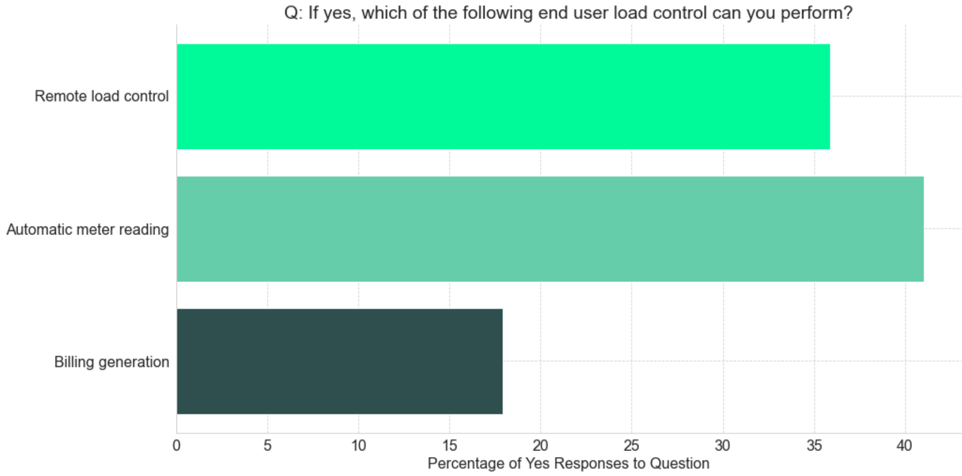
Figure 46: Feeder control activities performed by DSOs



Source: JRC, 2020.

Finally, with respect to end-user load control, 40% of the respondents underlines automatic reading and 36% is able to perform remote load control. Only 18% mentioned the possibility to generate billing automatically (Fig. 47).

Figure 47: End-user load control activities performed by DSOs



Source: JRC, 2020.

4.4 DSOs management of advanced technologies

In the following a view on more advanced technologies in place or under developments among DSOs is provided. We have divided them into seven categories, namely,

— Power flow tools,

— Data analytics for asset planning and investment strategies,

— Sensor technology for outage detection & prediction,

— Advanced load & storage management development,

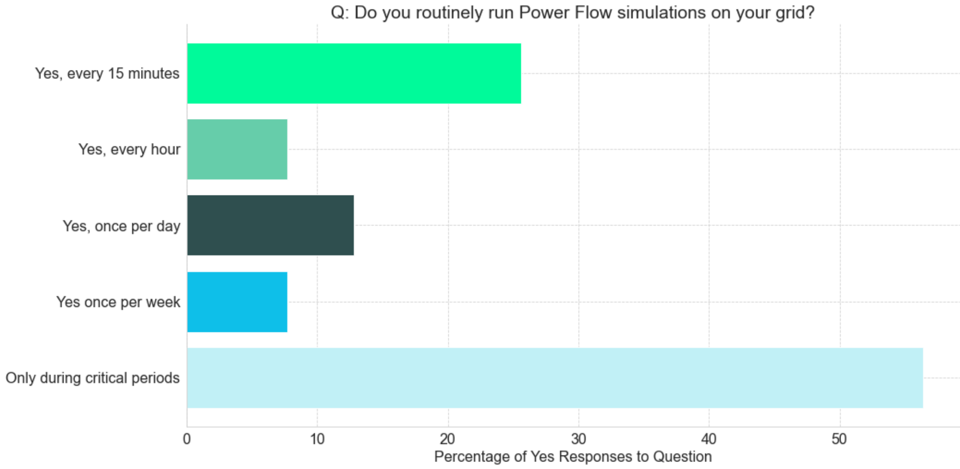
— DER visualisation and management tool,

— Drones technology for infrastructure monitoring,

— (Micro)-phasor measurement units.

As aforementioned, with an emerging number of actors (EVs, PVs, heat pumps, storage) connected to the distribution grids the complexity of a correct operation is increasing, as well, and expected to follow this trend. As a consequence of that, knowing power flows and their related quantities (voltages, losses, power, current) at the different buses that compose the networks is becoming increasingly more relevant also for DSOs. Given that, we have asked through our survey if power flow simulations are run over DSOs grids and how often this is done (Fig. 48). The highest response (56%) has been that this is made only during critical periods, but unfortunately we don't have an estimation of how often critical periods occur. On the contrary 25% of the respondents mentioned that power flow simulations are undertaken every 15 minutes: having these capabilities would definitely increase the efficiency of DER, EVs and DR integration into the distribution system.

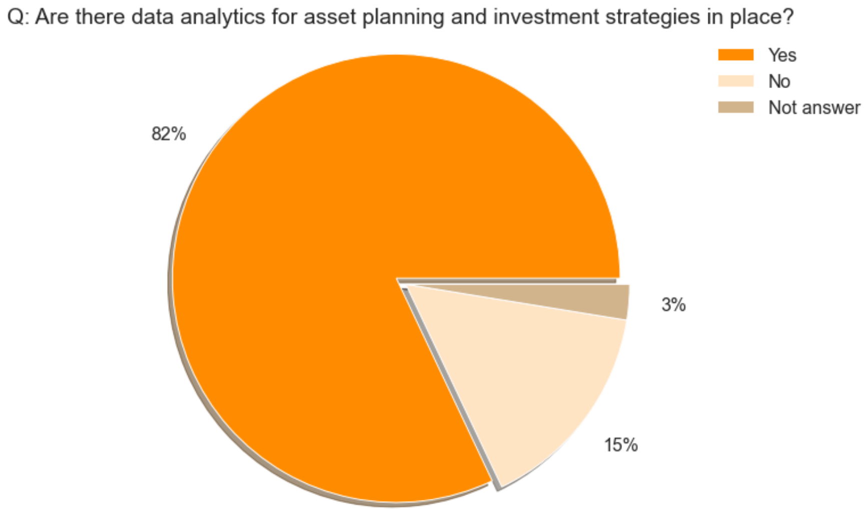
Figure 48: Power flow simulations



Source: JRC, 2020.

With respect to data analytics for asset planning and investments strategies, 82% of the respondents mentioned some related activity (Fig. 49). In particular, some DSOs make HV and MV grid planning based on SCADA data, and some use predictive maintenance for cable lines, which is later used for asset planning exercises and for estimating investments. Some DSOs mentioned the existence of an analytic system that based on grid data can help with condition based maintenance. In-house algorithmic tools are also used for instance to optimise the selection of transformers in the grid.

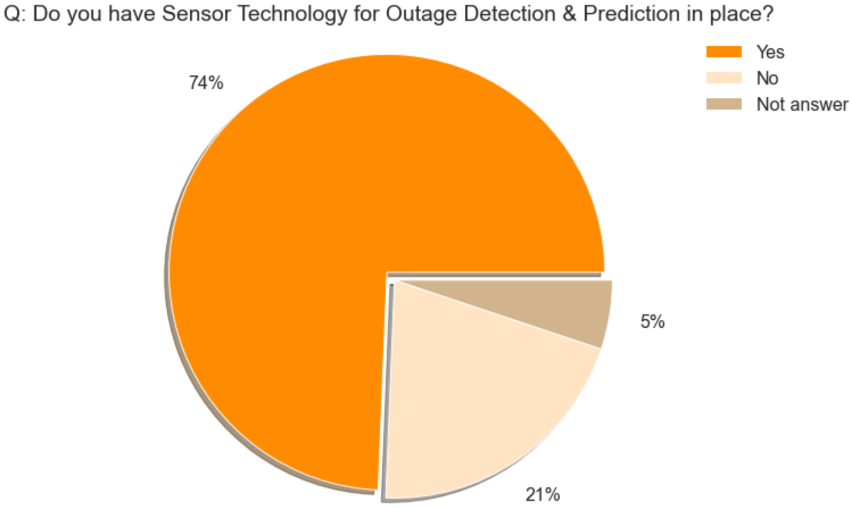
Figure 49: Data analytics for asset planning and investments strategies usage



Source: JRC, 2020.

