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Distribution System Operators observatory 2018

Overview of the electricity distribution system in Europe

Prettico, G., Flammini, M. G., Andreadou, N., Vitiello, S., Fulli, G., Masera, M.

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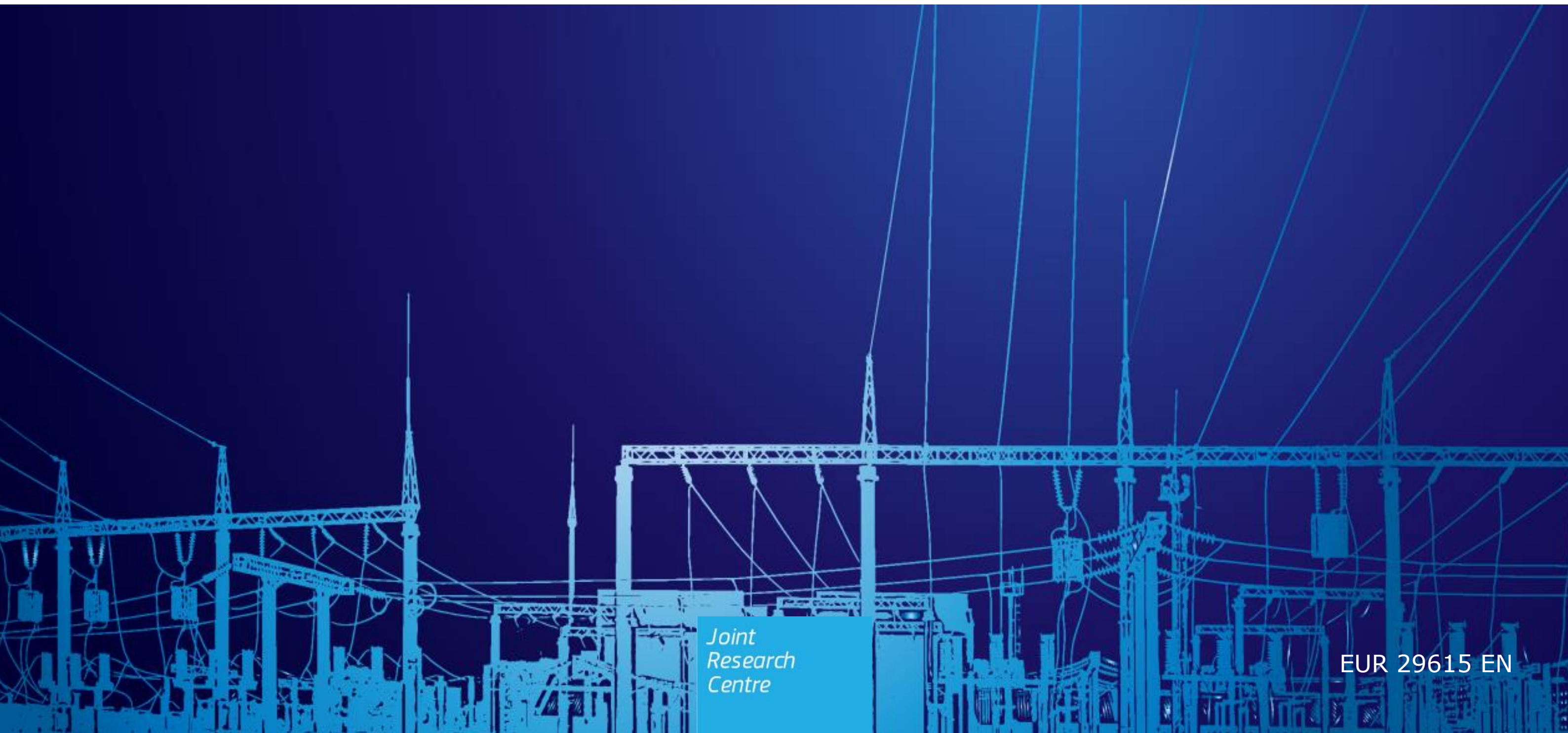

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Distribution System Operators observatory 2018

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Table of Contents

Abstract

The distribution system is a key part of the electricity chain. It links bulk production with end consumers. Recently, radical changes have taken place in every segment of the power industry. These are calling for a changing role of the Distribution System Operators (DSOs) in Europe. This report provides a clear picture of the features of distribution grids in Europe, on the way they are operated and how far DSOs are from the paved provisions proposed in the recent Electricity Directive of the European Commission.

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- Distribuidora Eléctrica del Puerto de la Cruz SA
- E-Distributie Banat S.A.
- E-Distributie Dobrogea S.A.
- E-Distributie Muntenia S.A.
- E-Distribuzione SpA
- E.DIS AG
- E.ON Dél-dunántúli Áramhálózati Zrt.
- E.ON Elnät Sverige AB
- E.ON Tiszántúli Áramhálózati Zrt.
- E.ON Észak-dunántúli Áramhálózati Zrt.
- EDP Distribuição
- Energis-Netzgesellschaft Düsseldorf mbH
- ELECTRICITY AUTHORITY OF CYPRUS
- ENDESA DISTRIBUCIÓN ELÉCTRICA
- ENERGA - OPERATOR SA
- ENSO NETZ GmbH
- ESB Networks DAC
- EVN Bulgaria Elektrorazpredelenie EAD
- EWE NETZ GmbH
- Eandis CVBA
- Eastern Power Networks Plc

- Electricity North West Limited
- Elektrilevi OÜ
- Elenia Oy
- Elmu Network Ltd.
- Émász network Ltd.
- Enea Operator Sp. z o.o.
- Enedis
- EnergiMidt Net A/S
- Energienetze Mittelrhein GmbH & Co. KG
- Energienetze Steiermark GmbH
- Enexis Netbeheer
- HEDNO SA
- HEP - Operator distribucijskog sustava d.o.o.
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- Kraftringen Nät AB
- Kymenlaakson Sähköverkko Oy
- LEW Verteilnetz GmbH
- Liander NV
- London Power Networks Plc
- MDN Main-Donau Netzgesellschaft mbH
- Mälarenergi Elnät AB
- NKM Power Network Distribution LTD
- NRM Netzdienste Rhein-Main GmbH
- Netz Burgenland GmbH
- Netz Niederösterreich GmbH
- Netze Augsburg GmbH
- Netze BW GmbH
- ORES Assets
- Orkuveita Reykjavikur – Reykjavik
- Oulun Energia Siirto ja Jakelu Oy
- Ovag Netz AG
- PGE Dystrybucja Spólka Akcyjna

- PREdistribuce,a.s.
- Pfalzwerke Netz AG
- SET Distribuzione
- SODO Sistemski operater distribucijskega omrežja z elektricno energijo, d.o.o.
- SP Distribution plc
- SP Manweb plc
- Schleswig-Holstein Netz AG
- South Eastern Power Networks Plc
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Authors

Giuseppe Prettico, Marco Giacomo Flammini, Nikoleta Andreadou, Silvia Vitiello, Gianluca Fulli and Marcelo Masera.

Executive Summary

This report presents an extended review of the situation of the European electricity Distribution System Operators after the first exercise undertaken in 2016. The report is based on information directly supplied by 99[1] (out of 191) DSOs serving more than 100,000 customers, and focuses on the technical and regulatory changes affecting them. In recent years, in fact, renewable energy sources (RES) have been widely installed in Europe, encouraged by inviting financial schemes put in place in several Member States. Policies and incentives were tailored somehow to increase the percentage of renewable production according to the European targets and especially to foster the emerging *"renewables"* market in terms of technological maturity, innovation and *"green"* jobs. This increase of RES connections has found however the distribution systems in certain Member States unprepared: distribution systems were in fact conceived more than half a century ago with the main scope of passively dispense electricity from the transmission grid to the final consumers. Due to it, distribution grids were usually oversized in terms of transfer capacity and not really automated nor digitalised. The *"fit and forget"* approach, adopted to connect new consumers and generators to the grid, proved however not to be suitable in the emerging scenario characterised by: distributed generators in large extent renewable connected to the distribution grids; moving electric vehicles which request high power peaks to be recharged in a fast manner; and consumers more actively interacting with the system, for instance through their electrical consumption of heating and cooling.

Policy context

In Europe, big differences exist among those grid operators, known as Distribution System Operators (DSOs), in charge of operating, maintaining and developing the distribution network to ensure that electricity is delivered to end-users in a secure, reliable and efficient manner. The Electricity Directive[2] (e-Directive) and the Electricity Regulation[3] (e-Regulation) proposals of the European Commission (which constitute a key part of the *Clean Energy for All Europeans Package*) take into serious account the changing role of the DSOs in Europe. Despite being an important step towards an overall improvement of the electricity market, these provisions might be proven as too general due to the simplistic separation of DSOs into only two main classes: those serving more than 100,000 customers and those serving less than 100,000 customers[4].

Objective of the report

The scope of this report is twofold. Firstly, it aims at updating and upgrading the distribution grid techno-economic data, which were collected in the first release of the DSOs Observatory, in 2016, through an on-line questionnaire directly filled by DSOs' representatives. In this second release in fact we expanded the available sample, having collected information from a wider pool of European DSOs representing a larger part of the European networks. Secondly, a new section about smart grid and digitalisation dimensions targeted by DSOs has been introduced in the new survey. This information has helped us to benchmark the European grids current status against the changes put forward by the e-Directive proposal. Therefore, this second edition offers a more comprehensive picture to stakeholders and policy-makers on the current status of DSOs in view of the forthcoming Clean Energy Package.

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[1] Actually our dataset comprehends the data of 102 DSOs, three of which are not European (two from Norway and one from Island). For this reason we have decided not to include these data in the analysis presented in the current report which is only focussed on the European situation.

[2] Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on common rules for the internal market in electricity

[3] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the internal market for electricity

[4] Subject to the unbundling requirements as indicated by the Directive 2009/72/EC

Key conclusions – Main Findings

Some of the insights emerging from this edition of our DSO Observatory project are:

- Big differences exist in the number, size and governance of the DSOs, even within each Member State. There are key differences in the way DSOs are remunerated through distribution tariffs: in most of the cases, use-of-system charges are based either on energy consumption (volumetric) or on contracted/measured power (capacity based tariffs). European tariffs range from purely volumetric to purely capacity based ones. In the emerging scenario, these differences might play an important role in facilitating or not faster distributed generation integration.
- Distribution average costs vary greatly from country to country in Europe. A detailed picture is provided.
- A restricted number of DSOs has started to put in place Demand Response. However, at the moment some financial benefits seem to be observable only for those consumers which are able to perform heating and cooling consumption shifting on request. Demand Side Management is used by certain DSOs to remotely control hot water boilers and heat pumps to alleviate constrained networks.
- The role of the DSO as a neutral market facilitator is also discussed together with the different data management models that have been planned to be put in place in certain Member States. The proposed models have been listed and briefly discussed.
- The data exchange interface between DSOs and Transmission System Operators (TSOs) has been analysed for its importance in the transition towards a more efficient electricity market and for the expected opportunities potentially offered to consumers. It is noted that currently data sharing and communication take place either frequently (in very few cases in almost real-time) or only in urgent situations, that is, only when mandatory. This intermittence can represent an important barrier towards an overall improvement of the electricity market.
- Network indicators of different nature (network structure and reliability indexes, network design, distributed generation by voltage level) are presented to provide a clear picture of how the distribution grids in place are designed and operated. Having a bigger number of DSOs, the indicators have been updated and can be compared with those in the previous release. Large ranges are observed for some indicators which show the large differences existing among the surveyed DSOs.
- Our assessment confirmed the importance of making available open data on distribution grids without infringing confidentiality clauses. Based on the reported network indicators, we describe a new web-platform on distribution network models (DiNeMo) currently under development in our team. The platform aims at representing a virtual place where representative distribution grids can be directly built, shared and validated by various users and relevant stakeholders. The platform provides representative distribution grids based on DSOs data but do preserve their confidentiality.
- The smart metering roll-out situation has been lastly updated. The unexpected outcome is that in certain MS where the last Cost-Benefit-Analysis (in 2014) proved negative, some DSOs decided to undertake the smart meters roll-out because they consider it as a milestone both for the centralisation of customers and for a better observability of their grid infrastructure.

Related and future JRC work

The Joint Research Centre supports among others policy-making activities in the energy sector. Several data collection exercises, aimed at filling knowledge gaps in the electricity sector evolution, are undertaken periodically. The DSO Observatory is at its second edition. The overall scope is to contribute to depict the development of smart grids in Europe and to provide tools to stakeholders and decision makers in the context of the energy systems digitalization. Several outputs can be related to the current observatory: the Smart Grid Projects Outlook 2017 (which started for the first time in 2011), which provides an overview and a categorisation of the Smart Grids pilot projects deployed in Europe in the last decade; the Cost-benefit analysis of Smart Grid projects (Rome, Isernia), addressing merits and opportunities behind Smart Grid pilot projects scalability; the inventory of Smart Grid Laboratories in Europe and beyond. All of these projects will continue in order to identify and analyse changes and updates in the smart grid realm.

Quick guide

The rest of the report is organized as follows: Chapter 1 presents an introduction to the subject. Chapter 2 provides the state of play of DSOs in Europe, taking into account the unbundling of DSOs and discussing some relevant parts of the electricity Directive in the Clean Energy Package. Chapter 3 presents the main findings of our study and compares them with results in the previous release. Technical indicators are updated due to the higher number of participants in this second collection exercise. Chapter 4 illustrates the smart grid dimension of the distribution networks, in particular by looking at the current stage of DSOs with respect to the foreseen changes (automation, ancillary services, prosumers, DSO-TSO coordination, data facilitation). Chapter 5 concludes the report and highlights future research activities related to the presented topic.

1 Introduction

The Paris Agreement requires countries that have signed it to undertake ambitious efforts to combat climate change and adapt to its effects. The central aim of the agreement is to strengthen the global response to the threat of climate change by keeping the global temperature rise (in this century) below 2 degrees Celsius with respect to pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. To reach these ambitious goals, appropriate financial flows, a new technology framework and an enhanced capacity building framework needs to be put in place (United Nation, 2015).

At European level, after previous legislative initiatives moved by the same end (EU, 2003), the European Council has invited the European Commission (EC) to present by the first quarter of 2019 a proposal for a Strategy for long-term EU greenhouse gas emissions reduction in accordance with the Paris Agreement, taking into account the national plans (Council of the European Union, 2018). Very likely by the same time the eight legislative proposals composing the "Clean Energy Package for All Europeans" (CEP, also known as Winter Package), made by the EC in November 2016, will be finally adopted[5]. The whole package covers different aspects such as: energy efficiency, renewable energy, the design of the electricity market, security of electricity supply and governance rules for the Energy Union (European Commission, 2016). All these measures will play a key role in the electricity sector which is considered one of the main contributors to decarbonise the economy. "*The EC wants the EU to lead the clean energy transition, not only adapt to it. For this reason the EU has committed to cut CO_2 emissions by at least 40% by 2030... The proposals have three main goals: putting energy efficiency first, achieving global leadership in renewable energies and providing a fair deal for consumers*" (European Commission, 2018).

Renewables and distributed generation will thus play a major role in the transition to a clean energy system. Within the CEP, the Renewables Directive for instance enables consumers to self-consume renewable energy without facing undue restrictions, and ensure that they are remunerated for the energy they sell into the grid. This fact represents an important change compared to the past when electricity was produced solely by large-scale, centralised power stations, primarily fired by fossil fuels, supplying passive customers at any time with as much electricity as they wanted in a geographically limited area – typically a Member State (MS). In this case the electricity was injected into the transmission lines at extra high voltage level, then stepped down to high, medium and low voltage in the distribution grid before reaching the majority of customers (residential, commercial, small industrial, etc.).

Nowadays in several MS more than 90% of the renewable distributed generators (which includes also roof-top solar panels) are connected to the distribution grid. In recent years in fact a massive number of renewable energy sources (RES) has been installed in Europe thanks to the advantageous fiscal policies and to the various incentives that have been put in place at national level in the different MS. Those policies and incentives pointed at increasing the percentage of renewable production according to the national set targets and at fostering the emerging market (mainly technology maturity and 'green' jobs). This explosion of RES connections in certain MS has unfortunately found an unprepared distribution system which was conceived to pass-on electricity from the transmission grid to end-consumers, as explained. This has led to fears over the impact that the deployment of distributed resources could have at system-level (e.g. that the costs of upgrading the network to integrate them would outweigh their combined benefits in other terms). Additionally, the present regulatory frameworks existing in the different MS often do not provide very often appropriate tools to distribution system operators (DSOs) to actively manage their networks. Moreover, the regulatory framework for

[5] The Clean Energy Package is actually in the process of being approved at time of this writing.

DSOs, which still in some cases is based on cost-plus regulation[6], does not provide proper incentives for investing in innovative solutions which promote energy efficiency or demand-response and fails to recognise the use of flexibility as an alternative to grid expansion (European Commission, 2016).

Smart grid solutions have been tested and are still being tested in Europe mainly through pilot projects which aim at addressing the arising challenges and at identifying the potential business opportunities which may come with them. Among the stakeholders involved in the pilots, DSOs show highest investments, followed by universities and technology manufacturers. For most of the categories, private financing is the main source of financing. For DSOs in particular, above 70% of investments are private, which in certain cases includes funding allocated through regulatory incentive schemes (F. Gangale, J. Vasiljevska, F. Covrig, A. Mengolini, G. Fulli, 2017) .

Indeed, identifying the best solutions for a more efficient working of the system as a whole requires a deep understanding of the impact of the different options on the distribution networks. Technical and economic assessments of alternative investments to grid expansion require a detailed knowledge of the networks and of the context in which they are operated. Such knowledge is also necessary to evaluate the viability of replicating and scaling up pilot experiences already successfully implemented in Europe (G. Prettico, F. Gangale, A. Mengolini, A. Lucas, G. Fulli, 2016).

Moreover DSOs and their future role are at the centre of a twofold debate which concerns the data protection of end-user and the improvement of data exchange, hence a better coordination, with Transmission System Operators (TSOs).

With respect to the first point, as made clear in the CEP, the real drivers of the energy transition will be consumers. New technologies like smart meters, smart homes, smart grids, increasingly competitive roof-top solar panels and battery storage solutions make it possible for energy consumers to become the new active players of the electricity market. Smart metering systems are believed to be the "right tools" for consumer empowerment, as they allow users to make decisions about their energy consumption by reacting to future real-time tariffs. The proper functioning of smart meters requires that a significant amount of sensing data will be collected and processed by eligible parties and made available to entitled stakeholders. This generates data protection challenges and creates new risks for the data subjects with a potential impact in areas (e.g. price discrimination, profiling, household security) previously absent in the energy sector. While the General Data Protection Regulation (GDPR) provides the general legal framework for ensuring privacy and data protection of final consumers in the context of the smart meters' roll-out, the Commission's proposal for a recast of the Electricity Directive (which is part of the CEP package and specifically regulates smart meters' deployment) includes detailed provisions to ensure that data protection issues are properly tackled (A. Fratini, G. Pizza, 2018).

With respect to the second point, to solve the arising challenges (e.g. congestion management and voltage control on their grids) in a cost-efficient way, both DSOs and TSOs will have to rely on a common set of supply and demand side resources. These kinds of resources may be offered through a market-based approach by emerging actors, as the aggregators. Ensuring coordinated access between DSOs and TSOs to this limited pool of assets is an essential ingredient for enabling them to fulfil their missions by minimising societal cost and maximising sustainability and security of supply of the power system (G. de Jong, O. Franz, P. Hermans, M. Lallemand, 2015).

[6] Under cost-plus regulation a company may have an incentive to signal incorrect costs to the regulator or to even opt for wasting resources in order to increase the cost base ("gold-plating") (CEER, 2017)

2 State of play of DSOs in Europe

2.1 Unbundling of DSOs and differences between Member States

The distribution system is a valuable part of the electricity chain, since it links bulk production with the end consumers. Traditionally, the European electricity sector was dominated by vertically integrated monopolies that were either state-owned or privately-owned. The primary components of the electricity system - generation, transmission, distribution, and supply – were therefore integrated within individual electric utilities.

The electricity system has seen radical changes within the last decades, which inevitably impacted all the components of the chain. Electricity markets were opened to competition in a gradual way during the 1990s in the European Member States. The goal was to accomplish competitive prices and establish a unified energy market (J. Glachant, J. Vasconcelos, V. Rious, 2015). The different parts of the electricity chain were divided in competitive and non-competitive ones, with the former category comprising of the generation and supply and the latter from the transmission and distribution networks. The distribution and transmission networks were classified as non-competitive, since they are considered a natural monopoly, and building alternative networks is in fact an extremely costly activity.

The Directive 2009/72/EC defined the EU electricity market legislation. According to it, unbundling requirements were introduced, which obliged Member States to ensure the separation of vertically integrated energy companies. The Directive divided the various stages of energy supply into generation, transmission, distribution and retail. Generation and retail were open to liberalization as competitive activities, whereas transmission and distribution were subject to regulatory control and were exempted from competition. As stated in this directive, the reasoning behind the new rules was 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*'. In addition, it is stated that for the distribution segment, the 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.

According to functional unbundling, the network 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 (DG Energy & Transport, 2014). 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 (S. Ropenus, S. Scroder, H. Jacobsen, L. Olmos, T. Gomez, R. Cossent, 2009).

These requirements were set as non-obligatory for the Distribution System Operators serving fewer than 100,000 customers or small isolated systems. Although, considering that more than 90% of the 2,400 European DSOs are beneath this limit, the number of DSOs serving more than 100,000 customers is considerable and the overall consumers served by them cover more than 70% of the European population. Table 1 shows the total number of DSOs in each country and those serving more than 100,000 customers (Eurelectric, 2013). As shown, there is huge diversity regarding the number of DSOs in each MS. Whereas some countries have only one (e.g. Ireland, Lithuania) or a few (e.g. Slovakia, Bulgaria, Hungary) DSOs, countries like France, Poland or Germany with more than 150, 180 and 800 distribution companies, respectively, have a sector structure being shaped by the presence of many small-scale DSOs supplying a relatively small area with a limited number of connected customers.

Table 1. DSOs number per Country[7] (Eurelectric, 2013),

Country	Total number of DSOs (2013)	DSOs > 100,000 customers
Austria	138	13
Belgium	24	15
Bulgaria	4	3
Croatia	n/a	1*
Cyprus	1	1
Czech Republic	3	3
Denmark	72	6
Estonia	n/a	1
Finland	n/a	7
France	158	5
Germany	880	75
Greece	n/a	1
Hungary	6	6
Ireland	1	1
Italy	144	3
Latvia	11	1
Lithuania	1	1
Luxembourg	6	1
Malta	n/a	1*
Netherlands	11	8
Poland	184	8
Portugal	13	3
Romania	n/a	8
Slovakia	3	3
Slovenia	n/a	1
Spain	n/a	5
Sweden	173	6
United Kingdom	7	7

(Eurelectric, 2013)

The extent of the unbundling also changes from country to country, with the more extensive form of separation, i.e. ownership unbundling, being adopted only in a minority

[7] Data for Malta and Croatia were not reported

of cases. Some concerns have however been raised in a study on the costs and benefits of ownership unbundling in the Netherlands (M. Mulder, V. Shestalova, 2006). The authors conclude that the net effect on welfare of ownership unbundling is ambiguous: a part from the major benefit of this measure that enables the privatisation of commercial activities while keeping the infrastructure in public hands; ownership unbundling reduces economies of scope, creates one-off transaction costs, and may also affect investments in generation by the currently vertically integrated Dutch utility holdings. Traditionally DSOs' role is to operate, maintain and develop the distribution network to ensure that electricity is delivered to end-users in a secure, reliable and efficient manner. Nowadays, the role of the DSO is broader and varies among countries due to their heterogeneity (Table 1) and differences in national regulation.

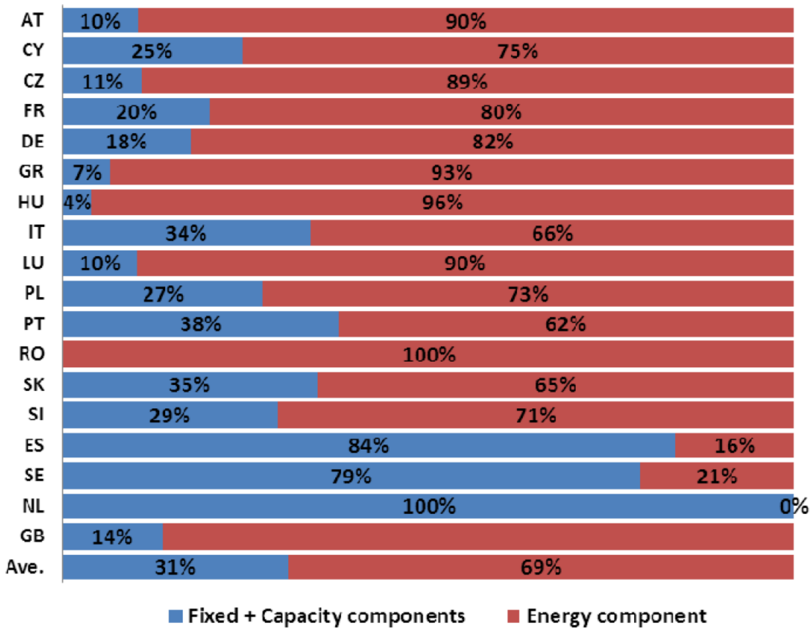
Being a regulated monopoly, the distributor, is allowed by the regulator to earn certain revenues during the regulatory period (usually corresponding to 4 or 5 years). The company receives this remuneration from the rates charged to end consumers. Costs are recovered under what are known as distribution charges. These charges are either a component of the integral tariff paid by regulated consumers, i.e. those who still buy their electric power at regulated rates, or form a part of the access tariff paid by non-regulated consumers for network services. Regulated charges should reflect the cost incurred to provide the consumer with the service but also ensure full recovery of the distributor’s total acknowledged costs.

Regulated distribution charges are typically structured as follows (Ignacio J. Pérez-Arriaga , 2013).

- The connection charge is a one-off charge, for a new grid connection or an extension of the existing grid;
- The use-of-system charge is typically paid periodically (monthly or bi-monthly) and, in general, it may include a component proportional to the energy demand (energy component in Euros/kWh) and another somehow proportional to the load contribution to the peak demand, or to the contracted demand, when this exists (capacity component in Euros/kW-month). This use-of-system charge is intended to recover the reminder (i.e., not included in the connection charges) of the distribution grid costs;
- The customer charge is typically paid periodically (monthly or bi-monthly, in Euros/month, depending on each type of consumer) and is designed to recover costs associated with consumer management and support. In some cases, this charge is incorporated as a use-of-system charge and is, therefore, not paid separately.

Looking at the European situation, in the majority of cases, use-of-system charges are based either on energy consumption (volumetric) or on contracted/measured power (capacity based tariffs). Even though, often the final customers' tariffs include both elements. From the end-users' side, volumetric tariffs are of a more immediate comprehension and promote energy efficiency: if they reduce their electricity demand, being the tariff proportional to it, the latter will be reduced as well. From the DSOs' side, grid costs are mainly driven by the peak energy flows which determine the necessary installed capacity and not from the amount of the distributed energy which is more related to the losses in the grid. Currently, the majority of DSO revenues are collected through volumetric tariffs, i.e. 69% of the revenue from household consumers, 54% for small industrial consumers and 58% for large industrial consumers. The rest is then collected through a capacity and/or fixed component in a two-part-tariff (Konstantinos Stamatis, 2016). Focusing on households, their distribution tariff picture is depicted per each MS in Figure 1.

