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COVER PICTURE CREDITS

70 MW PV facility in Rovigo, Italy; Courtesy: Bianca Barth.

PV GRID

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DISCLAIMER

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1. EXECUTIVE SUMMARY

PV GRID aims at enhancing PV hosting capacity in distribution grids while overcoming regulatory and normative barriers hampering the application of available technical solutions. Those solutions have been identified and explored by the PV GRID project consortium, including distribution system operators (DSOs), national and European PV associations and other electricity sector experts. Starting from the most effective solutions and by discussing the barriers to their application at both European and national levels, the project consortium has developed European-wide regulatory and normative recommendations aiming at reducing and removing the current barriers. The most important normative and regulatory recommendations are presented in this Advisory Paper.

Normative and Regulatory Recommendations

The normative recommendations address administrative barriers and other obstacles that either DSOs or prosumers have to face when implementing technical solutions that would instead allow for higher grid hosting capacity, such as inappropriate grid codes and insufficient technical standards. Regulatory recommendations, on the other hand, address the framework in which DSO and PV systems owners operate. For instance, a certain national regulatory framework may not allow a DSO to recover the costs of necessary grid-enhancing investments. Also, a PV system operator may not be correctly incentivised (by means of network tariffs, for instance) to make an efficient use of the distribution grid.

Technical Solutions for Grid Hosting Capacity

PV GRID has focused on identifying technical solutions to solve voltage and thermal issues in distribution networks. These solutions can be used to increase the PV hosting capacity in the distribution networks. They have been classified in DSO solutions, PROSUMER solutions and INTERACTIVE solutions and include the following:

- **DSO solutions:** network reinforcement, on load tap changers, advanced voltage control, static VAr control, DSO storage, booster transformers, network reconfiguration, advanced closed-loop operation;
- **Prosumer solutions:** prosumer storage, self-consumption by tariff incentives, curtailment of power-feed in at PCC, active power control by PV inverter, reactive power control by PV inverter;
- **Interactive solutions:** demand response by local price signals, demand response by market price signals, SCADA & load control, SCADA & PV inverter control, and wide area voltage control.

Cost and benefits of the different solutions were compared by applying an interactive method based on a multi-criteria analysis, complemented by several stakeholder workshops. In a second step, two multi-criteria indicators have been defined for assessing both the cost-benefit and the regulatory priority for each solution. Finally, the results for the different countries have been combined for defining a list with three effectiveness levels (high, medium, and low effectiveness) of technical solutions at European level for the low and medium voltage levels (LV and MV), by involving the expertise of distribution grid operators (DSOs), PV associations and other stakeholders.

The European Regulatory and Normative Framework

Many EU pieces of legislation, together with network codes and technical standards, can have an impact on PV deployment and specifically, on PV integration in distribution grids, including the technical solutions identified by PV GRID. Consequently, the PV GRID project consortium decided to provide the European context on relevant directives, network codes and other technical standards, which directly or indirectly influence national regulations. Broader recommendations aiming at changing the European framework in order to support adaptations on the national level are provided as well.

Within the European framework, of special interest are conditions under which priority dispatching and generation curtailment are considered. As the main driver for network investments is the peak power, the network is generally dimensioned in a way that enables the DSO to cope with all demand withdrawn from and production injected into the grid at any time throughout the year while still adhering to all (security and technical) parameters. If the production remaining after local demand has been met is higher than the demand peak the segment was planned for, probably the DSO will have to make a new investment to be able to accommodate that production peak in the grid under any circumstances. A large-scale introduction of PhotoVoltaics (PV) or other Distributed Generation (DG) into a specific distribution network segment is therefore clearly a driver for investments. Against this background, the question arises on whether, and if so, how and under which conditions, curtailment – understood in this case as PV peak shaving – could be used to increase distribution network hosting capacity and delay or even avoid PV-driven network investments.

EU network codes can have a positive influence on PV grid and market integration; however, they can imply high compliance costs for PV generators, thus slowing down the potential growth of the PV technology. Network codes are designed in order to address cross-border issues; they however have a strong impact on distributed generation, such as PV, and on distribution system operators. Such impact should be taken into account both at the design and implementation phase of network codes. It should be understood that PV systems use mass-produced components; therefore, the implementation of these network codes will only be cost-efficient if relevant standards exist and are fully used.

For mass-marketed equipment like inverters or other DER components, standardisation is the most effective solution to address the challenges related to grid integration of distributed generation while minimizing costs by avoiding products variance. Attention should be paid to the lack of appropriate standards and support should be provided to the relevant CENELEC technical committees.

Implementation of Technical Solutions at National Level

The discussion on the implementation of the technical solutions identified by PV GRID in the project's four focus countries (Germany, Spain, Italy and Czech Republic), has led to the identification of a series of barriers, either general (affecting all solutions identified) or specific (affecting mainly one or a few of the solutions identified) at national level. The barriers further examined include: DSO investment recovery, grid connection charges and distribution network tariffs, rules forbidding RES energy curtailment except for security issues, insufficient self-consumption framework, insufficient DSO access to advanced PV inverter capabilities, insufficient framework for prosumer storage, insufficient framework for demand response, incoherent metering framework and regulatory frameworks that do not incentivise Smart Grids. The barriers are illustrated on the basis of examples in the focus and other European countries. Also, general recommendations for mitigating them are provided.

DSO Investment Recovery

A number of technical solutions proposed in the PV GRID project affect the costs incurred by DSOs. Therefore, remuneration schemes need to be adapted to ensure that DSOs are encouraged to implement smart grid solutions when this can be considered efficient.

Grid Connection Charges and Distribution Network Tariffs

The grid connection of PV installations entails a certain amount of network costs, both at the point of connection and, in some cases, in the upstream network. Cost allocation between connection charges and distribution network tariffs should be evaluated in order to allow for a compromise between improving grid hosting capacity and promoting DG development. The higher the costs for connection charges, the more likely DG projects will not be realized due to lack of investment.

