SEVENTH FRAMEWORK
PROGRAMME

THEME [ENERGY.2012.7.1.1] Integration of Variable Distributed Resources in Distribution Networks

Sustainable

(Deliverable 8.2)

Scaling-up and replication rules considering the requirements and local conditions in demo sites

Lead Beneficiary:

COMILLAS

Table of Contents

List of Figures

List of Tables

List of Acronyms and Abbreviations

µG	Microgeneration
AMI	Advanced Metering Infrastructure
AMM	Advanced Metering Management
CAPEX	Capital Expenditures
CBA	Cost-Benefit Analysis
DER	Distributed Energy Resources
DG	Distributed Generation
DGA	Distribution Grid Area
DMS	Distribution Management System
DSM	Demand Side Management
DSO	Distribution System Operator
DSTATCOM	Distribution Static Compensator
DTC	Distribution Transformer Controller
DVR	Dynamic Voltage Restorers
ENS	Energy Not Supplied
ESCO	Energy Service COmpanies
EV	Electric Vehicle
ICT	Information and Communication Technologies
UPS	Uninterruptible Power Supply
FACTS	Flexible AC Transmission Systems
FiT	Feed-in Tariff
HHI	Herfindahl-Hirschman Index
HV	High Voltage
LV	Low Voltage
MV	Medium Voltage
NRA	National Regulatory Authority

OPEX	Operational Expenditures
OPF	Optimal Power Flow
PLC	Power Line Communications
PV	Photovoltaic
QoS	Quality of Supply
RES	Renewable Energy Sources
RTU	Remote Terminal Unit
R&D	Research and Development
ROCE	Return on Capital Employed
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition
SRA	Scalability and Replicability Analysis
SSC	Smart Substation Controller
SVC	Static VAR Compensator
ToU	Time of Use
TSO	Transmission System Operator
TVPP	Technical Virtual Power Plant
UoS	Use of System
V2G	Vehicle-to-Grid
VPP	Virtual Power Plant
WACC	Weighted Average Cost of Capital

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Executive Summary

This report aims to identify scaling-up and replication rules and methods of the SuSTAINABLE functionalities on Portugal, Greece, UK and Germany. The report represents the second step of the scalability and replicability of the SuSTAINABLE concept since it considers the insights of Deliverable 8.1 where questionnaires for replicability and scalability were distributed to project partners with the aim of identifying barriers for a large scale deployment. The study carried out in this report takes into consideration the approaches from other European projects like GRID+ and GRID4EU to provide relevant results from a different perspective, contributing to the definition of a scalability and replicability analysis methodology at European level.

In the present methodology, first the local implementation conditions for each country have been analysed. Four different types of conditions have been considered: geographical, technological, regulatory, and stakeholders. Then, the macro-scale replication of the functionalities developed in the project has been assessed. This has been performed by analysing the most important barriers identified in Deliverable 8.1 and determining their relevance and potential impact of the macro-scale replication of the SuSTAINABLE concept. Finally, the scaling-up and replication rules have been defined, where the major conclusions have been the following:

- In the case of RES forecasting, UK has been identified as the country with lower barriers to the deployment of this functionality, whereas Portugal has been presented as the region where the identified barriers have a higher impact.
- With regard to load forecasting, Germany has been shown as the region with the highest risk for the deployment of this functionality, conversely to Greece where the same conditions highlights this area as the most favourable.
- For the monitoring and state estimation functionality, UK has been identified as the most positive place for a large scale deployment and Portugal the less attractive.
- With regard to the coordinated voltage control, Greece and UK have been noticed as places with lower impacts than the others. Nevertheless, the scalability and replicability of this functionality presents high level of risk, since five different barriers were identified, being the second functionality with the highest amount of barriers after the TVPP.
- In the case of the TVPP, significant differences among all the countries have been identified, being Germany identified as the best region, followed by UK. On the contrary, Portugal has been noticed as the region with the highest level of risk, followed by Greece.
- For the provision of differentiated QoS, UK and Germany have been detected as the most favourable regions for the implementation of this functionality.
- The flexibility based reinforcement planning has been identified more risky in Portugal than in the rest of the countries.
- For the power quality planning, Portugal has been identified as the least favourable region, conversely, UK has presented fewer constraints.
- Regarding the advanced protection planning, Greece has been posed as the country that shows better conditions for the deployment of this functionality.

1. Introduction

This report aims to identify scaling-up and replication rules and methods of the functionalities developed in this project focusing on the demo sites of Portugal and Greece, and extending the analysis to UK and Germany. The report represents the second step of the scalability and replicability of the SuSTAINABLE concept since it considers the insights of Deliverable 8.1 where questionnaires for replicability and scalability were distributed to project partners with the aim of identifying barriers for a large-scale deployment. Nevertheless, the definitions of scaling-up and replication rules from other European projects are analysed to ensure that this report is aligned with the previous work and provides additional valuable insights.

The GRID+ project [1] developed an assessment tool based on a questionnaire to highlight barriers and R&D needs for scalability and replicability of smart grid projects. In the deliverable 4.4 of the GRID+ project the methodology developed to perform such assessment is described, as well as the conclusions of the study that collected the responses from a number of DSOs and TSOs involved in different projects. The adopted methodology is based on the analysis of technical, economic, regulatory and stakeholder-related factors that might be considered as a source of risks and barriers for scalability and replicability. The technical factors determine whether the project might be inherently scalable and/or replicable; the economic factors whether it is economically viable; and the regulatory and stakeholder-related reflect the extent to which the existing environment is suitable for receiving the project. In this regard, the methodology states that if a project is not technically scalable and replicable, it cannot be scaled-up and replicated, whereas if it is not economically or regulatory scalable and replicable, business models or policies could be adapted to make it more favourable for new deployments. The GRID4EU project [2] is another relevant initiative that analyses the results of demos in six different countries: Germany, Sweden, Spain, Italy, Czech Republic and France. The adopted methodology for Scalability and Replicability Analysis (SRA) substantially differs from the one developed in the GRID+ project, since in this case it is performed from a technical, quantitative analysis based on simulation to compute the values of KPIs under different boundary conditions. Additionally, the project also used different questionnaires to collect the regulatory and stakeholder conditions of the countries involved in the project. The GRID4EU technical SRA defines different approaches for scaling-up and replication. The scalability analysis may be performed in terms of density considering a larger penetration of technological factors in the demo region, and in terms of size considering a larger area that presents different types of networks but same regulatory and stakeholders boundary conditions. In regard to the replicability concept, the intra-national dimension is considered to perform analysis in different regions of the same country, which is quite similar to the approach of scaling-up in terms of size, whereas the international dimension covers the analysis in different countries considering their local boundary conditions. A similar technical SRA has been also applied for the demos of the iGREENGRID project [3].

The methodology followed in the SuSTAINABLE project aims to combine the approaches of the aforementioned initiatives to provide relevant results from a different perspective, contributing to the definition of a scalability and replicability analysis methodology at European level. In the present methodology, first the local implementation conditions for each country are analysed, where all the factors that affect the deployment of the SuSTAINABLE project are assessed. Then, the macro-scale replication of the functionalities developed in the project is assessed, based on the previously identified local conditions. Finally, the scaling-up and replication rules are defined.

2. Analysis of local implementation conditions

Local implementation conditions of a smart grid project represent the characteristics of the playing ground where new functionalities are to be deployed. In this project, local conditions have been classified in two major groups according to their nature, which can be intrinsic or extrinsic.

From the DSO point of view, intrinsic local implementation conditions comprise those that are inherent to the current state of the power system where the project takes place. These conditions have been divided in two types: geographical conditions and technological conditions. Geographical conditions comprise the population density, the orography, and the type of area (rural, urban). Technological conditions comprise all the technical aspects of the power system, which may be related to the network configuration, the generation mix, and the reliability and security in power supply, etc.

Extrinsic conditions include characteristics that are external to the power system itself but present an interaction that somehow affects the system operation and development. Again, two types of extrinsic conditions have been analysed: regulatory conditions and stakeholder conditions. Regulatory conditions include all the legislation and rules that affect the activity of the DSO, as well as economic incentives, connection charges, etc. Stakeholder conditions represent the relationship of the DSOs with other agents involved in the power system like DER owners or consumers, as well as their viewpoints.

Table 1 Summary of local implementation conditions considered in the SuSTAINABLE project

Nature	Type	Local implementation conditions
Intrinsic	Geographical	Population density Orography Type of network (rural/urban)
	Technological	Network configuration Generation mix Reliability of supply
Extrinsic	Regulatory	Operation rules Economic incentives Network access
	Stakeholder	Consumer perception Relationship with TSOs Supplier availability

Table 1 shows a non-exhaustive list of the aforementioned conditions considered for the purpose of the SuSTAINABLE project. In the following subsections these factors are analysed for Portugal and Greece, which are the countries where the demos of the project take place. Depending on the data availability, some factors have been addressed from a local perspective and others from a regional or country perspective.

2.1 Geographical conditions

The first type of local condition that affects a smart grid project is the scenario where the new functionalities have to be deployed. In the SuSTAINABLE project two major demo sites are covered: Évora in Portugal and Rhodes in Greece. The geographical characteristics of each region are described below. The data has been obtained from the statistics published by the World Bank [4] and the pictures are from two different sources, the population density maps were obtained from the web popdensitymap [5] and the geography maps from wikimedia commons [6].

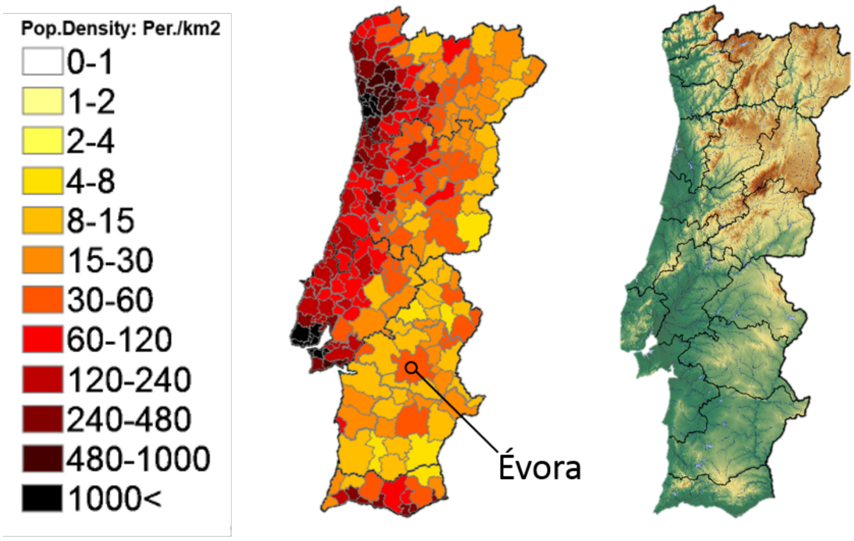

Figure 1 Population density and orography of Portugal

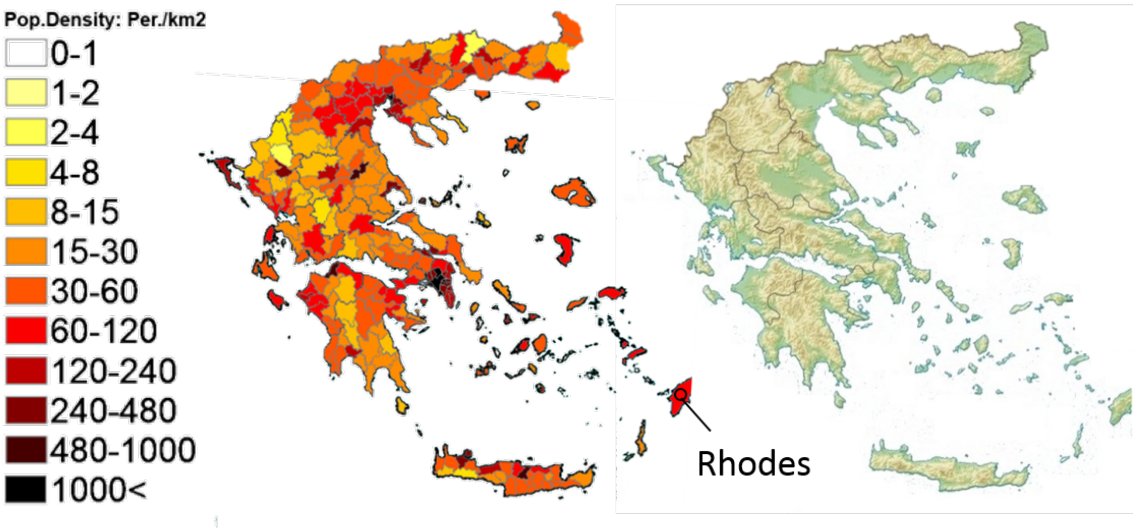

Figure 2 Population density and orography of Greece

Évora is a living lab for EDP InovGrid project, which represents one of the first European Smart Grid projects. The municipality has 54.000 inhabitants and 1.307 km^2 of area (urban and rural), and it is located in the hinterland of the south side of the country, which in total has 92.391 km^2 and the population in 2013 was 10.43 million people. The location of Évora, as well as the population density and the orography of the country, can be seen in Figure 1. As it can be seen in this figure, Évora presents an average population relatively to the country - around 10 times lower than Lisbon, which is the most populated region. It presents a very soft relief, conversely to other regions in the north of the country.