Figure 1. Distribution Tariff component weight in Households

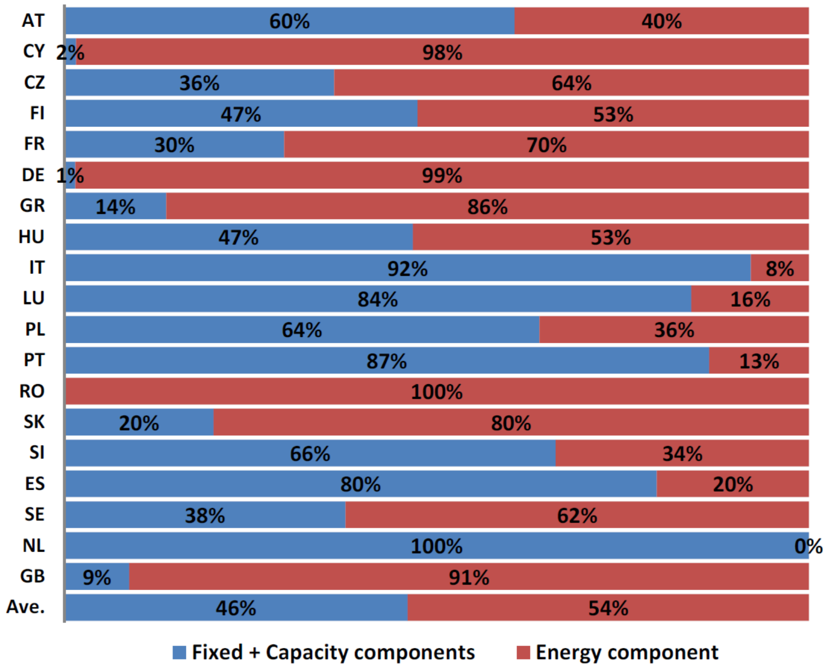


(Refe, Mercados, Indra, 2015)

As shown in the figure, a great variety exists at the moment, with two MS, the Netherlands and Romania, having a completely opposite strategy in place, with 100% capacity tariff and 100% volumetric tariff, respectively.

Some differences in the distribution tariffs can be observed for several MS when small industrial consumers are analysed, as shown in Figure 2.

Figure 2. Distribution Tariff component weight in Small Industrial



(Refe, Mercados, Indra, 2015)

Given the higher power requests which small industrial customers generally require to the distribution grid, when compared with households, tariffs seem more oriented towards capacity in this case. Only three MS (Spain, Sweden and the Netherlands) have a capacity and/or fixed component that weighs over 50% of DSO tariff for households' consumers. In contrast there are eight which have a capacity and/or fixed component that weighs over 50% of DSO tariff for the small industrial consumers. It is remarkable the case of the Netherlands which is the only EU country that applies a 100% capacity based tariff for small industrial consumers. On the contrary, Romania applies a 100% volumetric tariff for these customers. In the future with the expected rise of almost self-sufficient prosumers, purely volumetric distribution tariffs might not be cost reflective. As stressed in (Konstantinos Stamatis, 2016), even in the best case of a self-sufficient consumer scenario the need to use the grid for few hours a year, could impact the grid capacity in the same way (peak times) thereby imposing nearly the same costs as regular consumers. Additionally given the smaller volumes of energy flowing into the grid in such scenarios volumetric tariffs might be not cost-effective for DSOs anymore.

It is worth recalling that finding an optimum balance between costs associated with investment, operation, maintenance, energy losses and quality of service provided is at the core of the distributors business. The costs that the distribution companies face are grouped as follows (Ignacio J. Pérez-Arriaga , 2013)

- Grid infrastructure investment costs;
- Substations and electric power lines;
- Facilities and switching equipment: circuit breakers, protection relays, metering and monitoring devices and communications infrastructure;
- Operating and maintenance costs;
- Dispatching centres;
- Maintenance crews;
- Apprenticeship and continuing education courses;
- Other costs related to customer services and other corporate costs.

Additionally, distribution companies should reduce energy losses in the grid, and for this reason they must be incentivised to reduce them.

It might be interesting in this context to look at the distribution of network costs in each country. Figure 3 (ACER & CEER, 2016) shows the breakdown of the final price, based on a standard electricity offer (3,500 kWh), available in each European capital city. Moreover, it shows that the composition of the final electricity bill for household consumers varies greatly across Member States. For instance, in the case of Italy and France, in terms of absolute number compared to the total cost of the electricity bill, the distribution network costs corresponds to 16% and to 29% (119 € and 174 € on average per year), respectively. In Germany they account for 236 € a year (the third highest in Europe after Luxembourg and Portugal). Figure 4 shows a sorted view of the distribution network costs in percentage on the total bill per each country. The orange line indicates instead their value in absolute terms (euros). Understanding the main reasons behind these differences is not straightforward given the existing diversity of distribution grids in Europe, their size and position, their operation, the levels of distributed generation connected to it, the investments to actively manage them, to cite a few.

Figure 3. Electricity breakdown costs of the bill for household consumer (3,500 kWh per year)

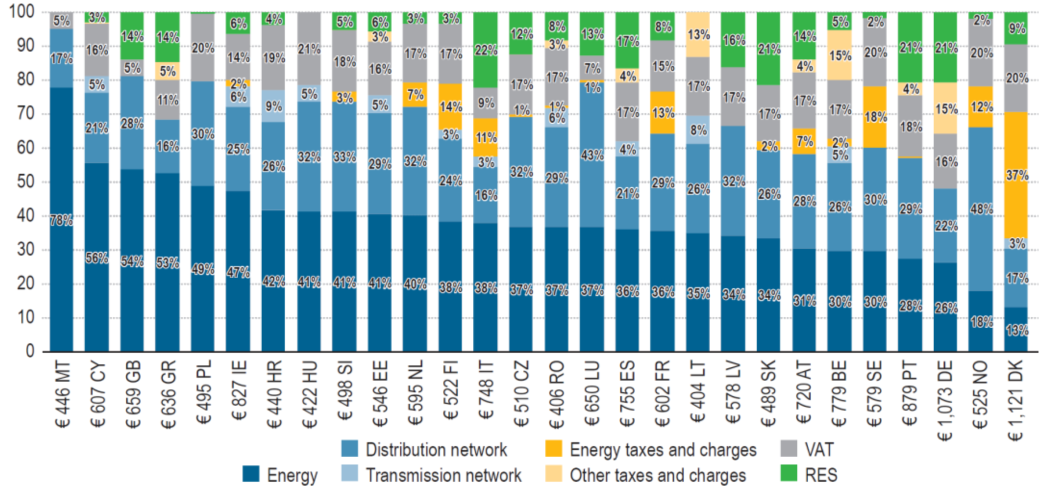
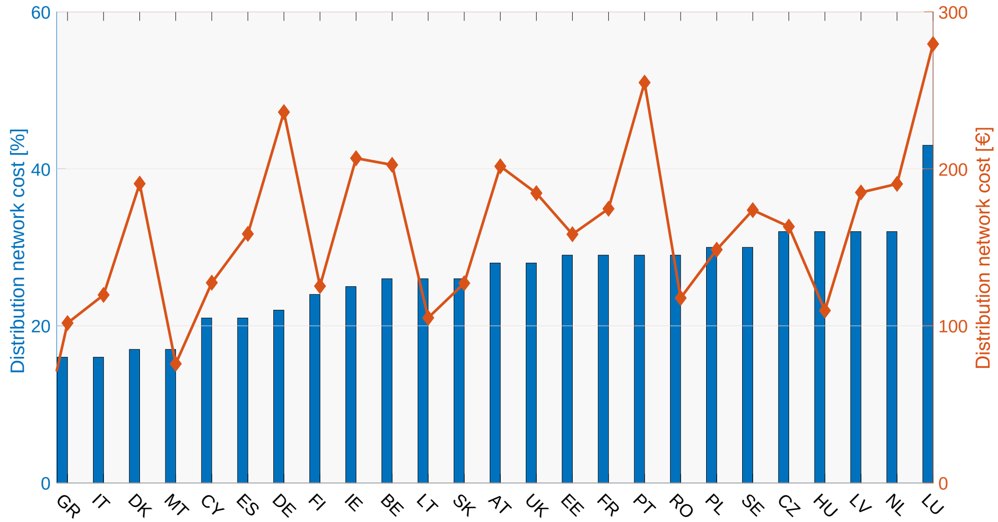


Figure 4. Distribution network cost related to the total cost in percentage (left) and in Euro (right)



2.2 New tasks for DSOs according to the Clean Energy Package

DSOs are nowadays asked to cope up with the big changes that are emerging in the electricity sector (as the increasing production from intermittent renewable energy sources, the effective integration of electric vehicles and of demand side flexibility, the changing role of future consumers). These changes are recognized and addressed in the Electricity Directive (e-Directive) and the Electricity Regulation (e-Regulation) proposals that the European Commission has presented to the European Parliament and to the Council in November 2016 (European Commission, 2016). The two proposals are part of the eight legislative initiatives which compose the Clean Energy Package (CEP). The following sections aim at providing the main insights of these two proposals focusing on the reality that DSOs need to handle and with a special focus on the duties they will need to carry out.

2.2.1 New rules for the internal electricity market

The Directive states for the internal electricity market the following:

> *The Directive* (European Commission, 2016) *establishes common rules for the generation, transmission, distribution, storage and supply of electricity, together with consumer protection provisions, with a view to creating truly integrated competitive, consumer-centred and flexible electricity markets in the [European] Union. Using the advantages of an integrated market, the Directive aims at ensuring affordable energy prices for consumers, a high degree of security of supply and a smooth transition towards a decarbonised energy system. It lays down key rules relating to the organisation and functioning of the European electricity sector, in particular rules on consumer empowerment and protection, on open access to the integrated market, on third party access to transmission and distribution infrastructure, unbundling rules, and on independent national energy regulators.*

The Directive aims at enhancing current market rules in order to create a level-playing field among all generation technologies and resources by removing existing market distortions. It addresses rules that discriminate between resources and which limit or favour the access of certain technologies to the electricity grid. Additionally, it stresses that all market participants will bear financial responsibility for imbalances caused on the grid and all resources will be remunerated in the market on equal terms. It also aims at strengthening short-term markets by bringing them closer to real-time in order to provide maximum opportunity to meet flexibility needs and to have more efficient balancing markets. Measures are included that would help pulling all flexible distributed resources concerning generation, demand and storage, into the market via proper incentives and a market framework better adapted to them and measures to better incentivise DSOs

With respect to the latter, it states that unbundling systems should be such so as to eliminate any conflict of interest between producers, suppliers and transmission system operators. This way, the introduction of new actors in the market is facilitated and motives for new investments are created.

At the Member States level, initiatives should be undertaken to facilitate the grid modernization and its transition into the smart grid. In addition, the European energy networks should be promoted; meaning that physical interconnection between neighbouring countries should take place.

2.2.2 Specific tasks for the DSOs

The Directive specifies particular duties of the DSOs with respect to the emerging scene. DSOs to manage some of the challenges associated with intermittent renewable generation more local, for instance, by letting them manage local flexibility resources, could significantly reduce network costs. However, since many DSOs are part of vertically integrated companies which are also active in the supply business, regulatory safeguards are necessary to guarantee the DSOs' neutrality in their new functions, e.g. in terms of data management and when using flexibility to manage local congestions. Access to the necessary data from the new actors is also a task that DSOs need to deal with. DSOs should also have a network development plan which should be updated every two years and should entail the utilization of demand response and storage resources. This duty is not mandatory for DSOs serving less than 100,000 customers.

In particular, regarding electric vehicles (EV), it is defined that DSOs are not allowed to own or manage recharging points, and this is reflected in the survey in chapter 4.5. They can own such points only under specific requisites, i.e. when other parties cannot be granted for the operation of charging points after an open and transparent competition. In case DSOs manage and own charging points, they must not favour particular system users. On the contrary, if they do not own the charging points they must cooperate with those that own them.

Regarding storage facilities, equivalently with EV charging points, the DSOs are not allowed to own or manage energy storage facilities. The exception is when such storage items are used for the secure operation of the grid and they are not used as means of buying or selling electricity to the market. Similarly to the charging points for electric vehicles, DSOs can own a storage facility if no other party is granted for the operation of it after an open and transparent competition.

The DSOs are also requested to collaborate with TSOs and facilitate the participation of the various actors in the market at retail, wholesale and balancing level. In addition, products and services for the secure grid operation should be a result of DSO – TSO collaboration.

The importance of data protection is also highlighted in the Directive. Security and privacy play a big role towards this direction. A duty that Member States have is to guarantee that all actors have access to the correct data. The DSOs on the other hand should maintain confidentiality of the data revealed during data processing (Council of the European Union, 2017).

2.2.3 Consumers at the core of the energy system

As mentioned earlier, special focus is given on the consumers' involvement in the energy market and on their active participation. As made clear in the whole CEP, they are the real drivers of the energy transition. New opportunities for consumers, who should be informed about their rights in terms of real-time energy consumption, tariffs, etc., can encourage them to adjust their consumptions and thus be an active part of the market. To this aim, comparison tools should be available for customers in order for them to be informed about offers and prices. Moreover, better comprehensive bills can help on this matter as well. Participation of consumers in Demand Response (DR) needs to be facilitated. To this scope, customers need to receive all necessary data that they request for free. For adjusting their consumptions, end consumers should be granted with a smart meter and even though smart metering roll-out does not take place in their MS, they should be able to have one when they request it. In general it is assumed that smart metering roll-out is based on economic evaluation(s), as explained later in section 4.4.1, and in the case in which the roll-out takes place this is supposed to be done according to European standards. Smart meters should facilitate consumers in changing their consumption patterns and offering their flexibility. It is also important that interoperability is a reality with respect to smart meters, which can enable supplier switching, when indicated by the customers. Interoperability[8] is also of great importance for a common data format and for enabling the assessment of meter data.

[8] The JRC in Ispra (Italy) has one of the most modern laboratories to test interoperability in the smart grids sector.

In the next chapters we try to connect the highlighted points in the e-Directive with the current situation at the DSOs level. Namely, we aim at showing how close or far they are from the paved changes to be implemented in the near future. Our analysis is built on the data that we have collected directly from the DSOs in Europe, in our second DSO Observatory survey, and complemented with pertinent studies and report opportunely cited.

3 DSOs Observatory

The European electricity sector is undergoing radical changes in every segment of the power industry, from generation to supply. The clean energy package proposal from the European Commission to the European Parliament and to the Council, as previously described, is setting ambitious goals to enhance competitiveness, to ensure security of supply and to build a more sustainable and efficient EU's energy system.

As known the energy chain deeply relies on the transmission and distribution infrastructure to deliver energy to the final customers. While for the former a consolidated knowledge is available and high levels of automation are put in place, the latter is 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*. Its aim was to contribute to a better understanding of the challenges that the transition to a new energy system is currently posing to European distribution system operators and to elaborate sound solutions to address them.

Following the great achievement and positive feedback received on the first DSO Observatory release (G. Prettico, F. Gangale, A. Mengolini, A. Lucas, G. Fulli, 2016), which focused on the collection of technical and structural data from the DSOs, a second DSO Observatory survey has been launched. The second release moved from a purely technical analysis to a more policy oriented analysis, in order to provide a broader overview of the current DSOs transformation.

Box 1. Main findings of the DSO Observatory 2016[9]

Of the 190 Distribution System Operators (in 2016) serving more than 100,000 customers, 79 responded to the JRC survey. Based upon the collected data, the main achievements obtained were:

- ✓ 36 distribution system indicators were built.
- ✓ 13 representative distribution networks with different voltage levels were built.
- ✓ 4 scenarios analysing the impact of increasing levels of renewables in terms of voltage unbalances and penalty cost functions were tested on two large scale representative networks (urban and rural).
- ✓ A reliability analysis of the System Average Interruption Frequency Index was shown as well. European DSOs Overview.

In Europe, there are 2,400 electricity distribution companies which deliver a total of 2,700 TWh a year to 260 million connected customers, 99% of which are residential customers and small businesses. The total power lines length of all DSOs is around 10 million km, which are connected to the transmission system through 10,700 interconnection points. Furthermore, there are more than 4 million distribution transformers in the whole Europe which reduce the voltage levels (Eurelectric, 2013) to high, medium and low voltage.

The DSO Observatory focuses on the largest DSOs in Europe, those serving more than 100,000 customers, and which are subject to the unbundling requirements indicated by the Directive 2009/72/EC. Our database gathers data from 99 out of the 191[10] larger DSOs. Although, in terms of DSOs number the survey coverage is slightly below 54%, these DSOs distribute almost 2,260 TWh (84% of total) per year of electricity to around 220 million customers (85% of total). The electricity is distributed across a total area of

[9] DSO - 2016: https://ses.jrc.ec.europa.eu/distribution-system-operators-observatory

[10] The first DSO Observatory survey received feedback from 79 DSOs. The new version collected 65 DSOs answers, which provided also several question regarding the smart grid dimension which were not present in the first DSO survey. For this reason, in this report the technical data presented combine the results of the 2 DSOs editions reaching 99 different DSOs. The smart grid dimension results are applied only to the 65 DSOs answering the latest DSO survey.

3.4 million km^2 through 8.6 million km of power lines. The results presented in this report therefore provide a fairly good representation of the reality of big DSOs in Europe.

3.1 Structure of the new DSO Observatory Report

This report can be seen as the follow-up of a periodic mapping and modelling exercise, which the JRC aims to continue with the support of the relevant electricity system stakeholders, in order to contribute to a better understanding of the challenges, the options and the impact that different policies might have on the electricity system transition.

As mentioned earlier in recent years the energy sector has experienced a deep transformative change. New challenges have in fact emerged including the rising of distributed energy resources (more than 90% of which installed at DSO level), the smart meters deployment, the integration and first planning of the electric vehicle recharging infrastructure, the need to protect customer data, the potential role of demand side management and the coordination between DSO - TSO (ACER, 2014).

These challenges have called for a pressing need to smarten the electricity grids, while keeping a reliable and safe matching of supply and demand. To cope with this development, distribution system operators are supposed to transform several functions and activities which have been absent or limited so far. The fit and forget approach is in fact not an option anymore and DSOs are pushed to take a more active role in the emerging scenario.

To this aim, the new DSO Observatory version, besides updating the technical aspects with more information, attempts to provide insights about the smart grid dimension of DSOs. In this chapter a general view of the DSO sample is reported, together with their technical features as listed hereby:

- **General and Technical Data**:
    - Customers served per voltage level;
    - DSO network length per voltage level;
    - Substations (capacity, number, etc.);
    - Reliability of the DSO network;
    - Electric mobility;
    - Distributed generation per voltage level.

In the next chapter we address instead what we define the Smart Grid dimension of DSOs: a list of features that DSOs should have or cope with, as anticipated in the CEP e-Directive. They are reported in the following:

- **Smart Grid Dimension:**
    - Demand Response programs;
    - Demand Side Management or Flexibility programs;
    - Remote control of substations;
    - DSO – TSO data management.

Additionally, the status of the DSOs with respect to the smart meters roll-out is provided. This information is then compared with that relative to the country in which the DSO operates. The information is categorized according to the cost-benefit analysis and its result (positive, negative, and non-available). The degree of automation and remote control in HV and MV substation is also presented as well as the situation with the electric vehicles charging points. A link is then established with the mentioned e-Directive. It is in fact crucial to understand what DSOs have already implemented with respect to the provisions in the Directive and how far they are from the set goals.

Before the results are shown, a general overview of the sample data is provided in chapter 3.2 by clustering DSOs in terms of connected customers, yearly distributed energy and market share of DSOs in their country chapter 3.2. After that, the technical part and the construction of the DSOs indicators is analysed in chapter 3.3. Later on the smart grid dimension is presented in chapter 4.

3.2 DSO new release results

Some useful figures are provided in the following based on our data collection. Table 2 summarizes the number of DSOs covered per country by our dataset with respect to the total number of DSOs active in that MS. Additionally the total number of customers served by them in each country expressed as a percentage of the total number of the customers covered by the large DSOs is also shown. In terms of coverage of the DSOs population, apart from Malta, data from at least one large DSO for each country has been gathered. Moreover, for 16 countries there is a complete coverage of all DSOs serving more than 100,000 customers. As mentioned, together, 99 DSOs cover on average 82.73% of the total customers connected to the European distribution grid and served by the large DSOs. For this reason, the survey can be considered a good representation of the current DSOs situation in Europe. Among the 28 Member States the average number of large DSOs per country is 6.8 with a median equal to 3. The "outliers" with a higher number of large DSOs are Germany which counts 75 large DSOs, and Austria and Belgium with 13 and 15, respectively. In comparison with the previous DSO observatory release, this contains data from a higher number of DSOs (99 instead of 79) that cover a larger amount of customers (84.6% instead of 74.8%), meaning that we have an increase in the total customers covered corresponding to +9.8%.

Table 2. Number of DSOs and customers covered per Country by the 2018 DSO Observatory

Country	Number of DSOs	Customers covered
Austria	4/13	27.9%
Belgium	2/15	77.0%
Bulgaria	1/3	34.3%
Croatia	1/1	100%
Cyprus	1/1	100%
Czech Republic	3/3	100%
Denmark	3/6	41.2%
Estonia	1/1	100%
Finland	7/7	100%
France	1/5	96.0%
Germany	31/75	49.7%
Greece	1/1	100%
Hungary	6/6	100%
Ireland	1/1	100%
Italy	3/3	100%
Latvia	1/1	100%
Lithuania	1/1	100%

Luxembourg	1/1	100%
Malta	0/1	0%
Netherlands	3/8	73.3%
Poland	5/5	100%
Portugal	1/3	99.0%
Romania	3/8	95.5%
Slovakia	2/3	73.3%
Slovenia	1/1	100%
Spain	5/5	100%
Sweden	5/6	78.5%
United Kingdom	5/7	70.7%
Total	99/191	82.73%

Figure 5 illustrates the distribution of connected customers served by the 99 DSOs considered. It can be noticed that more than half of the DSOs serve between 400,000 and 4 million customers. The situation has been similar also in the previous survey release; however, in this version, the number of DSOs serving a relatively small number of customers (150,000) has increased from around 6% to around 13% of the total number of DSOs. Furthermore, the biggest DSOs in Europe, in terms of connected customers, are *e-Distribuzione* (Italy) and *ENEDIS (ex ERDF, France)* which manage each more than 30 million connection points.

Figure 5. Distribution of connected customers

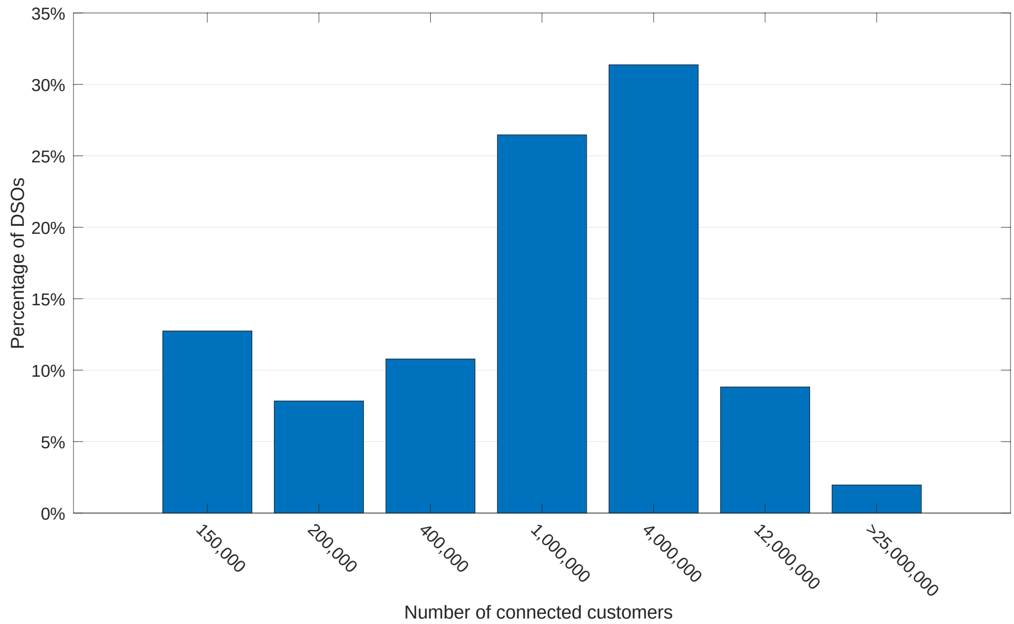


Figure **6** separates the DSOs with respect to the amount of energy supplied per year. In this case, more than 60% of the DSOs distribute between 3,000 and up to 60,000 GWh per year to their final customers. This situation was similar to the one depicted in the previous release. Once again, Italy and France can be considered as "outliers" due to the fact that they cover (each) more than 95% of their national distribution grid.

Figure 6. Distribution of yearly distributed energy

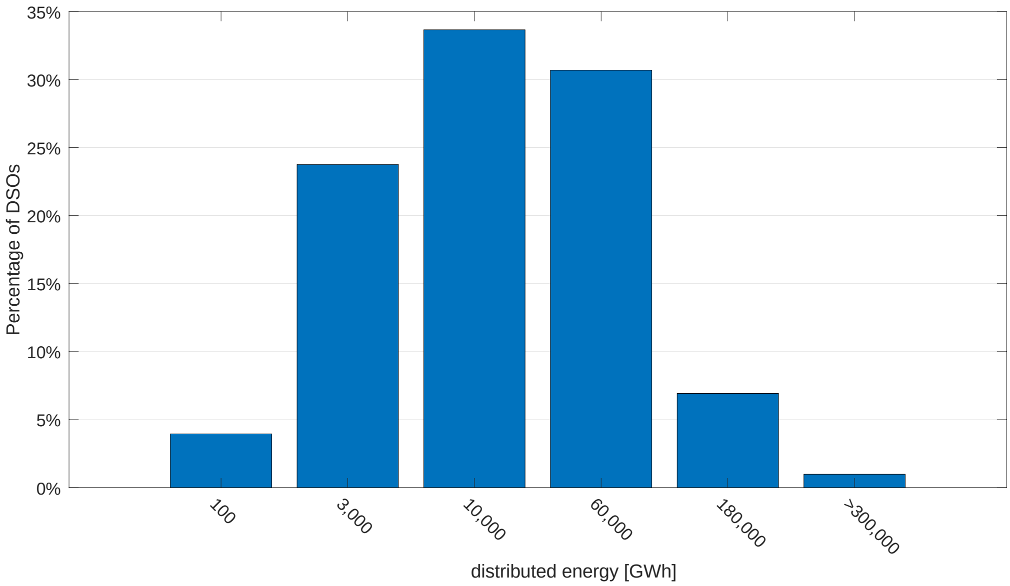


Figure 7 shows the yearly energy distributed by the largest DSO in each MS, as obtained from our dataset. Once again, Italy and France can be considered as an exception, because *e-Distribuzione* and *ENEDIS* deliver more than 180 TWh each per year.