Rules Forbidding RES Energy Curtailment Except For Security Issues

Curtailment is usually only accepted for emergency situations and generally managed by TSOs. Despite this, PV GRID acknowledges that there are cases in which DSOs should be allowed to curtail the output energy of PV installations. These cases are involved in the implementation of the following technical solutions that allow for enhancing the overall distribution gird capacity for PV:

- Curtailment of power feed-in at PCC;
- Active power control by PV inverter P(U);
- SCADA + PV inverter control (Q and P);
- Wide area voltage control

Therefore, PV GRID considers a EU-wide, fair and informed discussion on the issue to be worthwhile and in markets with high PV penetration levels even necessary and would like to foster such an informed and fair discussion. PV GRID has formulated some recommendations on boundary conditions for the use of curtailment that could serve as guidance to dialogue among all partners and to EU and national lawmakers.

Insufficient Self-consumption Framework

In addition to reducing a prosumer's electricity bills, self-consumption can bring benefits to the whole system, since it reduces the electricity that needs to be distributed or transmitted through the grid. These benefits are at their best if the overall peak power demand is reduced either globally or locally, since distribution and transmission networks have to be sized for the peak scenario. Countries that do not have a self-consumption framework in place, should consider legislation for allowing it. In addition, economic incentives stimulating PV electricity self-consumption to contribute to network operation (reducing peaks) should be assessed.

Insufficient DSO access to advanced PV Inverter Capabilities

Modern inverters are able to provide a lot of functionalities to support network stability. Although some of these solutions are already available from a technical point of view, in many countries the DSO cannot exploit such functionalities, as he does not have access to the PV inverter. In countries where DSO access is allowed, other barriers may include the lack of experience and clear rules, as well as the absence of standards. Hence, besides providing DSOs with access to advanced PV inverter capabilities, it will be important to define boundary conditions, standards and clear market rules.

Insufficient Framework for Prosumer Storage Solutions

Generally, prosumer storage solutions are allowed in most European countries. Though, in Spain there are certain cases (if a royal decree applies) where the application is explicitly forbidden. However, even in those cases where prosumer storage is allowed, it is not very spread, both because of profitability issues and lack of clarity on the connection and operation requirements in conjunction with existing DG. In Germany, an incentive program for storage that could be a reference for other countries has recently been launched. Furthermore, by means of connection conditions and other technical rules it should be ensured that prosumer storage does not pose a security problem to the system or interfere with the metering of DG production.

Insufficient Framework for DSO Storage Solutions

In principle, storage solutions can be used by DSOs to address the intermittency and variability of DG. However, due to the concept of unbundling, DSOs are not allowed to sell energy to final customers and they must be unbundled from any supply activities. Whether this automatically implies that DSOs are not allowed to own, operate or use storage is currently under discussion in several countries. Due to the versatile capabilities of storages to optimize the rate of grid utilization, there should be a reflection on how to activate its potential for DSO use.

Insufficient Framework for Demand Response

Basic demand response services are available in several countries in the form of tariffs with time-block discrimination. However, this type of demand response is only useful to reduce system peaks, and not for local violations of the technical constraints. Additionally, from the point of view of integrating PV installations, it is usually more useful to have the ability to increase demand rather than to reduce it. This requires more advanced and dynamic services of demand response including the necessary processes, market rules etc. especially in unbundled electricity markets. A detailed regulation on Demand Response is still not present in several countries, given the complexity of the topic and the strong connection with the future "Smart Grid" implementation.

Incoherent Metering Framework

The deployment of smart meters is connected with the ability of the distribution network to host more DG. However, it must be recognised that while smart meters are convenient for some solutions, they are not sufficient. They need to be complemented with other equipment that for example allows remote controlling, and with new business models that turn the available data into business opportunities. Furthermore, certain degrees of smartness can be achieved even without a complete rollout of smart meters.

Regulatory Frameworks that do not incentivise Smart Grids

The aim to develop smart grids at a European level is often in conflict with national regulations, which establish the specific conditions under which DSO recover their investments. Basically, the national frameworks tend to implement regimes that include elements of incentive regulation, which has the main objective of promoting only efficient investments, with the aim that this reduction in investment and/or operational expenditure will ultimately imply a reduction of prices for the consumer. In fact, smart grid solutions oftentimes rely on technologies that have shorter useful lives and/or are not fully proven yet. Consequently, DSOs could discard their implementation due to the technological uncertainties. Under these conditions, National Regulatory Authorities (NRAs) should consider setting specific incentives to adopt and test innovative solutions.

Application at National level

Aiming at providing guidance and advice to member states that either anticipate a significant increase in PV penetration or are planning for such an increase, a roadmap for “Increasing PV Penetration” in a given national context has been developed. Together with the technical solutions the roadmap can be used to identify gaps in the national regulatory and normative frameworks. To this end, it will support member states in their PV and overall Rewable Energy Sources (RES) strategy as it gives an indication whether the technical solutions to increase the hosting capacity of existing grids should be exploited.

National Case studies

Essential resources have been dedicated to further analyse the current regulatory and normative barriers towards the technical solutions in the four PV GRID focus countries : Spain, Italy, Czech Republic and Germany. Each case study sets out to describe the current situation of PV integration in the correspondent distribution grid and identifies the most relevant technical solutions for each country. Subsequently, insufficient regulatory and normative framework conditions are addressed by describing the current standards and regulations, including the problems and deficiencies, and by identifying the technical solutions affected by those standards and regulations. Finally, each case study provides recommendations on how to improve the framework conditions in each country concerned. Furthermore, four additional case studies have been prepared based on national consultation workshops on the PV GRID project results in the following countries : France, Greece, Netherlands and United Kingdom. Both, the focus country case studies and the additional case studies, are presented in the Annex and are available for download at : http://www.pvgrid.eu/results-and-publications.html.