Rhodes is a Greek island with 1.400 km^2 and 118.000 inhabitants in 2011, ranked as the seventh most populated region of the country. It represents the fourth largest island in Greece, which has around 200 inhabited islands. However, the rest of the islands are two thirds of the area of Rhodes, or smaller. Compared to Portugal, Greece is much more irregular, not only because of the number of islands, but also because of the geography, which is much more mountainous. The population of Greece was 11.03 million people in 2013 and the area is 131.960 km^2.

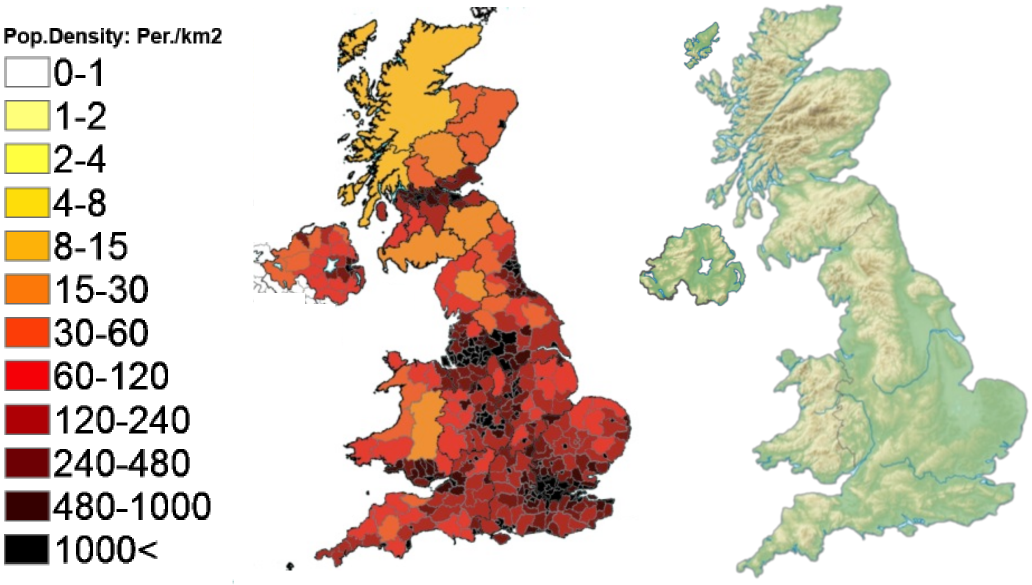

Figure 3 Population density and orography of UK

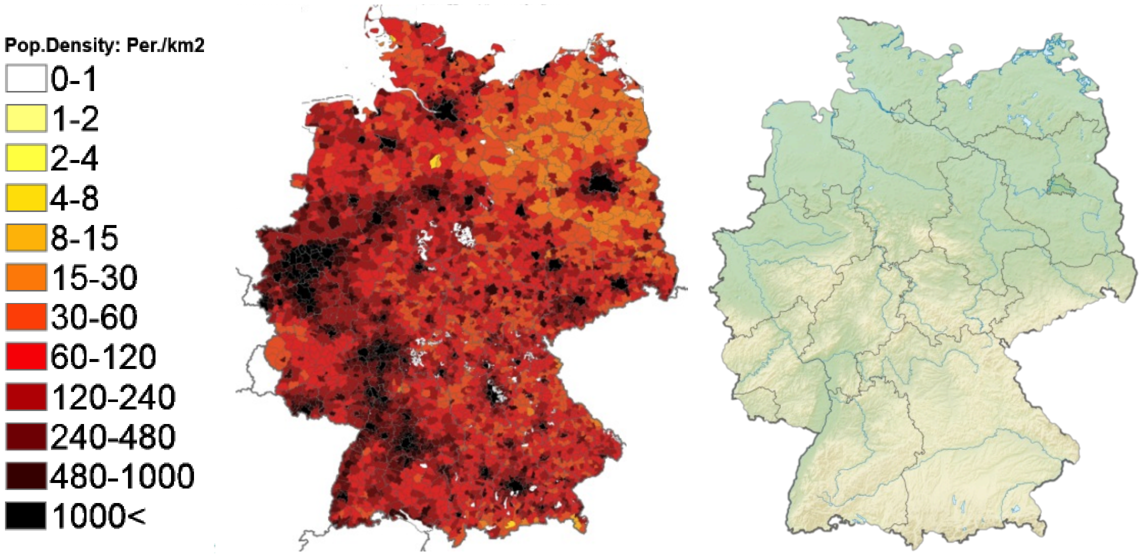

Figure 4 Population density and orography of Germany

Furthermore, the project considers two other regions according to the partners that develop the functionalities within the SuSTAINABLE concept, which are UK and Germany. The population density and orography of both countries can be seen in Figure 3 and Figure 4. These countries are much larger than Portugal and Greece, with a total area of 243,610 km^2 for the case of UK and 357,170 km^2 for Germany. The population is also substantially higher, being this parameter between 6 and 8 times the value of the previous countries. In respect to the orography of both regions, the geography of Germany is really flat, conversely to UK where the geography is more irregular and the most mountainous regions present the lowest population density rates.

Finally, Table 2 summarizes all the previous data, where the percentage of rural population for each country is also included. It can be seen that the country with the highest rural population is Portugal with almost a 40%, followed by Germany and Greece with 25% and 23% respectively, and finally UK with 18%.

Table 2 Summary of area and population statistics in Portugal, Greece, UK and Germany

	Portugal	Greece	UK	Germany
Total Area (km²)	92,210	131,960	243,610	357,170
Population (millions of inhabitants)	10.46	11.03	64.11	80.65
Rural Population (% of total population)	38%	23%	18%	25%

2.2 Technological conditions

After the analysis of the geographical conditions of each country, the next step is to analyse the technological conditions that constitute the power system of each region, such as the network configuration, the mix of generation technologies and the level of reliability of supply. Data has been obtained from technical questionnaires distributed to project partners as well as from public sources like Eurelectric, ENTSO-E, and CEER. The characteristics of the network configuration aggregated by country are summarized in Table 3. The data from Greece and Portugal has been obtained from technical questionnaires answered by the two DSOs from these countries involved in the SuSTAINABLE project. It can be seen that in general both countries present very similar values in terms of number of customers and total circuit length. However, in Portugal the number of customers connected to the MV network is significantly higher, as well as to the HV, while in Greece there are no customers connected to this voltage level. This makes HV network in Greece much shorter than in Portugal, and at the same time the MV network of Greece substantially longer, despite a smaller number of customers connected at this voltage level. In the case of LV network, Portugal has larger one. In terms of undergrounding, Portugal has 20% in LV and MV networks, which doubles the ratio in Greece where only around 10% of the cables are undergrounded. Regarding the substations, in Greece there are less HV/MV substation but with higher installed capacity per substation than in Portugal, whereas in the case of MV/LV substations, Greece has many more secondary substations than Portugal, but with smaller size. Finally, in terms of DER, Portugal has around 30% more installed capacity connected to the distribution network than Greece. However, 35% of the DER in Greece is connected to the LV network, compared to the 2% in the case of Portugal.

Table 3 Network configuration data in Portugal and Greece

	Portugal	Greece	UK	Germany
Total Number of Customers connected	**6,075,948**	**7,392,722**	**30,828,266**	**49,294,962**
of that LV (< 1 kV)	6,052,064	7,381,515		
of that MV (1- 36 kV)	23,536	11,207		
of that HV (> 36 kV)	348	0		
Total Circuit length (km)	**224,866**	**233,005**	**837,156**	**1,772,696**
LV (< 1 kV)	**141,324**	**123,352**	**408,875**	**1,152,138**
of that Overhead	108,197	109,190	70,276	143,516
of that Underground	33,127	14,160	338,599	1,008,622
MV (1-36 kV)	**74,239**	**108,804**	**352,841**	**506,671**
of that Overhead	58,195	98,486	193,102	122,226
of that Underground	16,044	10,317	159,739	384,445
HV (> 36 kV)	**9,303**	**849**	**75,440**	**113,887**
of that Overhead	8,779	639	50,462	106,869
of that Underground	524	210	24,978	7,018
Number of HV/MV Substations	**411**	**236**		
Total installed capacity of HV/MV Substations (MVA)	17,094	22,657		
Number of MV/LV Secondary Substations	**66,023**	**160,975**	**665,408**	**461,900**
Total installed capacity of MV/LV Secondary Substations (MVA)	19,833	28,453		
Total installed capacity of renewable generation connected (MW)	**4,935**	**3,725**	**9,000**	**79,652**
Installed capacity of renewable generation connected to LV networks (MW)	114	1,314		22,944
Number of electric vehicle public charging points	**1,056**	**0**	**8,478**	**4,900**

This analysis has been extended as much as possible to UK and Germany with information from the Eurelectric paper *Power Distribution in Europe – Facts and Figures* [7] and other public local sources [8]–[11]. These countries logically present much larger networks than Portugal and Greece. The network configuration in terms of LV and MV levels of UK is similar to the one presented in Greece, where the circuit length of LV networks is comparable to the MV networks. Conversely, the case of Germany is more similar to Portugal, where more than 60% of the lines are in the LV network, whereas the MV lines account for around 30% of total circuit length in both countries. In regard to the HV, UK has the largest HV network in relative terms (9%), in contrast to Greece which is the one with the smallest one (0.3%).

The undergrounding degree is another characteristic that considerably differs between these countries. Thus, UK and Germany present undergrounding levels in the LV network higher than 80%, which compared to the 23% of Portugal and the 11% of Greece makes a huge difference between these countries in this regard. In the case of the MV, Germany keeps a really high ratio with a 76% of undergrounding, whereas UK shows a more moderate 45%. Again these values are significantly higher than in Portugal and Greece. Furthermore, in the case of UK even the HV network presents a 33% of underground cables, but in this case Germany shows only a 6%, similarly to Portugal. Greece shows a 25%, but with a HV network size considerably smaller. In respect to the number of secondary substations, in Germany this number is lower than in UK, like the comparison between Portugal and Greece. In terms of DER, Germany clearly shows a very relevant high penetration, whereas in the case of UK this amount is much more moderated. Finally, regarding the electric vehicle market UK shows the largest penetration in the analysed countries, where Portugal and Germany present a more moderate penetration. Conversely, in Greece the presence of this type of vehicles is not expected to increase too much due to the lack of charging infrastructures. In regard to the generation mix, Table 4 and Figure 5 show the installed capacity by country, whereas Table 5 and Figure 6 show the yearly electricity generation by country. Data is related to 2013 and has been obtained from ENTSO-E [12] and other sources for the different countries, like REN for Portugal [13], IEA for Greece [14], DECC for UK [15], and Fraunhofer ISE for Germany [16].

In the case of Portugal, the main RES is hydro (accounting large and small hydro). Wind power is also quite important followed by solar PV and other RES. In the case of Greece, hydro is also the most significant RES. The next largest technologies are solar PV and wind. In the case of UK wind is the largest RES technology, followed by hydro. Solar and biomass technologies have similar values according to installed power. In Germany, solar PV is the largest RES technology and represents the second largest technology in terms of installed capacity in the whole electricity system, closely followed by wind power, which demonstrates the large share of RES in Germany and the strong support that RES technologies have in this country.

Among the analysed countries, Portugal shows the largest share of RES generation, mainly produced by hydro and wind. Greece has little share of RES output when it is compared with conventional generation, such as coal and gas. This situation is similar in UK, where RES share generation is small compared to conventional generation. In addition, nuclear technology has a significant output regarding its installed capacity. In Germany, despite the large RES penetration and the high level of production for these technologies compared to the other countries, it is not so relevant, as a carbon-based generation is still strongly implemented.