Figure 7. Energy coverage by the largest DSO in each MS (in MWh)

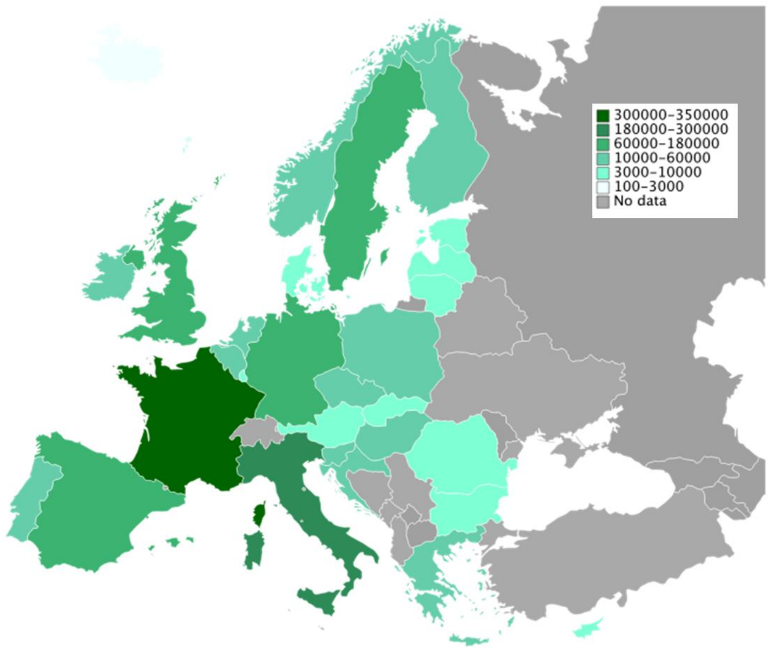
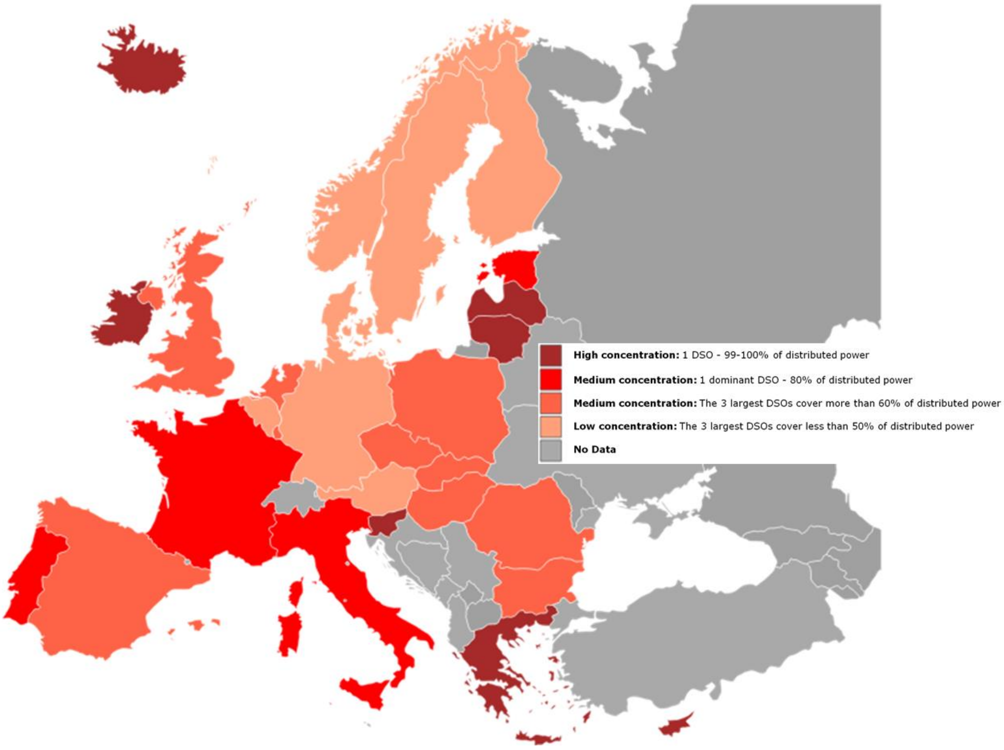


Figure 8 graphically highlights the concentration of the DSOs for each country. This categorisation follows that used in (Eurelectric, 2013) and it is based only on the DSOs data present in our dataset. It is remarkable to observe that in 9 MS out of 28, the largest DSO is distributing more than 80% of the yearly energy distributed.

Figure 8. The number and size of DSOs varies significantly across European countries



3.3 DSOs indicators

Through the technical data section, obtained from the 99 DSOs responses, it was possible to build 37 indicators. These indicators have been devised in such a way to allow for comparative analysis of the DSOs[11]. They can be summarized in three main categories:

- Network structure and reliability indicators (Table 3)
- Network design (Table 4)
- Distributed generation (Table 5)

The **network structure** and **reliability indicators** data, in Table 3, covers DSO's inputs referring to the main parameters, such as: number of connected customers, area of supply, distributed annual energy, and metrics at each voltage level concerning substations (capacity, consumers connected) and network (area, supply points, etc.). Furthermore, data regarding circuit length, underground and overhead, at each voltage level have been gathered. Finally, SAIDI and SAIFI indicators for long unplanned interruptions are analysed at urban, semi-urban and rural levels.

[11] The method used to build the indicators is the same used in the previous release of the DSOs Observatory (G. Prettico, F. Gangale, A. Mengolini, A. Lucas, G. Fulli, 2016).

Table 3. Network structure and reliability indicators

Network structure and reliability indicators
1. Metrics associated to LV network
LV consumers per area
LV circuit length per LV consumer
LV circuit length per area of distribution
LV underground and overhead ratio
2. Metrics associated to MV/LV substations
Number of LV consumers per MV/LV substation
Area per MV/LV substation
Capacity of MV/LV substations per consumer
Area covered per capacity of MV/LV substation
3. Metrics associated to MV network
Number of MV consumers per area
MV circuit length per MV supply point
MV circuit length per area of distribution
MV underground and overhead ratio
4. Metrics associated to HV/MV substations
Number of MV supply points per HV/MV substation
Area per HV/MV substation
Capacity of HV/MV substation per MV supply point
Ratio of capacity of MV/LV substations per capacity of HV/MV substation
Area covered per capacity of HV/MV substations
5. Metrics associated to HV network
HV circuit length per HV supply point
HV circuit length per area
HV underground and overhead ratio
6. Other relevant metrics
Number of electric vehicles public charging points per consumer
SAIDI for long unplanned interruptions
SAIFI for long unplanned interruptions

The **network design indicators,** in Table 4, comprehend metrics associated to substations and feeders like transformation capacity at urban and rural areas, and other relevant metrics such as: voltage levels, automation equipment (circuit breakers, switchers, etc.) and TSO-DSO interconnection points. This information aims to identify the typical parameters that are used by DSOs for sizing and designing distribution installations. Furthermore, the data includes the typical transformation capacity of the HV/MV and MV/LV substations as well as the number of substations.

Table 4. Network design indicators

Network design indicators
1. Metrics associated to substations
Typical transformation capacity of HV/MV substations
Typical transformation capacity of MV/LV substations in urban areas
Typical transformation capacity of the MV/LV substations in rural areas
Average number of MV/LV substations per feeder in urban areas
Average number of MV/LV substations per feeder in rural areas
2. Metrics associated to feeders
Average length per MV feeder in urban areas
Average length per MV feeder in rural areas
3. Other relevant metrics
Voltage levels
Automation equipment and degree of automation
TSO-DSO interconnection points

Lastly, the **distributed generation indicators** are collected in Table 5. Differently from literature, where only total distributed generation capacity and energy are available, in our case we are able to break them down per voltage level (LV, MV and HV). This indeed provides more information to modellers and stakeholders.

Table 5. Distributed generation indicators

Distributed generation indicators
4. Metrics associated to generation
Total installed capacity of generation connected
Percentage of generation connected to LV per technology
Percentage of generation connected to MV per technology
Percentage of generation connected to HV per technology

3.3.1 Main DSOs indicators explained

In this section a subset of the 37 indicators used to build the large-scale representative distribution networks are listed in Table 6. In the following figures the green and red lines will respectively show the average and median values of the parameters under analysis.

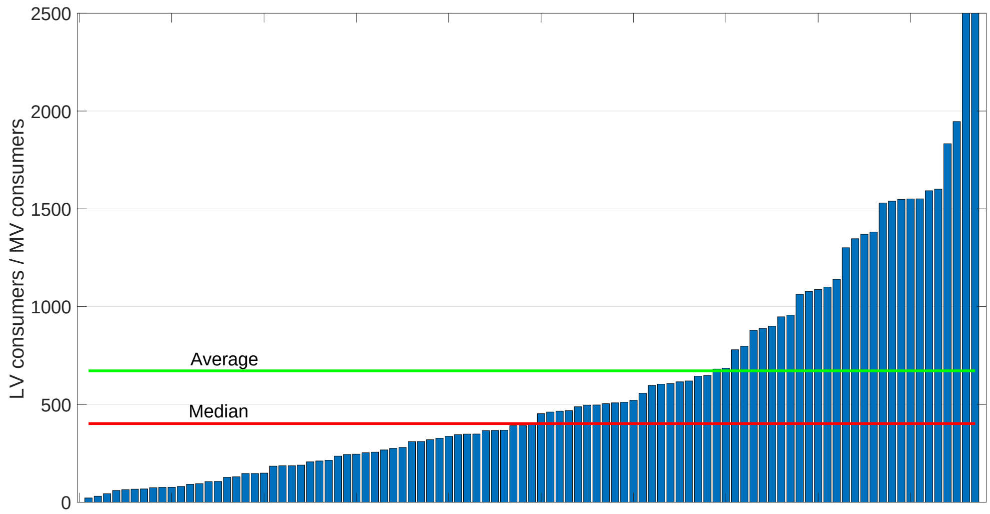
Table 6. Subset of the total DSOs indicators used to build the large-scale representative distribution networks

ID	DSOs indicators
1	Number of LV consumers per MV consumers
2	LV circuit length per LV consumer
3	LV underground ratio
4	Number of LV consumer per MV/LV substation
5	MV/LV substation capacity per LV consumer
6	MV circuit length per MV supply point
7	MV underground ratio
8	Number of MV supply points per HV/MV substation
9	Typical transformation capacity of MV/LV secondary substations in urban areas
10	Typical transformation capacity of MV/LV secondary substations in rural areas

A detailed representation of the main DSOs indicators, listed in Table 6, are described in the following, and a benchmarking is provided with respect to the data in the previous release. Figure 9 displays the ratio between **LV consumers and MV consumer per DSO**, which is a measure of the ratio between the LV residential and commercial consumers and the MV consumers (usually small-industrial consumer). The median indicator (red line) corresponds to 401 LV consumers per MV consumer; while the average value (green line) is 671. It can be noticed that the median value has been increased with respect to the previous release (401 instead of 354), making this indicator more representative of the European situation. Among the DSOs taken into account a huge difference can be observed going from 21 to 2500 LV consumers per MV consumer. This large gap can be partially explained by the fact that DSOs differentiate a lot in terms of size and population served as already observed in Figure 5 and

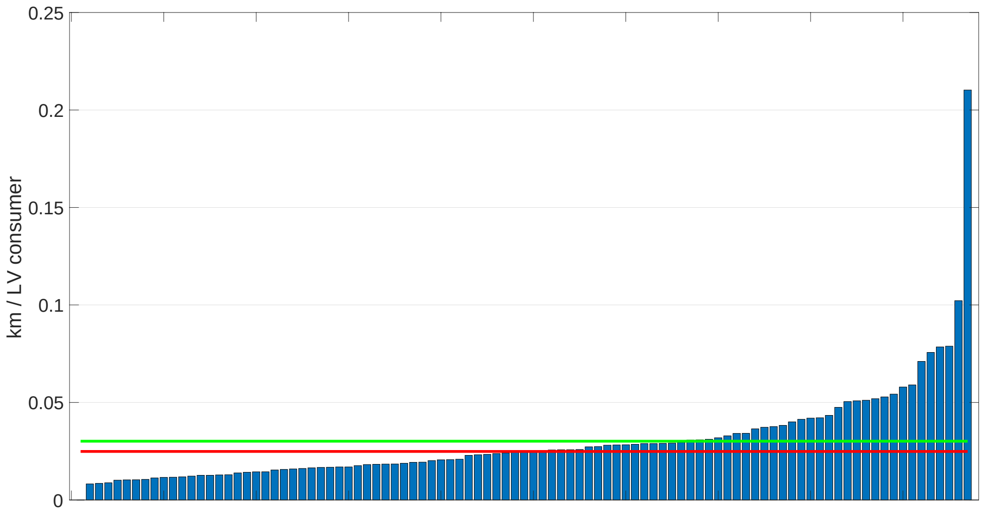
Figure **6**. Moreover, DSOs considered in the survey are supplying electricity to urban, semi-urban and rural areas, which clearly implies a higher range of values.

Figure 9. LV consumers per MV consumer



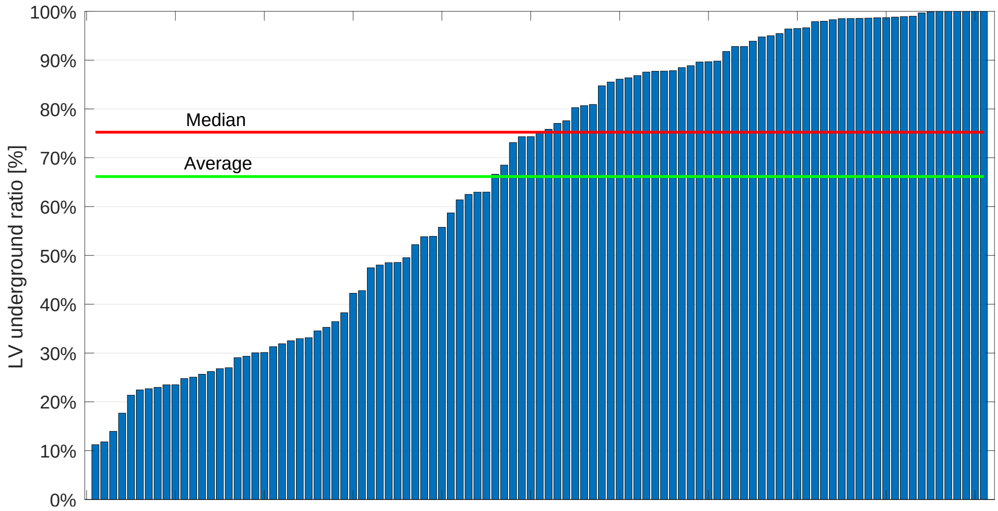
The **LV circuit length per LV consumer** (Figure 10) is based on the location and distribution of LV consumers, as well as the distance among them. The figure shows a narrow gap among DSOs with a median (0.025 km/LV consumer) and an average (0.03 km/LV consumer) values almost identical. It is also noticeable that the median value is almost identical to the one obtained in the previous release (0.023 km/LV). Higher values identify DSOs which are serving rural areas where indeed consumers (houses) are more spread (lower population density). The maximum value corresponding to 0.21 km/LV consumer relates to a Finnish DSO supplying a relatively small amount of electricity across a huge area. On the other hand, in cities, due to a high electricity density, the length of LV feeders is shorter. The minimum value is reached from a German DSO serving a city and its surrounding with a total population of 2.2 million. Note that longer cables imply higher CAPEX and OPEX for the DSO which is obliged to distribute electricity even in areas in which is not cost-effective.

Figure 10. LV circuit length per LV consumer



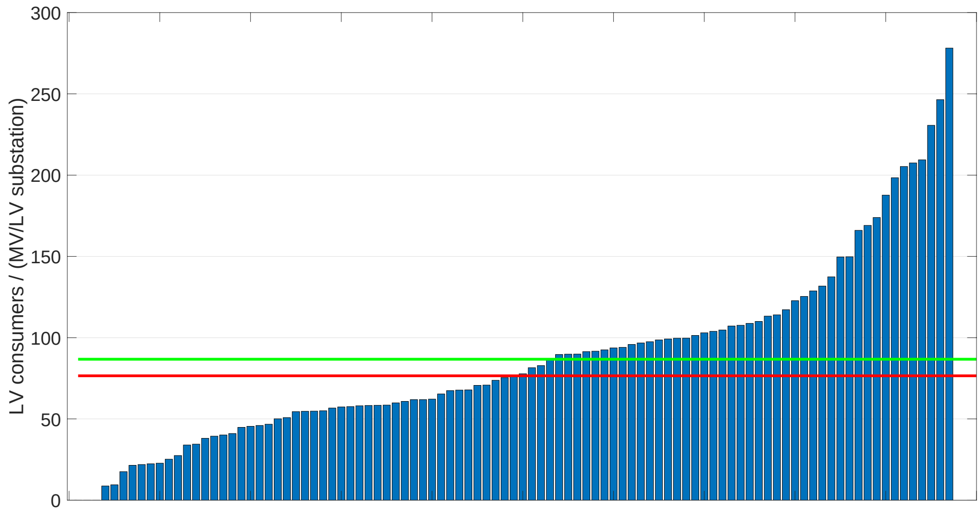
The **LV underground ratio**, presented in Figure 11, is defined as the ratio between the length of the LV underground circuits and their total length (sum of overhead and underground circuits). The median value, shown in red, corresponds to 75% and reaches a maximum value of 100% and a minimum value of 11.2%. The average value, in green, corresponds to 66%. Theoretically, underground installations are desirable to reduce the number of interruptions. Failure rate in this case are in fact lower due to the fact that they are less subjected to adverse weather conditions and to impact with moving objects (birds, tow trucks, drones and small planes). From the other side, it is more cumbersome and expensive to install, maintain and repair cables which are underground. Usually, it is common to have higher underground ratio inside settlements compared to the outside. The chart below indicates that the LV underground ratio below 30% might correspond to rural areas, between 30% and 80% to semi-urban areas and above 80% to urban areas as reported in the previous DSO Observatory release (G. Prettico, F. Gangale, A. Mengolini, A. Lucas, G. Fulli, 2016).

Figure 11. LV underground ratio



The **number of LV consumers per MV/LV substation** is presented in Figure 12, with a median value of 76 and an average value of 86. A tiny difference exists with respect to the previous DSO observatory release, where the median value was close to 90. This ratio strongly depends on the spread of consumers in the supplied area. In urban areas given the higher density this ratio is higher if compared with rural areas where customers are more distant between them.

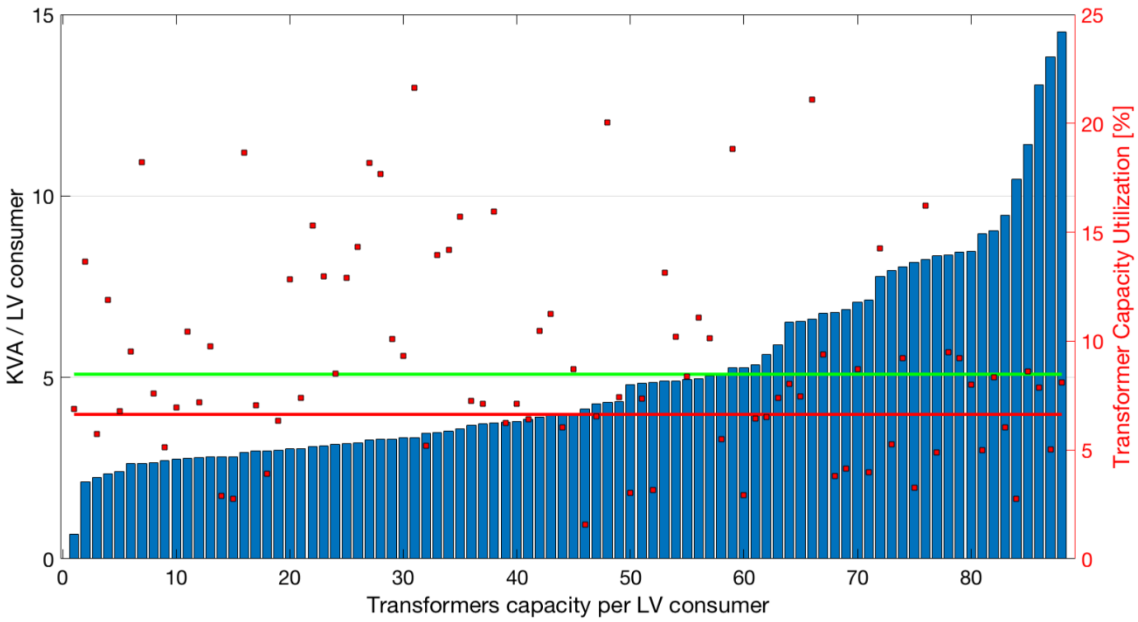
Figure 12. Number of LV consumers per MV/LV substation



The **capacity of MV/LV substation per LV consumer** in Figure 13 gives an indication of how much power (in kVA) is installed the MV/LV substation for each LV consumer. This parameter depends on the typical peak average power of consumers, energy efficiency of the devices and the simultaneity factor. This latter, depends on the size of the house and the number of people hosted per household. Furthermore, the higher the peak power of consumers the higher the capacity of the substation. The median capacity of MV/LV substation per LV consumer is 3.88 kVA (similar to the 2016 value, which was 3.66 kVA) and with an average value of 4.76 kVA. The minimum value is 0.68 kVA and the maximum reach 14.52 kVA. The highest capacity is observed for mainly two countries: Germany and Norway. This can be partially explained by the fact that Germany has the highest consumption in Europe due to a large portion of small industries and for Norway due also to a high number of recharging stations for electric vehicles.

From the introduced indicator another one, coming from the list of indicators proposed in (Refe, Mercados, Indra, 2015), can be calculated: the Distribution Transformer Utilisation. It is defined as the distributed electricity (in MWh)*100 divided by total distribution transformer capacity previously multiplied by the 8760 hours of one year. It indicates the effectiveness of distribution planning in matching transformer capacity with demand. A low utilisation implies a greater investment in distribution transformers. A higher utilisation implies higher efficiency in capital outlay on the distribution network. This indicator is reported on the right axis of Figure 13. As it can be seen it is quite low: it ranges from a minimum of 2% up to 21% which is quite far from 100%. As reported in (Van Tichelen, P., Mudgal, S., 2011), this might be due to the fact that oversizing of transformers is a good strategy to reduce losses[12], moreover it makes the grid more reliable. From a different point of view, this might pose the question about the cost effectiveness of the system. Higher investments in distribution transformer may in fact have repercussions on the served end-users.

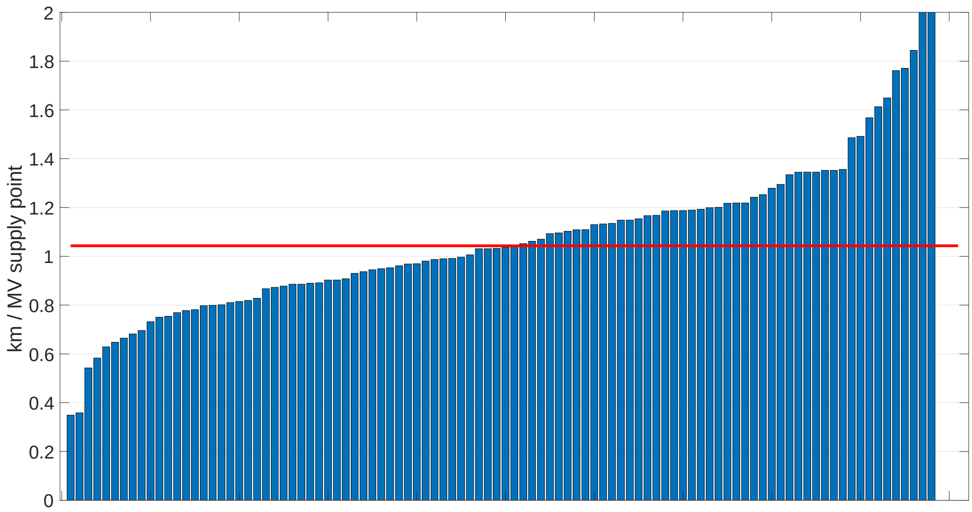
Figure 13. Transformers capacity per LV consumer



The ratio **MV circuit length per MV supply point**, in Figure 14, was selected to evaluate the MV network length, and it is a key item to understand the capacity to install future distributed generation (G. Prettico, F. Gangale, A. Mengolini, A. Lucas, G. Fulli, 2016). Compared to the ratio of LV circuit length per LV consumer plotted in Figure 10, this parameter is much higher because the number of MV supply points is much lower than the number of LV consumer. The median value is 1.04 km/MV supply point. Despite the fact that there is a high variability in the number of MV consumers per area, the MV circuit length per MV supply point does not differ so much among the regions, meaning that the DSO can have a limited control on this variable.

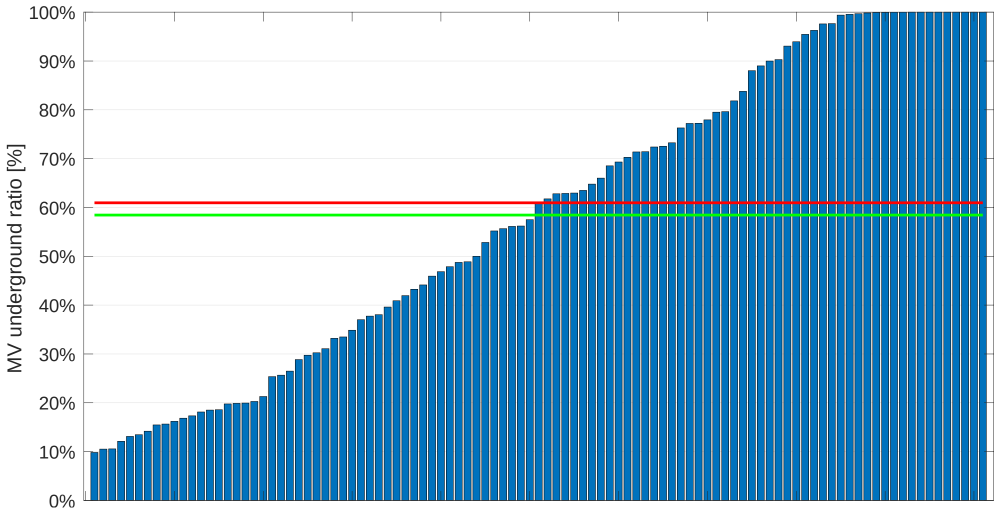
[12] At pag. 148 of the cited report the following examples are reported: According to T&B Consultancy (stakeholder meeting comments: Higher utilisation factors (e.g. sweating the assets) increases the costs of lost energy, lower losses can be obtained by operating at lower utilisation or transformers with larger than necessary conductors‵. Apparently low load factors and oversizing transformers might be a strategy to reduce load losses. For example, Pavg = 200 kW and α =0.50 with 400 kVA Ck (4600 W) results in 1150 W load loss while 630 kVA Ck (5400 W) and α=0.32 (200/630) results in only 540 W. As a conclusion oversizing is a good strategy to reduce losses, moreover it makes the grid more reliable.

Figure 14. MV circuit length per MV supply point



The **MV underground ratio**, represented in Figure 15, is defined as the length of the MV underground circuits divided by the total length of MV circuits (sum of overhead and underground lines). As expected the underground ratio is lower in rural areas compared to urban areas. The underground cables usually have on one hand a lower failure rates, and high reliability, and on the other hand, a higher repair time and more investments, as already mentioned. Nevertheless the decision upon installing underground or overhead cables sometimes depends on aesthetic issues. The median MV underground ratio is around 60.95%, with a maximum value of 100% for several DSOs, and a minimum of 9.4%. This huge difference can be due to specific national or regional regulation that imposes mandatory solutions, which cannot always be taken into account by DSOs in its planning phase.

Figure 15. MV underground ratio



As known, the HV/MV substations supply electricity to MV supply points (as MV consumers and MV/LV substations), and are in charge of connecting MV distributed generation if present in the area. The MV consumers and MV/LV substations are distributed along feeders, and therefore the **number of MV supply points per HV/MV substation**, in Figure 16, is the product of the number of feeders of the substations and the average number of MV supply points per feeder. The median value is 126.75 with a maximum of 1210.