2. INTRODUCTION

PV GRID is a transnational collaborative effort in which fifteen national and European solar industry associations, two distribution system operators (DSOs), a policy consultancy, a technical consultancy and a regulatory research institute cooperate within the Intelligent Energy Europe Programme. The project is coordinated by the German solar industry association, BSW-Solar.

The overall goal of the PV GRID project is to address the regulatory and normative barriers hampering the integration of PV into the electricity distribution grids in Europe through two main actions:

- the assessment and comparison of national frameworks for PV development in the 16 participating countries;
- the prioritisation of technical solutions available for enhancing PV hosting capacity in distribution grids and the formulation of regulatory and normative recommendations for their adoption.

Assessment of National Frameworks for PV Development

The assessment and comparison of national frameworks for first developing and then operating PV systems in 16 European countries is achieved by means of an extensive research activity involving fifteen national industry associations and coordinated by the policy consultancy eclareon GmbH, based in Berlin, Germany. The results of this assessment are disseminated through the online PV GRID database[1] and were presented in a series of national forums organised in each of the participating countries during the spring and summer of 2013.

Enhancing PV Hosting Capacity in Distribution Grids

The objective of enhancing PV hosting capacity in distribution grids is pursued by an initial prioritisation of available technical solutions, analysed by involving distribution grid operators (DSOs) and other electricity sector experts. This task, completed in May 2012, has built on the experience of two DSOs: ENEL Distribuzione (Italy) and RWE Deutschland (Germany) and was coordinated by DERLab, an association of laboratories and research institutes in the field of distributed energy resources based in Kassel, Germany.

Starting from the most effective solutions identified in the previous task and by discussing the barriers to their application at both European and national levels, the project consortium has developed European-wide regulatory and normative recommendations. This second step of the action, coordinated by the Institute for Research in Technology of the Madrid-based Comillas Pontifical University, culminates in this advisory paper.

The normative recommendations address administrative barriers and other obstacles that either DSOs or prosumers have to face when implementing technical solutions that would instead allow for higher grid hosting capacity, such as inappropriate grid codes and insufficient technical standards.

Regulatory recommendations, on the other hand, address the framework in which DSO and PV systems owners operate economically. For instance, a certain national regulatory framework may not allow a DSO to recover the costs of necessary grid-enhancing investments. Also, a PV system operator may not be correctly incentivised (by means of network tariffs, for instance) to make an efficient use of the distribution grid.

National and European Level Communication

The results of our work have been presented in a series of European national consultation workshops targeted at DSOs, regulators, policy-makers and other electricity sector stakeholders taking place between February and May 2014. The events also served as a platform for discussions among key stakeholders and provided the opportunity to seek feedback on the project results which in turn has been incorporated in the final European Advisory Paper. These national and European level communication activities for the dissemination of project results were coordinated by EPIA, the European PV Industry Association based in Brussels, Belgium.

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[1] See: http://www.pvgrid.eu/database.html

European Advisory Paper

This document aims at providing an overview of the issues and barriers that, at both European and national levels, need to be addressed in order to enhance the distribution grid capacity for PV and other distributed generation. A set of recommendations is presented in order to overcome these issues, allowing for the implementation of the identified technical solutions.

The following chapters are organised as follows:

- Chapter 3 presents an overview of the technical solutions identified in PV GRID;
- Chapter 4 describes current issues and provides recommendations at European level;
- Chapter 5 discusses the implementation of the identified technical solutions at national level;
- Chapter 6 provides a framework allowing for a customised application of the identified recommendations in different European national contexts;
- Chapter 7 presents the Conclusions and a broader Outlook on future research and work needed;
- Annex I offers a deeper analysis for the four PV GRID focus countries: Germany, Italy, Czech Republic and Spain;
- Annex II offers a deeper analysis of four additional countries: France, United Kingdom, Greece and the Netherlands;
- Annex III offers an overview of the national barriers assessment process and its results that was carried out in all 15 countries participating in PV GRID.

All three Annex documents are available for download as stand-alone documents at: http://www.pvgrid.eu/results-and-publications.html.

3. OVERVIEW OF TECHNICAL SOLUTIONS

3.1. Identification of Technical Solutions

When it comes to increasing the PV hosting capacity of distribution grids, voltage limitation is the most common constraint. Another limiting factor when increasing the installed PV capacity is the thermal limitation due to high current flow through electrical devices such as transformers. If these local problems are solved by giving the DSOs access to flexibility offered through different technical solutions, higher shares of PV can be integrated. The distribution network covers the Low Voltage (LV), Medium Voltage (MV) and sometimes High Voltage (HV) levels, and is functionally distinguished from the transmission grid. Due to the project's scope, issues that are associated with the transmission system, like frequency stability, are not discussed here. However, the PV GRID consortium is aware that system issues and the role of distribution networks in system operation will be increasingly important with an expansion of renewable generation. During the work of PV GRID, the project consortium has focused on the identification of the technical solutions to solve voltage and thermal limitations. These solutions can be used to increase the PV hosting capacity in the distribution networks. As indicated in Figure 3.1.1 they have been classified in DSO solutions, PROSUMER solutions and INTERACTIVE solutions.