Table 4 Installed capacity by country (GW)

	Portugal	Greece	UK	Germany
Coal and conventional	2.11	7.76	26.43	47.13
Gas	4.75	2.88	35.12	28.22
Nuclear	-	-	9.9	12.07
Wind	4.36	1.52	10.97	33.97
Hydro	5.65	3.23	4.3	5.62
Solar	0.28	2.41	2.82	36.71
Other RES	0.61	0.04	3.82	8.15
TOTAL	**17.76**	**17.84**	**93.36**	**171.87**
RES share (%)	**61.4%**	**40.4%**	**23.5%**	**49.1%**

Table 5 Electricity generation by country (TWh)

	Portugal	Greece	UK	Germany
Coal and conventional	11.39	23.23	132.8	255.85
Gas	6.9	12.15	96.02	39.58
Nuclear	-	-	70.6	92.13
Wind	11.75	3.39	24.5	50.8
Hydro	13.48	5.96	7.6	20.48
Solar	0.44	3.36	2.01	31
Other RES	2.7	0.19	21.65	47.6
TOTAL	**46.66**	**48.28**	**355.18**	**537.44**
RES share (%)	**60.8%**	**26.7%**	**15.7%**	**27.9%**

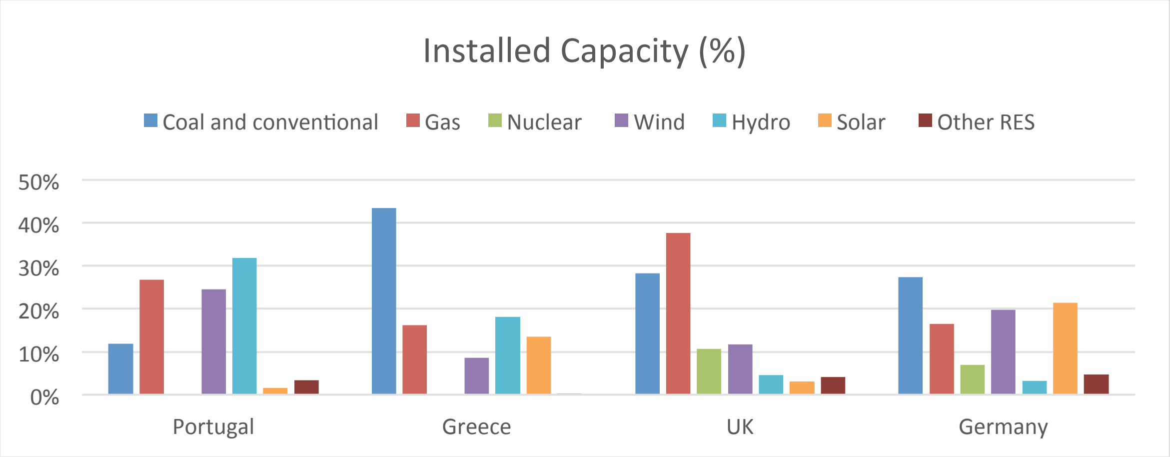

Figure 5 Installed capacity by country (%)

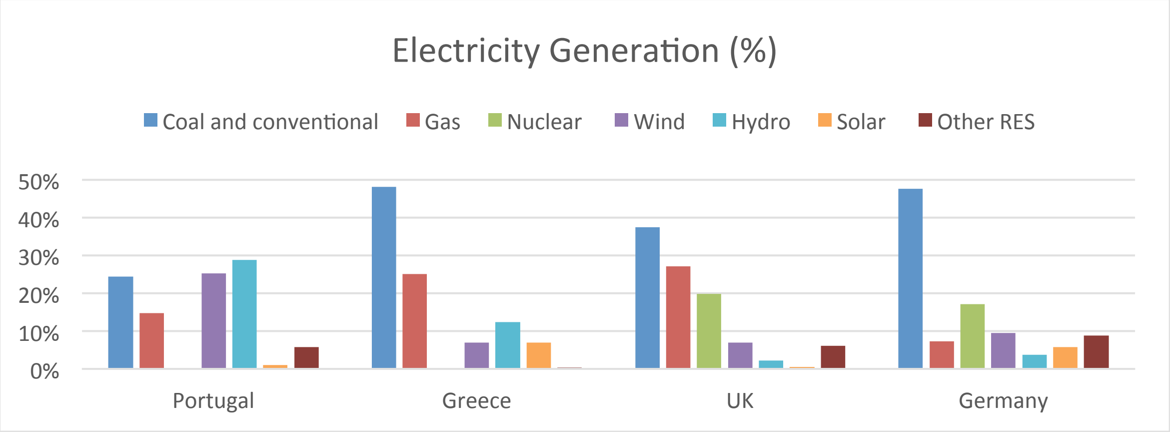

Figure 6 Electricity generation by country (%)

Additionally, the expected increase of RES for the 2020 horizon has been analysed. In Table 6 the expected RES installed capacity in 2020 for each country is included, whereas in Figure 7 the increase in RES capacity is shown as the difference between data in Table 6 and Table 4. This information has been obtained from the EU Industry Roadmap published in 2011 by the European

Renewable Energy Council [17]. It can be seen that the country with the largest increase of RES is UK, which compensates the current low levels of RES compared to the other countries. Conversely, Germany shows the lowest increase of RES, mainly because the current share of RES capacity is really high. By contrast, Portugal and Greece show moderate increase of RES.

Table 6 Expected RES installed capacity in 2020 by country (GW)

	Portugal	Greece	UK	Germany
Wind	7.50	6.50	38.92	55.00
Hydro	9.82	3.54	4.30	6.50
Solar	2.00	3.00	8.00	39.50
Other RES	1.74	1.12	6.15	9.96
TOTAL	21.06	14.16	57.37	110.96
RES Increase 2013-2020 (%)	80.8%	96.7%	157.4%	31.4%

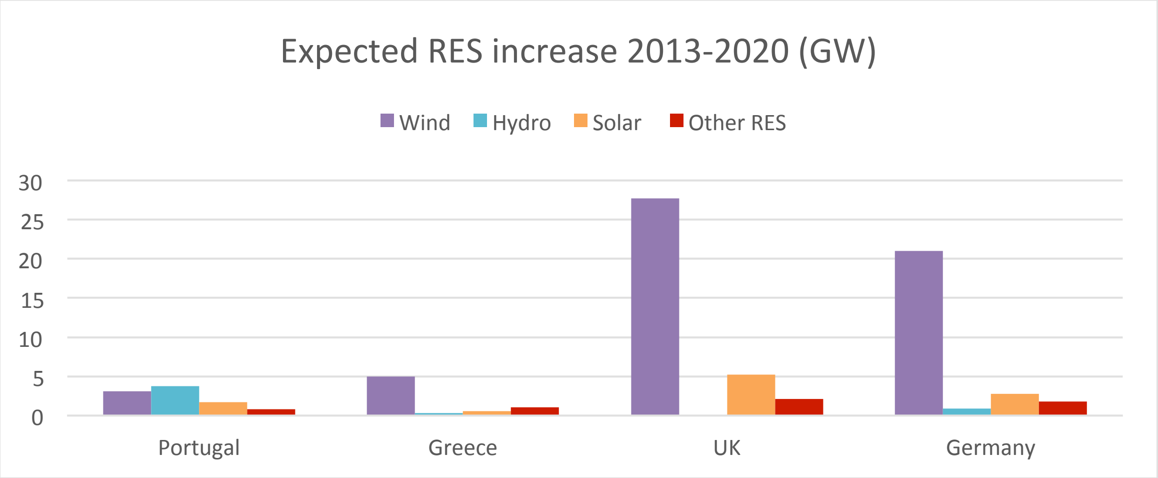

Figure 7 Expected RES increase between 2013 and 2020 by country (GW)

Table 7 includes the voltage limits and the SAIDI and SAIFI continuity of supply indicators for long interruptions excluding exceptional events, obtained from the *CEER Benchmarking Report on the Continuity of Electricity Supply* [18]. It can be noticed that the best reliability indexes are obtained in Germany and UK, where the highest undergrounding levels are achieved. Portugal and Greece have also good performance in terms of reliability. Indeed, despite the fact that Portugal is the region with the highest level of rural population, the reliability indicators are still low.

Table 7 Voltage limits and continuity of supply indicators by country

	Portugal	Greece	UK	Germany
Voltage limits	±5%	±10%	±10%	±10%
SAIDI (minutes)	88.7	96	54.71	15.32
SAIFI	1.75	1.6	0.58	0.47

2.3 Regulatory conditions

In this section the regulatory conditions related to DSOs and DER are analyzed. The required data has been mainly obtained from a regulatory questionnaire delivered to project partners, when complementary sources have been used their references are included in the related section. A template of the questionnaire is included in Annex 1. Additionally, relevant regulatory insights can be obtained from previous EU projects like SOLID-DER [19], DG-GRID [20], RESPOND [21] and RES INTEGRATION [22]. The following issues have been addressed for Portugal, Greece, UK and Germany:

1. DER participation in network services and relationship with DSOs
2. Business model for purchase and sale of energy by DER
3. Balancing markets in ancillary services
4. DER network access: connection charges and use-of-system charges
5. Effect of DER on planning, operation, network losses, reliability of supply and incremental costs
6. Active demand response and smart metering
7. DSO incentives for innovation

2.3.1 DER participation in network services and relationship with DSOs

DER units can potentially provide network services, such as voltage control or local congestion management, and thus contribute to improve system efficiency. However, the participation of DER in such services will be subject to the regulation in force.

In Portugal there are no specific requirements for voltage control. Conversely, in Greece the DSO selects by regulation the preferred combination of reactive power control between the following options: power factor range between 0.95 lagging to 0.95 leading; control of the power factor or the reactive output power to a specific level; and active voltage regulation respecting the injection and absorption capabilities of DER. These requirements are similar in UK, where DER shall operate at a power factor within the range 0.95 lagging to 0.95 leading unless otherwise agreed with the DSO, for instance for power factor improvement, but not for other flexibility services like local congestion management. In Germany, DER also participates in reactive power control, and the requirements mainly depend on the type of technology and size. For instance, for PV facilities between 3.68 kVA and 13.8 kVA the reference power factor is 0.95, whereas for bigger PV units a power factor up to 0.9 can be requested by the DSO, whereas in the case of wind units connected to the distribution network, the DSO can request a power factor between 0.95 lagging and 0.95 leading.

Regarding congestion management, in Portugal there is no legal framework for curtailment of DER installations, and compensations cannot be claimed. In emergency conditions, DER installations connected to distribution network can be disconnected when an upward or downward frequency variation from the allowed limits is presented in the distribution system. In Greece the active power production of DER can be limited or their operation can be interrupted in the following cases, but without any kind of economic incentives: in compliance with demands made by the TSO; in emergency situations (ensuring the safety of the users and the stability of the system/network); in case of equipment failure or maintenance works; and in case the technical examination during the connection phase renders this choice justifiable in both technical and economic terms. In Germany DER can only be curtailed for system security reasons and on the distribution level the curtailment has to be compensated by the responsible DSO, although only for certain situations covered by the feed-in-management scheme currently in place. However, DSOs are expected to reinforce their network to dissolve the bottleneck causing the curtailment. With regard to the communications, since January 2012 all new built PV plants >30 kWp are obligated to install a communication interface that enables the DSO to reduce the injected power of the plant. Furthermore, all DER plants have to provide instantaneous data about the supplied power via a bidirectional interface. Solar plants <30 kWp have a choice to either reduce injected active power to a maximum of 70 % of the installed capacity or to install the same technical equipment as plants >30 kWp. Most European countries like the ones involved in this project present unbundling of distribution and generation activities. However, in the non-interconnected islands of countries like Greece and Portugal the DSO is also responsible for managing the energy production, besides the planning, operation and maintenance of the distribution network. Regarding the availability of data required for network operation, DSOs generally does not have access to this information, but in Germany DER owners are obligated to install communication interfaces and provide instantaneous data about the supplied power.

2.3.2 Business model for purchase and sale of energy by DER

DG units produce energy that will be used to cover a certain demand from different consumers in the electric power system. This energy may be sold within different structures according to the regulation in force. Energy storage in the form of batteries connected to the grid or EVs with V2G capability can also buy and sell energy at different time periods.

In this sense new agents like aggregators or virtual power plants can interact with DER, but neither in Greece nor Portugal these are currently in place. Conversely, in Germany and UK commercial aggregators that manage different loads and participate in demand response already exist, as well as first prototypes of Virtual Power Plants (VPPs), but this type of businesses are only starting to arise. The figure of Energy Service Company (ESCO) is more popular in all these countries so additional services can be easily offered to consumers. In the case of Portugal, services like home energy management systems, energy audits, or quality of supply improvements like uninterruptible Power Supply (UPS) or capacitor banks installations are offered by these agents. In Greece the figure of ESCO is enacted by law 3855/2010 and considers mainly energy efficiency actions. However, the regulation related to the aggregator figure is still under development.

Regarding the process to sell energy from DER, different mechanisms can be adopted. In the four analyzed countries a feed-in-tariff (FiT) system has been adopted for the remuneration of energy from RES. In Portugal the incentives present different values according to the technology and also to the voltage level, whereas in Greece they depend on the nominal power. In UK green certificates have been also applied, so electricity suppliers are required to source a specified proportion of the electricity they provide to customers from eligible renewable sources. In Germany, feed-in-premium is also applied, where an extra payment is added to the wholesale price. Regarding the case for reselling energy from storage, regulation is not yet defined in most countries and in general DSOs are not allowed to own and operate storage. However in Germany DSOs might be able to contract storage as a service from a third party, although these costs are not clearly recognized by the regulator.

In Portugal self-consumption has recently been approved. For this type of customers there are two meters with hourly readings, and then for each hour if the consumption is higher than generation, the consumer pays for the difference at the standard retail price, and in case the generation exceeds the demand in that hour, the consumer receives the equivalent of 90% of the spot market price for this energy through the Last Resort Supplier, which is the responsible party for acquiring all the renewable generation and selling it in the market. In the case of Greece, self-consumption is also approved and net metering is possible for electricity consumers with PV installations meeting certain limits like a maximum of 20 kWp or 50% of the contracted nominal power in kVA. In Germany self-consumption is very common and was promoted with feed-in tariff incentives. Although these incentives have already finished for new installations, kWh used as part of self-consumption are not obliged to pay some fees like electricity tax or concession and network fee, which still makes the installation of small PV on houses very attractive. Furthermore, currently there is a sponsored program for storage that corresponds to PV systems for less than 30 kWp.

2.3.3 Balancing markets in ancillary services

The balancing markets are one service in the ancillary services aimed to maintain the equilibrium between generation and demand, keeping the frequency within the proper margins in order to ensure the integrity, stability and reliability of the electric system. Although DER does not currently participate in these services, the structure of the balancing markets of each country has been analysed to foresee the rules that could be applied for future scenarios where DER may be integrated in these markets. The information for this section has been obtained from Eurelectric [23] and complemented with different sources for each specific country, like technical papers for Portugal [24] and Greece [25], National Grid for UK [26], and Consentec for Germany [27]. Additionally, the project Market4RES [28] also provides useful insights related to the integration of electricity markets with large penetration of RES across Europe.