Figure 16. Number of MV supply point per HV/MV substation

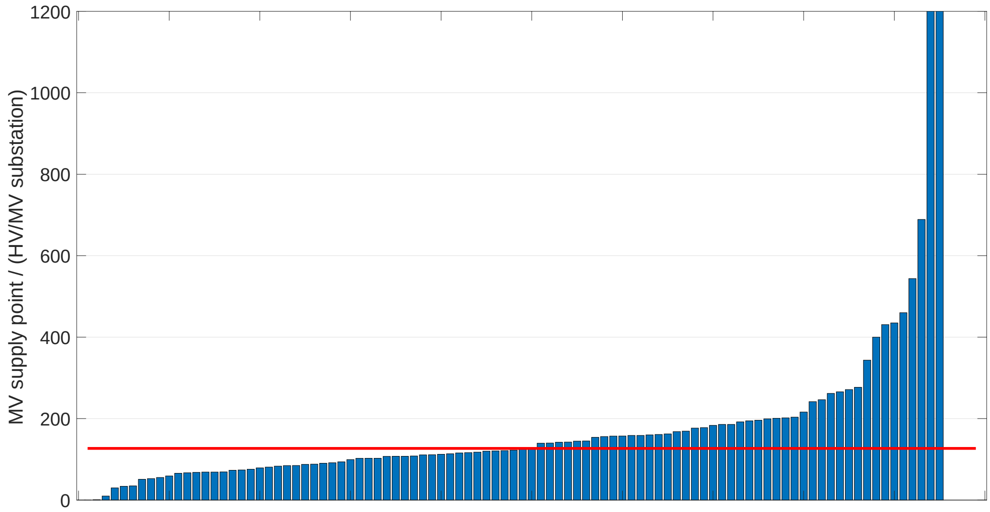
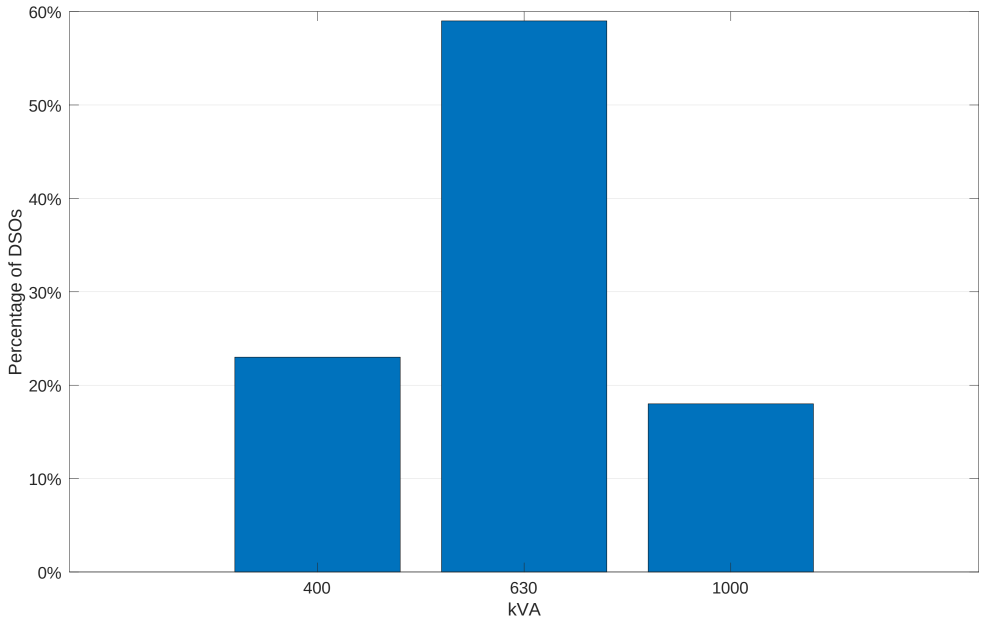


Figure 17 shows the **transformation capacity of MV/LV substations in urban areas.** This value is typically higher than in rural areas, due to the increased electricity density per area. There are 3 most typical value of MV/LV substation capacity: 400 kVA, 630 kVA (the most adopted one) and 1,000 kVA. By comparing these numbers with those presented in (Van Tichelen, P., Mudgal, S., 2011)[13], it seems that in recent years there has been a slight shift upward in terms of capacity: smaller old transformers might have been substituted with higher one (e.g. from 250 kVA to 400 kVA).

Figure 17. Typical transformation capacity of MV/LV secondary substations in urban area (kVA)



The typical transformation capacity of MV/LV substations in rural areas are plotted in Figure 18. They are generally lower than in urban areas, due to the higher distances existing between consumers and the reduced electricity density.

[13] At pages 100 and 101.

Figure 18. Typical transformation capacity of MV/LV secondary substations in rural areas (kVA)

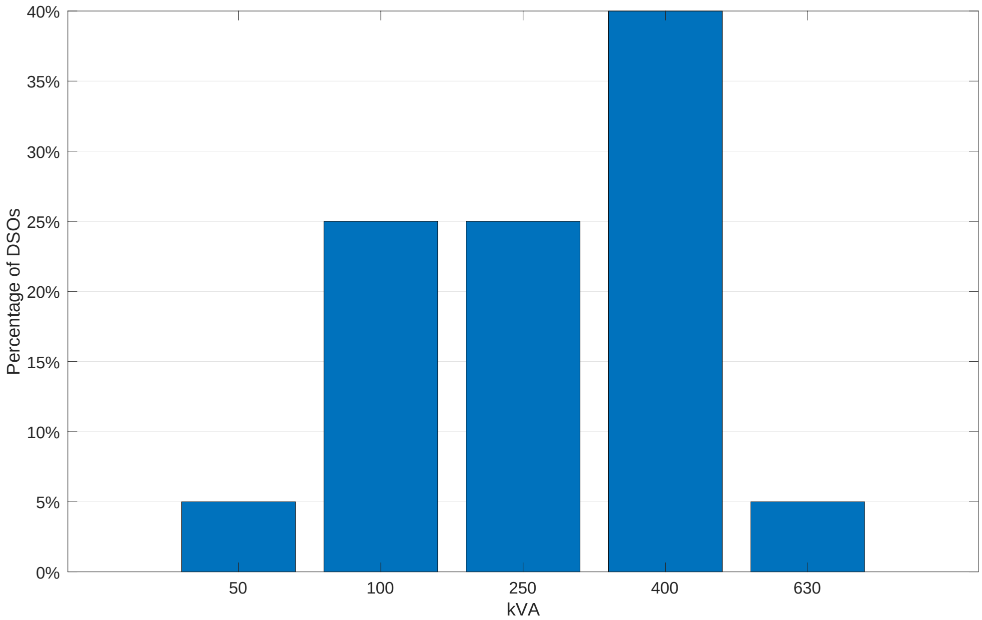
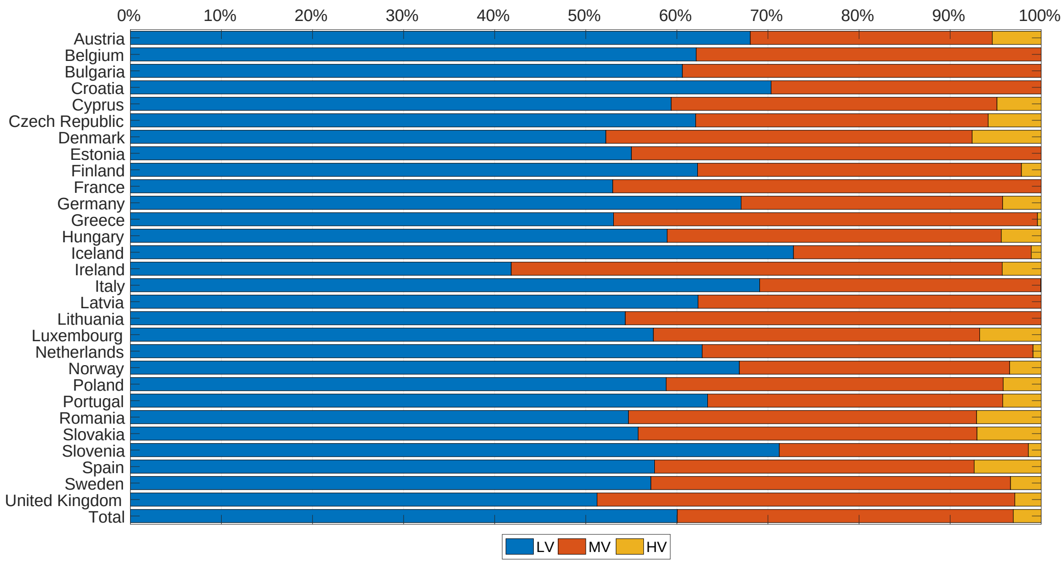


Figure 19 illustrates the shares of **LV, MV and HV line lengths** for each MS. The average value is reported below. The LV length amounts to 59.8%, to 36.8% for the MV and to 3.4% for the HV. Their standard deviations correspond 6.75, 6.82 and 3.3, respectively. Very different design features emerge: Ireland for instance has the lowest LV cable infrastructure and the largest MV lines installation. In contrast, Iceland, Croatia and Slovenia have the most expanded LV lines, which could probably suggest lower levels of industries supply from the DSOs who replied to the survey.

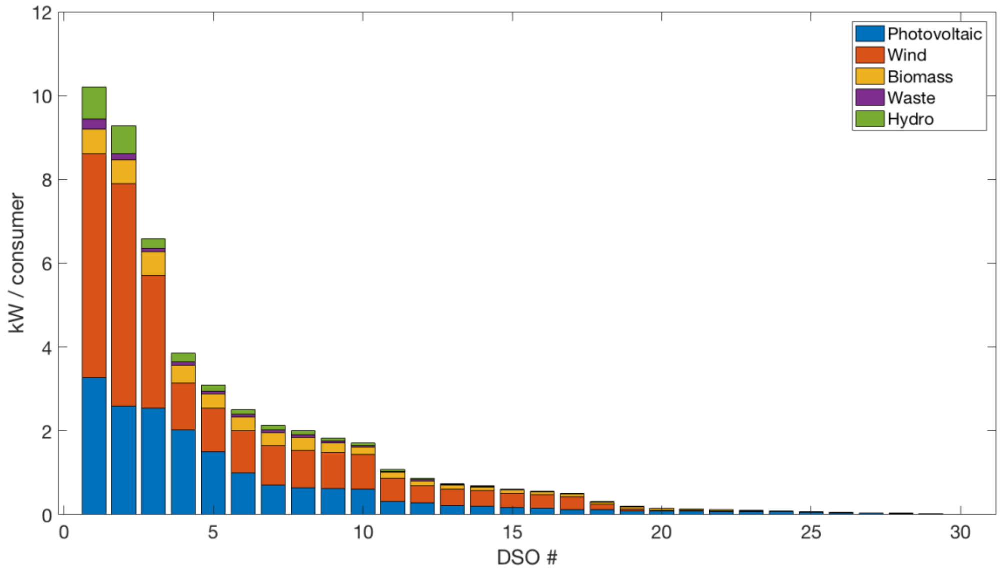
Figure 19. Share of distribution length lines per type (LV, MV and HV)



3.3.2 Distributed generation indicators

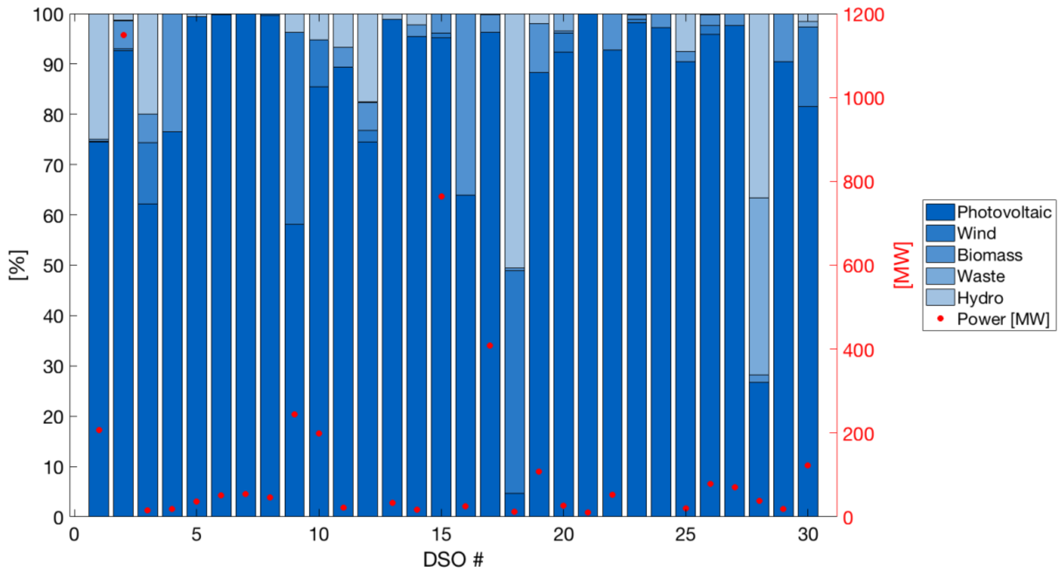
In the following the available data on distributed generation connected to the distribution grid is reported. In particular, Figure 20 shows the aggregated nominal distributed generation installed power, categorised by technology. Values have been normalised by the number of total consumers, supplied by each DSO, which has decided to share this data with us. At first sight the highest installed power per consumer corresponds to wind production, followed by photovoltaic generation. Though, as it can be noticed, from the following figures (Figure 21, Figure 22, Figure 23), there is a predominance of technology (wind, photovoltaics, biomass, etc.) per each voltage level.

Figure 20. Installed nominal distributed generation power per consumer



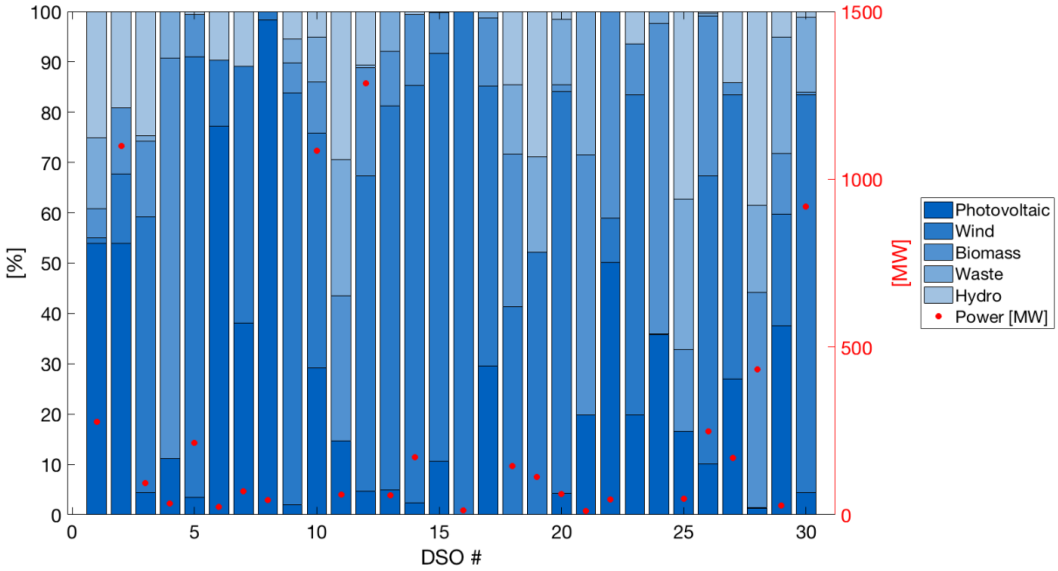
At the LV level, there is a predominance of photovoltaic installation (Figure 21). At this level in fact on average 84% of the distributed generation is of photovoltaic type. Only in the 10% of cases the photovoltaic (PV) installation is below 60%.

Figure 21. Installed nominal distributed generation power in percentage (left axis) and in absolute value (right axis) connected at the LV level.



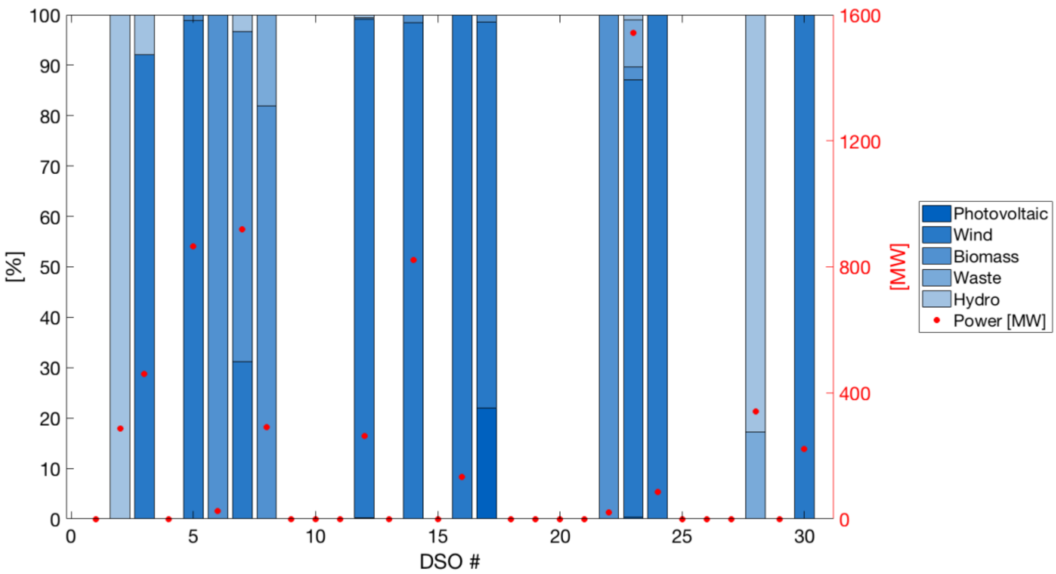
At the MV level, there is a predominance of wind installation (Figure ***22***). At this level in fact on average 42% of the distributed generation installation is of wind type, followed by photovoltaics (22% of the installed distributed generation power).

Figure 22. Installed nominal distributed generation power in percentage (left axis) and in absolute value (right axis) connected at the MV level.



Analogously to the MV level, at the HV level, there is a predominance of wind installation (Figure 23). At this level in fact on average 59% of the distributed generation installation is of wind type, followed by biomass 24%. Photovoltaic scores lowest, with only 1.5% of installations.

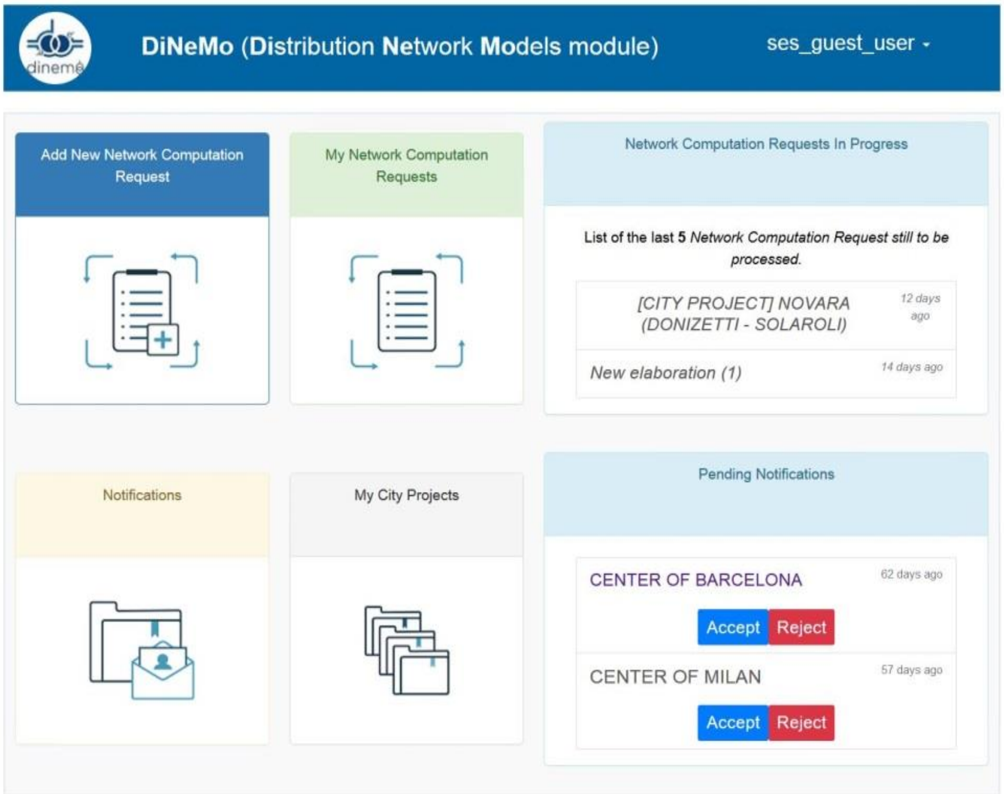
Figure 23. Installed nominal distributed generation power in percentage (left axis) and in absolute value (right axis) connected at the HV level.



3.4 DiNeMo web platform

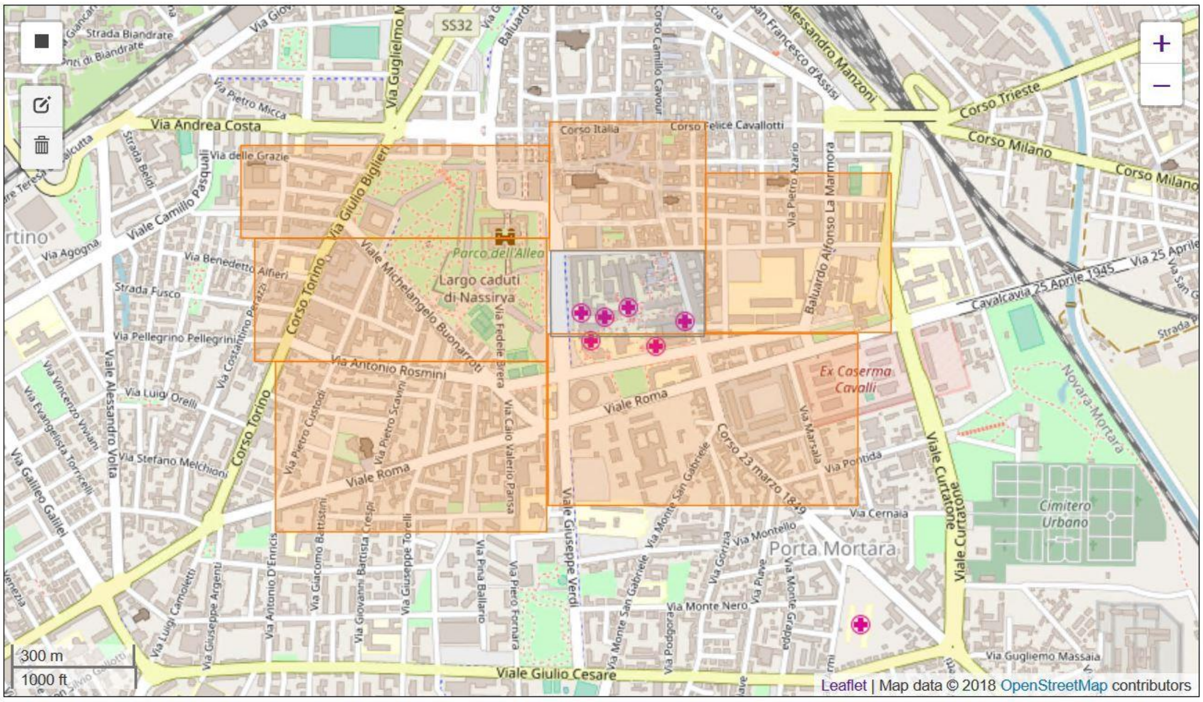
The Distribution Network Model (DiNeMo), in Figure 24, is the new platform that the JRC C3 Unit (Smart Electricity System and Interoperability team) is building to provide stakeholders in the electricity sector with a solid tool, that based on real data, is capable to reproduce the representative distribution grid of a given area of interest. The 10 indicators listed in Table 6 are used by the core platform to design at several levels the representative distribution grid of interest, once some other set of inputs on the area of interest is provided by the user. Apart from this aspect which definitely fills an existing gap in the distribution grid modelling, the platform is also bound to become the virtual place where diverse users, with different roles, will collaborate with the aim of building reliable models to be used in order to design and develop the smart cities of tomorrow. Inside DiNeMo in fact the so-called "city project" has been launched where users can collaborate by connecting together different neighbourhood with the aim of building distribution grids for whole cities. An example of this concept has been reported in Figure 25. In the screenshot several areas are highlighted in orange which corresponds to those parts of the city in exam for which other users have already calculated the representative distribution grid based on data they might have access to. If these users decide to share their networks with other users in the platform (which might be able to calculate other representative grids), networks, which are representative of bigger areas, might be used by all users in a given city project. It is important to stress that in the paved situation, those users which might have access to a certain kind of data, are not sharing these data with other users but only the result of the "network request computation", that is, the representative distribution grid. The same remains true for the data shared by the DSOs with us, which are a fundamental part of the representative grid computation[14].

Figure 24. DiNeMo user dashboard



[14] The platform will be available for test in the first quarter of 2109. A restricted list of interested volunteers will be contacted at this stage. The list will be composed of universities, research centres, companies, DSOs and public authorities' representatives. After this process, a beta version will be released to the general public.

Figure 25. Screenshot of the City Project in the DiNeMo platform



4 DSOs Smart Grid Dimension

As mentioned earlier, in recent years the energy sector has experienced a deep transformative change. New challenges have in fact emerged including the rising of distributed energy resources (more than 90% of which installed at DSO level), the smart meters deployment, the installation of the electric vehicle recharging infrastructure, the potential role of demand side management and the increasingly required coordination between DSO – TSO and the need to protect customer data. (ACER, 2014).

These challenges ask for a smartening of electricity grids, while keeping a reliable and safe matching of supply and demand. To cope with this development, distribution system operators are supposed to develop and build several functions and activities which have been absent or very limited so far.

This chapter investigates different aspects of this transformation: the DSO as a user of non-frequency ancillary services (section 4.1), the DSO – TSO data management (section 4.2), the meter data management (section 4.3), the role of the degree of automation and of remote control (section 4.4) and finally the impact of electric mobility on the distribution level (section 4.5).

4.1 DSOs as one of the key investors in Smart Grids

DSOs are among the stakeholders which in recent years have invested more than others (in absolute terms) in Smart Grids testing and solutions (F. Gangale, J. Vasiljevska, F. Covrig, A. Mengolini, G. Fulli, 2017). Looking at the available list which accounts for 950 Smart Grids projects, a set of five domains has been identified in the same report. They are listed as follows:

Smart Network Management: Projects which focus on increasing the operational flexibility of the electricity grid through enhanced grid monitoring and control capabilities. Typically, this involves installation of network monitoring and control equipment and fast and real-time data communications.

Demand Side Management: This domain includes both projects that aim at shifting consumption in time (demand response) and projects that aim at reducing the level of energy consumption while providing the same level of comfort.