Sensor technology for outage detection and for outage prediction is also a common practice among operators (Fig. 50). In fact, according to the collected replies, 74% of the DSOs has them in place. More in detail, protective relays and fault detectors for outage detection and short circuit indicators are a common choice. In certain cases fault detectors are used in the MV part of the grid while for the LV part signals from the meters are used. With respect to outages prediction apart from few pilots in progress, one DSO mentioned the existence of a working system for outage prediction based on machine learning algorithms. Some DSOs have mentioned the management of power outage databases, based on customer signs.

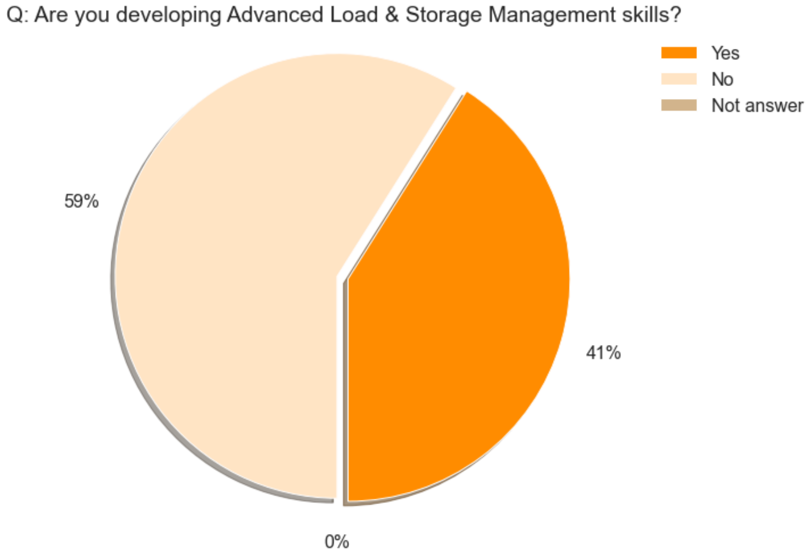
Figure 50: Sensor technology for outage detection and prediction usage



Source: JRC, 2020.

With respect to the advanced load & storage management developments, despite that 41% of the respondents has replied positively to this question (Fig. 51), these experiences refer all to pilot projects except for one case. In this case, an energy management system uses an OPF module to determine the optimal grid state by minimizing selected parameters (e.g. reactive power losses, active power losses, active power generation cost).

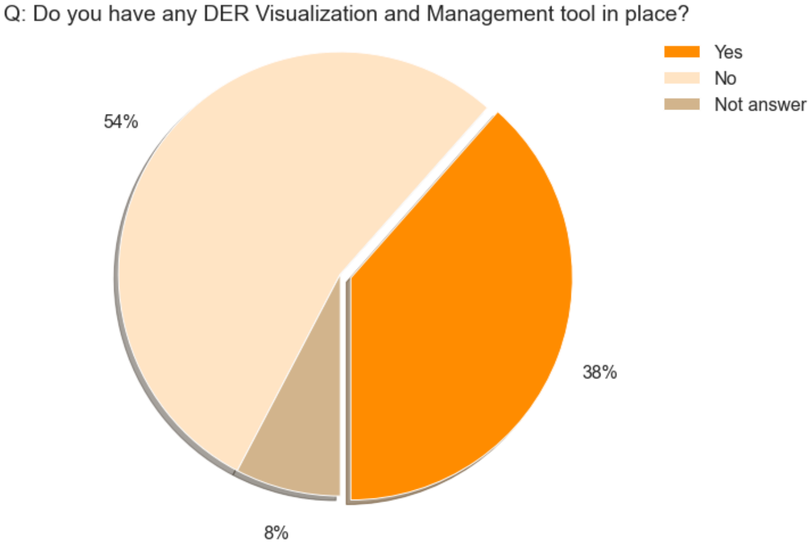
Figure 51: Advanced load and storage management skills



Source: JRC, 2020.

With the paved increase of DER, visualisation tools and management tools will become indeed indispensable for DSOs. We have asked our respondents about their current capabilities to tackle them. 38% of our interviewed utilities replied positively to this question (Fig. 52). Although some DSOs use their SCADA system to visualise DER production almost in real time, automatic managements tools are often not in place yet. Others have access to real time measurements of loads but can only monitor DER with an installed capacity over $1MW$. Remarkably, one DSO mentioned the utilisation of a Network Information System (NIS) for DER asset management and a Client Information System (CIS) for DER customer contract management. Additionally one DSO mentioned the development of a new platform to share detailed information directly between DER and DSOs and between different DSOs as well.

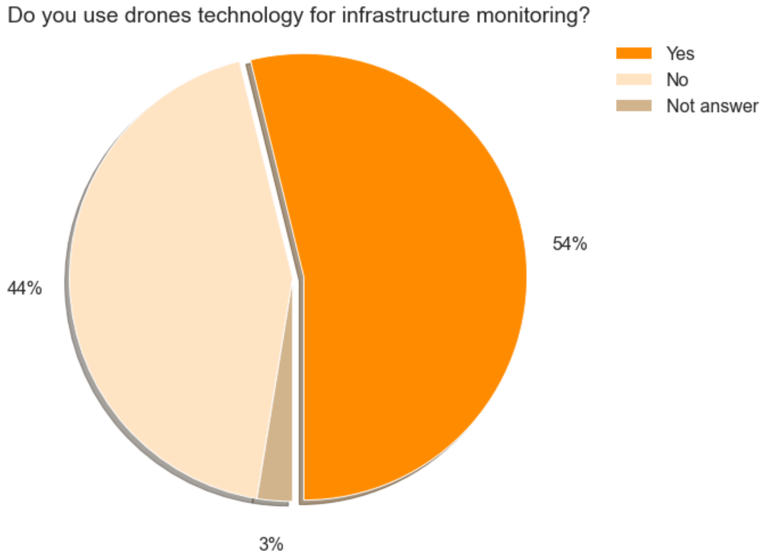
Figure 52: DER visualization and management tools capabilities



Source: JRC, 2020.

Infrastructure monitoring is really important to ensure the security of supply. In case of outages it is of utmost importance to promptly react and to make it correctly, and it is also necessary to understand the causes behind the interruption. In the last four years the market of drones([6]) has grown steadily. We have asked DSOs about the utilisation of drones for their infrastructure monitoring. 54% has replied positively to that (Fig. 53). Despite that the majority of them is referred to pilot projects, four DSOs have specified the scope behind their usage. The first one has mentioned their use for fault repair assistance and maintenance; the second one for HV overhead lines monitoring; the third one to monitor the condition of aerial power lines; the fourth one for improving the quality and completeness of defects' data, increasing the reliability (SAIDI) by reducing the number of outages.