Category	#	Technical solution
DSO	1	Network Reinforcement
	2	On Load Tap Changer for MV/LV transformer
	3	Advanced voltage control for HV/MV transformer
	4	Static VAr Control
	5	DSO storage
	6	Booster Transformer
	7	Network Reconfiguration
	8	Advanced Closed-Loop Operation
PROSUMER	9	Prosumer storage
	10	Self-consumption by tariff incentives
	11	Curtailment of power feed-in at PCC
	12	Active power control by PV inverter P(U)
	13	Reactive power control by PV inverter Q(U) Q(P)
INTERACTIVE	14	Demand response by local price signals
	15	Demand response by market price signals
	16	SCADA + direct load control
	17	SCADA + PV inverter control (Q and P)
	18	Wide area voltage control

Figure 3.1.1 - Technical solutions enhancing distribution grid hosting capacity

DSO solutions are installed and managed on the grid side and do not require any interaction with the consumers or the PV plants. PROSUMER solutions are installed before the meter, i.e. on the PV operator's premises, and react based on the grid characteristics at the point of common coupling, without any communication with the DSO. The INTERACTIVE category requires a communication infrastructure linking the hardware located in different grid locations.

This list of solutions has to be seen as toolbox that contains solutions addressing different technical problems. The selection of the best solutions may differ in each planning process, depending on network regional specifics and/or local feeder constraints.

DSO Solutions

Network reinforcement - Network reinforcement is the most traditional action carried out in order to ensure compliance with voltage and thermal requirements in case the connection of a new PV plant may bring variations outside the reference values. Further grid hosting capacity is provided by additional cable and transformer capacity installations. Hence, it is the most frequently adopted action today. However, costs can be significantly high in some cases.

On Load Tap Changer (MV/LV transformer) - OLTCs are and have been largely used in HV/MV transformers. In MV/LV transformers, tap changers are usually not automated and have to be parameterised manually based on information about the MV grid topology. OLTC on MV/LV transformers can significantly contribute to solve voltage control issues in LV networks.

Advanced voltage control (HV/MV transformer) - Through OLTC the output voltage of the transformer can be changed according to the value of some parameters: these parameters for HV/MV transformers are usually the voltage at the MV busbar and the HV/MV transformer load. The presence of distributed energy resources (DER) connected to MV feeders makes this regulation increasingly unreliable. Therefore OLTC must be combined with some advanced voltage regulation system by measurements within the MV and possibly the LV grid to get a better knowledge about the actual grid state.

Static VAR Control - Utilizing Static VAR Compensators (SVC) enables to provide instantaneously reactive power under various network conditions. Reactive compensation can be used to sustain voltage in a MV or LV distribution network. Reactive power contribution to voltage control in LV networks is smaller as the resistive part of the impedance is prevailing.

DSO storage - Static storage systems, although still very expensive and space consuming, are flexible tools and can be used for solving many problems in distribution grids. Typical applications are peak shaving, power shifting, ancillary services and backup in case of grid failure.

Booster Transformers - A Booster Transformer is a transformer of which one winding is intended to be connected in series with a circuit in order to alter its voltage and the other winding is an energizing winding. Boosters are MV-MV or LV-LV transformer that can be used to stabilize the voltage along a feeder. In the past, boosters have been generally installed in long feeders to compensate voltage drops exceeding standards. One can imagine using the same equipment for mitigating negative impacts of PV on voltage.

Network Reconfiguration - MV grids are usually topologically meshed, but operated radially. This means that in boundary points some switches are kept open and can be used for re-supplying the feeder in case of outages. In case of connection of a new DER plant or other significant changes within a feeder, it may happen that, by changing the substations that are used as boundary points a new configuration can be obtained which complies with all voltage requirements. However, this solution has usually a quite low impact and should be considered only as an initial measure that can be applied in regions with rather low DER penetration.

Advanced Closed-Loop Operation - Closed-Loop Operation (or Closed Ring Operation) is the method of grid operation where each point of a given part of a network is fed from two different sources along two distinct paths to decrease the circuit impedance. However, this solution significantly increases the complexity of the operation, while having a moderate impact on the investments necessary to integrate RES.

Prosumer solutions

Prosumer Storage - Storing electricity at prosumer level enables to mitigate local voltage and congestion problems provided that a reduction of the feed-in peaks can be ensured. The fluctuating generation is buffered by storage and can be used whenever needed. Prosumer storages are mainly interesting in areas where the DER is located next to comparable loads. This is especially the case for residential implementation of PV i.e. in LV grids. In areas with a high implementation of small DER this solution can also have benefits on higher grid levels.

Self-consumption by tariff incentives - An adequate measure to reduce the distribution grid load is to set up direct or indirect incentives for self-consumption of DER by the prosumers. The prosumer can optimise his own demand in relation to the fluctuating DER in his household. For instance, with a fixed tariff structure (e.g. feed-in price lower than consumption price), the prosumer is incentivised to shift his electricity consumption in order to reduce the PV production injected in the grid. Alternatively, self-consumption can be directly incentivised with a premium granted for all the electricity self-consumed. The benefit of such an incentive scheme is that the prosumer is able to decide by himself whether he wants to adapt his demand or not.

Curtailment of power feed-in at PCC – A device (e.g. the meter) at the customer's site controls that the feed-in power is never above the contracted maximum power or above a fixed value (e.g. 70% of the installed PV capacity as implemented in the German Renewable Energy Act). This solution requires the control device to be able to power down the PV production or to activate a dump load. Fixed curtailment makes sense as the real production of a PV system only seldom reaches values that are close to its installed capacity. Therefore even a significant reduction of the generated power (kW) would cause only a small loss of energy production (kWh) [1].

Active power control by PV inverter P(U) - Voltage and congestion problems can be solved by curtailing the PV feed-in power. Contrary to the fixed power curtailment as described in previous solution, the LV grid voltage could be used as a proxy indicator for the grid situation and for the curtailment level. For economic reasons, active power reduction should be used only when all other less expensive solutions have been applied. However, if over-voltages occur in LV grids that cannot be reduced by other measures, it is better to reduce the power than to shut off the PV inverter completely.