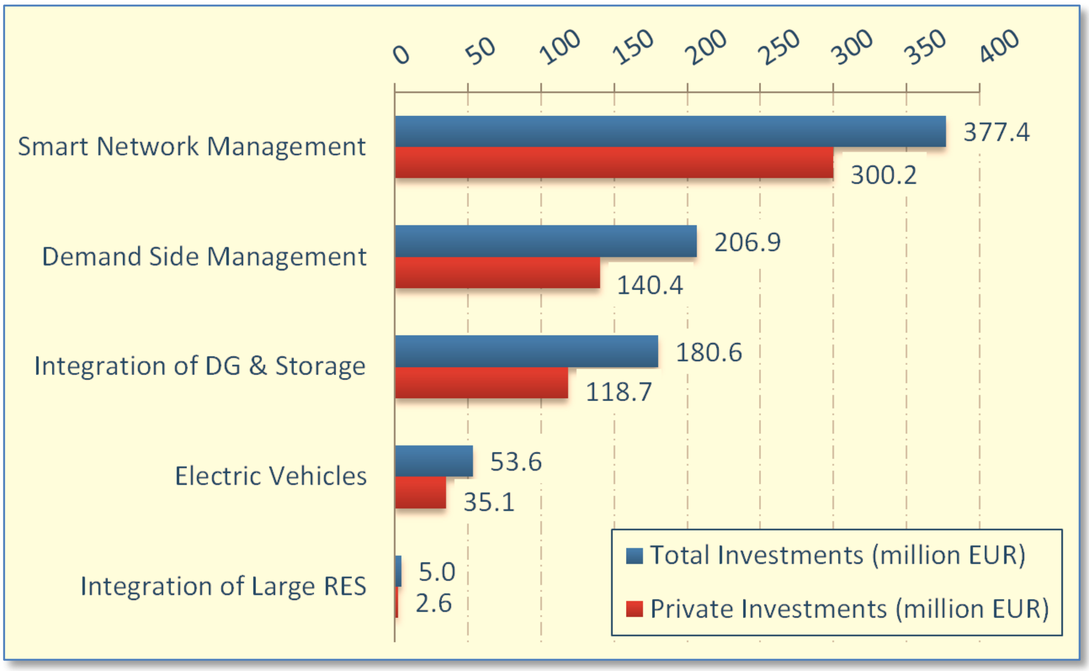
Integration of Distributed Generation & Storage: This domain includes projects focusing on advanced-control schemes and new ICT solutions for integrating distributed generation (DG) and energy storage into the distribution network while ensuring system reliability and security.

Electric Vehicles: Projects in this domain focus on the smart integration of electric vehicles (EVs) and plug-in hybrid vehicles (PHEV) into the electricity network.

Integration of Large RES: Projects in this domain mainly aim to integrate RES at transmission or high-voltage distribution network.

Figure 26 shows the investments that European DSOs have undertaken from 2004 until 2015 on Smart Grids projects, divided into the five categories introduced above. The terms private and total in the figure refer to the investments faced by the DSOs only and by taking into account also national and EC financing, respectively. As expected the highest investments have been undertaken in the smart network management category, which includes applications as: tools for network observability; tools for network reliability assessment; advanced sensors on network equipment to identify anomalies and communicate with nearby devices when a fault or another issue occurs; tools for grid self-controlling and self-healing that is, to automatically prevent, detect, counteract and repair itself; new capabilities for frequency control, reactive control and power-flow control; controllable distribution substations, smart inverters, smart protection selectivity (smart relays), dynamic line rating, deployment of leading-edge transformers, capacitors, VAR-control devices for reduced losses and voltage control. Considerable are also the investments done on demand side management, which includes applications as: the development of ICT solutions and services for demand response and energy efficiency; the implementation of initiatives and solutions to encourage residential, commercial and industrial consumers to modify their level and pattern of energy usage; the implementation of smart metering enabled services and awareness-raising initiatives. Almost comparable to the DSM investments are those devoted to the integration of RES and storage into the distribution grids. Applications included in this category are: the network planning and analysis tool for assessment of network capacity for DG connections; the active grid support (power-frequency control, voltage control) through smart inverters to facilitate DG connection; the centralised vs decentralised control architectures; the development of open and interoperable information and automation solutions for integration of DG&S; the aggregation of controllable DG and storage into virtual power plants and microgrids.

Figure 26. Smart Grid investments by category made by the DSOs in recent years



4.2 DSO as a user of non-frequency ancillary services

In this section we analyse the participation of DSOs in demand flexibility programs, which are divided, in the survey, in: demand side management (DSM) and demand response (DR). 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 reductions in energy demand (e.g. turning off or dimming lighting, shutting down a non-critical manufacturing process). More in detail, DR is a temporary reaction to price signals from end users which might be managed in a close future from a third party, as for instance, the aggregator (Gkatzikis L., Koutsopoulos I., Salonidis T., 2013).

In the following, we first report on the feedback collected from the questionnaires, while afterwards we present some relevant actions taken in several countries. Additionally, an explanation of the flexibility exercises and their analysis is also provided. For completeness, the current management (if any) of prosumers and active consumer operated by the DSOs in our database is presented.

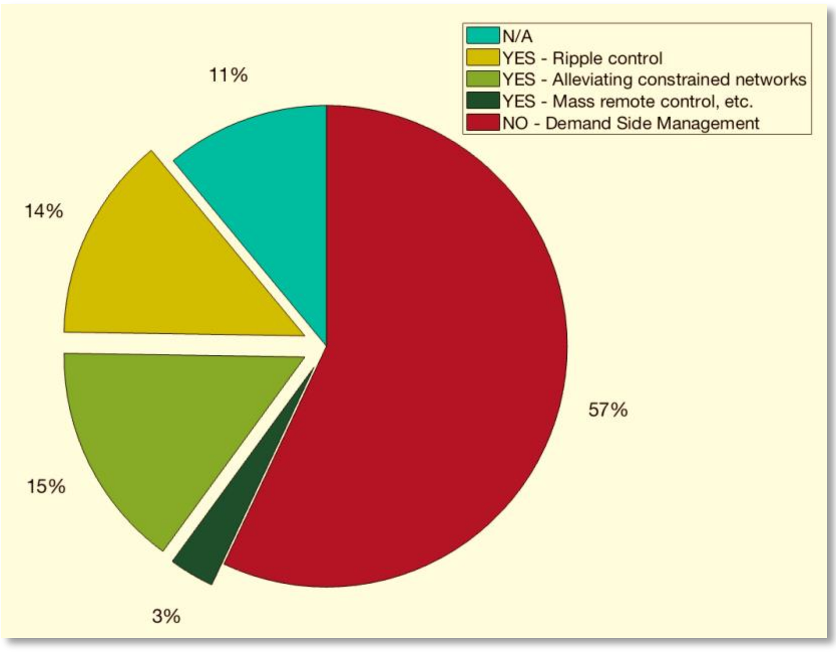
4.2.1 Results from survey

The survey showed that almost 57% of DSOs affirms that no Demand Response (DR), Demand Side Management or Flexibility programmes (DSM or DSF) are currently put in place. Although a small percentage of DSOs have mentioned that they are participating or have participated in the past to some pilot project focussed on the topic. 32% of the DSOs replied positively to the question: *Is your company managing Demand Response and/or Demand Side Management or Flexibility programmes?* Figure 27 helps visualize graphically the situation.

Out of the DSOs that have replied positively (32%), it is noticeable that 15% use DR, DSF or DSM to alleviate constrained networks, 14% uses ripple control and 3%for mass remote control purpose. More specifically, five DSOs explicitly mention that the ripple control is used to control hot water boilers and heat pumps. One DSO mentioned that their participation in DSF programs is limited to old programs with storage heating systems and heat pumps.

It is worth noticing that many of the DSOs that do not apply DSF programs have also commented on their indirect involvement with DSF, i.e. intentions to include such programs, participation in pilot programs etc. In particular, 19% of the DSOs that gave a negative reply stated their indirect involvement: 3 DSOs mentioned that although they do not explicitly implement DSF programs, they have participated in relevant projects or pilots ones; another DSO stated that DSF is used only for demonstrators; two DSOs declared their participation will begin in 2019, whereas one mentioned that they do collaborate with the equivalent TSO that runs such programs. It is also noteworthy to stress that one Italian DSO stated that the current regulatory framework does not foresee DSF participation.

Figure 27. Participation in Demand Side Management programs



With respect to who decides about the action on the final consumption, 21 DSOs have replied (

Table **7**). In the cases where the DSO is the actor who decides on the final consumption, there have been 3 DSOs stating that this is done mainly with the displacement of loads to off peak hours. It is remarkable that in 9 cases out of 21 customers have the possibility to decide about. This clearly goes in the direction paved by the e-directive as mentioned in earlier sections.

Table 7. Who/how is the final consumption of the DSF program decided?

Who decides on the final consumption of the DSF program	DSOs
DSO	10
Customer	6
Through mutual/contractual agreements	3
Automated network management systems determine the final generation export	2

4.2.2 Actions taken in several countries

This section is based on several documents that some participants have shared with us on this topic. In the Czech Republic, customers who use electricity for space heating and water heating make use of a double tariff system interlinked with remote control of appliances by district ripple load control. This system is used to remotely control groups of appliances according to the time schedules set, reflecting the status of the network. Thanks to this system distribution system operators are able to influence (optimize) daily load profile of the distribution networks within the limits of tariff framework, approved by the Energy Regulatory Office. The report (Ministry of Industry and Trade) also mentions that currently the potential of savings for customers who do not use electricity for space and water heating (considering the proportion of that consumption in total household consumption and its distribution in time), is considerably low.

In Spain, a surveyed DSO has mentioned about a recent proposal on demand side management from the TSO (REE), who is involved in the "GO15[15] Reliable and Sustainable Power Grids", has been presented for consultation. Real start seems to be foreseen by the end of 2019.

In Finland, pilots are in progress, which see the DSOs involved in testing flexibility solutions coming from household customers, mainly owners of (detached) houses who have electrical heating and/or water boilers that are connected to existing smart meter infrastructure. The purpose is to build a system, which a service provider (not DSO) can use to offer flexibility to existing and possible future market places, including DSO flexibility market place. Generally, from the survey emerges the fact that where DR or DSM schemes are operational, the management of the appliances under control (thus their consumption) is mainly left to the DSO (after agreement with the customers) and only in very few situations to end-users, which may receive notifications (price signals) on the current need of the system.

In Sweden smart-thermostats are being tested to assess the potential of flexibility in the residential sector.

In Germany, new applications for flexibility management and research based on the concept of "Smart Grid Traffic Light Concept" proposed by the German Association of Energy and Water Industries (BDEW) (E. Ahlers, B. Scholz, 2013) are matter of discussion. This methodology governs the fundamental interaction between market and network on the basis of system conditions of “green”, “yellow” and “red” in analogy with a traffic light. Network operators responsible for the stability of the system determine the current and forecasted condition of their network areas and continuously inform the authorised market participants accordingly in an automated manner. They use this information to handle their business models in an optimum way or to offer new "smart" products. During the green traffic light phase, there exist no critical system related network conditions. All market products can be offered and obtained without restrictions.

[15] "GO15 Reliable and Sustainable Power Grids” is a voluntary initiative of the world's 16 largest Power Grid Operators, with the aim of leading the transition to the future power grid. In this context, the Flexilwatts working group focuses on DSM. For more information, check the webpage https://www.ree.es/sites/default/files/go15_web.pdf

The market can utilise its potentials within the energy supply sector through financial incentives and thus make an essential contribution to the integration of intermittent generation feed-in. The network operator shall monitor the system. This does not exclude the use of control energy.

During the red traffic light phase there is an immediate risk to network stability and security of supply. The responsible network operator must exert direct control on its own equipment and the market (generation, storage or consumption units). For the red phase the existing mechanisms consist in direct instructions to the appropriate generating units, load shedding and feed-in management for renewables-based plants. In the interest of security of supply, this phase is to be prevented by all means. The most interesting phase is the yellow one in which intelligent interactions of network and market takes place and local and global system congestion, i.e. bottlenecks in distribution and transmission networks are managed and remedied by all market participants. Distributed decentralised generation structures lead to complex network situations. For instance, the coordinated provision of services maintaining system security is important during this phase in order to enable measures for local relief to be carried out. Among other things, the following measures can then be carried out:

- Pooling of flexibility: Market players (suppliers/aggregators, traders) collect flexibility on the basis of agreements with generating plants and consumers. Network operators address requests to market players which assure them of the respective flexibilities. The local constraint of the required flexibility is not affected when called in from the pool;
- Transmission and distribution network operators interact in order to guarantee the system security. The market players may be involved inasmuch as the flexibility requested by the upstream network operator is called off by the downstream distribution network operator;
- Network-related and market-related measures: active and reactive power requests;
- Re-dispatch at the distribution network level.

The utilisation of flexibility is requested by the distribution network operator either directly from the network user or from the supplier according to the contractual agreement. If there is sufficient time to respond, the responsible network operator will notify the forecasted demand of system services to the market participants. On the basis of values available from experience and the updated system forecasts, the responsible network operator will continuously forward its system services demand to the market participant.

4.2.3 Flexibility exercises and their analysis

Along this line a very interesting exercise was carried out by the USEF foundation on existing market-based congestion management models which rely on flexibility (H. Bontius, J. Hodemaekers, 2018). In this framework, the DSO is responsible for the active management of the distribution grid and may access five market-based different Aggregator flexibility services (USEF Foundation, 2015):

- To manage local grid congestions by reducing peak loads in order to avoid thermal overloads on cables;
- To tackle voltage problems mainly due to the injection of PV produced electricity;
- To reduce grid losses and enhance grid capacity management;
- To permit controlled islanding of grid sections during fault events on upstream nodes;
- To reduce frequency and duration of outages by supplying backup power during grid maintenance or by shedding loads in emergency situations.

In the eleven models analysed in the report, several roles are defined for the DSO in the different scenarios to manage congestions and capacity management in the distribution grid. The listed models present quite some differences and can be categorised according to chosen criteria. A first one is their orientation towards open market vs quota rules:

- quota- and rule-based, rely on a prequalification method (rule) and operationally, the measures taken when capacity is exceeded. These models are suitable for larger individual congestion issues and, within that segment, mostly for renewable production or limitation of peak demand. with specific or market-oriented remuneration;
- market-based, where the flexibility required for congestion management is obtained and priced through a (separate) market mechanism. These models contain or allow a marketplace/mechanism where flexibility for congestion purposes is traded and allocated. The market is constrained by a preliminary announced quota or a non pre announced market boundary. These models mostly allow aggregators or flexibility service providers to aggregate flexibility from multiple providers, as SME and residential customers.

A second one is that every model needs some form of load forecasting and state estimation of the distribution network, to be able to predict the global volume of congestion that will occur. The load forecasting on short term and lower grid levels is a new topic for DSOs which definitely will require some time.

A third distinctive element is that some models aim at a more 'holistic' approach, where all types of congestion and customer/flexibility type are addressed, while others are more 'case specific', for example, they manage only larger renewables customers. An intrinsic difference between these two classes is that the firsts are typically more expensive to implement' since they involve more market parties and separate flexibility markets, the seconds are already better known and tested and covered by regulation in some form.

A fourth element which is instead common to almost all the model presented is a colour code to describe the state of the grid (e.g. present or future if based on forecasts for the day-ahead congestions). Although the definition of the colour is not the same three main grid congestion statuses can be identified:

- *GREEN* - In this status, all models indicate that no risk of congestion is expected so there is no need for congestion management by the DSO;
- *YELLOW* -It is commonly where the 'soft' congestion management through a quota or market-based coordination takes place. The actual congestion is announced and the available flexibility is supposed to avoid the congestion;
- *RED* - In some models, the red regime is where direct load control is performed. A (tele-) control infrastructure or a code red mechanism that forces the load to switch off or reduce is a prerequisite. Some models use the colour orange for the direct control of loads. Black is the common colour for 'black out' or a grid safety-based grid state, where all the connections in the congestion area are disconnected for grid safety reasons.

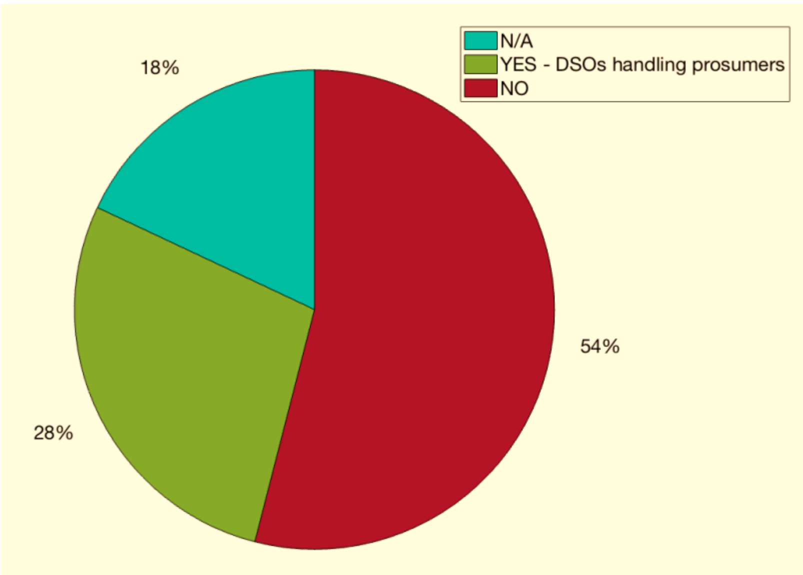
Additionally, in the emerging context the centralized flexibility used by the TSOs for balancing gradually will be reduced and they will have to look for flexibility provided by prosumers in the distribution grid. In some of the discussed models, the potential congestion caused by the TSO services is specifically addressed. In other models, the TSO does not take part directly in the flexibility market. As it will be discussed in the TSO-DSO data management in section 4.3, it is anyway recommended that DSOs and TSOs act in a coordinated manner to the cost-effectiveness of the grid as a whole.

4.2.4 Managing Prosumers and Active Consumers

The active participation of consumer is seen, in the Clean Energy Package, as essential for the effective roll-out and development of a wide range of smart energy technologies, micro-generation and energy demand policies. Active consumers encompass a level of participation by consumers in the purchase or use of products and services (E. Fox, C. Foulds, R. Robison, 2017). Prosumers are the new dynamic variable in an evolving electricity grid. The integration into the market of prosumers lead to a more closer collaboration and coordination of TSO-DSO in order to make it easier for prosumer to transact, trade and buy energy from renewables, as mentioned.

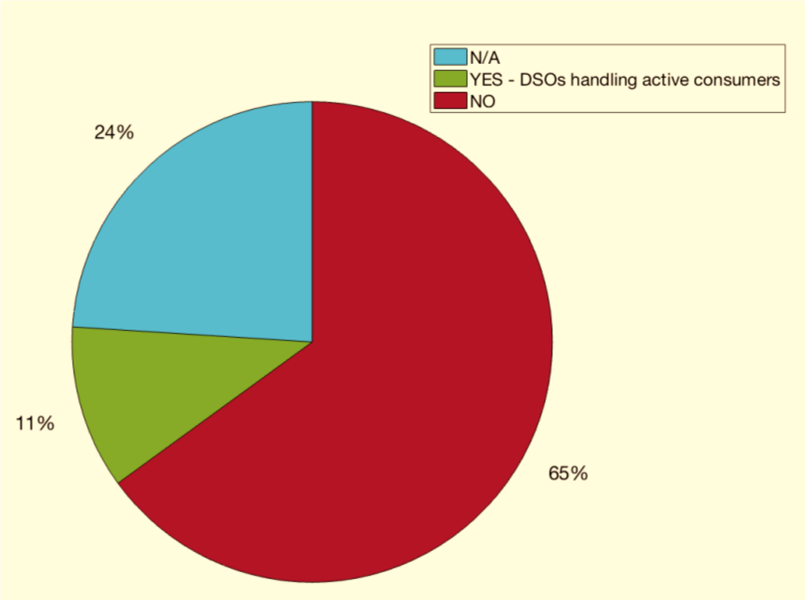
In this section we examine if the DSOs are moving toward this direction, and how they are handling prosumers or active consumers. Figure 28 shows the situation with respect to prosumers. From the collected answers in our survey, only 28% replied positively, and it seems that at the moment prosumers are not really managed, but generally treated as normal connection points. Some exception sees the management of distributed resources when considered big enough (> 100 kW) or in emergency situations. Among the positive replies, it has been stated that prosumers are mainly involved with solar cell production (one DSO), whereas another DSO stated that prosumers are treated only in case of emergency. By further analyzing the negative replies, it can be seen that the reasons behind not actively managing prosumers vary a lot. More specifically, 2 DSOs stated that prosumers are handled in development or pilot projects; another DSO stated that prosumers are foreseen for the future. One DSO mentioned that, although they manage distributed generators bigger than 100 kW, these are not used for ancillary services. Another DSO stated that there are prosumers, but according to the regulatory framework, they are not managed by them. One DSO stated that the same rules apply to consumers, or prosumers, as to any other connection point.

Figure 28. DSOs handling prosumers



The situation is more or less the same with respect to handling active consumers, with the majority of the DSOs replying negatively. Figure 29 reflects the situation regarding active consumers. Similarly to the prosumers case, there are DSOs that although they replied negatively, they stated that are handling active consumers in pilots initiatives or projects (4 DSOs). In addition, one DSO stated that such activities are foreseen for the future. On the other hand, one DSO replied that the regulatory framework is still under definition regarding the management of active consumers. Among the positive replies (11%), it is worth noting under which conditions and how active consumers are handled: one DSO stated that this is done via timeclock; another stated that they have flexible loads with grid fee reduction, which are remotely controllable; one DSO declared that active consumers are handled in emergency cases and for massive remote control.

Figure 29. DSOs handling active consumers



Generally, it seems that nowadays the number of DSOs handling prosumers and active consumers is still very limited. However the trend is supposed to move towards a more comprehensive management being recognised the importance of these two key elements in the electricity grid, as well as in the CEP. Given the direction emerging in the e-directive, it is very likely that as soon as more successful cases of integration of these actors emerge in more virtuous countries, they will be replicated in other MS.

4.3 Data to be exchanged between DSOs and TSOs and survey results

DSOs and TSOs have different roles and responsibilities in different countries as both network operators and neutral market facilitators. TSOs are responsible for overall system security through frequency control, load-frequency control block balancing and both congestion management and voltage support in the transmission network. As responsible of the grid management, both DSOs and TSOs are accountable for the secure operation of the networks they operate, which involves managing congestion and voltage levels on their grids. DSOs and TSOs have both an important role in providing information and support to the electricity market participants, each at their respective level. They provide different services to diverse market participants: connection of users and grid access; supplier switching, when applicable; activation of flexible resources; communication of public data (e. g., suppliers, aggregators, ESCOs) and public authorities, etc. All these tasks need to be performed in a transparent and non-discriminatory way. But mostly important data needs to be shared in a structured and continuous way between these two fundamental actors and other parties. With the increasing growth of renewable energy sources and with the advent of demand response (mainly connected at the distribution level) coordination between TSOs and DSOs has become of utmost importance in order to avoid system disturbances. To this aim, several initiatives have been put forward to increase the cooperation and interaction between TSOs and DSOs. Data exchanges between TSOs, DSOs and market parties are in fact a key point to enhance the value that customers can bring to different markets (use of flexibility by the Balancing Responsible Parties (BRPs), balancing, congestion management, etc.). Regarding grid operations, data exchanges would provide an overall view of the grid state and allow TSOs and DSOs to perform more efficient actions, with respective required timeframes that could be very close to real-time.

In our survey, we have inquired the DSOs about several features related to the exchange of data between them and the TSOs. In the following, we present some information about specific data exchanged.

Regarding data on network conditions shared with the TSO, a relatively small percentage of the questioned DSOs gave feedback on this, namely the 19%. With respect to the granularity of data exchange, a very diverse picture has emerged. In fact, we see at the two extremes, cases in which no communication is exchanged at all between them and on the opposite, cases in which active and reactive power measurements are shared in real-time for relevant agreed nodal areas. In the middle, there are situations in which new systems are being built which allow to share relevant data between the two (or more grid operators) with an hourly time step. For instance, in Germany this system is called "GLDPM-General load Data Process Management System". In certain cases DSO have a partial access to the transmission Supervisory Control and Data Acquisition (SCADA) measurements. In addition, two DSOs explicitly stated that the exchange of such data is done hourly, whereas three more declared that the exchange is done yearly.

Before analyzing the other data categories, it is worth mentioning that there was specifically one DSO that mentioned in details the data needed to be exchanged between them and the respective TSO. These are listed as follows:

- Daily exploitation report;
- Monthly monitoring of compliance of voltage control;
- Short term, weekly and annual plans;
- Non-periodic report in cases of generation limitations, in anomalous network situations (restrictions) and modifications of power factors for voltage control (when they arise);
- A list of generators connected to the grid annually communicated;
- Bimonthly meetings with all agents (registered incidents are shared, generation coupled with typology, demand forecasts, generation coverage, legislation);
- TSO shares the assigned consumers for each period of interruptability.

With respect to the demand and generation forecasts data exchange between the two parties, the 40% of the questioned DSOs have given some relevant feedback. Cases in which no communication at all is shared between them are seen throughout the questionnaires. Others, in which generation forecasts are sent from TSO to DSO and demand forecasts from DSO to TSO on an hourly basis even though not through a common digital platform. In general, the frequency with which the parties exchange data varies a lot; specifically, 7 DSOs have stated hourly communication with TSO for this specific category of data, 2 stated daily communication, 4 monthly and 7 yearly respectively. In addition, there have been two DSOs that have declared communication every two years[16], whereas another one stated communication twice per year. Another DSO stated that they plan to have hourly communication for future purposes.

With respect to the scheduled data of each power-generating facility connected to the grid, the 34% of the questioned DSOs gave feedback. The granularity of data exchange varies from hourly to daily to weekly to monthly. In few cases, once a year DSO gives information about the connected distributed energy resources (DER) amount. Also for this kind of data, there are many DSOs which stated that no data are exchanged about this. There is one DSO that has indicated that hourly communication is foreseen for future purposes, whereas two more state that it is not their responsibility to send such data; instead the generators directly communicate with the TSO. Among the positive replies, one DSO specified that information is sent only for fossil plants, whereas they are

[16] In these cases we think that there has been interpretation of the question: the respondent might have interpreted the question as asking about the forecast on new installed RES at the distribution level.

not obliged to provide data for renewable power generation facilities. Another DSO specified that the actual generation value is sent hourly, whereas daily communication takes place for industrial outputs and hydro power plants.

Regarding real-time measurements, 55% of the questioned DSOs have mentioned some activity. The majority of these DSOs provides real-time data (39% of the DSOs which have positive replied) through an online connection. One DSO stated that real-time data is provided according to an agreement between the DSO and TSO, whereas another one stated that such data is sent every half an hour.

Real time measurements are provided in a few cases for HV substations and, when TSO demands it, for PV production. Active power measurement of PV-facilities in medium voltage from DSO to TSO and active power measurement of feeders in high voltage from DSO to TSO are also shared in certain cases. In Germany there is no legal obligation to have real time measurements and PVs infeed (in absolute terms and as a percentage of total installed capacity) per network area are provided by the network control centre. Regarding ex-post data (metered data), the major part of the questioned DSOs has given positive feedback. Table 8 informs about the frequency with which such data are exchanged.

Table 8. Frequency with which ex-post data are exchanged with TSOs and percentage of DSOs[17]

Frequency	%
Yearly	6%
Monthly	17%
Weekly	6%
Daily	23%
Hourly	26%
Real-time	4%
Other[18]	18%

In one case, ex-post data are shared daily for the previous day with a 15-minutes scale resolution. In another case load profiles for generators with a nominal power greater than 25 MW are daily communicated to the TSO. In certain cases, the DSO sends to the TSO the monthly load curves of customers with power greater than 55 kW and yearly the aggregate consumption of customers with power installed less than 55 kW.

Regarding the data that the DSO receives instead from the TSO, the majority of the participants gave positive feedback (63% of participants). The frequency with which data are sent varies a lot from yearly exchanged data, to monthly (i.e. TSO-DSO meetings), to hourly (i.e. restriction or unavailability) and to real-time (i.e. switching status, SCADA measurements, when level changings occur). The data exchanged between TSO and DSO can be grouped in the following actions:

- TSO sends information concerning the interruptions in the Network (planned and unplanned interruptions in the Network of TSO);
- Information needed for grid dispatching, transmitted continuously and in every two years in case of developments;
- Generation output, circuit breaker status and measurements as required, case by case basis;

[17] (in total 47 DSOs that gave positive feedback about such exchange)

[18] (on case basis, ad-hoc basis, according agreement, every 15')

- Traffic light System for pushing power flow into the TSO grid System;
- Signal on congestion and request to reduce infeed from renewables due to Network constraints of the TSO;
- Structural, Schedule and real time: Comprises all data of the DSO observability area;
- Voltage, Frequency, kW, Congestion;
- Current and voltage in HV/MV substations, measurement data of HV/MV substation and of HV customers;
- Power flow, power injected in the distribution network;
- Flow forecast, planned generation, planned investments and switchers in TSO networks;
- Information when energy is transmitted to the DSO network (this is usually done in real-time);
- Information according to an agreement between TSO and DSO.