Balancing services in Portugal include the typical primary, secondary and tertiary reserve. Primary reserve in Portugal is a mandatory and non-remunerated service provided by generators that should change its nominal operation point at least 5% of their output power. The Portuguese TSO is responsible for communicate the secondary reserve request in the day-ahead, then generators send bids composed of the up and down reserve band (MW) and the price thereof (€/MW), the eligibility is based on least cost and the capacity price corresponds to the last accepted bid. As the energy deployed in secondary band is treated as secondary energy, it is paid according to tertiary reserve price. Tertiary reserve is also procured by the TSO, and it is organized through a market. The bids from generators include the up and down tertiary reserve powers in MW together with the corresponding energy price in €/MWh. The deployed energy is remunerated at the marginal price of the up or down auctions.

The ancillary services in the Greek system are procured by the TSO also based on primary, secondary and tertiary reserve. These services are provided through the wholesale market, where energy and ancillary services are traded and committed in the generation units. The primary reserve is remunerated through a clearing price set at the last accepted primary reserve bid. The secondary reserve (up and down) is paid with the same method as the primary, i.e. with a common price corresponding to the highest accepted secondary reserve price offer. However, the tertiary reserve is a non-remunerated service within the Greek electric system. In addition to these reserves, it exists another mechanism to restore the equilibrium and ensure active power quantity, called standing reserve. The scheduling of the standing reserve is the TSO responsibility, nevertheless this service is not remunerated in the current market design.

In the UK, the frequency control must provide by each capable generation unit through the modulation of active and reactive power; three different actions are considered for this service: primary response, secondary response and high response regarding the time duration. The TSO is responsible for the procurement of this frequency control, which is mandatory to generators, although large electricity consumers that are able to interrupt their demand can also provide this service. The payment for frequency control consists in two types of payment: a holding payment (£/h), made when the unit is able to provide response when it has been included in the frequency response mode and a response energy payment (£/MWh), which remunerate the amount of energy delivered when it has been providing frequency response. Another balancing service presented in the UK electricity system, is the reserve services. Although there are different types of reserve: fast reserve, short term operating reserve, balancing mechanism start-up. This type of balancing service is used by the TSO when demand is larger than forecasted or in case of emergency, for instance when a power plant breakdowns. The reserve requirement is daily set by the TSO for each hour depending on the forecasted demand, and the method to determine which agents should provide this service is obtained through a tendered bidding process. Providers of this service receive an availability fee (£/h) for each hour specified in the tendered service period where the service is available and a utilization fee (£/MWh) for the energy delivered. In regard to the start-up balancing mechanism, this service is remunerated with a start-up payment (£/h) to reflect the costs associated with starting up. In addition a hot standby payment (£/h) is made to cover the cost of sustaining a state of readiness. Since the current UK market is based basically on bilateral trades and self-dispatch of power plants, the market poses a low liquidity problem that creates a high risk for small and variable generators. The gate closure of intraday market was reduced to one hour in order to improve liquidity and to react imbalances on a continuous basis before physical delivery, however these measures did not improve the situation. This might be because the pay-as-bid mechanism does not generate a common and transparent price like the marginal pricing system, and RES imbalances are compensated with own flexible plants, performed by large-scale utilities that remove the position of individual producers.

In Germany, where there are four TSOs, they have to coordinate among them in order to maintain the equilibrium between generation and consumption within their control areas. Three different actions are performed in order to control this, the primary control reserve, the secondary control reserve and minute reserve, also called tertiary control reserve. The German TSOs procure this service through an open, and non-discriminatory market. Market participants are both plant operators and electricity consumers; small generation units and also controllable loads can be aggregated to reach the minimum size for providing this service. The main differences between the reserves are explained afterwards: Secondary and tertiary upward and downward can be offered separately, however the provision of primary must be a symmetric product. Primary and secondary are contracted for a weekly period, unlike tertiary reserve, whose tender period is daily. The unit assignment varies from primary to secondary and tertiary, in the case of primary reserve, the assignment is based on capacity price merit-order, instead the energy price merit-order that follows the secondary and tertiary. The remuneration system consists in pay-as-bid, for primary reserve only the capacity provision is paid, whereas the deployed energy is not paid; on the other hand, secondary and tertiary reserve receives a separately payment depending on the capacity and energy. The German regulator changed the accessibility of balancing markets for RES, reducing the minimum bid size for the primary, secondary and tertiary reserves as well as the tendering period from one month to one week, in order to promote the possibility of small producers and RES technology to participate in these ancillary services; however RES generators under the feed-in tariff support are not allowed to participate in balancing markets. In addition, a further reduction of tendering periods to daily would boost intermittent RES to participate in balancing markets.

2.3.4 DER network access: connection charges and use-of-system charges

Regulation should on the one hand, ensure fair and non-discriminatory network access for DG agents, and on the other hand, should allow DSOs full recovery of the costs for the accommodation of DG. Furthermore, there is a trade-off between providing incentives for the optimal and cost-reflective siting of new generation capacity and facilitating entry for small-sized DG operators. For this purpose, connection charges and use-of-system (UoS) charges may be designed by the regulator for all agents connected to the distribution network, including DG.

In Portugal and Greece connection charges are deep so they include the network reinforcement and expansion costs, and in both countries the connection criterion follows non-discrimination policies. However, in Portugal DER does not have to pay use of system charges, whereas in Greece these charges are applied to DER units for the operation and maintenance cost of the part of the network that is exclusively used by the generators and allocated according to the contracted maximal power.

In the case of UK deep connection charges and use of system charges by size are also applied to DG, although for single DG units with less than 3.68 kW per phase and connected to 230V system single phase, the use of system charge is not applied. Finally, in the case of Germany shallow connection charges are considered and use of system charges are not applied, which represents the most favorable condition for DG connection among the four analyzed countries.

2.3.5 Effect of DER on planning, operation, network losses, reliability of supply and incremental costs

On the one hand, high levels of DER penetration cause the increment of CAPEX & OPEX for the DSO, mainly in network investment and energy losses costs. On the other hand, DER may represent a potential replacement for network investment, and should be therefore considered by DSOs throughout the network planning process. The regulatory framework may implement different options to compensate DSOs for the incremental costs, and it may affect the consideration of DER for network planning by DSOs.

In the case of Portugal, the CAPEX is assessed with the WACC and the OPEX with a price cap, based on a linear programming model using benchmarking (Data Envelopment Analysis). Incremental costs due to DER are taken into account by the regulator to set the UoS charges. In the case of Greece, for the CAPEX the regulator defines a Return on Capital Employed (ROCE) on an annual basis, and a cost-of-service for the OPEX subjected to a possible adjustment if it is considered necessary. In this case incremental costs related to the connection of DER that have been already covered by the connection charges are explicitly excluded from the calculation.

In UK the new price control scheme RIIO-ED1 started in April 2015, and was set for an eight-year period. This scheme follows the concept of *Revenue = Incentive + Innovation + Output* and is designed to drive real benefits for consumers. The WACC and price cap criteria are used, but including explicit incentives for efficiency gains and penalties when delivery targets are not met. In the case of Germany, the ARegV defines an incentive regulation with a revenue cap with a five year regulatory period investment, although the established limits can be revised in case of special investments are deployed, such as improving the grid for the integration of RES. Nevertheless, the German framework is currently under review to improve certain key points, which are focused on improving investment conditions, creating greater incentives for energy efficiency, facilitating procedures for smaller DSOs, increasing transparency and maintaining quality of supply.

Regarding the mechanisms for investment deferral, although flexibility management tools are in general only available by TSOs, the Portuguese regulator explicitly considers that when the DSO invests in innovative technology, one of its main benefits should be the possibility to postpone network investment. Therefore, cost-benefit analyses of innovative investment have to estimate how much investment can be reduced/postponed.

Energy losses in distribution networks are affected by DER and explicit incentives are usually included by the regulator to improve system performance. For low DER penetration levels usually DER would reduce network energy losses, while higher DER penetration levels would increase energy losses. In the case of Portugal, there is a fixed reference value for total losses of 7.8% and a symmetric dead band around the reference value of 1.7% under which the losses are valued at 1/3 of the average energy price in the pool market. In the case of Greece, a bonus-malus scheme is used for calculating the DSO incentive or penalty for the same year with a pre-defined reference losses level and basing the calculations also on the prices from the wholesale market.

In UK the RIIO-ED1 includes a losses discretionary reward as part of environmental incentives. The discretionary reward provides financial payments for DSOs that undertake additional losses reduction actions over and above those set out in business plans. In Germany energy losses are capped at different maximum percentage values per network level, so the maximum amount of kWh the regulator recognizes as losses can be calculated by multiplying the maximum percentage value per network level with the amounts of energy transported. The price of losses is calculated using a percentage figure for base and peak electricity and the 365-day average EEX prices for these futures which were realized on the market approximately 18 to 6 months in advance.

DER may also have an effect on quality of service and offers potential for quality improvement thanks to the possibilities of operation in islanding mode in case of network outages, however islanding operation in distribution grids is usually not yet allowed by DSO. In Portugal the number and frequency of interruptions are monitored with the reliability indicators SAIDI and SAIFI. Conversely, in Greece there is no current legislation related to meet continuity of supply but there is a legislation in progress to set specific targets at least for SAIDI and SAIFI. In both countries DER is not yet considered a real alternative to improve continuity of supply. Nevertheless, voltage and congestion problems as well as reverse power flows have been detected in various locations in Greece, where DER may have positive impact. By contrast, in Portugal power quality issues in general are not a big problem.

In the case of UK, DSOs are incentivized on the number and duration of network supply interruptions and considers both unplanned power cuts and planned outages. The target setting mechanism for unplanned interruptions is based on industry benchmarks, whereas the planned outages are derived from past performance. In Germany the quality regulation focuses on SAIDI for low and medium voltage levels, providing bonus or penalties for high or low quality, setting a cap of 2-4% of the individual revenue cap and considering a value of lost load of approximately 8 €/kWh. Additionally, power quality in Germany is considered an important issue in distribution networks, where voltage fluctuations caused by massive impact of PV is one of the main problems in this regard.

2.3.6 Active demand response and smart metering

Demand response is essential for smart grids, since it offers the potential of a more efficient use of the network system. Regulation may incentivize consumers to become more active. In order to enable demand response, Advanced Metering Infrastructure (AMI) must be deployed. In this section additional data has been considered from the report *Benchmarking smart metering deployment in the EU-27 with a focus on electricity* published by the European Commission [29]. The ADVANCED project also provides useful insights from a European perspective [30].

In Portugal and Greece flexibility contracts are in place but are only managed by the TSO and for large customers, and for smaller consumers the major flexible option are Time of Use (ToU) tariffs but just for a couple of periods. As consequence, the AMI already deployed is not offering all the possible benefits. Among the envisaged functionalities for smart meters, in Greece the smart meters comply with most of the functionalities described in the Commission Recommendation provided by the government, which include update meter readings frequent enough to provide energy savings and also to be used for network planning purposes, two-way communication for maintenance and control like connection/disconnection or power limitation, support advanced tariff systems, provide secure communications and enable fraud prevention and detection. In the case of Portugal, the considered functionalities are similar but the current applications are more focused on metering and commercial remote services like tariff changes or cut-offs.

In the case of UK, ToU tariffs and interruptible contracts are also applied, but mainly for large customers. An example of a ToU program is the Economy 7, where customers using electrically charged thermal storage heaters can meet their space heating needs from off-peak electricity between 01:00 and 08:00. The main functionalities considered for smart meters are remote meter reading, two-way communication, and support for ToU tariffs and Demand Side Management (DSM), although demand response programs in the domestic sector are only deployed in pilot projects carried out by the regulatory authority. In Germany DSM is applied in a similar way to the Economy 7 program of UK, given the high penetration of domestic heating appliances. In both countries these devices usually have their own meter, which can be controlled by the DSO or the supply company that provides this service. Smart meters in Germany are expected to be a combination of an electronic meter and a smart meter gateway with a protection profile for information security, although the technical minimum requirements are still unfinished.

In Portugal, the metering activity is regulated and DSOs are in charge of the smart-meter implementation and ownership. Thus, the DSO incurs the cost of this equipment but with no recognition in the asset base, although it can be considered an innovative investment. Nevertheless, currently there is not a commitment of a deployment strategy in the roll-out and the decision is still government pending. Studies focused on smart metering roll-out in Portugal determine that the metering point cost is almost 100 € and the potential benefits per point are slightly above €200. The main benefits come from the demand reduction (55.3%), the peak reduction (13.3%) and commercial losses reduction (11.1%). On the other hand, the cost sources are the supplier profit reduction by consumer demand reduction (47.4%), acquisition and installation of smart meters (31%) and communication infrastructure (14.6%). The peak load shifting has been estimated as 2% and the energy saving achieves as a 3% of total electricity consumption.