Reactive power control by PV inverter Q(U), Q(P) - Providing reactive power as a function of the local voltage value [Q=Q(U)] or as a function of the active power production [Q=Q(P)], limits the voltage rise caused by distributed generation. With this solution, the reactive power of the inverter can be a function of its active power production [Q=Q(P)] or a function of local voltage measurements [Q=Q(U)]. The effectiveness of this solution on managing voltage ultimately depends on the impedance of the feeder and is lower in case of high R/X ratio. This technical solution is therefore more effective in MV networks than in LV ones.

Interactive solutions

Demand response by local price signals - Demand response can be triggered by local price signals (different from market prices, e.g. through variation in the network tariff that the supplier passes through to the consumer) available only to consumers located in feeders that experience voltage and/or congestion problems. These price signals can be set directly by the DSO or indirectly by energy aggregators, based on the estimated grid situation respecting demand and generation forecasts. In this approach, different consumer electricity price areas are defined within the DSO network according to the grid loading. This solution requires the installation of a smart prosumer energy interface (smart meter) able to receive the variable price signals, as well as a smart network information and control system (smart SCADA) on the DSO side and a communication infrastructure between them.

Demand response by market price signals - Demand response can be triggered by electricity market price signals, which are identical for consumers wherever they are located. However, having a global price signal for all prosumers will not allow distinguishing between the different local situations in the distribution grid. Therefore this solution is more appropriate for the electrical market than for grid integration issues.

SCADA + direct load control - In critical grid situations, DSOs or energy aggregators are allowed to remotely activate or curtail dedicated consumer loads, based on agreed contract. A capacity payment would be offered to the customers who allow third parties to make use of their flexibility in emergency cases. In principle, direct load control can be applied both in MV and LV networks with comparable results. However, implementing interactive measures on LV grids implies a larger number of installation points, resulting in an increased level of complexity of the system while the relative size of installation is smaller.

SCADA + PV inverter control (Q and P) - The level of reactive power provision and the active power reduction of dedicated PV inverters are remotely controlled by a feeder supervisory control system. This solution is potentially feasible, from a mere technological point of view, and can be implemented in selected portions of existing networks. The more sophisticated the sensors' and communication infrastructure requirements, the less adequate (from the techno-economic point of view) they are for LV networks.

Wide area voltage control - This solution includes all Voltage and VAR control technologies available in the distribution grid, combined to efficiently monitor power, determine control settings, and then adjust voltage and reactive power. Pieces of equipment like OLTC transformers, distribution capacitor banks, distribution voltage regulators or PV inverters are coordinated to optimize voltage and power factor in the whole DSO area. Smart grid technologies are applied to enable measuring the voltage and power factor at several points, controlling the equipment, coordinating and optimizing the generation and load.

3.2. Prioritisation of Technical Solutions

For the purpose of comparing the benefits and costs of the different possible technical solutions for increasing the grid hosting capacity for PV and due to the many different conditions existing in European distribution grids (such as PV penetration levels, feeder characteristics, load profile, load density), the PV GRID project consortium decided to apply an interactive method based on a multi-criteria analysis, complemented by several stakeholder workshops.

Initially, the different technical solutions have been evaluated against common criteria (cost, availability of technology , impact on grid hosting capacity, applicability within existing regulations) for four grid type categories (rural LV, suburban LV, rural MV and suburban MV grids) in each of the four focus countries.

In a second step, two multi-criteria indicators have been defined for assessing both the cost-benefit and the regulatory priority for each solution. The cost-benefit indicator is based on the three criteria cost, impact on voltage and impact on congestion. The regulatory priority indicator is based on the two criteria availability of technology and applicability within existing regulations. During the evaluation process, the distinction between rural and suburban grids was evaluated as not very relevant and only two grid categories (LV and MV) remained for consideration.

Finally, the results for the different countries have been combined to define a list with three effectiveness levels (high, medium, and low effectiveness) of technical solutions at European level for two grid types (LV and MV), by involving the expertise of distribution grid operators (DSOs), PV associations and other stakeholders.

Figure 3.2.1 shows the prioritisation for the low voltage networks, while Figure 3.2.2 shows the prioritisation for the medium voltage networks

Effectiveness of solutions	Technical solution	CZ	DE	ES	IT
HIGH EFFECTIVNESS	Curtailment of power feed-in at PCC	🟥	▨	🟥	🟥
	Network Reinforcement	🟩	🟩	🟩	🟩
	Reactive power control by PV inverter Q(U) Q(P)	🟥	🟩	🟥	🟩
	Active power control by PV inverter P(U)	🟥	🟥	🟥	🟥
	Prosumer storage	🟥	🟩	🟥	🟩
	On Load Tap Changer for MV/LV transformer	🟩	🟩	🟩	🟩
NORMAL EFFECTIVENESS	SCADA + direct load control	🟥	🟥	🟥	🟥
	Network Reconfiguration	🟩	🟩	🟩	🟩
	Self-consumption by tariff incentives	🟩	🟩	🟥	🟥
	Wide area voltage control	🟨	🟨	🟩	🟨
	Static VAr Control	🟩	🟩	🟩	🟩
	Booster Transformer	🟩	🟩	🟩	🟩
	SCADA + PV inverter control (Q and P)	🟨	🟥	🟨	🟨
	DSO storage	🟥	🟥	🟥	🟥
LOW EFFECTIVENESS	Demand response by local price signals	🟥	🟥	🟥	🟥
	Advanced voltage control for HV/MV transformer	🟩	🟩	🟩	🟩
	Demand response by market price signals	🟨	🟨	🟨	🟥
	Advanced Closed-Loop Operations	⬜	🟩	🟨	⬜

🟥 Adoption of solution requires regulatory development
🟨 Adoption of solution requires regulatory and technology development
🟩 Solution can be applied where problems occur
⬜ Technology for the solution is not mature

Figure 3.2.1 - Summary of technical solutions for voltage quality and congestion problems, priorisation for the low voltage networks.[2]

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[2] As curtailment is legally possible in Germany under the Renewable Energy Sources Act (EEG), but is considered to be an exemption from the DSO's general duty to provide capacity and to enhance the grid infrastructure, German members of the PV Grid consortium opted for a "green/red" indication, i.e. curtailment can be applied if problems occur, however, a more general adaption of the solution requires regulatory development. Cf. the extensive discussion of the curtailment issue within the German context in Annex I.