Figure 53: Drones technology for infrastructure monitoring usage

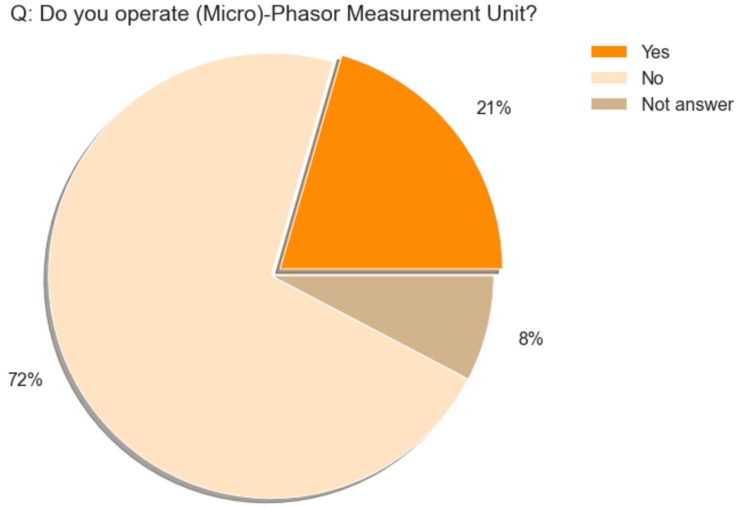


Source: JRC, 2020.

With respect to phasor measurement units (PMU) 21% of the DSOs replied that they have them in place. Some use PMU to send input to the SCADA system to operate the grid in a stable condition. Others for the observation of stability, for frequency measurements with high resolution , and for grid restoration. The remaining ones referred to pilot projects.

([6]) https://www.toptal.com/finance/market-research-analysts/drone-market

Figure 54: Micro phasor measurement units technology usage



Source: JRC, 2020.

4.5 DSO-TSO coordination

DSOs and TSOs are responsible for the operation of their respective network and at the same time they have to act as neutral market facilitators. Their tasks are thoroughly described in Articles 31 and 40 of (European Parliament, 2019), where it is also mentioned that *Distribution system operators shall exchange all necessary information and shall coordinate with transmission system operators in order to ensure the optimal utilisation of resources, to ensure the secure and efficient operation of the system and to facilitate market development.* Thus, besides the necessary upgrades to the infrastructure of both distribution and transmission networks, the ongoing electricity system transformation requires changes in the current working practices of both DSOs and TSOs, as well as increased sharing not only of their knowledge and experience, but also of their available data. In the above context, our survey has investigated the way and the frequency that DSOs exchange data with the relevant TSOs, regarding five different categories of data:

— Data shared with TSO - demand and generation forecasts

— Data on the network conditions - scheduled data of each power-generating facility

— Data on real time measurements (SCADA)

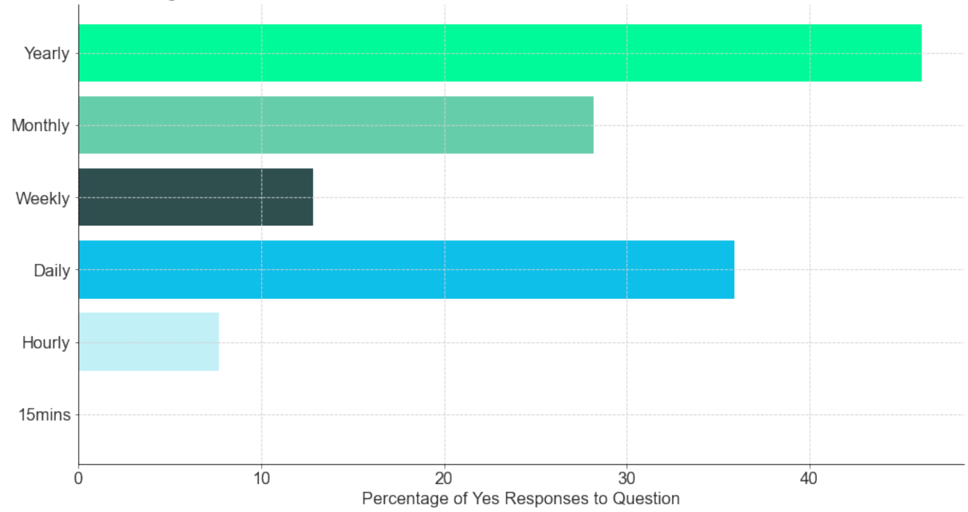
— Data on ex-post measurements (metered data)

— Data on the networks

Data shared with TSO - demand and generation forecasts

The first category of data refers to forecasts of demand and generation. As it is shown in Figure 55, almost half of the DSOs exchange such data at least on a yearly basis and more than a third on a daily basis, as well. About one in every four DSOs exchanges such data every month, whereas a few DSOs have answered that the exchange is weekly or hourly. Note that no DSO exchanges such data on a 15 minutes basis.

Figure 55: Data shared with TSO - demand and generation forecasts



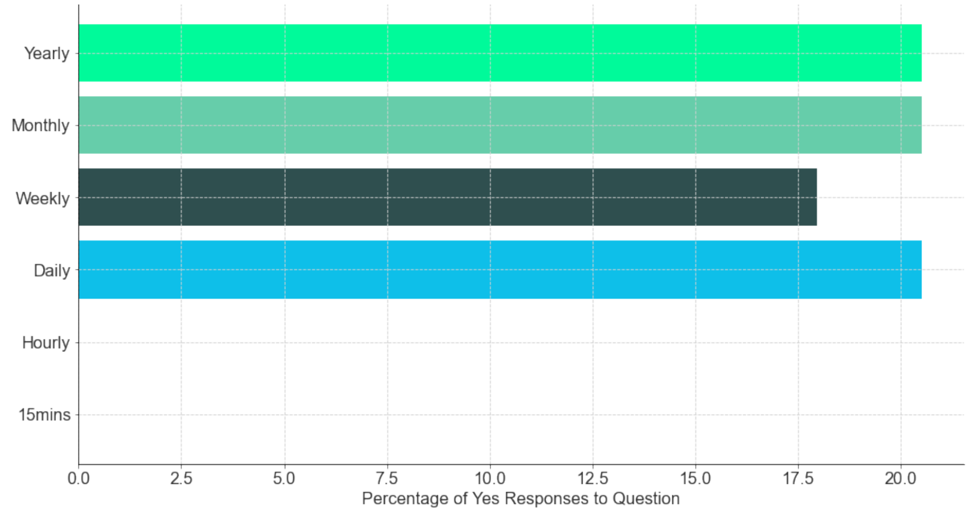
Source: JRC, 2020.

Finally, as far as the mandatory or voluntary nature of this exchange is concerned, one third of the DSOs have answered that this is mandatory, while only 5% do it voluntarily. The rest of the DSOs have chosen not to answer to this question.

Data on the network conditions - scheduled data of each power-generating facility

The next category refers to data on the network conditions, and most specifically to the schedule of each power generating facility. As shown in Figure 56, the answers were equally distributed among yearly, monthly, weekly, and daily exchanges of data, with almost one-fifth of the DSOs for each answer, whereas no DSO exchanges such data on an hourly or 15 minutes basis.

Figure 56: Data on the network conditions - scheduled data of each power-generating facility



Source: JRC, 2020.