In Greece the national implementation of smart meters must account for 40% by June 2017 and for 80% by 2020; the metering activity is considered under a regulated framework and DSO is responsible for the meter installation having the ownership thereof, so the cost related to these infrastructures have to be covered by them but unlike Portugal it is a recognized cost included in the asset base. In addition, the DSO must grant third-party access to metering data. According to the CBA in Greece, the metering point cost is €309 and the benefit per connection point would be €436. The main benefits that can be achieved are the consumption reduction through direct feedback (44%), the meter reading savings (14%) and reduction in carbon usage (11%), the main source of costs would be the procurement and installation of meters (55%), the display costs (20%) and the communication infrastructure (9%). Energy savings have been computed as 5% of total electricity consumption, and same figure can be achieved in the peak load shifting. Therefore, positive business case is presented for Greece, and consumers can benefit due to the management of their energy consumption and potential for electricity bill reduction.

In UK the roll-out of smart meters must account for 100% by 2020 and the responsible for the ownership and operation of the AMI is the Data and Communication Company, whereas the metering and billing is responsibility of the supplier. The costs of AMI are paid by both parties through a monthly fixed charge per meter and they are not allowed to set any charge for this service to the consumers, but there is no specific form to pass these costs to the customers. From the CBA perspective, cost per metering point might be €161 and the benefits might be around €377. The main benefits that domestic customers can obtain are the supplier cost savings (54%), the energy savings (28%) and the carbon usage savings (7%). However, the cost on domestic side rises up from CAPEX and OPEX of smart meters (43%), communication CAPEX and OPEX (23%) and installation costs (15%). The energy savings derived from the smart-meter implementation are 2.2% on average of the total electricity consumption, and the peak load shifting is between 0.5% and 1% of the total consumption. The economic assessment demonstrates that UK actions are aimed to consumer side, empowering the consumer to better understand and manage its energy consumption.

In Germany the decision for the rollout is still under consideration, similarly to Portugal, and the ownership and operation of the devices is expected to be assigned to the gateway administrator, although this role might be played by the DSO or an independent party, and the costs are expected to be borne by the customer although the methodology is not defined yet. The metering activity is considered in a competitive environment. Projects regarding cost-benefits analysis on smart-meters have not recommended a large-scale roll-out for smart metering as for final users with low consumption the equipment cost is higher than potential savings. The same study also establishes the metering point cost as €546 and €493 are the potential benefits it might bring. The total benefits can be divided in energy savings (33%), load shifting (15%) and avoid investment in distribution network (13%). On the other hand, the total cost can be broken down in investments smart metering systems (30%), the communication costs (20%) and the IT-costs (8%). The study estimates energy savings as 1.2% of total electricity consumption and 1.3% peak load shifting until 2022.

2.3.7 DSO incentives for innovation

The implementation of smart grids poses on DSOs new challenges in network planning, operation, and control to be cost effective. DSO regulated business are risk averse to make investments on new technologies that are not mature enough.

In Portugal there is a specific incentive for innovative investments whereby innovative projects submitted to the regulator have to account for a minimum of 2.5% of the investment, in case the DSO wants the regulator to classify the project as innovative. In case of approval, the DSO earns an extra rate of return on that investment for 6 years. In the case of Greece, the current mechanism for innovation is also through research and technology projects submitted to the regulator. In UK the RIIO-ED1 increase the incentives for innovation to DSOs, and there is also a Low carbon Network Fund which supports projects to try out new technology, operating and commercial arrangement, whereas in Germany DSOs are eligible for a Research and Development Budget which result into prices for network costs, but these initiatives can be also supported by the Federal Government.

2.3.8 Summary of regulatory conditions

Finally, in Table 8 a summary of the aforementioned conditions is presented.

Table 8 Summary of regulatory conditions by country

	Portugal	Greece	UK	Germany
DER participation in voltage control	no	yes	yes	yes
DER participation in local congestion management	no	yes	no	yes
Aggregators	no	no	yes	yes
ESCOs	yes	yes	yes	yes
Self-consumption	yes	yes	yes	yes
DER supporting scheme	FiT	FiT	FiT, Green certificates	FiT, feed-in-premium
DER participation in balancing markets	no	no	no	yes
DER conection charges	yes (deep)	yes (deep)	yes (deep)	yes (shallow)
DER Use of System charges	no	yes (by size)	yes (by size, smaller units are excluded)	no
DSO CAPEX revenue scheme	Weighted Average Cost of Capital	Return on Capital Employed	Weighted Average Cost of Capital	Weighted Average Cost of Capital
DSO OPEX revenue scheme	price cap	cost-of-service	price cap, incentives and penalties	revenue cap
DSO energy losses incentives	yes	yes	yes	yes
DSO continuity of supply incentives	yes	no (in progress)	yes	yes
Power quality problems identified	no	yes	yes	yes
Demand response mechanisms	Time of Use tariffs	Time of Use tariffs	Time of Use tariffs	Time of Use tariffs
Smart meter rollout	Decision in progress	yes (80% by 2020)	yes (97% by 2020)	Decision in progress
Incentives for innovation	innovation projects	innovation projects	RIIO-ED1 and innovation projects	innovation projects

It can be seen that each country has different regulatory conditions. However, some similarities can be found like the feed-in-tariff as DER supporting scheme, which means that all countries try to promote the utilisation of DER as an alternative from conventional energy sources. On the other hand, demand side can contribute to a more efficient integration of these resources through time of use tariffs and self-consumption, being both allowed in the four countries. The future of these two measures might be guaranteed just in Greece and UK, since in Portugal and Germany the decision of smart meter roll-out is still government pending.

The role of DER in system operation varies depending on the country. For instance, Germany is the only country between the considered countries where DER can participate in balancing markets. DER in Portugal cannot provide services regarding voltage control nor congestion management, unlike Greece where DER are allowed to participate in these services, whereas in UK DER can just participate in voltage control. The connection charges are another issue concerning the deployment of DER. Shallow charges are established in Germany, but in the other countries a deep charge scheme is in place. In Portugal and Germany, DER do not have to pay use-of-system, however in Greece and UK DER have to pay it according to their size. Regarding the DSO remuneration, all countries present some kind of WACC scheme for CAPEX, while in the case of OPEX there are more differences among countries. Additionally, incentives for innovation, quality of supply and losses are generally established in all countries, although UK is more focused on incentives with their RIIO-ED. Finally, aggregators can be set up as the intermediary between the DSOs and DER, providing services for both parties, but just in Germany and UK this figure has been recognized.

2.4 Stakeholder conditions

In this section the stakeholder conditions are analyzed. It is important to identify what are the expectations of other stakeholders involved and why or how they could oppose to the development of the smart grids. The following stakeholders have been addressed for this purpose for Greece and Portugal:

1. National Regulatory Authorities
2. Transmission System Operators
3. Distributed Energy Resources
4. Consumers
5. Manufacturers and Providers
6. Retailers

2.4.1 National Regulatory Authorities

NRAs are responsible for setting the rules to favor the transition to the smart grid paradigm. In Section 2.3 the analysis of regulatory conditions has shown the impact of regulation in different issues that are important for the DSO activity. In this sense, both Portugal and Greece present stable and transparent NRAs that foster innovation and economic incentives to ensure system efficiency and reliability. Additionally NRAs from these countries are involved in the approval of innovation projects.

However, there are some activities in progress that may affect to the development of smart grids, such as the decision of the smart meter roll out in Portugal and Germany or the new legislation for continuity of supply in Greece. Moreover, there are important issues that are not currently addressed by local regulations and may have a significant impact in the smart grids deployment, like promoting the participation of DER in network services in Portugal or including specific incentives to mitigate the power quality problems detected in Greece. NRAs have to deal with new legal forms, such as aggregators or VPP. In Portugal and Greece, these entities are not regulated, so an uncertain regulatory framework is presented. On the other hand, in Germany and UK, there are commercial aggregators that are currently operating in the system, as VPP demos, which establish a well-built regulatory scenario for the continuous promotion of these agents. Additionally, ESCOs operate in Portugal and Greece and are recognized by law, providing energy efficiency actions for consumers. Energy from storage device is another issue that has to be regulated, as in the assessed countries the payments for this energy is not yet developed. In addition, DSOs cannot own or manage storage devices within their own distribution networks. Solely in Germany DSOs can obtain energy from storage, nevertheless the storage owner has to fall on a third party and the remuneration is not clear for this service.

The integration of DER impacts on energy losses and incentives have to be included in NRAs framework to improve the system performance. In Portugal, there is a fixed value for the total losses and a symmetric band around this value at which the losses are valued at 1/3 of the average pool price. In Greece, a profit-losses schemes is arranged for DSO with a reference losses level and prices related to wholesale market. DSOs in the UK are incentivized to undertake additional losses reduction. German regulator establishes different maximum percentage values per network level. Quality of supply is another fact that NRAs have to regard and identify the potential of DERs. In Portugal and Greece, in spite of that SAIDI and SAIFI are controlled or are expected to be controlled, DER are not considered as an option to improve the continuity of supply. Nevertheless, in the UK, DER receive incentives if they are able to supply electricity when power cuts occur. Quality regulation in Germany is focused on SAIDI, providing bonus or penalties according to high or low quality. Finally, NRAs have to foster DSO incentives for innovation in order they make investments on new technologies. In Portugal, specific incentives for innovative investments are set out. In the case of Greece, research represents the single way as innovation mechanism accepted by the regulator. Last regulation in UK, establishes incentives for innovation to DSOs. In Germany, DSOs are chosen for a Research and Development Budget which results in helps for network costs.

2.4.2 Transmission System Operators

The relationship with TSOs is very important since they control the upstream network where the distribution network is connected and have larger visibility of the current state of the power system. Indeed, the TSO may ask the DSO to fulfill certain technical requirements.

For instance, in the case of Greece the TSO can ask the DSO to limit the active power production of DER. This is similar in German, where TSOs usually do not interfere with RES installations directly but are allowed to request that DSOs execute the interventions that were considered necessary by the TSOs. In the four evaluated countries, the TSO is responsible for the procurement of balancing services. As the expectation of the continuous participation of DER in the ancillary services is increased, either directly or through an aggregator, communication between TSO and DSO has to be improved, since the DSO is responsible for the operation of DER within its own distribution network.

2.4.3 Distributed Energy Resources

The penetration of DER in the power system involves new challenges to the system operation and planning to ensure supply reliability and economic efficiency. The correct connection of DER and their participation in networks services may contribute to achieve these goals but an appropriate regulatory framework should be in place so DER perceive the right incentives.

In Portugal, distributed generation does not have to pay use of system charges, whereas in Greece, DG units have to pay it, in both countries connection charges include the network reinforcement. In UK, the connection charges and use of system are applied depending on the DG size and just for very small producers (3.68 kW), use of system are not applied. In Germany, a favorable scenario for DG connection is laid out, since the connection charges are low compared to the rest of assessed countries and the use of system fees are removed.

In the case of Portugal DER are not required to participate in network services unlike Greece, where the production of DER may be limited under different conditions, although with any kind of economic incentives. In the UK, as in Portugal, DER do not have to participate in flexibility services such as congestion management, however they can agree a specific power factor with DSO. DER in Germany are obligated to contribute in reactive power control through a specific power factor; furthermore DER can be curtailed when system reliability is jeopardized, and DSO has to compensate it.

2.4.4 Consumers

Consumers are the end user of the power system but historically they have been considered only as passive actor. However, within the smart grid paradigm they are expected to play an active role, although this change highly depends on their degree of awareness with all the new opportunities that are starting to arise, like participating on Demand Side Management programs or adopting dynamic pricing or self-consumption initiatives.

In the case of Portugal and Greece Time-of-Use tariffs and self-consumption are currently in place, but there is a huge potential to improve customer engagement into the smart grid concept. Indeed, in Portugal the decision of full deployment of smart meters is still government pending and this decision will affect the consumer opportunities in the smart grid. Additionally, the penetration of electric vehicles may also affect to the development of smart grids. For the moment about 1350 charging points have been installed in Portugal. The penetration in Greece is much lower. So at least in these two countries consumers are not expected to adopt this technology in the short term. In the UK, demand response programs are carried out through pilot studies, these studies will bring conclusions for the potential benefits of active consumers within the system, moreover the roll-out of smart-meters has been approved, and the target is to achieve almost 100% by 2020 and consumers will not have to pay any extra charge for the metering service. In Germany, DSM studies are focused on the potential from thermal storage heaters at home and self-consumption has increased considerably, although the roll-out of smart meters has not been launched yet.

Consumers’ trust to electricity services depends on the country assessed [31]. Germany has the largest satisfaction degree with the electricity supply, where 58% of Germans evaluate their trust to suppliers with 8 points or more out of 10, and only 7% of consumers rate these services with less than 5 points. Conversely, Portugal, Greece and UK present relevant distrust levels, with 37%, 29% and 30% of consumers giving a rate lower than 5, respectively. However, 32% of consumers in UK rate their trust above 8 points, which is significantly higher than the 25% of Portugal and 24% of Greece, so the situation in UK is more favorable.

2.4.5 Manufacturers and Providers

Equipment manufacturers and ICT service providers are also key actors to make smart grids happen. The large scale deployment of smart grids requires the integration of a number of new devices and makes use of secure and reliable communications infrastructures. Notwithstanding, the use of standard, open and interoperable technologies is critical to ensure the proper functioning and efficiency of smart grid implementation.

For instance, in Portugal the facilities from the demo site comply with several international standards, like IEC 60870-5-104 for the communications between the Distribution Transformer Controller (DTC) and the SCADA system and use GPRS communications, whereas the second generation of smart meters that are being deployed support PLC PRIME and DLMS/COSEM [32], [33]. Additionally, the participation of one equipment manufacturer in the SuSTAINABLE project consortium eases the attainment of a correct integration. In Germany, DER owners have to install communication interfaces to communicate with the DSO, which sets out a favorable scenario for ICT manufacturers and service providers.