Effectiveness of solutions	Technical solution	CZ	DE	ES	IT
HIGH EFFECTIVNESS	Network Reinforcement	🟩	🟩	🟩	🟩
	Reactive power control by PV inverter Q(U) Q(P)	🟥	🟩	🟥	🟩
	Curtailment of power feed-in at PCC	🟥	▨	🟥	🟥
	Active power control by PV inverter P(U)	🟥	🟥	🟥	🟥
	Network Reconfiguration	🟩	🟩	🟩	🟩
	SCADA + PV inverter control (Q and P)	🟥	🟥	🟥	🟥
	Advanced voltage control for HV/MV transformer	🟩	🟩	🟩	🟩
NORMAL EFFECTIVENESS	Static VAr Control	🟩	🟩	🟩	🟩
	SCADA + direct load control	🟨	🟨	🟥	🟥
	Self-consumption by tariff incentives	🟩	🟩	🟨	🟥
	Wide area voltage control	🟨	🟨	🟩	🟨
	DSO storage	🟥	🟥	🟥	🟥
	Prosumer storage	🟥	🟩	🟥	🟩
LOW EFFECTIVENESS	On Load Tap Changer for MV/LV transformer	🟩	🟩	🟩	🟩
	Booster Transformer	🟩	🟩	🟩	🟩
	Demand response by local price signals	🟥	🟥	🟥	🟥
	Demand response by market price signals	🟨	🟨	🟨	🟥
	Advanced Closed-Loop Operations	⬜	🟩	🟨	⬜

🟥 Adoption of solution requires regulatory development

🟨 Adoption of solution requires regulatory and technology development

🟩 Solution can be applied where problems occur

⬜ Technology for the solution is not mature

Figure 3.2.2 - Summary of technical solutions for voltage quality and congestion problems, prioritisation for the medium voltage (MV) networks[3]

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[3] As curtailment is legally possible in Germany under the Renewable Energy Sources Act (EEG), but is considered to be an exemption from the DSO's general duty to provide capacity and to enhance the grid infrastructure, German members of the PV Grid consortium opted for a "green/red" indication, i.e. curtailment can be applied if problems occur, however, a more general adaption of the solution requires regulatory development. Cf. the extensive discussion of the curtailment issue within the German context in Annex I.

4. EUROPEAN CHALLENGES AND RECOMMENDATIONS

While discussing the implementation of the identified technical solutions, the PV GRID consortium has recognized a series of Europe-wide challenges. In the next sections, these challenges are illustrated and a series of broad recommendations are provided both to European and national policy-makers.

4.1. Challenges

4.1.1. Recovery of DSO Investments and Costs

DSOs are so-called natural monopolies, which is why they are regulated. They are responsible for investing in, operating and maintaining distribution networks. Several technical solutions identified in PV GRID require DSOs' investments in new equipment to be recovered over time via their allowed revenues.

The European legislation, and in particular article 37 of Directive 2009/72/EC concerning common rules for the internal market in electricity sets the principles of transparency and sufficiency in relation to DSOs' allowed revenues, but leaves national regulatory authorities (NRAs) free to implement different solutions and does not mention DSOs' investments explicitly [2].

Investment Recovery Schemes

As a consequence, national regulations differ quite a lot, especially with regards to the treatment of DSOs' investments. Generally speaking, there has been a EU-wide trend towards systems of incentive regulation in the past 20 years. Systems of incentive regulation are either focused on OPEX alone or on both OPEX and CAPEX or even on the sum of OPEX and CAPEX without discriminating between the two (TOTEX). They stem from the so-called "new regulatory economics", a body of economic theory that criticised "cost-plus-regulation" for not being able to incentivize companies that hold infrastructure monopolies to become more efficient.[4] Systems of incentive regulation imply fixed revenues or fixed prices that are kept for a whole regulatory period of 3 to 5 years and might even be combined with an efficiency target.

This poses two main challenges : on the one hand, DSOs may start recovering their new investments only after some years, i.e. within the next regulatory period. On the other hand, DSOs may limit their investments so as to yield as high profits as possible under the cap. Some Member States have recently addressed this problem explicitly either by yearly updating individual CAPEX within a regulatory period or by setting up so-called investment budgets, mechanisms or surcharges. In other countries policy makers have so far chosen not to tackle the investment issue explicitly or have addressed only certain types of investments at certain network levels.[5]

A third challenge is linked to the fact that some of the technical solutions discussed by PV GRID to a certain extent change DSOs' costs and DSOs' cost structures :

- These solutions are (in the best possible case) cheaper than conventional solutions in the medium to long term. However, they are also most probably more expensive than conventional solutions in the short term, as additional (technical) capabilities and qualified employees are needed ;
- Some identified technical solutions involving increased smartness go along with lower CAPEX and higher OPEX compared to conventional network reinforcements.

Even reformed systems of incentive regulation sometimes do not reflect these evolutions in DSOs' costs and cost structures. Notwithstanding some specific exemptions, they imply that DSOs only earns money on the invested equity (as everything else is costs payable). Hence, when implementing such lower CAPEX and higher OPEX smart solutions, DSOs may earn less compared to using conventional solutions.

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[4] For more information on the subject the reader can consult Laffont/Tirole : A theory of incentives in procurement and regulation ; MIT Press 1992.