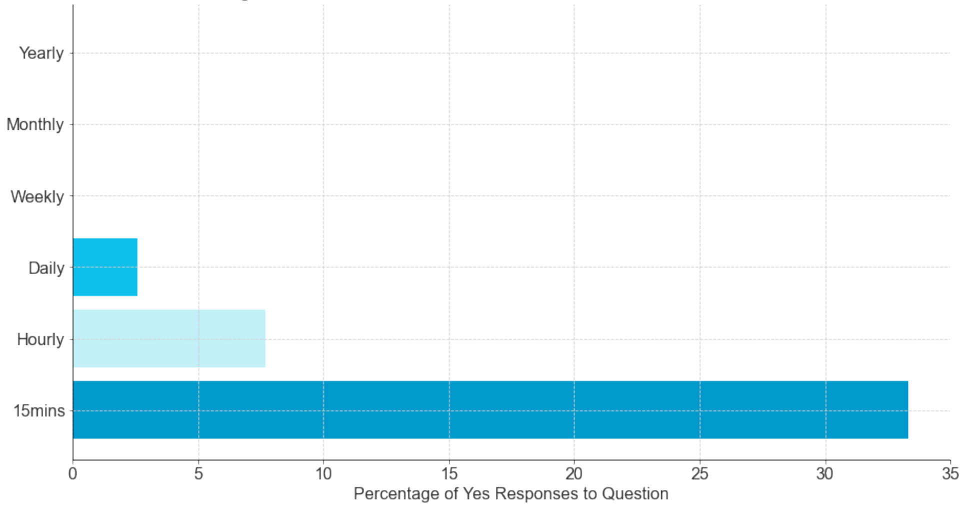
Finally, one-fifth of the DSOs have answered that the above data exchange is mandatory, while only one DSO does it voluntarily. The rest of the DSOs have chosen not to answer to this question.

Data on real time measurements (SCADA)

Both DSOs and TSOs generate huge amount of real-time measurement data from their SCADA, which are deployed in multiple locations in their network (mostly substations). The value of such data is obviously tremendous for the secure and stable operation of the whole system, but this value is also time-limited. Thus, the exchange of such real-time measurement data, as it is also visible in Figure 57, is done primarily on a 15

minutes basis, and to a lesser degree hourly or daily.

Figure 57: Data on real time measurements (SCADA)



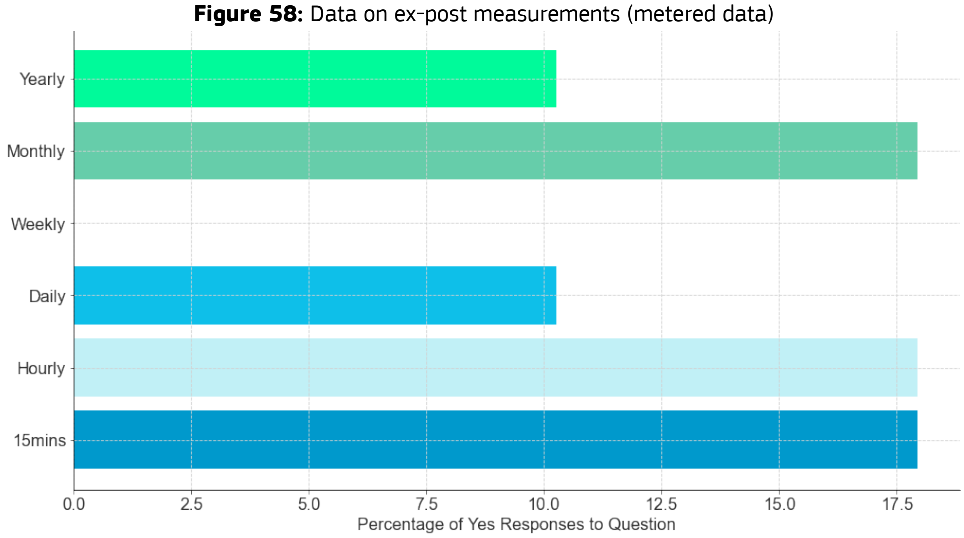
Source: JRC, 2020.

More than one-fourth of the DSOs have answered that the above data exchange is mandatory, while 10% of the DSOs do it voluntarily. One DSO has answered that the system to exchange such data is in the process of integration, and another one said that such real-time data are indeed exchanged but only for substations on DSO-TSO interconnection. The rest of the DSOs have chosen not to answer to this question.

Data on ex-post measurements (metered data)

Besides the real-time data mentioned above, DSOs and TSOs generate also large amounts of other metered data, which they can share ex-post. Such data are shared in different frequencies, as it is shown in Figure 58, where more than one-fourth of the DSOs shares data on monthly and/or yearly basis, whereas almost half of the DSOs share such metered data much frequently on a daily, hourly or even 15 minutes basis. Although it has not been clarified, it is logical to assume that the difference in the exchange frequency refers also to different type of metered data. One in every three DSOs is obliged to exchange such data with the TSO, while 10% of the DSOs do it voluntarily. One DSO has answered that some of the data exchanges are mandatory and some voluntary, and another one has answered that the exchange is performed voluntarily only on demand. The rest of the DSOs have chosen not to answer to this question.

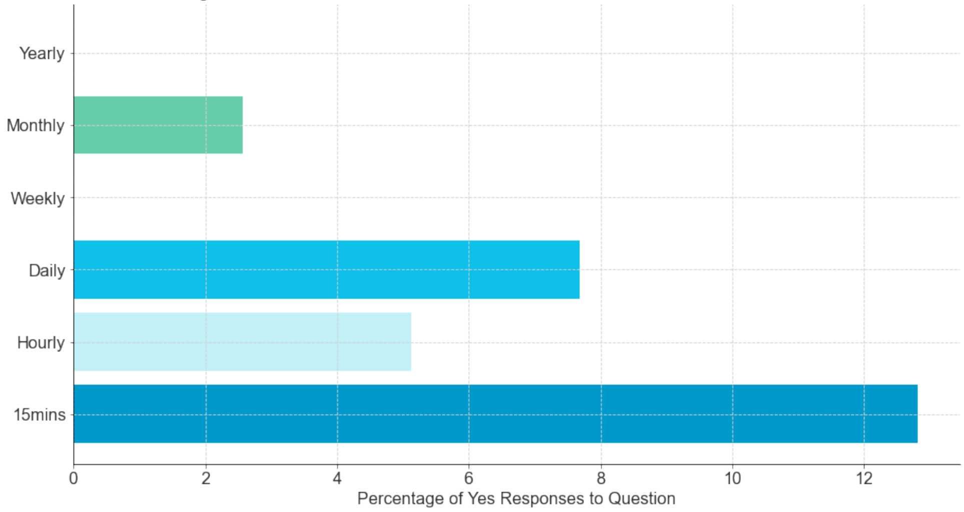
Figure 58: Data on ex-post measurements (metered data)



Source: JRC, 2020.

Data on the network conditions received from TSO
The final category refers to data on the network conditions that the DSO receives from the TSO. Such data can be very valuable for the DSO to guarantee the security of supply to its customers and prepare for planned disruptions coming from the transmission side. Therefore, as shown in Figure 59, one-fourth of the DSOs have answered that they indeed receive such data from the TSO on a daily or hourly or 15 minutes basis. In addition, one other DSO receives such data every month, whereas the rest of the DSO have not provided any answer to this question.

Figure 59: Data on the network conditions received from TSO



Source: JRC, 2020.