4.4 Meter Data Management

With respect to potentially useful data, a vast quantity is daily produced which consists mainly of measurements of selected physical or non-physical magnitudes. Stakeholders and customers need to have access to them even though for different aims. For instance, data are needed to allow consumers to switch retailer and to bill their consumption. At the same time, they are also necessary for the development of energy services and to engage customers more and more into an active participation in the electricity markets. Currently, meter data management can be done in different ways and is a corner stone to a well-functioning energy market. In many countries a point-to-point or "decentralised" approach is in place, which in many cases means that the DSO owns the database and is the hub for metering data and acts as a market facilitator for other stakeholders. In other countries a different approach was chosen so far whereby Meter Data Management (MDM) is under the responsibility of a single actor who manages their storage and enables access to data through a central point of communication with third parties. Examples of this kind constitute a "centralised" approach.

It is worth mentioning that the level of centralisation can vary between the models. To this aim, the CEER report (CEER, 2016) addresses current and future data management models for the following MS: Belgium, Denmark, Germany, Great Britain, Italy, Norway, Spain and the Netherlands. We provide in the following an excerpt of the mentioned report.

In Belgium, both current and future models provide low-cost access to data, thereby ensuring that this does not represent an entry barrier for new market actors. The future system will strengthen consumer empowerment, as it will enable new services and their use for consumers and/or prosumers. Currently in Belgium, DSOs manage the metering systems and are responsible for their functioning. In the new model, data management will be handled by the Central Market System (CMS), which will act as a hub for data transfers. With respect to customer data, in the current model: DSOs manage supply points databases while in the new model the CMS will centralise crucial customer data, but without providing a direct access to customers in the first stage of development. TSOs are in charge of measuring and collecting data of some network points (boundary points and big industries which are connected to the TSO grid directly) and the rest of the network (distribution grids) is collected and metered by the DSOs. Generally, DSOs measure and store their network data. DSOs and TSOs are responsible for validation of their data

In Denmark, Energinet.dk (the Danish TSO) administrates the DataHub. The suppliers are responsible for customers' data (responsible of registration of customer information etc.). The DSOs are responsible for data on metering points (registration of disruption of grid connection, new grid connection etc.), but the responsibility of storing, metering, collecting and to secure the validation of data is again under Energinet.dk. This latter is responsible for being in compliance with the EU directive on data protection. The directive is incorporated into Danish law. The DataHub can be considered as a supplier centric model that strengthen empowerment and creates incentives for suppliers and third parties to create new products and services.

In Germany, customers' access to data and full control over who gets access to data is believed to be crucial for a real empowerment of customers. Standardisation of business processes, technical requirements and strong customer protection are important principles on which to build upon. The Federal Office for Information Security (BSI) is in charge of the development of security and interoperability requirements for German Smart Meter Gateways, additional components and services. Privacy requirements are directly integrated in technical specifications.

In Great Britain, empowering consumers and providing a platform for new consumer devices and services is at the centre of the national approach. Consumers will be able to access their data through an in-home display (IHD). By giving consumers control over who can obtain and use their data, it provides an incentive on suppliers and third parties to offer services that the consumer values in exchange for providing that data. A centralised data management system is in place where a single neutral entity, Smart Data and Communications Company (DCC) provides access to data.

In Italy DSOs are responsible for providing suppliers with data, but the SII (Integrated Information System) owned and developed from a third party company Acquirente Unico (AU), on National Regulatory Authority (NRA’s) behalf, will get a more central role. It will host a complete database of customers’ records and meter data and it will become a central hub for cross-operator data communication, with decreasing responsibilities for DSOs. Currently, the information exchange occurs between DSOs and suppliers through a decentralised communication model consisting of direct and standardised exchanges of information and meter data between a DSO and a supplier. The DSO is responsible for meter readings and technical activities. It collects and stores metering data, validates them and make them available for market participants on a non-discriminatory basis. In future, the information exchange will occur between the DSO and the SII and between the SII and the supplier. Meter, technical and commercial data will be held in the SII and the SII will be responsible for making them available to suppliers. The DSO will be responsible for meter readings, for technical activities, for collecting and storing metering data and to validate them. Additionally, with second generation smart meters, which are already being installed in the Italian peninsula, data will be also directly available in real time at home, through users’ in home devices (IHDs).

In the Netherlands, EDSN (an ICT-organisation owned by all DSOs) is responsible for the implementation, the maintenance and the technical development of the central databases and the communication protocols. The DSO's, suppliers, and metering operators are obliged to co-operate to setup the rules for storage and exchange of consumer data. The central database contains consumer data of which protection is responsible the DSOs. Suppliers and third party service providers are responsible for ensuring that they have received consent from customers to access the data. The main strengths of ESDN are the centralisation and national standardisation of rules and implementation. Previously the system was decentralised and suppliers needed contracts with each individual DSO, which clearly represented a barrier to access data. Additionally, consumers with a smart meter can access data through the local access port on the metering device.

In Spain, customers' empowerment is based on the fact that a single point of contact for all DSOs databases, and a common data format, can guarantee neutrality, non-discrimination and efficient processes. The metering system (SIMEL) is managed by the TSO which is also responsible for its proper functioning. In the future model, TSO will measure and collect data of some network points (boundary points) and the rest of the network data will be measured and collected by the DSOs. DSOs and TSOs are responsible of storing and validating their data. In the new model, the Comisión Nacional de los Mercados y la Competencia (CNMC) also collects DSOs' databases and standardises the format constituting a single contact point for suppliers to access them. The NRA also collects DSOs' databases and standardises the format constituting a single contact point for retailers to access them.

In Norway, the Elhub is being built on the principles of customers' access and ownership to consumption data which are considered key to empowerment of consumers. Easy access web interface and easy identification will facilitate such a process. In the existing model, DSOs are responsible for registering and storing metering values, making them available for market participants on a non-discriminatory basis. DSOs are required (regulation no. 301) to collect metering values every three months. With Elhub and smart metering, all metering values will be reported automatically every day to Elhub, which will be the sole entity responsible for data management.

4.4.1 Smart Metering

The internal electricity market, since its implementation in 1999, has seen radical changes which aim at: new business opportunities, more cross-border-trade, enhance security of supply, higher standards of service as well as achieving efficiency gains. At the same time the evolution of the distribution grid toward a system able to manage numerous generation and storage devices, both in an efficient and decentralized way, has called for the deployment of more advanced metering systems. The implementation of smart metering (at LV and MV levels) aims at monitoring several key parameters as power quality, remote service switch, outages, which will definitely help DSO in their load forecast process hence in a more effective operation of their grid. Proper use and measurement of electrical magnitudes is important for DSOs to calculate non-technical losses (distribution losses range between 1% and 13.5% in the best cases) which are not always easy to calculate. The use of smart meters helps reduce metering errors and identify fraud, and reduces the gap between peak demand and the available power at any given time as well (Council of European Energy Regulators, 2017).

With this respect, the Smart Grid Task Force set up by the European Commission has identified in particular 10 specific functionalities that can be enabled by Smart Meters:

1. Provide the readings directly to the consumers or to a 3rd party;
2. Update readings frequently enough to use energy savings schemes;
3. Allow remote reading by the operator;
4. Provide 2-way communication for maintenance and control;
5. Allow frequent enough readings to be used for network planning;
6. Support advanced tariff schemes;
7. Allow remote ON/OFF control of power supply and/or flow or power limitation;
8. Provide secure data communication;
9. Allow fraud detection and prevention;
10. Provide import/export and reactive metering.

In recent years, MSs have developed a cost-benefit analysis (CBA) for smart metering roll-out plan including some or all the functionalities listed above. The JRC has analysed in depth the national CBAs and the status of implementation of each functionality according to the national plans presented[19].

[19] The overview on each smart meter functionality per MS can be monitored at the webpage: http://ses.jrc.ec.europa.eu/smart-metering-deployment-european-union by selecting in the menu "Smart Meters functionalities")

The decision of installing or not smart meters across MS is, as reported in the Third Energy Package (European Union, 2009), subjected to long-term cost benefit-analysis. In case of a positive CBA, the roll-out target is to have at least an 80% market penetration by 2020. Based on the results of the CBA conducted in 2014, Member States committed to the roll-out of almost 200 million smart meters (for electricity) with a potential investment of EUR 35 billion (F. Gangale, J. Vasiljevska, F. Covrig, A. Mengolini, G. Fulli, 2017). The estimated energy savings related to this action amounts to 3% of the total consumption (SESI, 2018). According to the report conducted in 2014 from the EC (European Commission, 2014) countries who presented a CBA were 20 out of the 27. Among those 20 countries only 13 gathered a positive outcome in their analysis, and consequently started to plan a wide-scale roll-out. The 7 Member States, which did not conduct a CBA at that time, were: Bulgaria, Cyprus, Hungary, Italy (as smart metering roll-out was already complete well over 80% of electricity customers), Malta, Slovenia and Spain.

The data collected in this edition of our DSO Observatory are useful to understand the current smart metering status but also shed some light on future planning and implementations in Europe. To provide a clearer picture of the current status MS have been clustered in 3 categories:

- CBA conducted with positive outcome;
- CBA conducted with negative outcome;
- CBA not available.

This section focuses firstly on those MS with a positive CBA and secondly on those which obtained a negative results from the CBA in 2014.

4.4.1.1 CBA conducted with positive outcome

Table 9 reports the Member States in which the cost-benefit analysis was positive in 2014. The second column of the Table 9 shows the decision on the wide-scale roll-out made in 2014 based on the CBA, meanwhile on the third column there are the results of the DSO Observatory Survey done in 2018. For those Member States in which more DSOs replied, a weighted average coverage, based on the number of consumers and smart meters installed, is calculated.

Among the countries with a positive CBA, Denmark and United Kingdom did not participate in sharing the current smart metering roll-out situation. Even though, we had no answers for this survey, the Smart grid project outlook 2017 (F. Gangale, J. Vasiljevska, F. Covrig, A. Mengolini, G. Fulli, 2017) which analyses the investments on this technology and the report (Escansa, 2016) helped us to have a better idea of the smart meters deployment in these two countries. Indeed, Denmark and United Kingdom are among the top 3 countries investing in initiatives and projects (around 200) to smarten the distribution grid. These investments are partially oriented to the implementation of smart meters, which cover in the case of Denmark more than three-quarters of the consumption, meanwhile in United Kingdom due to technical issues only 6% of households (2.75 million) have a smart meter. DSOs in Estonia, Finland and Sweden already reached almost complete customer coverage two years in advance; in the case of Estonia, this was possible probably due to the fact that the largest DSO Elektrilevi OÜ owns 88% of consumers. In fact, the company started with pilot projects already in 2012 and completed the full roll-out by January 2017 (Escansa, 2016); Finland was one of the first countries starting a widespread roll-out already in the early 2000's, and from August 2019 will start a bidirectional data flow between TSO-DSO; In Sweden the roll-out of the second generation smart meters has already started and few DSOs are also offering more dynamic hourly-priced tariffs to final consumers.

Table 9. Member States with positive CBA overview

Country	Wide-scale roll-out (2014)	DSO Observatory Result (2018)
Austria	Yes	3% - 100%
Denmark	Yes	NA
Estonia	Yes	100%
Finland	Yes	100%
France	Yes	37%
Greece	Yes	37%
Ireland	Yes	0%
Luxembourg	Yes	41.6%
Netherlands	Yes	85.2%
Poland	Yes – Official Decision	1% - 11.5%
Romania	Yes – Official Decision	12% - 14%
Sweden	Yes	90% - 100%
United Kingdom	Yes	NA

Austria had a weighted average installation of 6.3% smart meters in 2014, and even if it had a positive CBA, it looks clear from the survey result that they will probably fail to reach the "at least 80% target" by 2020 as a country (except for one DSO who already completed the roll-out). ENEDIS (previously ERDF) in France installed over 11 million smart meters covering the 37% of final consumers showing a situation partially behind schedule, if compared with the result of (Escansa, 2016). In Greece MV and relatively big LV customers (> 85 kVA) have already installed smart meters and 37% of the energy is monitored through them. In Ireland, after the testing phase in the period 2015-2017 a target of 100% smart meters installations by 2023 has been set. The deployment will start in the beginning of 2019. Luxembourg reached in mid-2017 almost 42% of consumers and the goal is of reaching 95% by end of 2019. In the Netherlands the smart meters installations vary from 52% to 85% depending on the DSOs, for this reason the overall goal of "at least 80%" might likely be achieved. In Poland, despite the positive CBA result, the current situation suggests that the target set by the (European Union, 2009) will be hardly reached by 2020. A more realistic year to reach the set target might correspond for Poland to the year 2024. A similar situation is observed for Romania with an achieved roll-out of 14%.

To summarise, out of the 13 countries with a positive CBA, three, Austria, Poland and Romania will most likely not reach the target of 80% smart meters market penetration by 2020. On the other hand, 3 out of 13 already exceeded the smart meters deployment target.

4.4.1.2 CBA conducted with negative outcome

It is interesting to deeply analyse the roll-out scale evolution of those countries with a negative CBA conducted in 2014 which are summarized in Table 10. Belgium reported a negative CBA in 2014 and decided not to undergo for a wide-spread smart meters roll-out. Lithuania, which has one of the lowest average electricity consumption in Europe, launched few pilot projects to test the feasibility of a complete roll-out, and so far ESO (DSO) installed 3,600 smart meters. EDP Distribuição, the main Portuguese DSO, installed up to 200,000 smart meters, but for a complete roll-out 6 million are necessary (Escansa, 2016). Regarding Czech Republic, the DSOs proceeded with several smart meter pilot projects in the range of 3,000 to 32,000 smart meters. The German case is by far the most complicated one also because is the country with the biggest number of large DSOs. Indeed, there are 79 DSOs which supply electricity to more than 100,000 customers. Although the CBA was negative, Germany decided to go for a selective roll-out. The delay of a widespread adoption of smart meters seems to be mainly connected to the lack of a clear definition of the requirements to ensure data protection and data security. This lack of clearness is translated into a compromise between DSOs and TSO. Some pilot projects are in place and at the moment smart meters roll-out range between 2% and 15% across DSOs. Among the MS with a negative result on the CBA, Latvia is the closest one to have a complete smart meters roll-out. Currently, 45% of the final consumers has been covered. The full coverage is planned to be reached by 2022. The Latvian case seems to indicate that a signal arrived from final customers with respect to the installation of smart meters at their premises (Sadalestikls, 2018). A situation similar to the Latvian one is that of the Slovakian case. In this MS it was decided to go for a selective approach, apart from a mandatory roll-out for customers with annual consumption above 4 MWh. So far, Slovakia has already achieved 18% roll-out and is aiming at 600,000 smart meters by 2020.

To summarise, out of the 7 countries which found a negative CBA in 2014, Latvia and Slovakia are going for a full smart metering roll-out. On the other hand, except for Germany which has extreme differences across DSOs in terms of smart meters market penetration, our DSO Observatory survey shows that only pilot projects are at the moment in place for the remaining countries with a negative CBA.

Table 10. Member States with negative CBA overview

Country	Wide-scale roll-out (2014)	DSO Observatory Result (2018)
Belgium	No	NA
Czech Republic	No	Pilot projects
Germany	Selective	2% - 15%
Latvia	Selective	45%
Lithuania	No	NA
Slovakia	Selective	18%
Portugal	No	NA

4.5 Automation and remote control in HV and MV substation

This section provides a helicopter view of the current degree of automation and remote control present on HV and MV substations which emerged from our survey. Figure 30 shows the number of automated HV/MV substations for each DSO that replied positively on this subject. It also shows the percentage (on the right axis) of the HV/MV automated substations out of the total number of substations that each DSO owns. It is worth noticing that only three DSOs, among the 62% of the total number of DSOs replying positively, deal with a large number of automated HV/MV substations (over 1200). All the rest handle much fewer automated HV/MV substations (lower than 450). The majority deals with fewer than 100 substations. It is also remarkable that 18% of the DSOs has not any automated HV/MV substations at all or has preferred not to fill this record in the question. On the other hand, 22% of them stated that all of the substations they handle are automated. Only one DSO stated that 95% of its substations are remotely handled.

Figure 30. Number of automated HV/MV substations for the DSOs that deal with automated substations

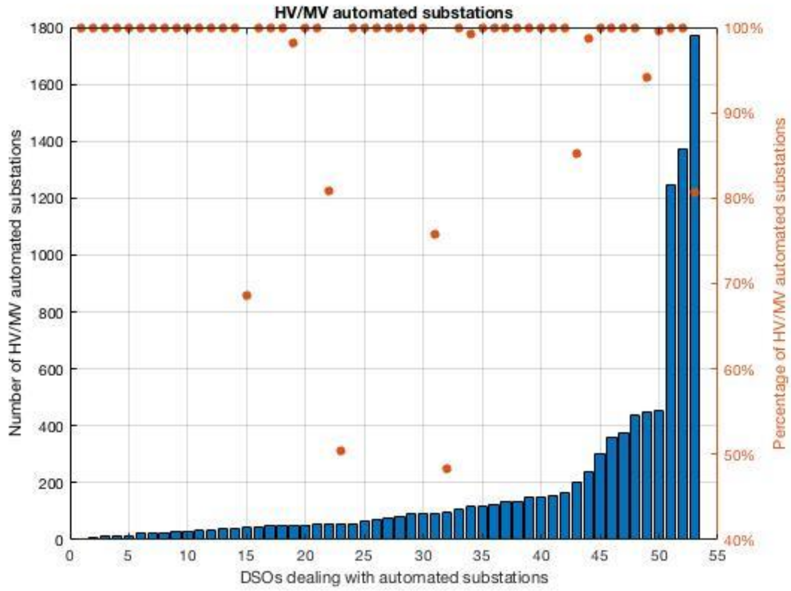
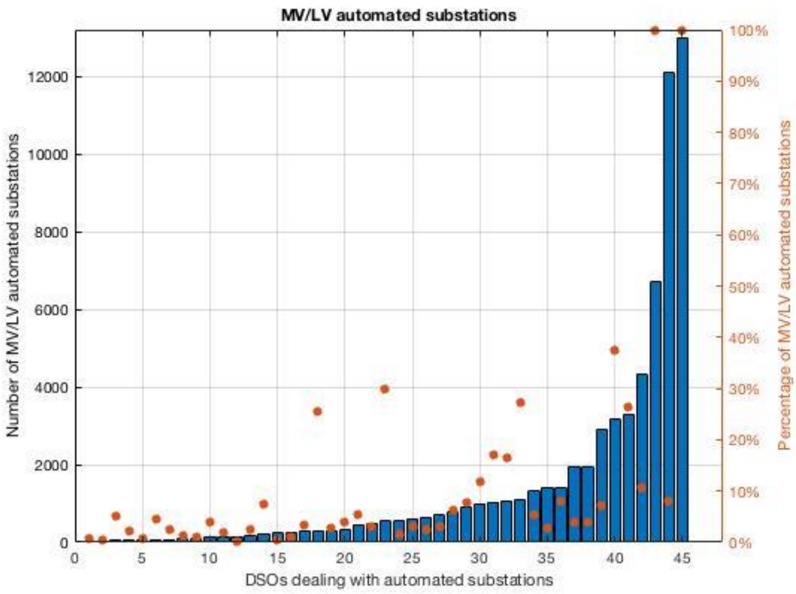


Figure 31 shows the number of automated MV/LV substations for each DSO replying positively to this question. It also shows the percentage (on the right axis) of the MV/LV automated substations out of the total number of substations that each DSO owns. It should be mentioned that the two biggest DSOs have not been included in the graph, since they deal with a larger number of automated MV/LV substations, namely 25,000 and over 130,000 respectively. Other information also came out from the survey; specifically, one DSO stated that they also have 210 MV/MV substations remotely controlled. Other three DSOs mentioned that they have remote controlled pole mounted switches (807, 1176 and 738 respectively). It is also worth noticing that 27% of the DSOs (out of 65) have no remotely controlled MV/LV substations. However, some DSOs that do not deal with remotely controlled substations stated that their implementation is planned for the future, when SCADA will be in operation.

Figure 31. Number of automated MV/LV substations for the DSOs that deal with automated substations



Other relevant information regards the installed equipment responsible of automated procedures in the MV network. From our data, the most utilised devices are those needed to detect overcurrent fault, undercurrent fault, sparking and voltages unbalances. They can be grouped as follows:

- Fault detector: It monitors a system, identifying when a fault has occurred and pinpointing the type of fault and its location;
- Circuit breaker: It automatically operates to protect the electrical transmission lines from damage due to excess current from an overload or short circuit;
- Tele controlled circuit breaker: Differently from the circuit breaker, it can be automatically reset to resume normal operation;
- Tele controlled switch: It is capable to switch off the power lines under nominal load;
- Recloser: It allows switching off and on again the power lines under short circuit. They are typically installed on the overhead poles at the beginning of sections behind the substations.

Generally the transformer's ratios for primary substations at transmission level and for secondary substations at (sub transmission) distribution level are more or less aligned among the MS. The most typical capacity for primary substations (HV/MV) is 25, 30, 40, 80 and 100 MVA. Based on the result of the DSO Observatory Survey the frequent values for transformation capacity of the MV/LV secondary substations are different for urban and rural areas. With respect to the urban case, the capacity is typically 400 kVA or 630 kVA. In rural areas due to a lower simultaneity factor considered in the planning of the grid but also due to the lower energy density the capacity values are 100 kVA, 250 kVA and in certain cases up to 400 kVA.

It is worth to remark that 80% of the interruptions are due to failures at the distribution level and for this reason modern system protection schemes usually use multiple layers of coordinated protection devices, such as fault detector, circuit breaker and remote control switchers. With the supposedly increasing levels of DG it will be harder to detect faults and to manage protection devices properly. Outage management systems and self-healing capability will be more effective if real-time information about the operation of the network is collected by DSOs, which will be able to remotely understand the nature of connected resources and dynamically manage protection devices' (John G. Kassakian et al., 2011).

4.6 Electric vehicle integration

In the next decades the expected growing number of EVs and consequently the installation of EVs charging infrastructure, if not properly managed, will exacerbate local peak load conditions and consequently force utilities to invest in infrastructure reinforcement (transformers, cables, circuit breakers, etc.). Indeed, higher power rates directly impacts the aging of transformers, and dynamic pricing or ad hoc tariffs are necessary to shift consumers' behaviour. An interesting fact comes out from the survey: a lack of information exchange among the utilities installing charging infrastructure and DSOs exists. DSOs are in fact not always aware about the existence of home charging infrastructures. This is mainly due to the fact that in several MS even residential customers might ask for high levels power (e.g. up to 8.8 kW peak). This could lead, among several issues, to wrong demand forecast and to higher balancing cost for final consumers. Generally, our survey shows that there are several public charging points in the territories that the DSOs operate. Only 5% of the questioned DSOs have stated that there are no public charging points in their managed area, or that they are not aware of. Figure 32 depicts this situation.

Figure 32. Number of DSOs with public charging points in their territory

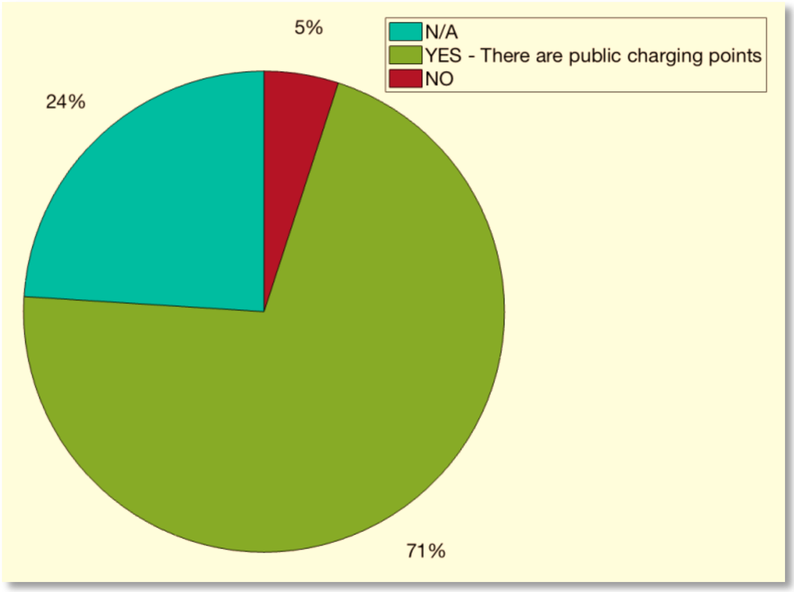
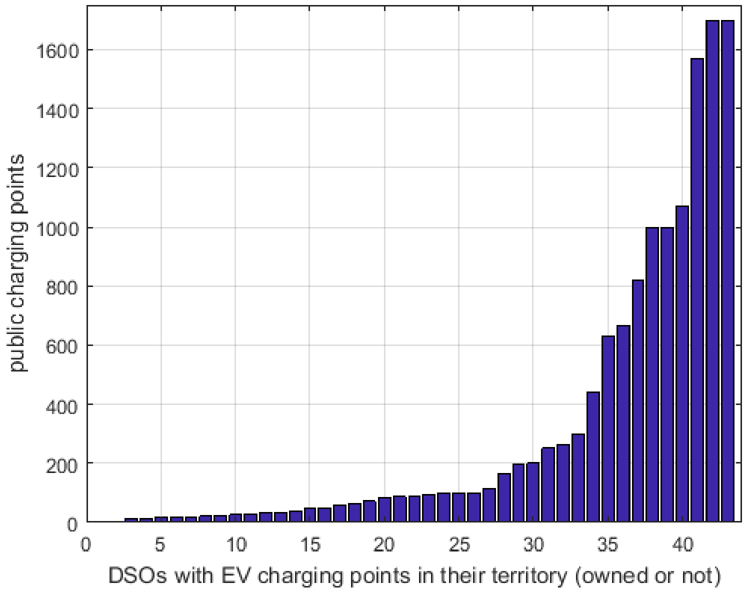


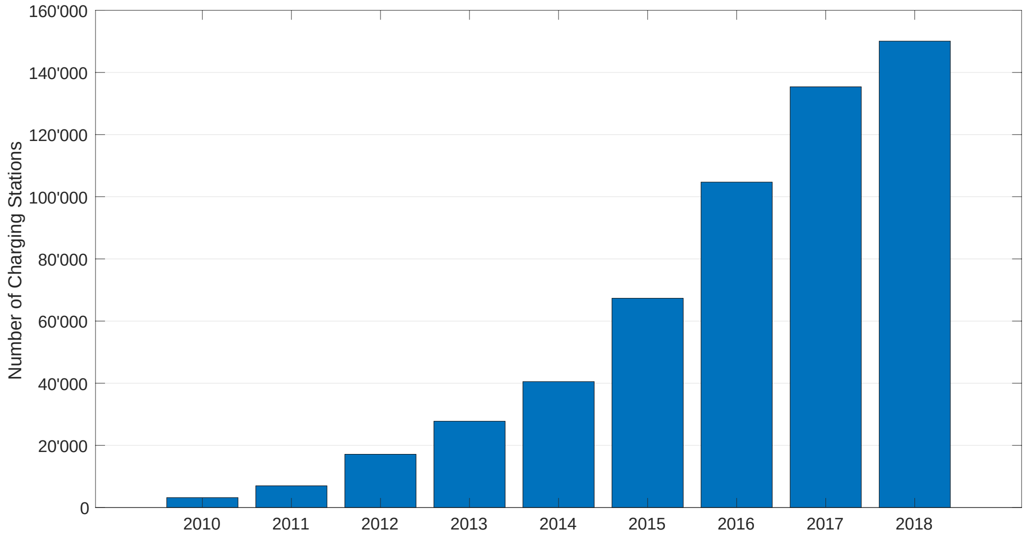
Figure 33 shows the number of public charging points on each DSO. As it can be noticed it varies a lot from a DSO to the other. In the majority of cases, there are fewer than 200 charging points. Only 8 DSOs have more than 1,000 EVs charging points in the territory they operate in; six of them are depicted in the graph while the other two have not been reported for scaling reasons. They amount to 2,898 and 7,800, respectively.