[5] cf. the latest amendment to German regulation which opens investment budgets for DSOs who invest in 110 kV systems.

Within this framework, R&D and pilots are treated like any other cost, i.e. there is no specific compensation for the risks involved in testing new technologies and processes, little support can be expected to Smart Grid development.

Innovative solutions must not be subject to the same “tightening” efficiency requirements as conventional ones; on the contrary, the higher technology risk inherent in such investments must be taken into account.

Grid Connection Charges and Distribution Network Tariffs

Grid connection charges and distribution network tariffs are important components of DSOs’ allowed revenues. Grid connection charges are those costs paid to DSOs by agents (either generators or consumers) requesting a connection to the grid; these costs are paid at the moment of connection, and the philosophy behind their calculation varies across Member States.

The remaining part of connection costs that are not charged to the connectee are generally socialised among all electricity consumers through distribution network tariffs. These tariffs lead to payments by consumers for withdrawing power from the network as well as payments by generators for injecting electricity into the grid; albeit these so-called g-components exist in some member states only. Such tariffs cover many different costs related to inter alia investment in and operation of DSOs’ assets. While their actual type and level vary sensibly from one EU country to another, they most often constitute so-called two part tariffs, i.e. a fixed or load dependent fee is combined with a fee per kWh.

All DSO technical solutions identified by PV GRID imply implementation costs on the part of the DSO (CAPEX and/or OPEX). Such costs are partly recovered via the above-mentioned:

- grid connection charges paid by PV system owners requesting the connection;
- distribution network tariffs paid both:
    - by PV system owners when injecting their electricity into the grid (only in a limited number of countries) and
    - by consumers (including PV system owners in cases where generation and consumption share the connection point) buying their power supply from the network (socialisation of costs).

Existing literature distinguishes three different connection charges regimes: shallow, deep and shallowish [3]. Normally, under a shallow connection charges regime, PV operators, as well as any other connectee, only pay for the cost of direct connection lines. On the contrary, under a deep connection charges regime, PV operators and other parties generally pay not only for the direct connection, facilities but also for any necessary upstream reinforcement (e.g. a transformer upgrade). Shallowish connection charges constitute an intermediate approach where PV owners and other parties only pay for part of the network reinforcements (e.g. only those reinforcements within the same voltage level). Of course, it must be borne in mind that the higher the connection charge, the lower the cost that will be socialised among electricity consumers but the lower the PV system profitability.

Nonetheless, in most European countries the connection charges paid by PV system owners, as well as by consumers, do not exactly correspond to the direct or indirect cost incurred by the DSO due to the new connection. In these countries, connection charges can rather be described as lump sums, which are calculated in accordance with a price list of typical grid investment items. The more transparent and accessible this list is, the easier it is for a PV project developer, when preparing his business plan, to calculate the amount of money he will have to pay for the grid connection.

Distribution grid tariffs paid by consumers are volumetric, i.e. based on energy consumed (kWh), in most European countries; tariffs can also be partly or entirely capacity-based, i.e. based on the contracted power (kW). In some countries, the amount paid for the kWh is higher during critical or peak times (time-of-use billing).

From the PV GRID consortium point of view, three main aspects can be highlighted in relation to grid connection charges and distribution network tariffs.

Firstly, in certain countries PV system owners connected to distribution grids may pay a different grid connection charge type compared to other types of generators with equivalent connections. In fact, as opposed to large generators, PV systems can be installed in conjunction with consumption facilities already equipped with a connection to the grid. When this is the case, it may happen that the new PV system, which does not need a new connection but shares the consumption connection, does not trigger costs on the part of the DSO. Under these circumstances, it is understandable that PV systems, pay low or no grid connection charges. However, if the connection of new PV systems triggers additional costs on the part of the DSO (e.g. when the PV system is oversized compared to the consumption behind the connection point), the reasons why this type of generation pays a relatively smaller connection charge compared to large generators are rather political: they stem from the political willingness to support the growth of distributed, renewable generation.

Secondly, in most European countries PV system owners do not pay distribution grid tariffs for the electricity injected into the grid. On the contrary, other generators connected to distribution grids may pay injection tariffs. In this respect, PV system owners benefit from an advantage due to their limited size.

Thirdly, in most European countries no distribution grid tariffs or other levies are applied to the electricity generated from PV and directly consumed before the connection point (self-consumption schemes). This is understandable as such electricity remains within the customer's premise without touching the public grid. On the other hand, unless the electricity is self-consumed during peak hours, DSOs' costs do not decrease. In fact, as explained in section 4.1.4, the latter are related to the maximum amount of power installed that distribution grids need to deal with.

As a direct consequence, in those countries such as Italy and Germany, where PV self-consumption is allowed and volumetric distribution grid tariffs apply, the payment of the same amount of distribution grid costs is spread over less KWh: as a result, consumers (including PV system owners for the part of electricity still withdrawn from the grid) pay higher distribution grid tariffs. This fact may raise economic sustainability and PV acceptability challenges, especially when PV penetration levels become considerable. Such challenges in many European countries have led to discussions on a possible transition from volume-based to capacity-based distribution grid tariffs. Basically, customers would not pay distribution grid tariffs according to the consumed electricity anymore but according to the maximum amount of power they are able to consume. However, a change from volumetric to capacity-based tariffs may have a negative impact on the profitability of existing PV systems. Capacity-based grid tariffs - when they constitute a large part of the consumer bill- may also discourage energy saving behaviours and penalise consumers not using their full connection capacity, as the amount of money paid to finance the distribution grid is fixed.

4.1.2. Moving towards "Smart Grids"

Directive 2009/28/EC on the promotion of the use of energy from renewable sources, establishes in Art. 16 that Member States shall take the steps to develop intelligent networks [4].