Only one in every five DSOs has answered that such exchange with the TSO is mandatory. One DSO has answered that the TSO shares such data based on the System Operation Guideline (European Commission, 2017), while another one said that the system to exchange such data is in the process of integration. Finally, other DSOs have answered that they receive only specific data from the TSO, as in the following:

— data for Frequency/Voltage for each feeder

— data for load capacity, and short circuit levels

— data for positions of the transformer breakers

— data for power angle, voltage, short circuit power, available transit capacities (some data in real time if emergency)

— data for real time current and voltage in HV/MV substations at TSO-DSO interconnection points

— data in real time values in voltage and current

— structural data, scheduled data and real time measurements

— meter reading (hourly consumption data) once per day

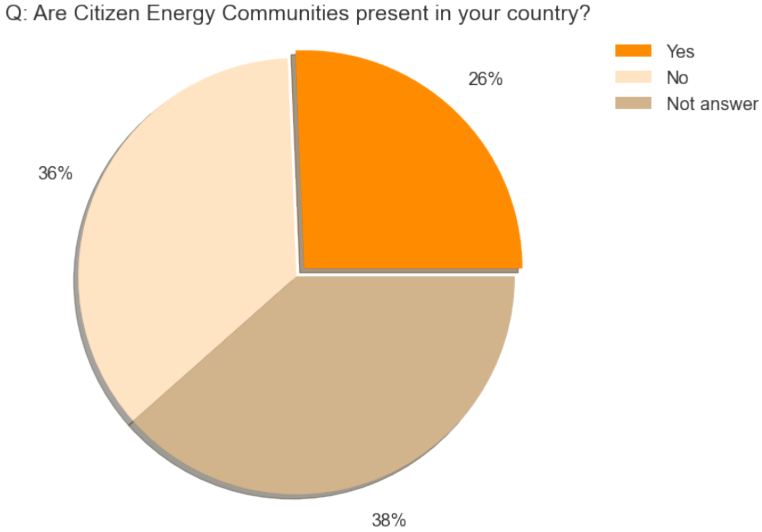
Finally, 19 of the DSOs have chosen not to answer to this question.

4.6 Regulatory challenges for DSOs in Europe

The distribution industry is today at the forefront of regulatory innovation in the electricity sector: no other area of the value chain is undergoing the same transformations. In this section, we present some data on a selection of regulatory issues.

The first dimension of innovative regulation in the distribution sector is represented by Citizen Energy Communities: they may include managing distribution grids among other features (DER, aggregation of energy demand,, supply, storage, management of EVs, etc.). In case the CECs so requests, DSOs need to guarantee the connection to CECs in a non-discriminatory manner. Such provisions from the Clean Energy Package (Directive 2019/944) have probably left the DSOs wondering what could be the practical implications: will CECs become well-spread? will they imply an additional burden on the DSOs' system operation tasks? In order to understand what could be the size of such a phenomenon, we asked European DSOs if they are aware of CECs in their own country. As shown below, (Fig. 60) CECs are still not so common across Europe: only the DSOs operating in 10 countries, representing 26 percent of the survey responses, indicate that they are aware of CECs experiments. However, a clear definition of CECs has not been agreed upon yet across the different National Regulatory Authorities within the EU and therefore the figures mentioned might not be exact. Nevertheless, the informative value still stands: several EU countries, especially those belonging to the so-called Central-West electricity region, have experiences in CECs. These national experiences will need further investigation to understand their characteristics and their interaction with DSOs.

Figure 60: Citizen Energy Communities according to European DSOs



Source: JRC, 2020.

Another important form of development in innovative regulation is what we call *regulatory experimentation*. The reference for this is a specific taxonomy proposed by (Lo Schiavo, 2020) which differentiates regulatory innovation into two dimensions:

— Physical area of innovation: it can be system-wide innovation or zone-wide innovation

— Operators involved: Grid Operators only or Grid and Market Operators together

The resulting combinations define 4 types of regulatory experimentation:

— Incentives for innovative roll-out: they concern the whole distribution system, but are carried out by grid operators only;

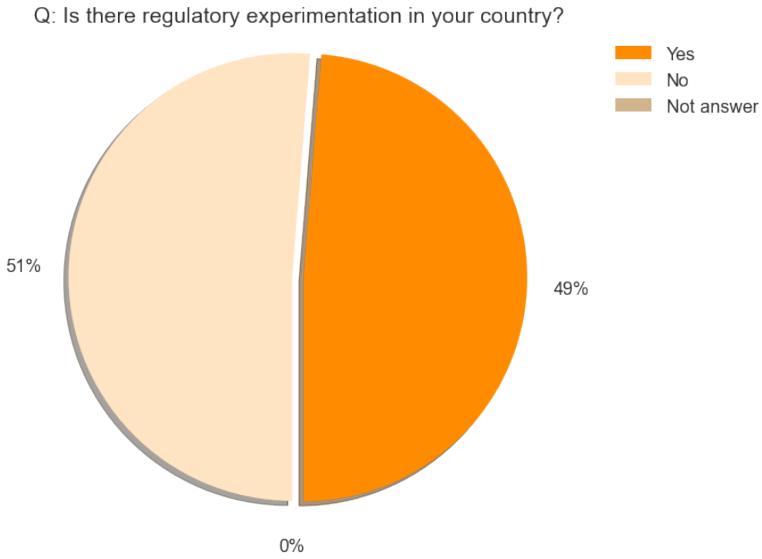
— Pilot Projects: they are realised only on a specific area of the distribution grid, still realised by grid operators only

— Pilot Regulations: in this category fall the system-wide innovations realised by grid and market operators together

— Regulatory Sandboxes: they are only local solutions, but realised thanks to the collaboration between Grid and market operators.

This taxonomy helps in overcoming a quite common terminology issue: what is a regulatory sandbox in a country, might well be a pilot regulation in another, while incentives might be well misinterpreted for pilot regulations, and so on. Such lack of precise definitions makes difficult to carry out international comparisons, to define rules or best practices at EU level, and therefore, using it for our data collection exercise, we hope to raise awareness about the importance of using a common language when defining regulatory innovations.
According to data collected, half of the DSOs that responded to our questionnaire indicated some sort of regulatory experimentation in their country (Fig. 61).

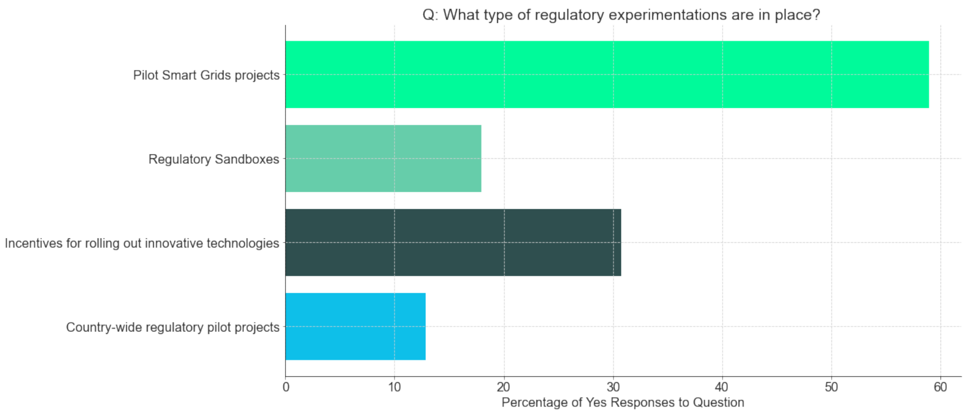
Figure 61: Regulatory Experimentation



Source: JRC, 2020.