Figure 33. Number of public charging points



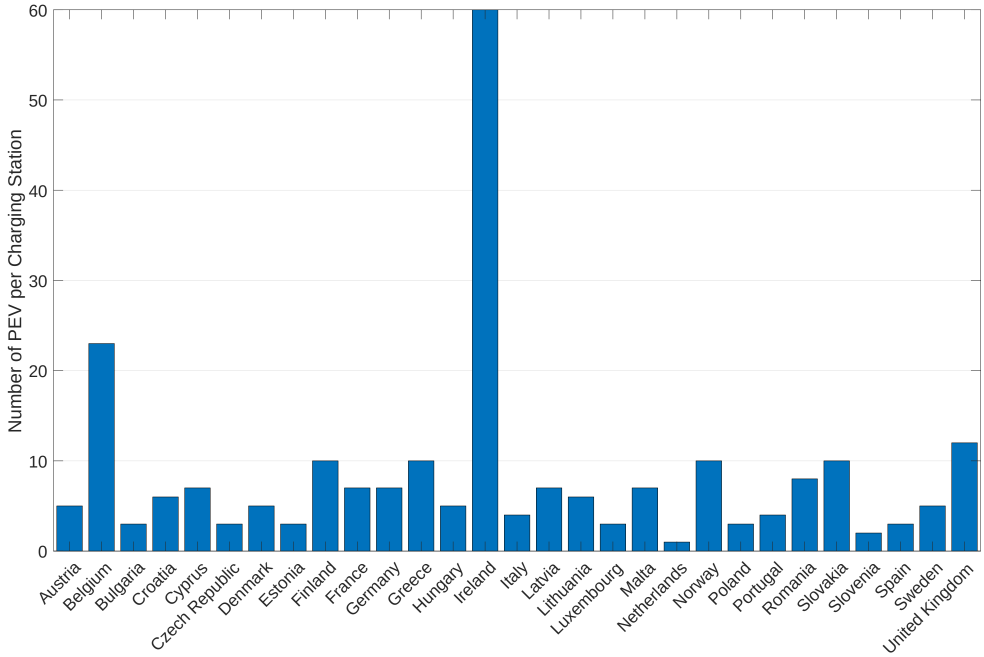
Remarkably, the vast majority of the DSOs in our dataset are not owners of the charging points. This fact is aligned with what mentioned in the e-directive. 10% of the DSOs with charging points in their territory have mentioned that they own a percentage of them. More than half of these DSOs operate less than the 9% of the charging points. It is expected that the number of charging points will increase in the close future with the expected increase of EVs. So far, the trend has been increasing. As shown in Figure 34, in 2018 only, more than 150,000 charging points have been installed across Europe (EAFO, 2018).

Figure 34. Total number of plug-in electric vehicle charging points



On the other hand, Figure 35 plots the number of plug-in electric vehicles per charging position for each Member State and Norway (EAFO, 2018). This figure highlights the huge difference across countries, which might be due to factors such as population density, geographical constraints, and urban/rural ratio. This will inevitably influence the distribution grid, and they way DSOs manage EV charging.

Figure 35. Number of plug-in electric vehicle per charging position



5 Conclusions

The results and insights presented in this report are an update and a considerable extension of the findings of the first exercise on Distribution System Operators (DSOs) Observatory started in 2016 by the JRC. The aim of this periodical data collection and analysis exercise is to help depicting the situation of the distribution grids in Europe.

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 subjected to the unbundling requirements of the EU electricity Directive 2009/72/EC.

The work has been based on a survey, which can count on the successful participation of many European DSOs. The data collected in fact represent 99 out of the 191 active larger DSOs, which cover 84.6% of the total European customers. This corresponds to an increase in the total customers covered by 13.1%, with respect to the previous release.

In this work 37 technical infrastructural indicators have been built, from them 10 DSOs indicators have been extracted and explained in great detail. This subset of indicators is in fact fundamental to provide a valid input to the DiNeMo (Distribution Network Models) web-platform, that our team is building to provide various stakeholders with representative distribution grid models of interest.

Additionally a set of indicators, divided per voltage level (LV, MV, HV), on the distributed generation connected to the distribution grids of the DSOs which have participated to our survey, has been showed. These indicators are of utmost importance as inputs for studies focused on the impact of Distributed Energy Resources on the distribution grids. Information about reliability indicators (mainly SAIDI and SAIFI) has also been updated.

The report gives a clear idea of the current distribution European grid, thus providing a valuable tool to the research community for examining the power distribution system from a technical and economical point of view. Furthermore, in this second release, the smart grid dimension of DSOs has been investigated. It includes a detailed picture of the technological mechanisms and conceptual shifts put in place by DSOs to move towards the transition paved in the Clean Energy Package (in particular in the e-directive and in the e-regulation proposals of the EC) such as the implementation and access to smart metering, the ability to store and perform data handling, the implementation of flexibility programs which aim at a greater engagement of end-users and the better coordination with the Transmission System Operators.

Apart from the technical indicators, valuable conclusions have been also drawn regarding the smart grid dimension. To this respect, information is retrieved from the last data collection, since this is a novel record introduced in the DSO observatory.

In a nutshell, the majority of the respondents' states that no DR, DSM or Flexibility programs have been put in practice so far. On the other hand, almost one third has some of these mechanisms already in place. The main tool used to this scope is a ripple control system which is able to turn on/off hot water boilers, heat pumps, electric stoves but also agricultural sprinklers and animal food heaters. The utilisation of flexibility is requested by the distribution network operator either directly from the network users or from the supplier according to the contractual agreement.

From the collected answers it seems that at the moment prosumers are not really managed, but generally treated as normal connection points.

With respect to the DSO/TSO data exchange, a very diverse picture has emerged. There are cases in which no communication is exchanged at all between these two actors and on the opposite, cases in which active and reactive power measurements are shared in real-time for relevant agreed nodal areas. In the middle, there are situations in which new systems are being built which allow to share relevant data between the two (or more grid operators) with an hourly time step.

The smart metering roll-out situation has been updated, showing that there is a great variation among countries with respect to the status of their smart meter roll-out. It is shown that some countries have already completed the smart meter roll-out in advance (with respect to the target of 80% coverage by 2020), some are likely to achieve it by the target year, 2020, whereas some others fall far behind from this goal. Surprisingly, countries which had a negative CBA in the past have completed or are expected to accomplish the smart meter roll-out.

The DSO Observatory aims at offering valuable information about current status of the distribution grids in Europe but also on the way they are operated by DSOs hence on general trends which emerge from our scanning exercise. Future research activities will be devoted to understand under which mechanisms efficiency can be improved at systemic level. Results and insights emerged in this work will definitely be a solid basis to build upon.

The JRC will continue to carry out its scientific and policy support activities in the power system fields to better understand and address the challenges DSOs face in the transition to a smarter energy system. In order to increase the knowledge base of the evolving electricity distribution sector, the results of these activities will be made publicly available at no cost for everyone interested in deepening her/his comprehension of this topic. The JRC aims at continuing with the support of the relevant electricity system stakeholders, in order to help understanding the merits, challenges and options of the electricity system transition.

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List of abbreviations and definitions

AU	Acquirente Unico
CBA	Cost-Benefit Analysis
CEP	Clean Energy Package
CMS	Central Market System
CNMC	Comisión Nacional de los Mercados y la Competencia
DCC	Data and Communications Company
DFM	Demand Flexibility Management
DG	Distributed Generation
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution System Operator
EC	European Commission
EU	European Union
EV	Electric Vehicle
GDPR	General Data Protection Regulation
GLDPM	General load Data Process Management System
JRC	Joint Research Centre
HV	High Voltage
ICT	Information Communication and Technology
IHD	In-Home Display
LV	Low Voltage
MDM	Meter Data Management
MS	Member States
MV	Medium Voltage
RES	Renewable Energy Sources
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control And Data Acquisition
SESI	Smart Electricity Systems and Interoperability
SII	Integrated Information System
TSO	Transmission System Operator

List of figures

List of tables

Annexes

Annex 1. Indicator box plots

The following figures represent the box plot of the main used indicators as obtained from the DSOs Observatory database. Additionally, the values corresponding to the year 2014 and 2018 are plotted separated and then combined together in "All". The red line is the median, the blue box represents the interval comprised within the 0.25 (Q1) and 0.75 (Q3) percentiles, meaning that 50% of the DSOs have an indicator value which is contained in the box. The black dashed lines indicate the full range, including the minimum and the maximum values. The red summation symbol highlights the outliers' values, which are considered as such if they exceed the sum of the third quartile plus one and half time the interquartile range (Q3 – Q1).

Figure 36. LV consumers per MV consumer

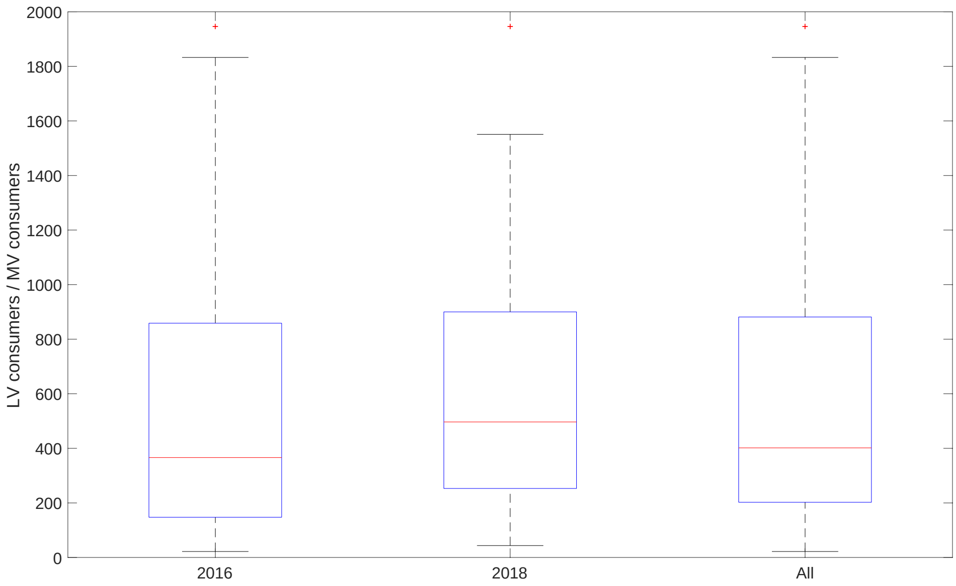


Figure 37. LV network length per LV consumer

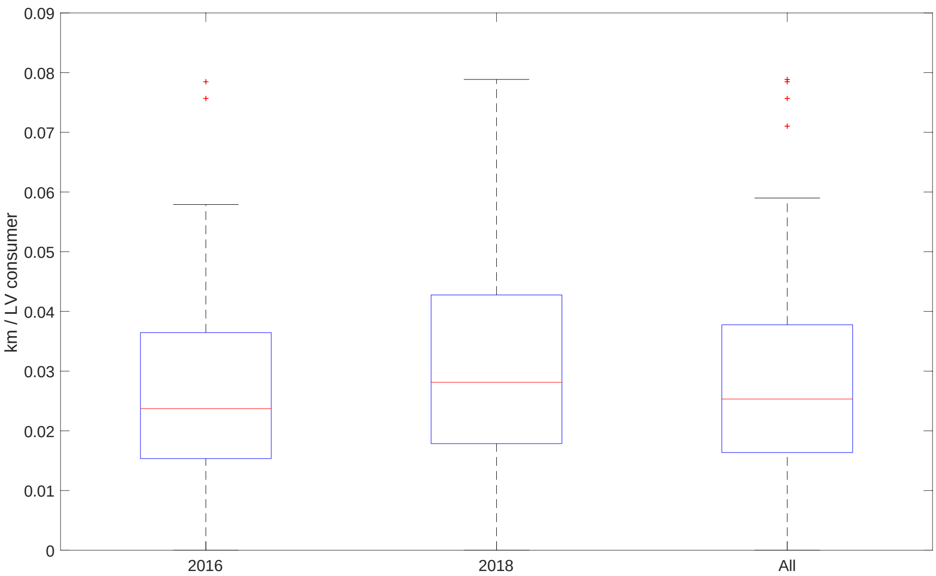


Figure 38. LV underground ratio (LV underground circuit length divided by the total LV circuit length)

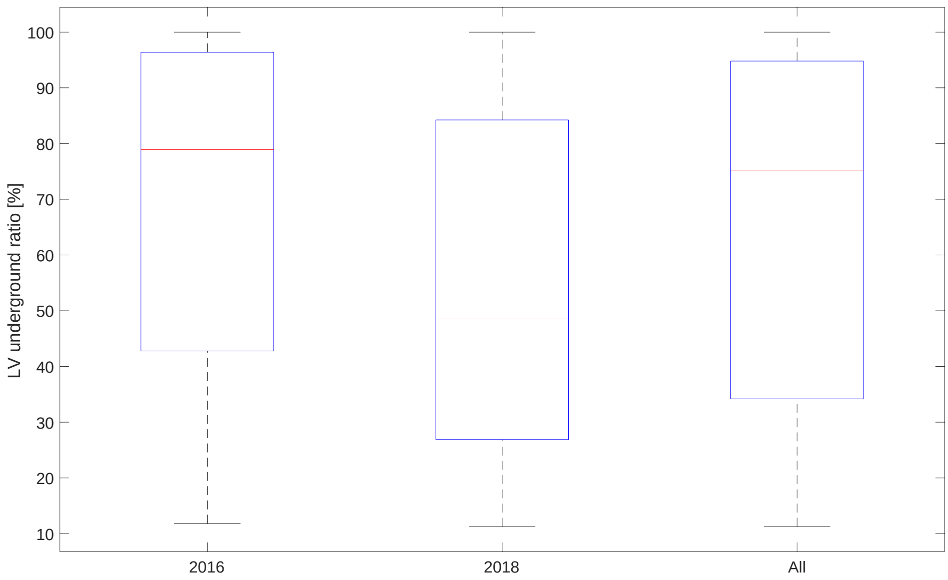


Figure 39. Number of LV consumers per MV/LV substation

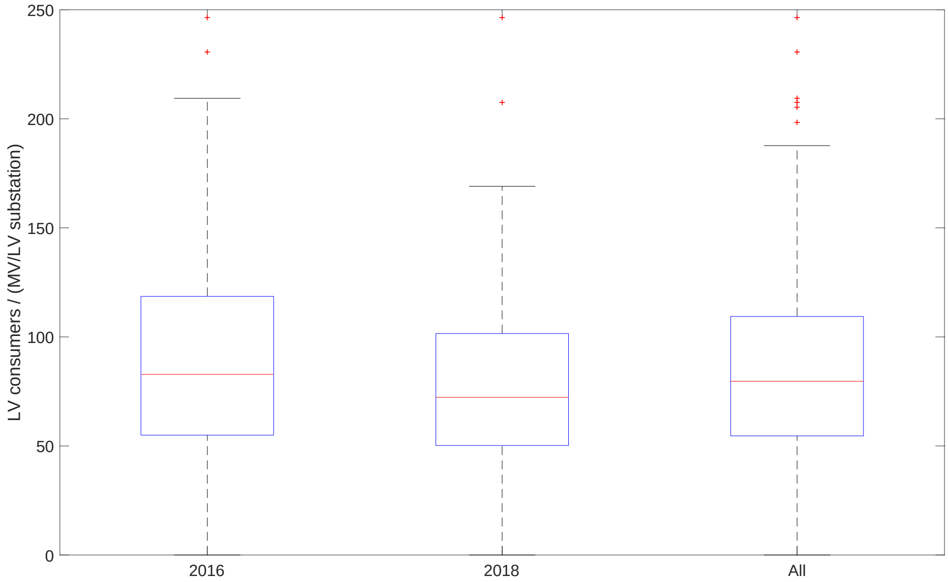


Figure 40. MV/LV transformer capacity per LV consumer

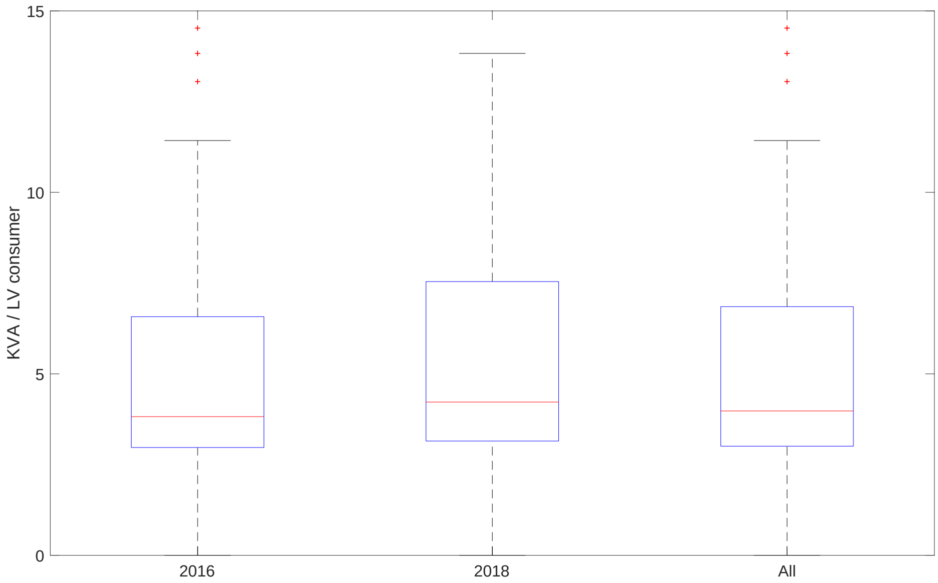


Figure 41. MV network length per MV supply points

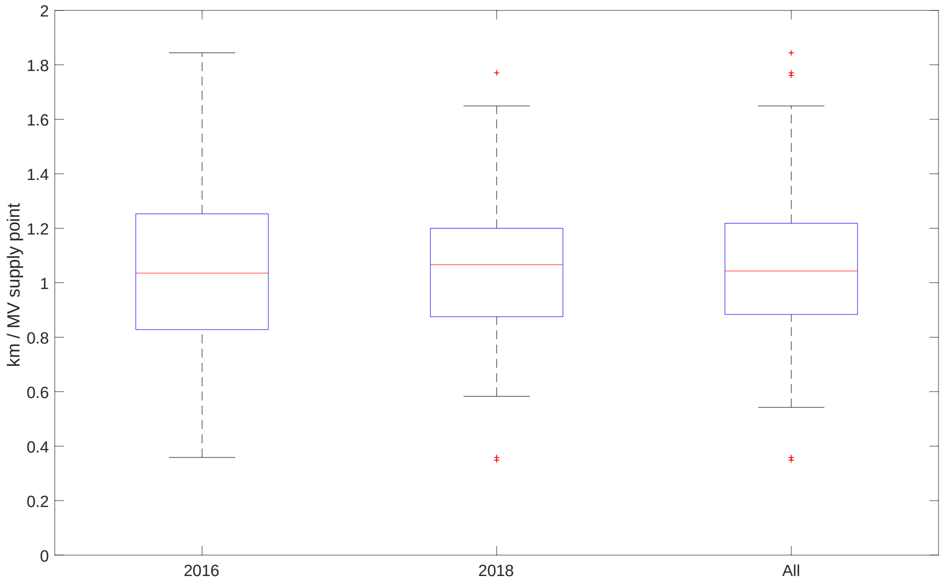


Figure 42. MV underground ratio (MV underground circuit length divided by the total MV circuit length)

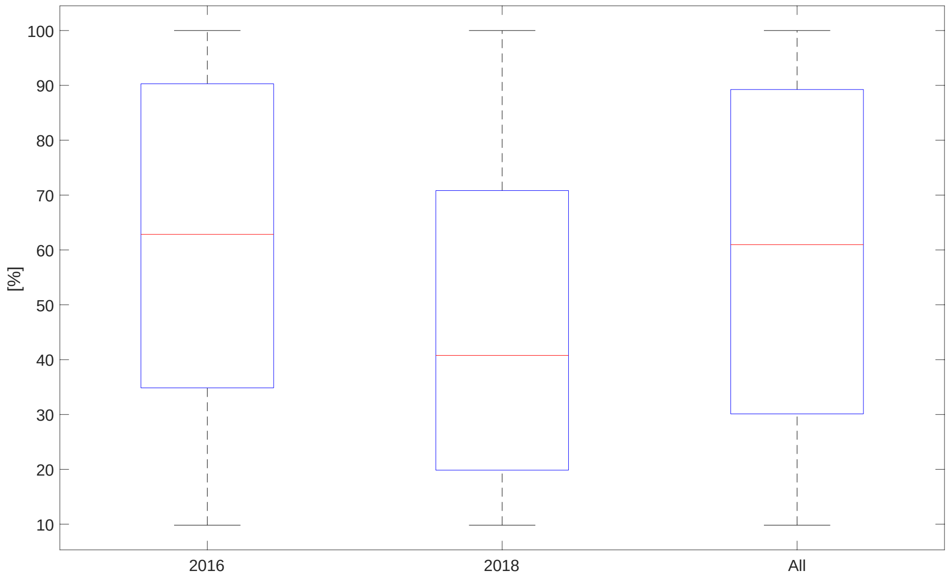
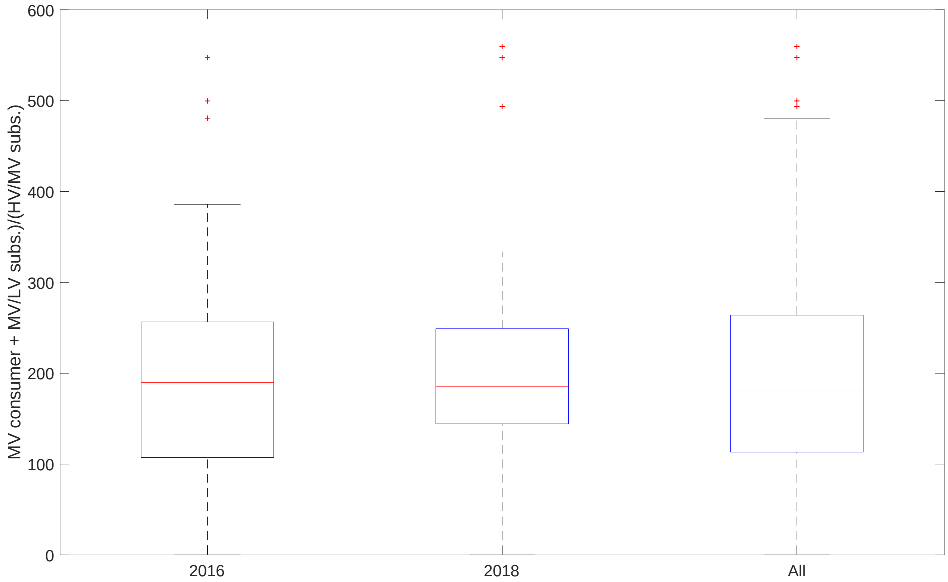


Figure 43. MV supply points per HV/MV substation



Annex 2. Other indicators

In this annex the remaining indicators not presented in the previous chapters are reported for the interested reader. In the following figures the green and red lines will respectively show the average and median values of the parameters under analysis.