2.4.6 Retailers

Retailers represent the commercial interface with the end users, so they are directly involved in the engagement of the consumers with smart grid deployments. In all the analyzed countries the retail market is liberalized and consumers can freely choose the retailer they prefer based on the tariffs or other factors like customer service. Indeed, conventional retailers are not the only agent that consumers can interact, since ESCOs may also contribute to improve energy efficiency for their customers and provide other services than simply energy billing, bringing more opportunities to take advantage of smart grid deployments. The aggregation of customers is another potential service that may be offered by this type of agents, in which case they will act as aggregators. Although this figure is not currently in place neither in Portugal nor Greece, pilot projects like SuSTAINABLE are trying to assess their viability.

Regarding retail market structure, the Herfindahl-Hirschman Index – HHI –, measures the market concentration [34]. In the Portuguese case, there are 10 retailing companies in the market and the HHI for domestic consumers is 6.918; this index indicates that Portuguese retail market is still concentrated, as the market share of the three largest companies in the liberalised market is almost 85%. The retail market in Greece is made up of 11 electricity retail companies; the HHI for the retail market is above 9.600, which is close to 10.000, that represents a monopoly market; therefore there is one main electricity retailer in the Greek system, consequence of the past vertically integrated company owned by the state. In the UK, there are 12 domestic retail companies in the electricity retail market. The HHI index for the British retail market is 1.720, demonstrating a spread market power; nevertheless the retail market is dominated by 6 big suppliers each one with a market share of above 10%. The HHI index of the German retail market is 2.021, which is reasonably competitive, although the four largest suppliers own nearly 45% of the market share. More than 1,000 retail companies integrate the retail market, being one of the broadest retail market in Europe.

2.5 Conclusions

Table 9 summarizes the conclusions of all the aforementioned conditions.

Table 9 Summary of local conditions by country

Condition	Type	Portugal	Greece	UK	Germany
Orographic barriers	Geographical	medium	high	medium	low
Population size	Geographical	low	low	medium	high
Population density	Geographical	medium	medium	high	high
Rural areas	Geographical	high	medium	low	medium
Feeder length	Technological	high	low	low	high
Undergrounding degree	Technological	medium	low	high	high
DER penetration	Technological	medium	medium	low	high
RES generation	Technological	high	medium	low	medium
RES increase 2020	Technological	medium	medium	high	low
Reliability of supply	Technological	medium	medium	high	high
Regulation stability	Regulatory	medium	medium	high	medium
Innovation promotion	Regulatory	medium	medium	high	medium
Communication TSO/DSO	Regulatory & Stakeholders	low	medium	low	medium
DER participation in network services	Regulatory & Stakeholders	low	medium	medium	high
DER connection incentives	Regulatory & Stakeholders	medium	low	medium	high
Consumer engagement	Stakeholders	low	low	medium	high
ICT and smart equipment deployment	Regulatory & Stakeholders	medium	medium	medium	medium
Energy services market development	Stakeholders	medium	medium	medium	medium

The geographical conditions show the differences between all the countries in terms of population and orography. UK and Germany are considerably larger than Portugal and Greece and present higher population density and lower orographic barriers, so in this sense they could be attractive choices for further deployments. In respect to the technological conditions, the network configuration shows some similarities between Portugal and Germany networks like the feeder length, as well as between Greece and UK. However, the degree of underground cables is much higher in Germany and UK, where higher reliability of supply indicators are also achieved. In regard to the generation mix, Germany shows the highest penetration of DER and Portugal the highest ratio of RES generation. UK shows the lowest RES and DER ratios, so the replication of the SuSTAINABLE concept could be less beneficial from the point of view of a large scale deployment. Nevertheless, regulatory conditions are especially favorable in UK where the new regulatory framework RIIO-ED1 has been implemented to foster innovation, but in general the regulation of all countries is still under development to cover all the important aspects related to the adoption of smart grids and renewable energy integration, like communication between TSOs and DSOs, DER participation in network services, or DER connection incentives. In this regard, Germany currently shows a favorable scenario for the promotion of RES that could encourage the adoption of new smart grid functionalities. Additionally, Germany also shows the highest consumer engagement, which contrasts to Portugal and Greece where lack of engagement could be a problem to involve consumers in new services. Finally, in terms of ICT deployment and energy services market development, all countries are showing progress and interesting initiatives in this regard, although the pending decision of smart meter roll-out in Portugal and Germany could reduce the opportunities for all these new services.

3 Macro-scale replication of the SuSTAINABLE concept

In this section the potential scaling-up and replication barriers for the functionalities developed in the project detected in Task 8.1 are analysed considering the boundary conditions of the demo sites described in the previous section. The barriers detected in Deliverable 8.1 are shown from Table 10 to Table 18 including the type of barrier, where four types of barriers can be found: technical, economic, regulatory and stakeholder.

3.1 RES Forecasting

The main objective of the RES forecasting tools is to make reliable predictions of DG units (exploiting as primary energy resource wind or PV) at the MV level. This system is installed at the central management level, in the DMS of the DSO, although it can be virtually distributed by HV/MV substation using information from secondary substations connected to different HV/MV substations. The prediction tool relies on a record of all the data that can be measured and it is available, such as recent states of the system, forecasts for neighbouring DG units, forecasts for regional solar PV and wind power production, and a record of recent measurements of weather variables. From all this information, the prediction tool extracts point and probabilistic forecasts for wind power generation and solar power generation.

Table 10 Potential scaling-up and replication barriers for RES forecasting

Barrier	Type	Portugal	Greece	UK	Germany
Computational expenses	Technical	medium	medium	low	high
Essential communication infrastructure	Technical	high	medium	medium	medium
Unavailability of data	Regulatory	high	high	medium	medium

Computational expenses may be affected by the amount of RES units that has to be forecasted, so countries with higher penetration of RES at the distribution level may be higher affected. However, this barrier could be solved with higher performance equipment, but this measure will increase the investment costs. The major barrier that this functionality may address is to define the framework for data exchange between DER owners and DSOs. The four analysed countries have to cope with this barrier since these procedures are not regulated yet. However, on the one hand the UK regulatory framework seems to be the most flexible to promote this type of service, and on the other hand Germany regulation is encouraging DER to participate in network services, so in these two countries this barrier could be less risky. Finally, in case essential communication infrastructure may be posed as a barrier to the large-scale implementation of this functionality, the ICT deployment of each country like the smart meter roll out in Greece and UK could help to achieve the communication requirements. Additionally, in Germany DER owners have to provide instantaneous data about the supplied power, so these countries in principle may be better prepared in terms of communication infrastructure for RES connected to the distribution network. Regarding the communication infrastructure, it is important to bear in mind that the specific technical solutions being implemented should ensure the accomplishment of the information exchange requirements. Otherwise, conventional roll-outs will not be capable to solve these barriers and additional actions should be taken.

3.2 Load Forecasting

The main objective of the load forecasting tools is to make reliable predictions of load at the MV level. As in the RES forecasting, the load forecasting tools are installed in the DMS, although it can also be distributed by HV/MV substation. The result of load forecasting not only includes an accurate forecast of the amount of load demand, but also addresses the composition of the forecasted load and the expected evolution of its components, distinguishing particularly between controllable and non-controllable loads. The information of the LV network is aggregated by secondary substation DTC to provide aggregated LV network information to MV buses, so that MV connected customers with smart meters will have synchronized information about the load at all MV buses.

Table 11 Potential scaling-up and replication barriers for Load Forecasting

Barrier	Type	Portugal	Greece	UK	Germany
Increasing penetration of the market by electric vehicles	Technical	medium	low	high	medium
Limitations of the existing communication infrastructure	Technical	high	medium	medium	high
New types of loads affecting quality of forecasts	Technical	high	high	high	high
Costs of measuring devices and their installation and maintenance costs	Economic	medium	medium	medium	high

Similarly to the case of RES forecasting, in case essential communication infrastructure may be a barrier to this functionality, the ICT deployment of each country could help to achieve the communication requirements. In this case, the decision of the smart meter national roll-out is especially important since the required information could be provided by these devices, considering smart meters comply with communication requirements for this purpose. For this reason, this barrier has higher impact in Portugal and Germany where the decision of the national roll-out is still government pending. The increase of new types of loads or the penetration of electric vehicles may create technical barriers to implement this functionality. In the case of electric vehicles, a significant increase is not expected to occur in the short term although in some countries like UK the promotion of electric vehicles is producing a not negligible penetration into the market, so this barrier could be very relevant in this country, but insignificant in Greece where practically there are no electric vehicles. However, new consumption patterns like the ones produced to self-consumption may be more probable in all these regions in a similar way, so the algorithms should be adapted to perform properly under these conditions. Finally, the cost of measuring devices may be an economic barrier to the deployment of this functionality. The impact of this barrier has been assessed considering the estimation of the cost per smart meter reported in [29], as well as the regulatory framework. Portugal and UK reports show the lowest costs for these devices, although in the case of Portugal it is not defined how to recover this cost, whereas in the case of UK the cost has to be covered by the Data Communication Company and the supplier. Greece by contrast shows a higher cost, but the cost of the devices can be included in the asset base so the risk is lower. Finally, Germany shows the highest cost for this equipment and a negative cost-benefit result, so the deployment of measuring devices may be strongly hampered by this economic barrier.

3.3 Monitoring/State Estimation

The main objective of the state estimation functionality is to face lack of information collected from the smart meters or RTU located in the grid by using additional historical information stored in the system data base, with the aim of making the network fully observable and guarantee an adequate degree of redundancy. The state estimation is installed at the central management level and implemented at the functional level of the HV/MV primary substation, where only the MV level state variables are calculated. In order to reduce the computational burden of enormous volumes of data produced by the smart meters and the generation of pseudo-measurements algorithms, decoupled processing is implemented to divide the network into different zones (one zone for each MV/LV substation and its associated feeders). Due to frequent reconfiguration actions and limited or missing switch status information, the algorithms have to detect topology changes and identify the correct network topology.

Table 12 Potential scaling-up and replication barriers for Monitoring/State Estimation

Barrier	Type	Portugal	Greece	UK	Germany
Limitations of the current communication infrastructure for real-time data measurement	Technical	high	medium	low	medium
Limitations of current practices and regulations for monitoring devices placement	Regulatory	high	medium	medium	high

As in the case of the RES and load forecasting tools, the monitoring and state estimation functionality depends on a robust communication infrastructure that fulfils the communication requirements to collect the relevant information from the network. In this regard, local conditions like the orographic barriers, the proportion of rural areas or the feeder length could jeopardize the performance of communication networks when collecting real-time data from monitoring devices, UK presents less stringent conditions, so the impact of this barrier may be reduced. Additionally, limitations of current practices and regulation for monitoring devices placement have been noticed as a regulatory barrier. In this sense, the smart meter roll-out could help to the deployment of this functionality. Therefore, UK may be identified as the most positive place for a large scale deployment and Portugal the less attractive one considering these barriers.

3.4 Coordinated Voltage Control

The main objective of the coordinated voltage control is to maximize the integration of energy from RES while ensuring that voltage profiles are kept within an admissible range. The proposed methodology exploits two different levels of control. At the MV level, a multi-temporal Optimal Power Flow (OPF) located at the SSC coordinates the several DER in order to avoid technical problems in terms of voltage profiles. At the LV level, local droop functionalities implemented in some inverters interfacing the DER are available and a centralized voltage control algorithm housed in the DTC remotely updates the parameters of these droops based on a set of rules. The articulation between the “centralized” control scheme and local control scheme is ensured by allowing remote adjustment of droop parameters.

Table 13 Potential scaling-up and replication barriers for Coordinated Voltage Control

Barrier	Type	Portugal	Greece	UK	Germany
Automation limitations of DER	Technical	high	medium	low	high
Automation limitations of storage systems	Technical	medium	medium	medium	medium
Cost of installation and maintenance of measuring devices	Economic	medium	medium	medium	high
Competitive environment preventing exchange of data between different entities in a power system	Regulatory	medium	medium	high	high
Unwillingness of DER owners to participate in coordinated voltage control	Stakeholder	high	medium	medium	medium

The coordinated Voltage Control presents the four types of barriers. The technical barriers are related to possible automation limitations of DER and storage systems. The limitation of RES automation depends on the amount of RES connected to the distribution system, so Germany faces a real challenge in this regard, whereas in UK this problem is not so critical. Additionally, the regulatory framework for voltage quality also affects to the performance of automation devices, so in Portugal the more stringent voltage quality requirements makes this barrier also important. In the case of storage, all countries present high uncertainty due to lack of proper regulation and the penetration of storage in distribution networks is really low, and DSOs are not allowed to install this type of technology.

As in the case of the functionality of load forecasting, the cost of installation and maintenance of measuring devices has been identified as a potential economic barrier, where Germany presents the highest risk considering the cost per equipment and the regulatory framework that does not promote the national roll-out of this technology. The competitive environment preventing exchange of data has been also considered an important regulatory barrier. Since the metering activity in Germany and UK is liberalised and left to the market competition, this barrier is directly affected by this condition in these countries, despite Portugal and Greece where metering is responsibility of the DSO. However, the regulatory framework should define the correct operating procedures to facilitate data exchange under all circumstances.