Pilot projects are the most well-known form of experimentation, a foreseeable result considering the significant amount of investment in Smart Grid pilot projects in the EU, realised also thanks to substantial EU funding. Second common type of innovation is the set-up of incentive schemes for the roll-out of innovative technologies in the distribution grid. Regulatory sandboxes, while often considered the "newest" type of regulatory innovation, are also well-represented among respondent DSOs. Country-wide regulatory pilot projects are instead less common, probably given their complexity and also considering that not all National Regulatory Authorities might have the same approach or interest towards innovation. The two charts combined provide an interesting snapshot of what innovation means when dealing with regulatory aspects impacting the distribution grids (Fig. 62).

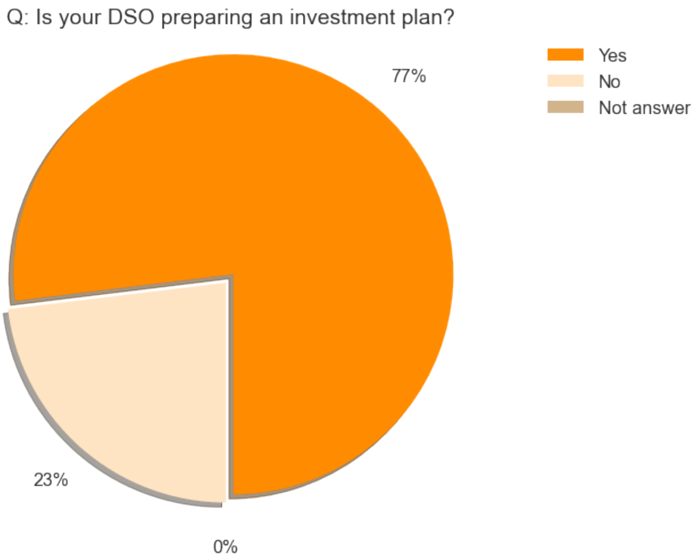
Figure 62: Regulatory Experimentation by type according to Taxonomy (Lo Schiavo, 2020)



Source: JRC, 2020.

Following, we analysed the readiness of DSOs in preparing the requested investment plans (Fig. 63). Almost three quarters of respondents stated that they are preparing an investment plan, providing a very promising picture on the take up of long-term planning also at distribution level. When these plans will be possibly combined with ENTSO-E's Ten Year Network Development Plan, forecasting and modeling of the future European grid might result in very useful insights at both transmission and distribution level. This will possibly provide a more spatially accurate overview on additional RES being able to be connected to the grid, on evolution of loads, and on necessary congestion management capabilities, including the use of flexibility in specific areas of the grid.

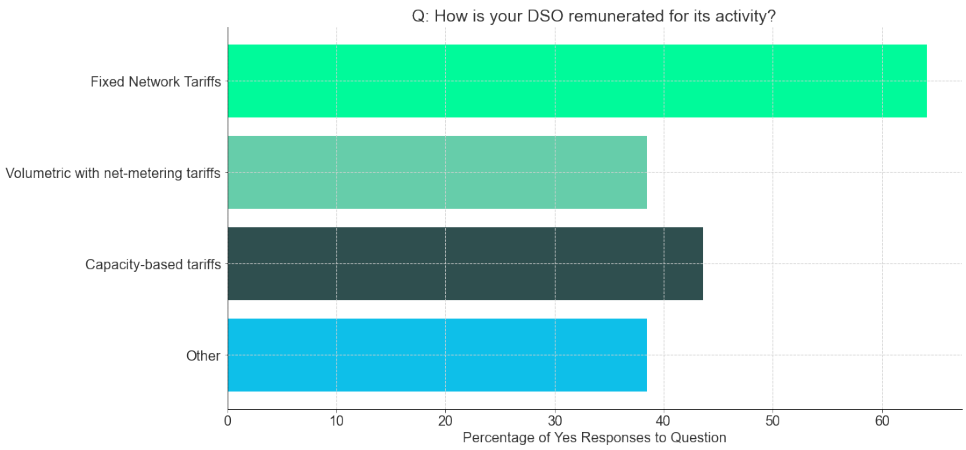
Figure 63: DSOs' investment plans



Source: JRC, 2020.

Another complementary aspect when analysing investments is the source of remuneration for the DSO: the different schemes may surely provide hidden incentives towards specific directions of grid development, or long term planning, as for example the use of specific incentives not tailored to the context might derail the DSO's investment plan from what would be socially optimal (Gunther et al., 2017). Certainly, innovative DSOs tasks require innovative regulatory frameworks. In Figure 64, an overview of the most common remuneration mechanisms among the respondent DSOs is given.

Figure 64: DSOs' remuneration schemes



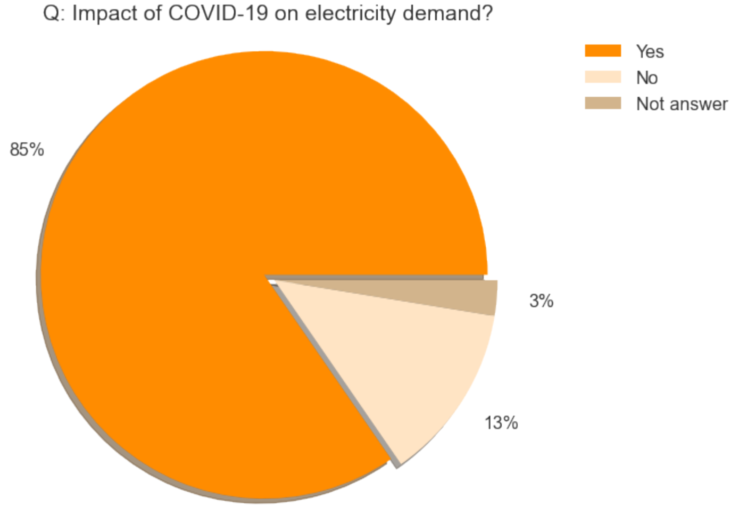
Source: JRC, 2020.

4.7 Covid's impact on DSOs activities

Lastly, another key factor to consider is the ability of the European Distribution System to be resilient to shocks, like the COVID-19 pandemic. The DSO association EDSO already in 2019 (EDSO, 2019) identified as one of its priorities the "innovative resilience", pointing out that climate change and other critical events are expected to pose increasing challenges to distribution grids operation. In order to respond, there is a need for developing additional or more appropriate metrics of distribution grid resilience, which can capture the granularity of unprecedented events. Such granularity tends to fade away when analysing year-round indicators like SAIDI and SAIFI, which cannot capture the frequency of high impact, low frequency events, just like the COVID-19 pandemic.

In order to provide a solid base to future research targeting DSO's resilience, we asked DSOs whether COVID-19 related events implied a decrease in electricity demand. As it can be seen in Figure 65, the vast majority of DSOs has experienced a decrease in electricity demand, which ranges from an estimated 17% decrease of electricity demand over the lockdown period in countries where the isolation measures were particularly harsh to figures in the range of $1-3\%$ in other less affected areas, with a median value of 5%.