Figure 44. LV consumers per area

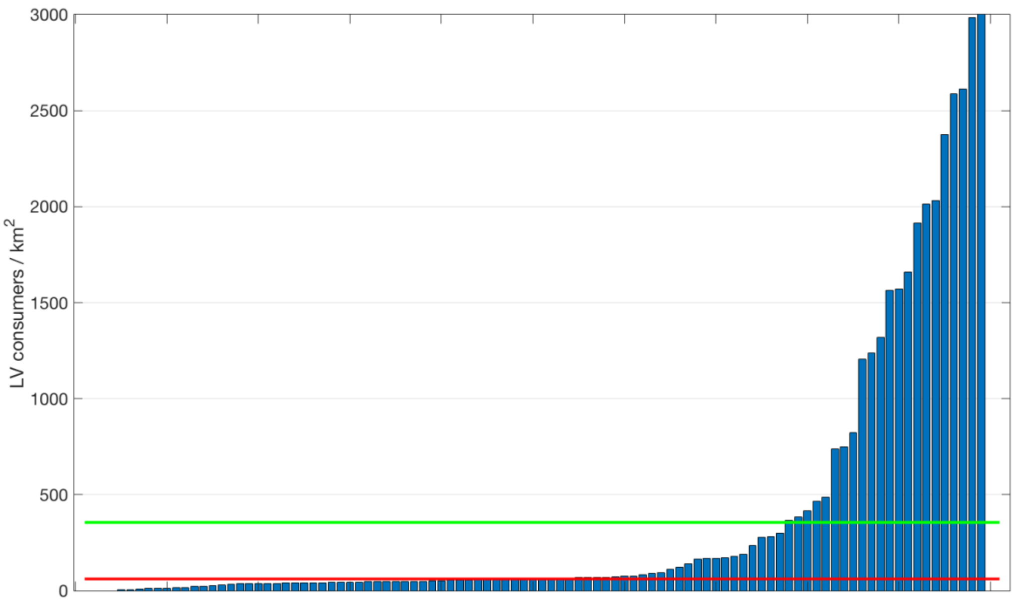


Figure 45. Area per MV/LV substation

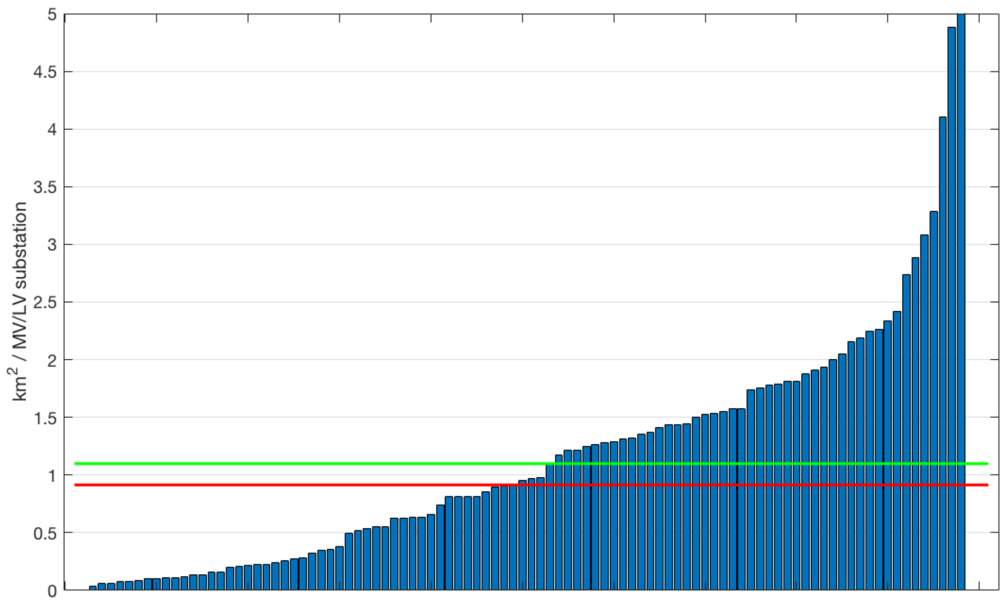


Figure 46. Number of MV consumers per area

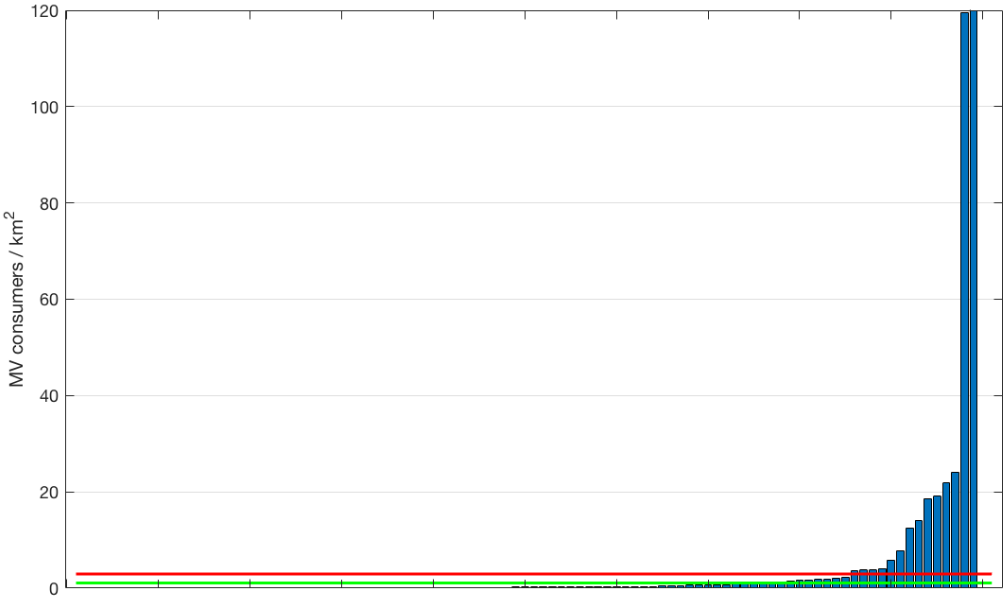


Figure 47. LV circuit length per area of distribution

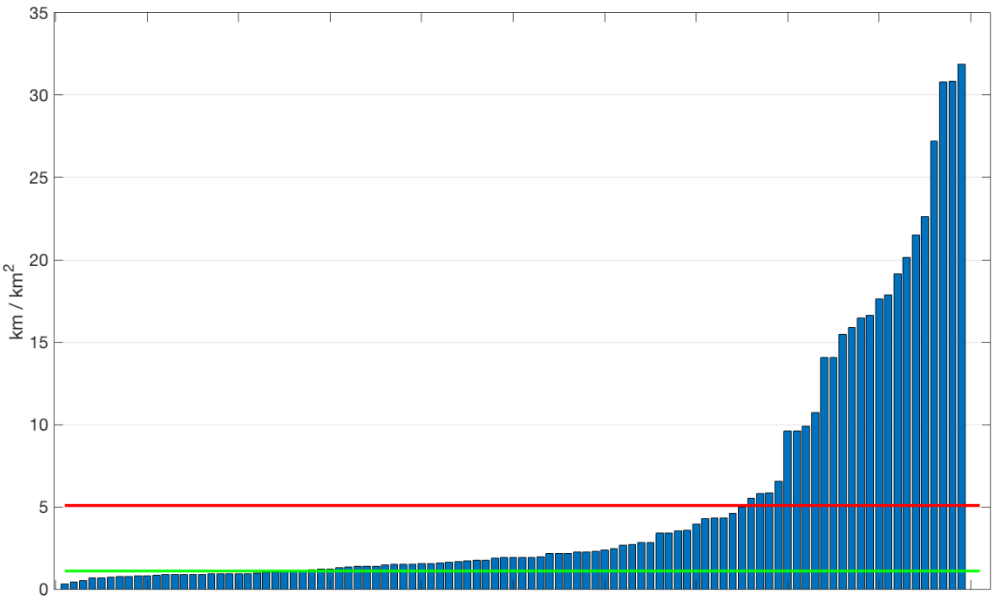


Figure 48. MV circuit length per area of distribution

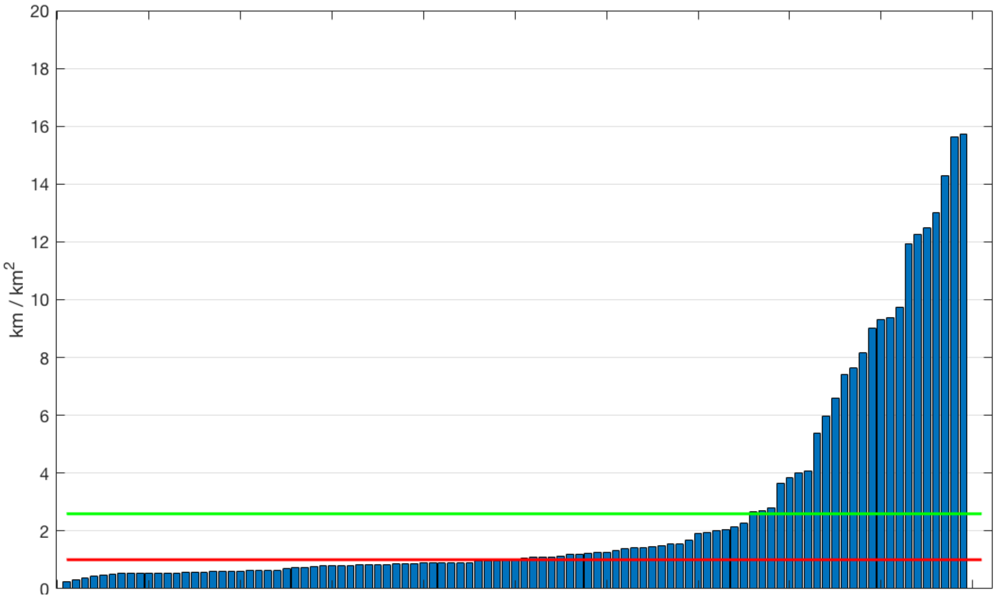


Figure 49. Area covered per capacity of MV/LV substation

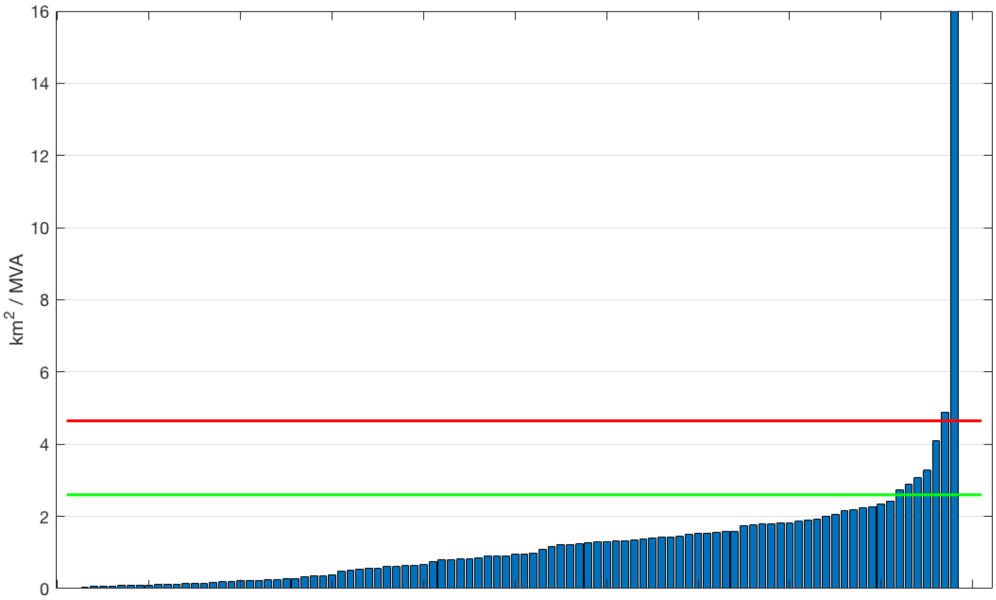


Figure 50. Area per HV/LV substation

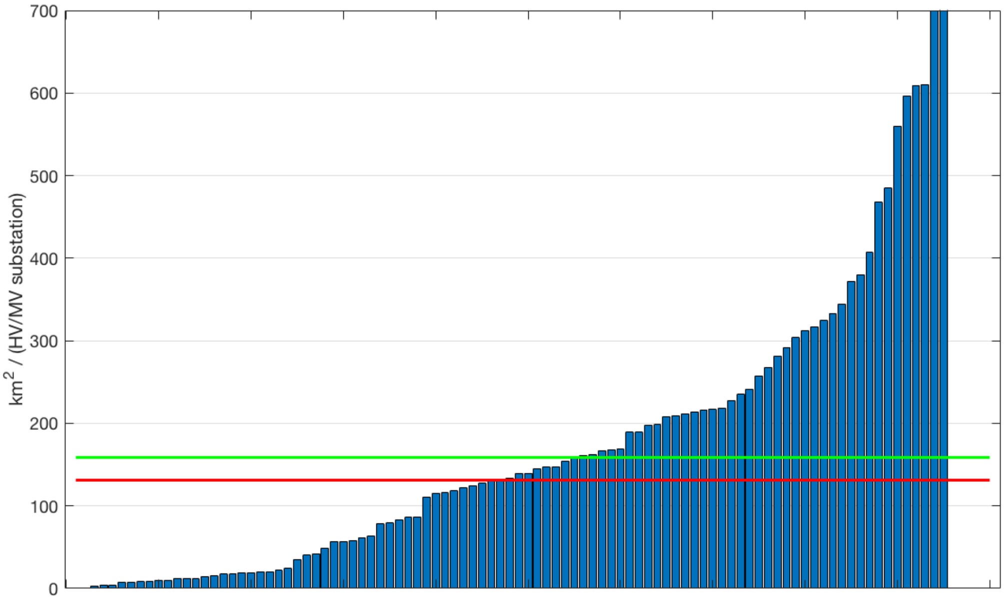


Figure 51. Capacity of HV/MV substation per MV supply point

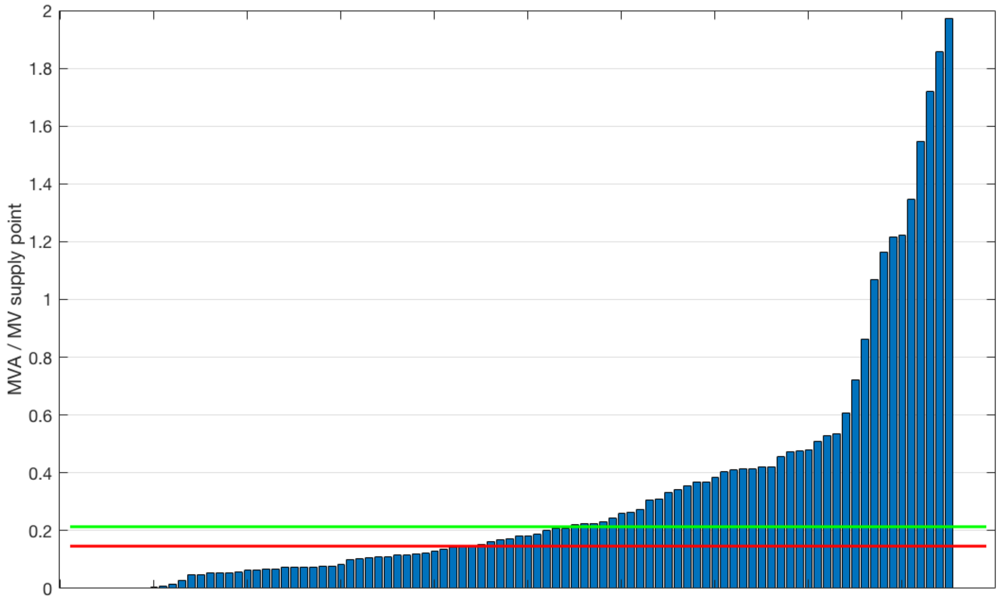


Figure 52. Ratio of capacity of MV/LV substations per capacity of HV/MV substations

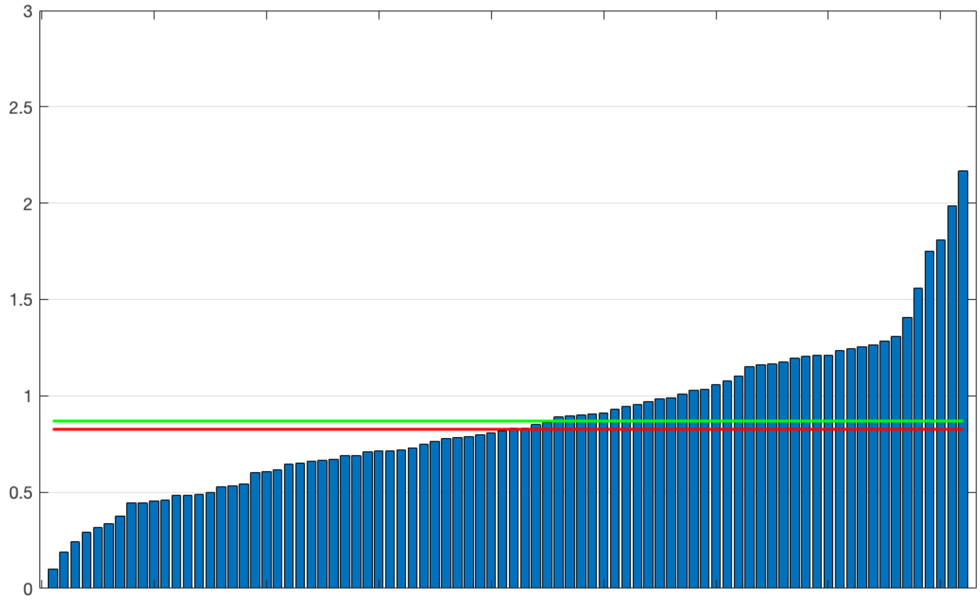


Figure 53. Area per capacity of HV/MV substations

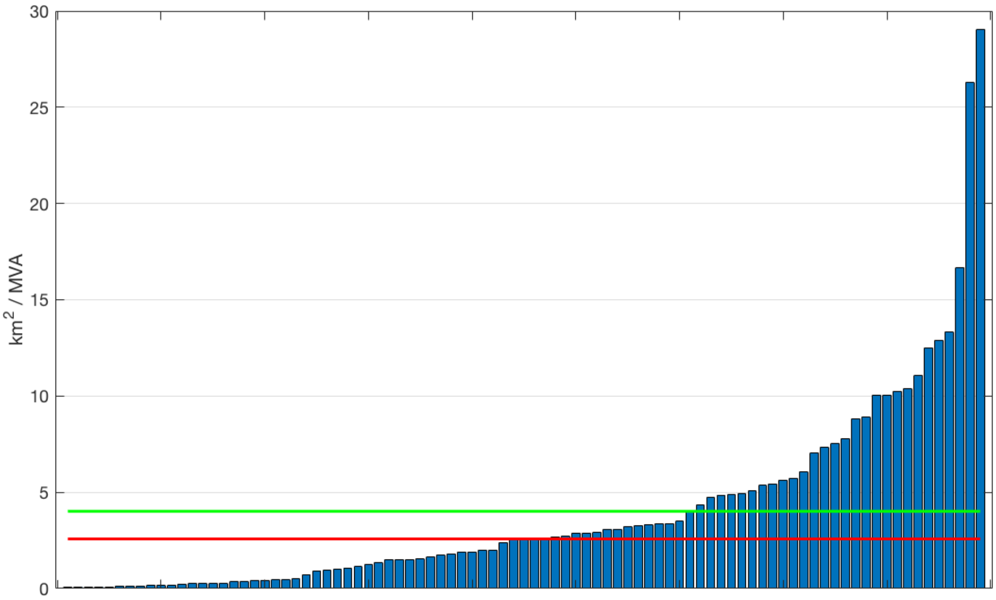


Figure 54. HV circuit length per HV supply point

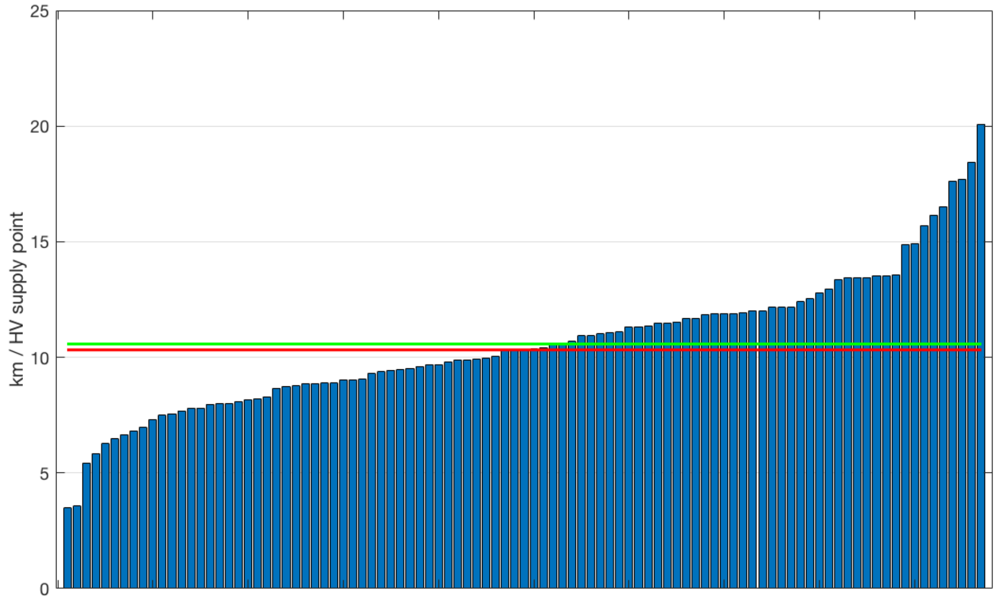


Figure 55. HV circuit length per area

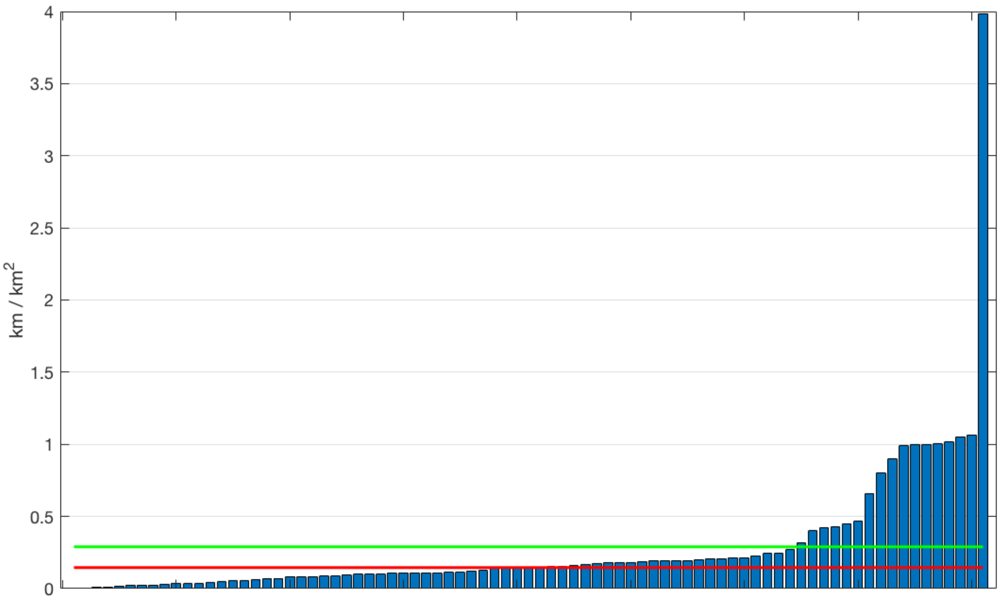


Figure 56. HV underground ratio

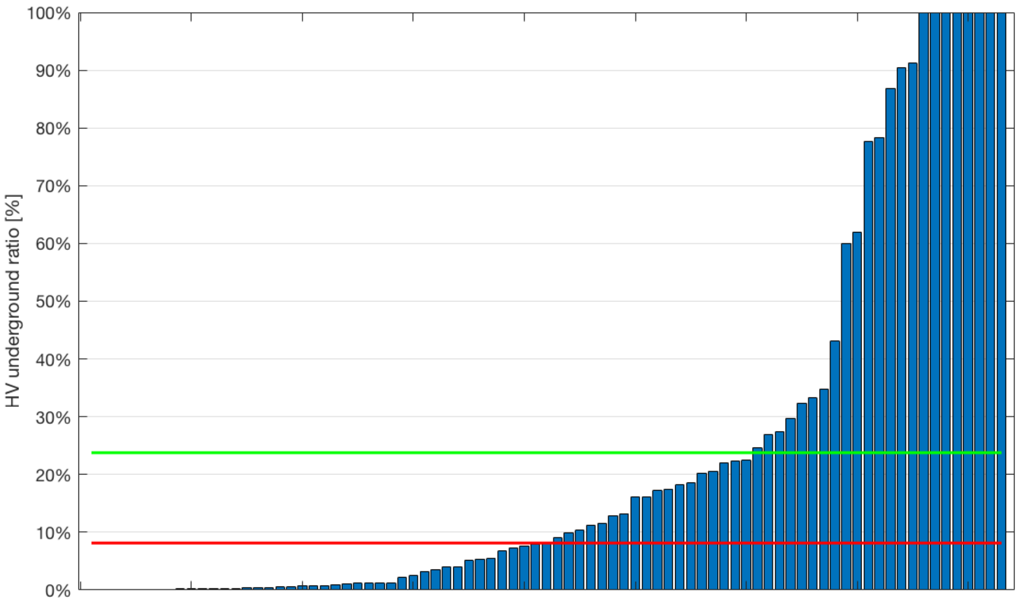


Figure 57. Number of electric vehicle public charging points per consumer

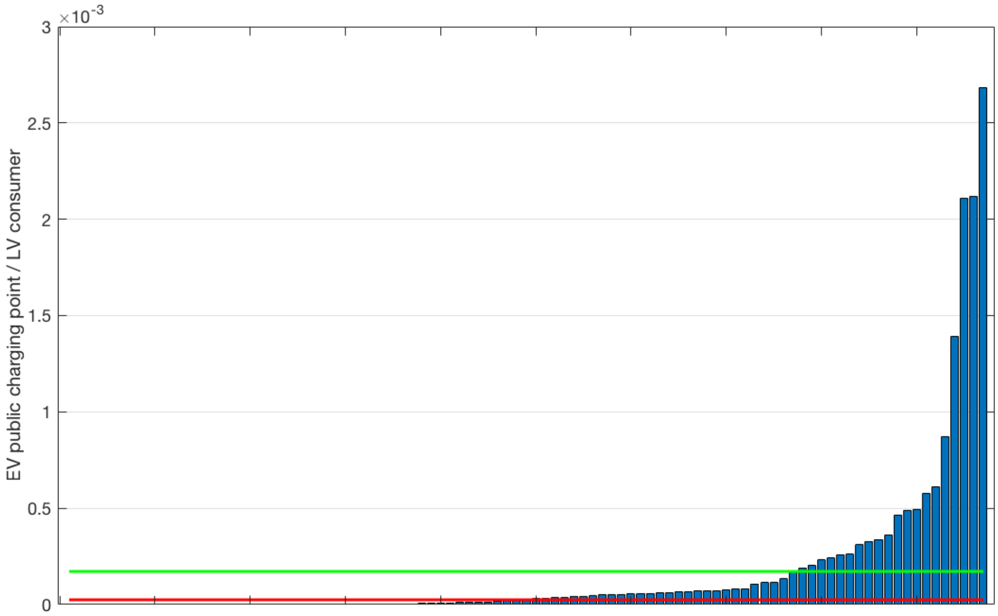


Figure 58. SAIDI (min./consumer*year)

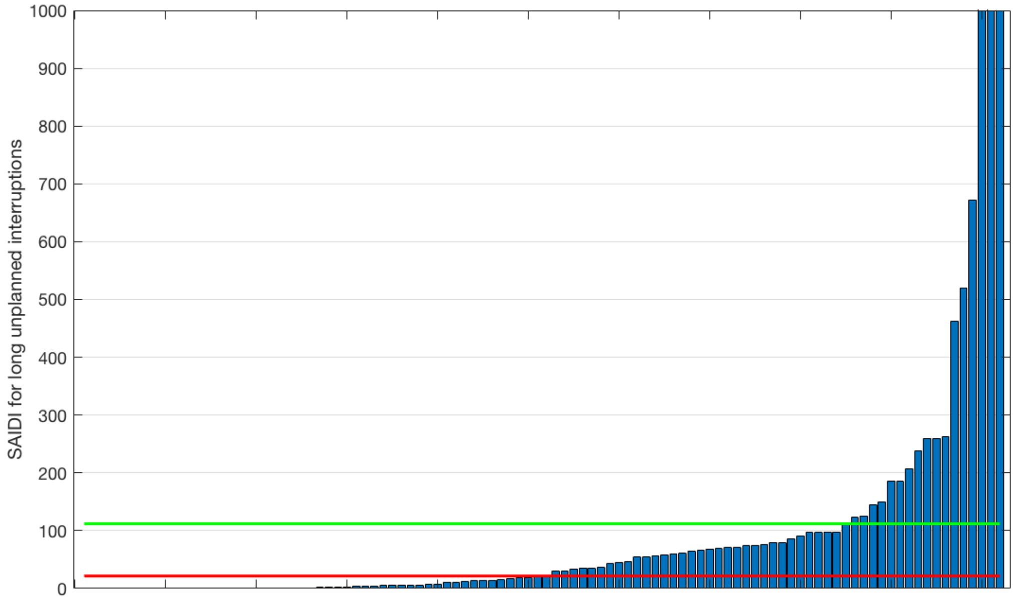
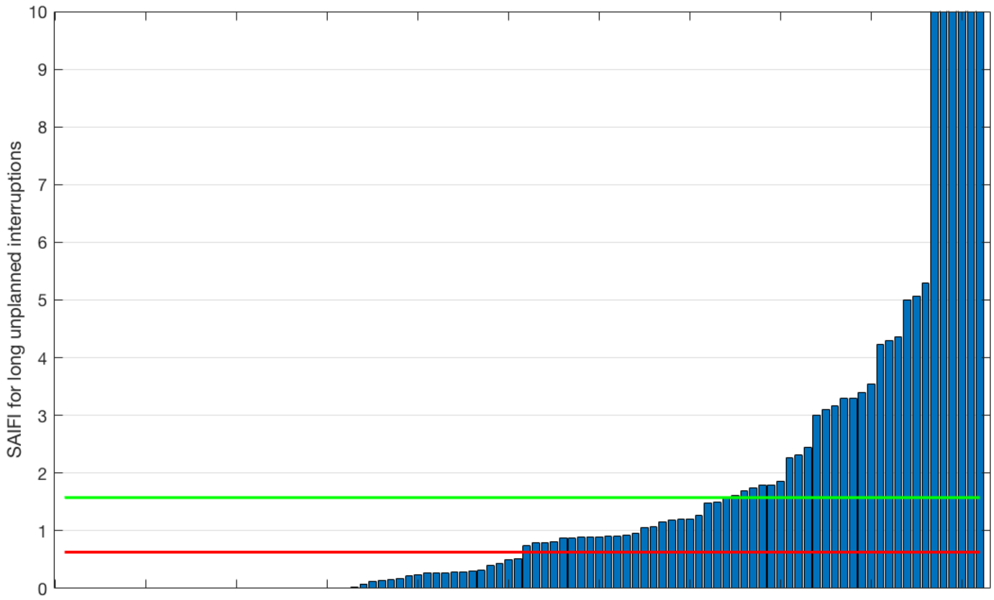


Figure 59. SAIFI (int./consumer*year)



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