Finally, from the stakeholders' point of view, the unwillingness of DER owners to participate in coordinated voltage control may be a significant barrier. DER participation in network services and regulatory incentives are also important to mitigate this barrier. In the case of Greece, UK and Germany this barrier is not so critical since the regulation allows DSOs to limit or interrupt the production of DER, but in Portugal the situation is not the same so the new regulatory mechanisms or other incentives may be introduced to mitigate this barrier.

3.5 TVPP as a support for DSO/TSO

The TVPP is responsible for the operation of the various VPP actors in order to provide system management and support its real time operation. It consists of the TVPP control centre and three agent levels at the HV/MV primary substation, the MV/LV secondary substation and the DER located at the LV network.

The TVPP control centre utilizes the forecasting tools and the results of the multi-temporal OPF available in the DSO tool portfolio for the management of the distribution system. The objective is to maximize the integration of energy from RES in the distribution grid while mitigating the impact on the transmission network of variable generation connected to the distribution grid under very high penetration of RES. Moreover, the operating strategy of the VPP that contributes to the provision of differentiated Quality of Supply (QoS) and ensures a reliable system operation.

Table 14 Potential scaling-up and replication barriers for TVPP as support for DSO/TSO

Barrier	Type	Portugal	Greece	UK	Germany
Limitations of the existing communication infrastructure	Technical	high	medium	medium	high
Unavailability of reliable load and RES data necessary for forecasts of acceptable quality	Technical	high	high	medium	medium
Unavailability of reliable load and RES forecasting techniques	Technical	high	medium	low	medium
Cost of storage systems	Economic	high	high	high	high
Constraints related to current regulation practices of ancillary service markets	Regulatory	high	high	high	low
Constraints related to current regulation practices regarding renewable energy integration	Regulatory	medium	medium	medium	low
Unwillingness of customers to provide DR	Stakeholder	high	high	medium	low

From the technical point of view, the barriers related to load and RES forecasting tools directly impact to the deployment of TVPP, so these barriers should be also mitigated to ensure good forecasts quality and the correct performance of this functionality at a large scale, where communication infrastructures play an important role. The cost of storage systems has been identified as an economic barrier for this functionality, and since this functionality is left to the market, the responsible for the TVPP has to bear this cost. This poses a significant barrier regardless the country for the large scale deployment, considering that energy storage is not yet mature and prices are still high.

In regard to the regulatory barriers, current practices for ancillary service markets and renewable energy integration have been identified as critical issues for the correct deployment of the TVPP. In the case of ancillary services, in Portugal and Greece these markets for RES are not yet well defined, whereas in UK some measures have been already implemented to promote the participation of RES although the results have not been very successful and small producers continue facing problems to participate in these markets. Finally, Germany shows the most positive framework for ancillary services since they have reduced the minimum bid size and the tendering period to promote the participation of small producers and RES in these services. In the case of the barriers for renewable energy integration, all countries have included supporting schemes to promote RES investments, but participation of DER in network services and connection incentives should be revised to achieve a better integration of these technologies, where Germany represents again the most favourable scenario.

The unwillingness of customers to provide Demand Response is presented as a barrier from the stakeholders' point of view. In this sense, consumers' trust to retailers may affect their engagement on the participation of these services, so in Portugal and Greece this could be a significant barrier given the low trust reported by the consumer market monitoring analysis. Furthermore, the presence of ESCOs and aggregators may also improve the participation of consumers in these services, and Germany and UK show higher penetration of these new agents so this barrier could also be mitigated in this way.

3.6 Provision of Differentiated QoS

The aim of this functionality is to provide varying grades of power quality at different pricing levels to different parts of the power distribution network. This implies to monitor, diagnose, and respond to power quality deficiencies like harmonics, voltage imbalance and voltage sags. These actions lead to a dramatic reduction in the business losses of customers based on customers' willingness to pay.

The methodology developed establishes the level of QoS at key buses in the network at different times, based on existing monitoring devices installed through the distribution network, namely at the MV buses. This essentially involves estimation of QoS parameters at monitored and non-monitored buses and comparison of those with required threshold values at corresponding locations. Furthermore, it also proposes approaches for tuning and coordination of mitigating devices according to the specific QoS requirements of individual or groups of customers. This includes tuning of active and passive harmonic filters, voltage regulation devices and custom power devices in order to ensure contracted QoS to different customers while providing other services like local reactive power compensation.

Table 15 Potential scaling-up and replication barriers for Provision of Differentiated QoS

Barrier	Type	Portugal	Greece	UK	Germany
Unavailability of commonly accepted practices and techniques for selecting mitigation devices and optimizing their placement	Technical	high	high	medium	high
Cost of mitigation devices and their installation and maintenance costs	Economic	high	high	high	high
Unwillingness of customers to participate	Stakeholder	high	medium	medium	low

The unavailability of commonly accepted practices and techniques for selecting mitigation devices and optimizing their placement has been identified as the main technical barrier for this functionality. Since this functionality proposes a new concept of power quality delivery, the pilot tests should provide relevant conclusions to improve the performance of the developed methodology. In this regard, the regulatory incentives for innovative investments could help to support the deployment of this functionality, which could make UK more favourable to receive such an initiative considering the new RIIO scheme. From the economic point of view, the cost of mitigation devices and their installation and maintenance costs have been detected as important economic barriers for large scale deployment of the functionality. Apart from the economic support that could be obtained from the funding of innovative projects, the agent in charge of providing this functionality will have to bear all the costs related to the deployment and operation and maintenance. Especially in this case a thorough cost-benefit analysis may be critical to determine how much this service should cost to make this functionality economically attractive, which poses a high challenge for all countries. Additionally, the consumers may not be very interested in taking part of this new mechanism, which may be mainly affected by the current level of quality of supply that they are receiving. Then, Portugal could be the country where consumers are less interested in receiving such service, given that power quality problems have not been identified as a critical issue, considering the answers obtained from the surveys of each country. The consumers' engagement to energy services could also benefit the adoption of this functionality, where Germany is seen as the most favourable country. Educational campaigns may be added to ensure the effective deployment of this functionality.

3.7 Flexibility Based Reinforcement Planning

Flexible network reinforcement planning is considered through simulation of MV and LV networks. At MV level, several plausible scenarios for high DG deployment, distribution storage devices and flexible loads are considered, with typical days being investigated for each stage of the planning horizon. At LV level, simplified models are used for representing the load diagram, PV and other RES, µG, distributed storage devices, electric vehicles (with smart charging), and flexible loads connected at the MV/LV substation level.

By combining the MV and LV scenarios (and their respective levels of distributed energy resources) an updated load diagram can be obtained which reflects the benefits of predictive management and distributed flexibility. This new load diagram allows calculating the yearly aggregated operation costs due to losses, flexible loads and distributed storage device management, where the latter can even result in a profit depending on their ownership. The simulation process also allows identifying the limits of the network imposed by technical constraints, namely maximum branch loadings and maximum voltage drops. The network's technical limits will determine which reinforcement investments are required within each planning stage.

Table 16 Potential scaling-up and replication barriers for Flexibility Based Reinforcement Planning

Barrier	Type	Portugal	Greece	UK	Germany
Assumptions related to load and renewable generation growth	Technical	high	high	high	medium
Limited amount of historic data related to specific loads	Technical	high	medium	medium	high

The barriers identified for this functionality are mainly technical, and are related to the input data required to run the planning algorithms. On the one hand, the assumptions related to load and generation growth may lead to inappropriate decisions that could cause problems in the network operation, which could entail an increase in costs. In this sense, countries like Portugal, Greece and UK that are expected to experience a large increase of renewable energy may present a higher risk to the performance of the planning tools, compared to Germany where this increase is expected to be more moderate. On the other hand, the availability of historic data related to specific loads may also be a problem for certain types of loads. In this regard, the deployment of smart meters may help to obtain more accurate data from the consumer side, so in the countries where the roll out has been already approved the availability of these data is expected to be higher, which may be the case of Greece and UK, whereas in Portugal and Germany where the deployment is not yet approved, the amount of historic data to input the planning tools could be much lower.

3.8 Power Quality Planning

The objective of power quality planning is propose compensation strategies to provide online real-time compensation detecting power quality events using custom power devices and harmonic filters. With these mitigation devices, an optimal deployment methodology for mitigation solutions is applied to identify the most appropriate type of mitigation, rating of devices, location of their placement in network based on the objectives of maximizing the profit of the DSOs and minimizing deviation from guaranteed quality levels for each category of customers. The four types of FACTS models analyzed in this project are Dynamic Voltage Restorers (DVR), Static VAR Compensator (SVC), Distribution Static Compensator (DSTATCOM) and Passive Filter.

Table 17 Potential scaling-up and replication barriers for Power Quality Planning

Barrier	Type	Portugal	Greece	UK	Germany
Unavailability of information	Technical	high	medium	medium	high
Cost of mitigation devices and their installation and maintenance costs	Economic	high	high	high	high
Constraints related to current practices and regulations	Regulatory	high	high	medium	high
Unwillingness of customers to participate in power quality planning	Stakeholder	high	medium	medium	low

This functionality presents some barriers in common with the functionality of provision of differentiated quality of supply, like the cost of mitigation devices and the unwillingness of customers to participate, so the expected impact of these barriers for each country is practically the same as described in Section 3.6. However, in this case the unavailability of information has been noticed as a technical barrier, so like in the case of the reinforcement planning, the deployment of smart meters could benefit the collection of these data for the power quality planning purposes, so in the countries where this decision is not yet approved more difficulties for collecting data are expected. Finally, current practises and regulations could compromise the deployment of this functionality from the regulatory point of view. Again, similarly to the case of the differentiated quality of supply functionality, the innovation incentives of each country could support the development of this type of planning in the initial states, where UK has been identified as the country with the most innovation-focused regulatory framework.

3.9 Advanced Protection Planning

Advanced protection systems planning incorporate flexible schemes for distribution network protection and grid interconnection protection of DG units, in order to minimise/avoid protection failures. The Distribution Grid Area (DGA) concept is applied to assess the DG dynamics, which represents a network area defined according to utility criteria for fast and accurate protection schemes coordination. An intelligent system sited at the primary substation plays the role of DGA master, which holds a data model of all downstream feeders, their tie points to other feeders, and their relation with adjacent substations, as well as of all DG assets present in the feeders.

The centralized SCADA/DMS performs network assessment tasks over the whole network divided in several DGAs, sending pertinent short-circuit power data to each DGA's SSC, as well as assigning them with a tag for autonomous protection parameterization. The model aims at improving the selectivity of protection relays, by performing dynamic tuning of their protection setting, enhancing the role and performance of DG, as well as minimizing nuisance tripping to limit the impact of adjacent feeder faults.

Table 18 Potential scaling-up and replication barriers for Advanced Protection Planning

Barrier	Type	Portugal	Greece	UK	Germany
Limitations of communication infrastructure at the distribution network level	Technical	high	medium	low	medium
Cost of protection devices and their installation and maintenance costs	Economic	medium	low	high	high

The limitation of communication infrastructures has been identified as a main technical barrier for the deployment of this functionality. Similarly to the case of monitoring and state estimation, the geographical local conditions may affect the performance of the communication networks so the impact of this barrier is similar to the one described for that functionality. From the economic point of view, the cost of protection devices and their installation and maintenance costs has been detected as another barrier. Since UK and Germany present higher undergrounding degrees, this barrier may be more critical in these regions since the installation and maintenance of this devices in underground lines are more complicated, whereas in the case of Greece the effect may be the opposite.

4 Scaling-up and replication rules and methods

After the analysis of the barriers for the SuSTAINABLE functionalities in each country, the scaling-up and replication rules and methods have been defined. This rules and methods have been defined based on the relative impact of the implementation barriers of each functionality at each region. For this purpose a numerical score has been used, assigning marks of 1, 2 and 3 points for low, medium and high barriers, respectively. Finally, the average has been computed for each country so the overall impact of the functionality can be easily compared among countries. Table 19 shows a qualitative comparison of the impact of the implementation barriers of each functionality in the different regions.

Table 19 Relative impact of the implementation barriers of the SuSTAINABLE functionalities by country

Functionality	Portugal	Greece	UK	Germany
RES Forecasting	above average	average	below average	average
Load Forecasting	average	below average	average	above average
Monitoring/State Estimation	above average	average	below average	average
Coordinated Voltage Control	average	below average	below average	above average
TVPP as a support for DSO/TSO	above average	above average	below average	below average
Provision of Differentiated QoS	above average	average	below average	below average
Flexibility Based Reinforcement Planning	above average	average	average	average
Power Quality Planning	above average	average	below average	average
Advanced Protection Planning	above average	below average	average	above average

In the case of RES forecasting, UK has been identified as the country with lower barriers to the deployment of this functionality, whereas Portugal has been presented as the region where the identified barriers have a higher impact. However, considering the expected benefits derived from this functionality, the high level of RES penetration in Germany may result in more benefits, so this country could also be really interesting for the deployment of advanced RES forecasting tools. With regard to load forecasting, the decision of smart meters roll-out and the estimation of the cost of these devices provided by the national cost-benefit analyses have posed Germany as the region with the highest risk for the deployment of this functionality, conversely to Greece where the same conditions highlights this area as the most favourable, considering also the lower impact of electric vehicles.