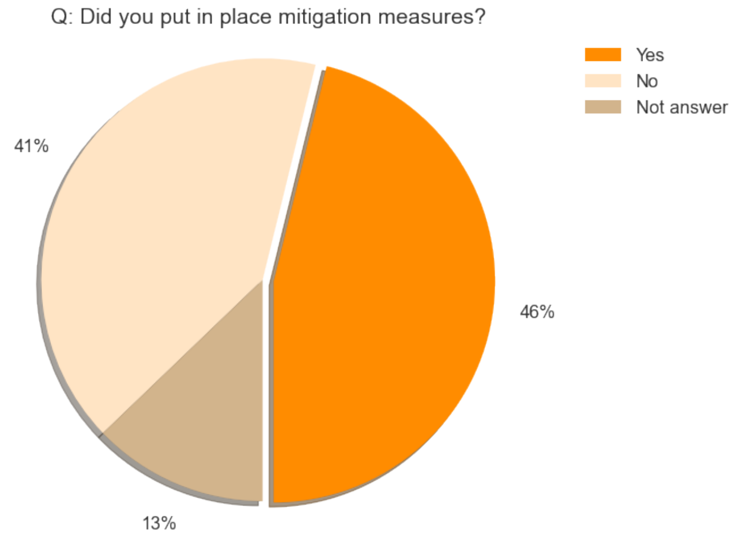
Figure 65: Impact of Covid-19 on electricity Demand



Source: JRC, 2020.

Finally, an overview of the response of DSOs to the pandemic (Fig 66): only about half of the respondents affirmed that they have put in place mitigation measures, mostly related to personnel safety like strict shifts and, when possible, reduction of the personnel present at the premises.This, therefore, highlights how the pandemic has found many grid operators still unprepared. Within this context, we would recommend including in the future DSO investment plans also a related risk plan, which will help the DSOs in identifying the proper crisis management and response when needed, mitigating the expected effects not only on operational activities but also on long term investments.

Figure 66: Impact of Covid-19 on electricity Demand: mitigation measures



Source: JRC, 2020.

5 Conclusions

The third edition of the European DSO Observatory aimed at capturing all the various directions towards which DSOs are evolving. While the first edition of the report, issued in 2016, presented a picture of DSOs still anchored to mostly traditional tasks of system operation and grid stability, the 2018 integrated data on more innovative services, like customer data management and data sharing with TSOs, advanced smart metering roll-out, use of flexibility sources, and integration of EVs charging points in the distribution grid. In this report, the evolutionary path taken by European DSOs is even clearer: they are more and more enabler of the energy transition that will take place in the continent over the next decades.

Given the several thousands of DSOs active in Europe, the mapping effort has been limited once again to the bigger DSOs, namely those which serve more than 100,000 customers subjected to the unbundling requirements of the EU electricity Directive 2009/72/EC. Also this edition presents data based on a survey directly filled by individual DSOs, collecting new data for around 44 DSOs.(7)

The data collected have been shown through several graphs and metrics. Some data are currently used by DiNeMo a collaborative web-platform allowing researchers and DSOs alike to simulate directly the reference distribution network for a specific area in Europe, on the basis of a simple selection of the area of interest on a map.

Some indicators have also been combined to build scatter plots showing graphically the relationship between e.g. customers served and the dimension of the area of operation or energy distributed and the area of operation. These data, together with those about line length, indicators per voltage level and statistics about the type of cables used, ratio of HV substations over MV/LV substations, SAIDI and SAIFI, provide a very detailed overview on the technical characteristics of DSOs in Europe.

Moving beyond the merely technical data, the report considers the Smart Grid dimension of European DSOs, an aspect of their activity that is more and more important and that places the DSOs at the core of the European climate and energy policy. First, we present the DSOs as users of non-frequency ancillary services, like Demand Side Management, Demand Response and the management of active customers. The most interesting result of this section comes from the use of DSM and DR as alternatives to investment in grid capacity: although today this is not implemented yet, some DSOs are already considering it as a concrete possibility for the immediate future. On a related topic, a minority of DSOs (13%) report of managing active consumers in their distribution grid, while another 41% have experience with it but only in specific context. Active consumers are mostly managed directly by the DSOs themselves, or, in about 15% of cases, also through aggregators.

Another innovative dimension related to Smart Grids is the DSO management of DER, EV and storage systems. On the basis of data provided by respondent DSOs, it has emerged that only a quarter of them had connected DER generating for more than 2000 equivalent full hours, a figure that is independent from the total capacity of DER installed and connected to the DSO's grid. This indicates that more efforts are needed, especially in some countries, towards actually enabling DER to generate and inject their electricity in the distribution grid, for example by implementing advanced grid management tools including artificial intelligence. It should also be taken into account that different solutions might be ideal in different situations: high penetration of solar w.r.t. wind generation certainly has implications in terms of average nominal DER capacity per customer managed by the DSO.

Another interesting aspect of the Smart Grid dimension of DSOs is their relationship with electromobility. We report data concerning both the EV connection points per DSOs and those managed by third party operators (on average a connection point includes two charging stations). It emerged that often DSOs today still cannot see (and optimise when needed) the connection and charging points that are placed "behind the meter", therefore in this latter case EVs charging is managed at customer level. We underline that, for half of the survey respondents it is not-mandatory to report to the DSO the installation of new EV charging infrastructure. Such an arrangement clearly hinders the ability of DSOs to manage and optimise their grids considering also EV charging.

Concerning storage, 8 out of 35 DSOs communicated that they own storage, which is mostly storage set up along the grid to power substations or consumers in critical situations. Such current arrangement is in line with what provided by the Clean Energy for All Europeans legislative package: DSOs can only own storage facilities if these are connected to the DSO's grid and are used for grid stability purposes.

Another trend emerging as crucial in the DSO operation is digitalisation: managing DER, EVs, and flexibility sources requires much more monitoring and controllability than the traditional DSO network, at least in the same level as a TSO network, and this can be done if the monitoring and observability of what happens along the grid are in place. The latest figures about smart metering roll-out are reported, and they point to the fact that the target of having 80% of consumers equipped with a smart meter device by 2020 has not been achieved, although there is a clear polarization: many DSOs have completed their roll-outs, while many others have barely started yet: it is clearly visible that the commitment at policy-making level in each country has steered the

(7) For clarity, it is worth mentioning that 6 DSOs were aggregated into one reply by a DSOs association, for this reason in the indicators appearing throughout the report there are 39 replies maximum. It is also relevant to say that these 6 DSOs together with another one (corresponding thus to two replies) are non EU DSOs.