For the monitoring and state estimation functionality, UK has been identified as the most positive place for a large scale deployment and Portugal the less attractive. With regard to the coordinated voltage control, Greece and UK have been noticed as places with lower impacts than the others, since the barrier related to the unwillingness of DER owners to participate in voltage control may be mitigated by the local regulatory frameworks that promote the participation of DER in network services, as well as lower impact of automation limitations thanks to lower presence of DER than in other countries. Nevertheless, the scalability and replicability of this functionality presents high level of risk, since five different barriers were identified, being the second functionality with the highest amount of barriers after the TVPP. Thus, in the case of the TVPP, significant differences among all the countries have been identified, being Germany identified as the best region for the deployment of this functionality thanks to more favourable regulatory and stakeholder conditions, followed by UK. On the contrary, Portugal has been noticed as the region with the highest level of risk, achieving a high impact for almost all the barriers identified for this functionality, followed by Greece.

With respect to the provision of differentiated QoS, UK and Germany have been detected as the most favourable regions for the implementation of this functionality, where QoS has been identified as an important concern and consumers' engagement is relatively higher, supported by incentive mechanisms for innovative projects. The flexibility based reinforcement planning has been identified more risky in Portugal than in the rest of the countries mainly because in this country an important increase of RES is expected in the following years, which could affect the assumptions and decisions of the planning algorithms, and also because the deferral of the smart meter roll out may impact the availability of historic load data that may also increase the uncertainty of the results provided by the planning strategies. For the power quality planning, again Portugal has been identified as the least favourable region, where all the barriers have been identified with high impact. Conversely, UK has presented fewer constraints thanks to better data availability, regulatory framework and consumers' engagement. Finally, regarding the advanced protection planning, Greece has been posed as the country that shows better conditions for the deployment of this functionality, where the limitations of communication infrastructures and the installation and maintenance cost of protection devices could be less negative affected by the geographical and network conditions of the country.

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Appendix A. Regulatory questionnaire

This questionnaire is aimed at gathering information on the regulation that governs the regions where validation sites and proof-of-concept demonstrations of the SUSTAINABLE project take place. This is an adaptation of the questionnaire used in the GRID4EU project, also based on previous surveys carried out for other European projects, such as DG-GRID and SOLID-DER, and MERGE. The main objective is to complete this survey with information from countries included in the SUSTAINABLE project but not considered in the GRID4EU, which are Portugal, Greece and UK, and also to adapt the survey to particular aspects of this project.

The questionnaire will consist on different sets of open questions to address different aspects of the regulation of distribution, mainly those concerning smart grids, distributed resources and smart metering. The term distributed resources (DER) is used throughout the questionnaire to comprise distributed generation (DG), electric vehicles (EVs), demand response and energy storage.

Please help us define the regulatory boundary conditions in your country by answering this questionnaire, considering both current regulation and any potential legislation change that you consider may take place in the near future. Please provide any references where this regulation may be found.

DER participation in network services and relationship with DSOs

DER units can potentially provide network services, such as voltage control or local congestion management, and thus contribute to improve system efficiency. However, the participation of DER in such services will be subject to the regulation in force. Regulation may or may not allow coordination agreements between DER, and DSOs. The objective of this block of questions is to characterize the current regulatory framework governing the location of the demonstration carried out by your company.

Questions:

1. Can DER participate in voltage control? Is there any specific requirement for voltage support (a fixed power factor, reactive consumption, constant voltage, etc.)?
2. Can DER participate into local congestion management, provide flexibility services or any other services to the DSO in your country?
3. What is the reason DER provide services? Is that because they are obliged or incentivized by regulation? Or is because they can make contracts with DSOs to provide services and receive a payment?
4. Can DSOs own DER under specific circumstances? Are there specific problems related to

DSO unbundling and DER network integration?

5. Does the DSO have visibility of the DER generation/consumption profiles for grid operation purposes?
6. Are there any plans to modify in the near future the current situation regarding DER as a provider of network services?

Business model for purchase and sale of energy by DER

DG units produce energy that will be used to cover a certain demand from different consumers in the electric power system. This energy may be sold within different structures according to the regulation in force. Energy storage in the form of batteries connected to the grid or EVs with V2G capability can also buy and sell energy at different time periods.

Questions :

1. Are there agents, such as aggregators, virtual power plants (VPPs), EV charge management agents or EV supplier aggregators or other business arrangements that manage different loads (commercial and domestic consumers) and DER connected to the distribution network? What is the regulation concerning these agents and how can they interact with other agents?
2. Is the figure of new energy service companies (ESCOs) contemplated by regulation? What kind of additional services do they offer their clients?
3. What is the regulation regarding the relationship between aggregators and DSOs? Can they interact and sign agreements?
4. How can DER owners sell their energy and under what conditions (in the wholesale market, through contracts with suppliers or aggregators, etc)? How is production from RES remunerated (dynamic prices, feed-in tariffs, incentives, green certificates, etc.)?
5. Is electricity resale for storage and EVs with V2G capability allowed? How is it regulated? Who can own storage facilities?
6. How is EV charging regulated? Are final customers (potential EV users) connected to a low voltage grid obliged to go to the retail market or can they stay under a regulated tariff?
7. Are DER owners (mainly domestic consumers with DG and/or EV) obliged to have a separate metering for generation and consumption or are metering and tariffs based on net consumption? Is the figure of prosumer contemplated by regulation?

DG network access: connection charges and use-of-system charges

Regulation should on the one hand, ensure fair and non-discriminatory network access for DG agents, and on the other hand, allow DSOs full recovery of the costs for the accommodation of DG. Furthermore, there is a trade-off between providing incentives for the optimal and cost-reflective siting of new generation capacity and facilitating entry for small-sized DG operators. For this purpose, connection charges and use-of-system (UoS) charges may be designed by the regulator for all agents connected to the distribution network, including DG. The following block of questions focuses on these two network charges.

Questions:

1. What kind of connection charges are applied to DG connections in your country?
2. Are they calculated or set by simple and transparent rules? Who set the rules? How they are approved?
3. Are there practical experiences or real situations where connections charges are used by DSOs as a way to discriminate or delay DG access to the network?
4. Are there any plans to modify in the near future the current situation regarding connection charges applied to DG?
5. Have DG to pay UoS charges in your country?
6. What is the structure of current DG UoS charges? Are they applied to kWh, to kW, or both? Are there differentiated by network voltage levels, by DG sizes or technologies?
7. Are there any plans to modify in the near future the current situation regarding UoS charges applied to DG?

Effect of DER on planning, operation, network losses, reliability of supply and incremental costs

On the one hand, high levels of DER penetration cause the increment of CAPEX & OPEX for the DSO, mainly in network investment and energy losses costs. On the other hand, DER may represent a potential replacement for network investment, and should be therefore considered by DSOs throughout the network planning process. The regulatory framework may implement different options to compensate DSOs for the incremental costs, and it may affect the consideration of DER for network planning by DSOs.

Furthermore, energy losses in distribution networks are affected by DER. For low DER penetration levels usually DER would reduce network energy losses, while higher DER penetration levels would increase energy losses. In some EU countries, in each regulatory period, regulators set the target for energy losses for each DSO. A bonus/penalty scheme is implemented based on the relationship between actual energy and the target. In other EU countries, DSOs have to compensate energy losses on his grid by contracting more energy from the TSO or DER. Regulation must adapt to consider the effect of the penetration degree of DER.

Additionally, DER may have an effect on quality of service and offers potential for quality improvement thanks to the possibilities of operation in islanding mode in case of network outages. Regulation should consider DER when setting quality of service targets for DSOs.
The questions presented below are aimed to characterise the regulation regarding these matters.

Questions:

1. What is the current scheme to recognize DSO costs (OPEX and CAPEX) when calculating DSO revenues in your country? (pass through or benchmarking -econometric, engineering models-, ...).
2. Are incremental DSO costs (OPEX & CAPEX) due to the connection of DER taken into account when DSO revenues are calculated under the current regulatory scheme in your country? Is this mechanism consistent with the policy adopted on DER connection and use-of-system charges?
3. Is DER explicitly considered by DSOs in order to postpone or reduce network investment?
4. Are there any plans to include such impact on further regulatory developments? What kind of regulatory scheme in opinion of the regulator is the most appropriate to deal with this problem?
5. What regulatory mechanism is used in your country to compensate and provide incentives to DSOs for energy losses reduction?
6. Is the impact of DER on energy losses explicitly considered by the previous described mechanism? Are there DER operators explicitly rewarded for reducing network losses? At what rate?
7. Are there any plans to include the impact of DER on losses when regulating efficient losses targets?
8. Under the current DSO regulatory scheme in your country, are DSOs required to meet specific continuity of supply targets? Do they receive incentives (penalties) if the achieved performance is better (worse) than required? Is there an economic evaluation of the expected energy not supplied? How continuity of supply is measured/estimated (SAIDI, SAIFI, ENS, value of lost load, etc)? What is the methodology followed to design the regulatory incentives?
9. Is DER seen by DSOs as a new control element that can help improving current continuity of supply levels? Or by the contrary, DER is seen as a new source of potential continuity of

supply problems? Can you report real experiences on that?

10. Is power quality an issue in distribution networks in your country? Are there any problems, could you report on experiences regarding this subject?

Electric vehicles charging infrastructure and tariffs

Electric vehicles require specific regulation for their well functioning and proper integration into the electric power system. The following questions are designed to analyse the existing regulatory framework for EVs.

1. What is the regulation concerning EV charging infrastructure? Are there both domestic and public or private infrastructure?
2. Who is the owner and operator of public charging infrastructure? How is the process for such infrastructure and who is in charge of the authorization (municipal licensing, contracts with the DSO, etc)?
3. In the case of private charging infrastructure, are there any regulatory provisions to have and independent meter for EV charging at home or is it going to be another load integrated with the rest of domestic devices at home?
4. How are settlements for the procurement of energy in the retail market currently made? Do consumers purchase this electricity from suppliers or specific agents? Are there any standardized load profiles for those customers (and if so, what are the application criteria)?
5. Are there any regulatory incentives for EV users to promote any optimal charging strategy?
6. What types of contracts with the final EV customers are allowed (consumption based vs. time and parking space based)?
7. Does regulation allow for some DSO controlled/smart charging or V2G charging modes management to mitigate operational problems in specific circumstances?

Active demand response and smart metering

Demand response is essential for smart grids, since it offers the potential of a more efficient use of the network system. Regulation may incentivise consumers to become more active. In order to enable demand response, advanced metering infrastructure must be deployed. This set of questions analyses the current possibilities for cooperation between the DSO and consumers in the field of demand response, as well as regulation on smart metering.

Questions:

1. Demand response may be regulated from the side of the DSO, having the possibility to

switch of certain consumers. This is mostly regulated through a contract between DSO (and energy supplier) and consumer through lower electricity tariffs (or network tariffs). Is something introduced in your country (or in some regions?) For what kind of consumers (industrial, commercial, domestic)?

2. Is there any kind of regulatory incentives for consumers to actively control their load pattern? Are regulated and competitive tariffs obliged to include an economic signal for consumers on time period of consumption (price differentiation for peak/base periods, super-valley tariff, dynamic pricing, etc)?
3. Are tariff schemes already adapted to the data provided by smart meters or is the regulator planning on changing current tariff schemes?
4. Is the implementation of smart metering regulated (is it mandatory or left to DSO or market initiative)? Are there any specific smart metering rollout programs?
5. What is the infrastructure considered by regulation (just the smart meters at consumers' location, does it also include data concentrators, communication networks, etc)?
6. What are the functionalities considered for smart meters (remote reading, load limitation, etc)
7. Who is the owner of the required infrastructure (AMI) (the DSO, the supplier, an independent agent)? In case it is property of the DSO, how is it accounted for by regulation? Is it included in the asset base?
8. Who is in charge of AMI operation and maintenance (the DSO, the supplier, an independent agent)?
9. Who is in charge of AMM (reading, billing) (the DSO, the supplier, an independent agent)?
10. Who bears the costs of AMI (investment, operation and maintenance, management)? How are these costs passed through to consumers (do consumers pay a fixed amount for AMI rental)?
11. Are there any problems with confidentiality and data protection? What is the regulation on this topic? Who is the owner of consumers' data and who is allowed to access the information?

DSO incentives for innovation

The implementation of smart grids poses on DSOs new challenges on network planning, operation, and control to be cost effective. DSO regulated business are risk adverse to make investments on new technologies that are not enough mature. Even more, regulation in European countries typically lack of mechanisms to promote network innovation, but mostly promotes cost and investment reductions. The following questions concentrate on this aspect of regulation.
Questions:

1. Do DSOs in your country have incentives for network innovation? Are there any specific terms to account for the implementation of smart grids technologies (e.g.: advanced operation and automation of the grid with self healing, network diagnosis, remote operation, etc)?
2. What kind of mechanism, in the regulator opinion, is the most appropriate to promote DSO innovation in smart grid technologies?
3. Are there any plans to implement incentives to DSOs in order to explore ways of how DER can contribute to improve network and system efficiency?

Standardization and interoperability

In order to ensure the proper functioning and efficiency of smart grid implementation, interoperability is a key issue. Standards must be designed for all companies involved.
Questions:

1. Do DSOs in your country use standard, open and interoperable technologies (CIM, IEC 61850, etc.) to a certain extent? Are any regulatory requirements in place? Being this the case, could you please describe the current situation?