DSOs in one direction or the other. Control and observability over the distribution grid can also be achieved by remotely controlling substations: data point to the fact that while this type of asset control is well-spread at the HV - MV substations, it is not common at MV level: over 3/4 of respondents had less than 7.5% of their MV substations remotely controllable. Conversely, the use of SCADA systems is in place for almost all DSOs in our sample. When dealing with management of advanced technologies, the picture becomes fragmented: they are used for asset planning and investment strategies, sensors are wide-spread for detection of outages, while the majority is not implementing advanced load, storage or DER management tools.
The picture is scattered also for data coordination with TSOs: while demand and generation forecasts, scheduled data of generation facilities, SCADA, ex-post measurements data are usually shared or received from TSOs, data on network conditions are seldom received from TSOs.
On the regulatory aspect, DSOs are likely to be more and more at the core of regulatory innovation over the next years. Their first, obvious role will be as enablers of regulatory experimentation in the power system at large: their cooperation with other actors involved will be key to determine the further uptake of Renewable Energy Sources, of Electric Vehicles, of Renewable Energy Communities or Citizen Energy Communities.
A second important role of DSOs will be as the leading actors of regulatory experimentation: in this second case we refer to the taxonomy proposed by (Lo Schiavo, 2020). The importance of using a clear taxonomy resides on the fact that it will allow to compare different forms of experimentation across different EU countries, and will help in identifying the results of different regulatory approaches and the possible policy gaps to be filled. All this will ultimately contribute to speed up the uptake of the different forms of regulatory experimentation, and improve its outcome. Today, according to the results of our survey, the most common form of regulatory experimentation to which DSO take part in Europe is represented by Pilot Smart Grid projects, well established since almost 20 years now. Its success is certainly also linked to the consistent intervention and funding from the European Union on this field, thanks to the financing ensured by European Framework Programmes for Research and Innovation. Another well-spread form of regulatory experimentation is the use of incentives for rolling out innovative technologies, in use in several EU countries and mostly managed at country level by each single National Regulatory Authority. A third, emerging form of regulatory experimentation are regulatory sandboxes: they take place only in specific zones of the distribution system, but are realised thanks to the cooperation of both market and grid operators. At the moment, they are still not much widespread in Europe, but certainly their development in the coming years is expected to be significant. Finally, a last solution is represented by country-wide regulatory pilot projects, a solution that is at the moment tested only in a handful of European Countries.
Another interesting insight from this year's JRC survey concerns the readiness of DSOs to prepare 10-years network investment plans: more than 75% of the respondents are already preparing their investment plans, although at the moment no clear guidance on the content of such plans has been set at European level.
Finally, the surveyed DSOs provide important information on their actual remuneration schemes: around 70% of them are funded through Fixed Network Tariffs. In addition, capacity based tariffs and volumetric with net-metering tariffs are also commonly in use. The structure of such tariffs and the incentives they provide should be analysed in detail to understand if they are able to push DSOs appropriately towards innovation.
The year 2020 has also seen the appearance of the first pandemic on a global scale, that has also hit Europe harshly. Electricity demand has decreased significantly, ranging from a -17% in some countries to a median value of -5% over the lockdown period. The effect of Europe-wide lockdowns on the electricity system is still to be understood in full, however these data point to the fact that DSOs, even in such an unforeseen situation, could cope well with the sharp decrease in demand, keeping the system stable and ensuring reliability of electricity distribution.

5.1 Policy Conclusions

This third edition of the JRC DSO Observatory provides updated data on the variegated world of Distribution System Operators in Europe. The data reported have been collected through a survey completed over the summer of 2020 on the activity of the European DSOs serving more than 100,000 customers.
From the data analysis presented in the previous chapters, several policy recommendations emerge. First, we would recommend to adopt a EU-wide approach on DSO technical data gathering: a need that has been already emerging throughout the years, for example with reliability indicators like SAIDI and SAIFI that are now very widespread. A subset of the JRC's indicators presented can for example serve as an initial basis, allowing to identify the characteristics of all European DSOs, including those serving less than 100,000 customers, and help in defining country-specific characteristics. Accurate information can certainly help European policy-makers but also National Regulatory Authorities in performing their duties, and in particular will help in tracking the progress towards the defined climate targets. Such indicators can also be included in National Energy and Climate Plans, or complement them.
Second, a serious reflection is needed at policy level concerning the use of grid enhancement, like digitalisation,

vs. grid expansion, namely investments in increasing the grid capacity. Appropriate policies are those providing incentives to achieve a socially optimal solution: provided the diverse reality of DSOs across Europe a one-size-fits-all solution can hardly be optimal. Nevertheless, DSOs should be incentivised, when drafting their investment plans for example, to evaluate according to specific metrics and indicators the best solution for them to contribute to reaching the European *Fit for 55* targets (reduction of GreenHouse Gases emissions by 55% by 2030): shall they invest in digitalisation, including for example automated control or monitoring of the grid, or rather on increasing their grid capacity in order to allow more RES to be effectively dispatched into the power system? The answer to such questions will be specific to each DSO, but a common methodology can certainly make the task easier for them. On the specific aspect of Smart Metering roll-out, the present report shows how many DSOs are still far from reaching the 80% of their consumers, and this would require additional significant investments (we estimated roughly EURO 4.6 billion only for the 37 European DSOs included in this survey, for up to 23 million new smart meters). The JRC has already a years-long experience on such methodologies, as with the Smart Grid Cost Benefit Analysis which is now applied world-wide to evaluate smart grid projects.
Particular attention should be dedicated to the role of DSOs as enablers of innovation in the electricity grid: specific attention should be devoted to their role of DER managers, flexibility providers and fall-back emergency providers of services like EV charging where no other party can provide them. The provision of such services, fundamental for the development and innovation for the European power system, needs to rely on a clear, possibly European-wide, tariff scheme designed in a way that ensures a level-playing field for the different technologies and ensures that innovations are embraced, not discouraged because they might be complex to handle. Summing up, a regulatory approach that incentivises innovation is needed, and in order to define it a common methodology might be helpful.
Still on the regulatory aspect, the taxonomy mentioned above can be used as a tool to define the map of innovative regulation in Europe, and assess the merits and pitfalls of each approach. Such evaluations can be carried out by the JRC, in cooperation for example with the associations of regulators like CEER - Council of European Energy Regulators and will be able to provide policy makers interesting insights on the innovation taking place in the European distribution grids.
Investment plans will also provide interesting information, however a standardised set of minimum content should be defined at EU level, possibly as an exercise within the future DSO-Entity. A possible step forward would be the integration of DSO investment plans with TSOs ten year development plans, in order to provide a clear picture of the whole electricity system, not only of a portion of it. This is also coherent with a more integrated view of the power system.
Finally, another aspect needing attention by policy makers is the response to the COVID-19 pandemic. As mentioned, the long-term effects of the pandemic on the operation of the European power system are still to be seen. However, a coordinated response, involving TSOs and DSOs associations alike, would probably be much welcome. At the moment, in fact, the most common safety measures taken by TSOs and DSOs alike deal with personnel co-presence and rotation, creation of teams that are stable over time, etc. This is certainly important, but very small attention has been given to the implications in terms of long-term stability of the grid, revision of investments in both digitalisation and grid expansion to respond to the falling electricity demand. When the dust settles, the distribution grid and policy makers should reflect together on how the long-term electricity demand will be affected by the present pandemic or other crises, in order to clarify if there are opportunities along the obvious threats and to define an appropriate response.

Overall, this third DSO Observatory report contributes to shed light on a variety of DSO-related topics, especially looking at their Smart Grid dimension, and sums up the main developments as the use of advanced technologies and regulatory experimentation.

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List of abbreviations and definitions

AC Alterning Current

ACER Agency for the Cooperation of Energy Regulators

CEER Council of European Energy Regulators

CEP Clean Energy Package

CHP Combined Heat and Power

DAM Day-Ahead Market

DC Direct Current

DERs Distributed Energy Resources

DSO Distribution System Operator

EC European Commission

ENTSO-E European Network of Transmission System Operators for Electricity

EUPHEMIA Pan-European Hybrid Electricity Market Integration Algorithm

EV Electric Vehicle

HV High Voltage

IDM Intra-Day Market

IEM Internal Energy Market

ICT Information Communication Technology

JRC Joint Research Centre

LV Low Voltage

MV Medium voltage

MS Member State

OPF Optimal Power Flow

PMU Phasor Measurement Unit

PX Power Exchange

RES Renewable Energy Sources

SCADA Supervisory Control And Data Acquisition

TEP Third Energy Package

TSO Transmission System Operator

WAN Wide-Area Network

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