Some of the technical solutions evaluated in PV GRID require more advanced system services and online monitoring of grid operating conditions, including an intensive use of communication systems and technologies, commonly referred to as "smart grids". In particular, advanced-close loop operation, advanced voltage control for HV/MV transformers, wide area voltage control, control based on supervisory control and data acquisition (SCADA), storage and demand response may require the integration of new communication systems into the distribution networks.

Since the term "smart grid" is widely used with different meanings, the PV GRID project will stick to the definition provided by the Expert Group of the EU Commission Task Force for Smart Grids[6]:

> *"A smart grid is an electricity network that can integrate in a cost efficient manner the behaviour and actions of all users connected to it - generators, consumers and those that do both - in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety."*

Even though elements of smartness already exist in many European grids, the difference between today's grid and a smart grid of the future is mainly the grid's capability to handle more complexity than today in an efficient and effective way. A smart grid employs innovative products and services together with intelligent monitoring, control, and communication technologies.

The main users of smart grid structures are:

- Network operators: transmission and distribution system/network operators (TSOs and DSOs/DNOs).
- Grid users: generators, consumers (including mobile consumers), and storage owners.
- Other actors: suppliers, metering operators, ESCOs, aggregators, applications and services providers, power exchange platform operators.

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[6] http://ec.europa.eu/energy/gas_electricity/smartgrids/taskforce_en.htm

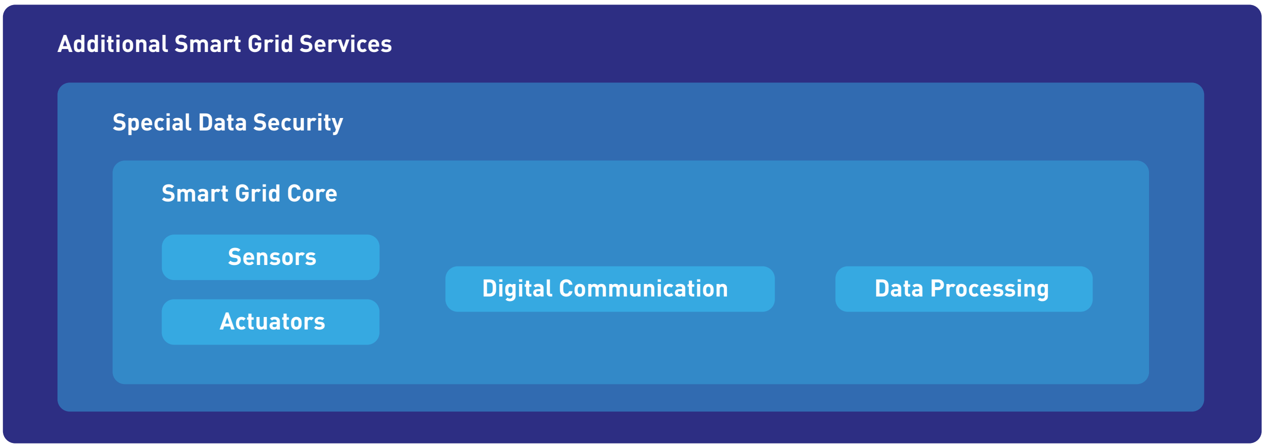

Figure 4.1.1 - Diagram of core components needed for smart grid and additional functions. Source: BSW-Solar.

A smart grid infrastructure at a minimum contains the following components:

- sensors (e.g. voltage, current, active/reactive power);
- energy meters (that cover some / all sensor capabilities and can at least be read remotely);
- actuators (e.g. tap changers, DSM);
- a bi-directional communication infrastructure that connects sensors, energy meters and actuators to one or more “central” (DSO) control systems and that fulfils the necessities of all use-cases in terms of security, reliability, latency etc.;
- one or more DSO control systems that enable a secure system operation under normal and emergency conditions by making use of the data provided and/or the possibilities to “steer” the network provided by the smart grid components;

A smart grid infrastructure enables DSOs to satisfy the definition given above, i.e. they are enabled “to integrate in a cost efficient manner the behaviour and actions of all users connected to it in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety.”

With rising percentages of RES generation, more ancillary services have to be delivered by the distribution grid. An intelligent control of its loads and generators will be the key measure to fulfil this new responsibility.

Smart grids can bring about many advantages, such as a more sustainable, efficient and secure electricity supply to customers. However, these benefits are accompanied by significant costs related to the purchase, operation and maintenance of the required components. In particular, smart grid solutions may introduce significant operational costs necessary to manage the information (e.g. settings, software, etc.,) relative to decentralised equipment at network and Prosumer levels. In all cases, careful consideration of both costs and benefits are required, e.g. certain degrees of smartness can be achieved even without a complete rollout of smart meters.

Generally speaking, systems of incentive regulations implemented at national level do not adequately promote smart grid solutions. They mainly focus on promoting efficient investments, with the underlying assumption that this reduction in investment and/or operational expenditure will ultimately imply a reduction of prices for the costumers. They do so by decoupling DSOs’ revenues from their real investments. In this way, DSOs generally limit their investments and tend to implement only mature technologies. As some smart grid solutions typically rely on electronic components that have shorter useful lives and/or are not fully proven yet, they can be discarded by DSOs.

4.1.3. The Ecodesign Regulation for Transformers

The Ecodesign Directive 2009/125/EC is a framework piece of legislation providing consistent EU-wide rules for improving the environmental performance of energy related products [5][7]. Working Plans issued by the European Commission contain lists of products to be considered in priority for the adoption of implementing Regulations.

The Ecodesign Regulation for Transformers "COMMISSION REGULATION (EU) No 548/2014 of 21 May 2014 on implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to small, medium and large power transformers" recently issued, mandates the use of transformers with a very low level of energy losses, with the objective of reducing losses in the power grid. This objective is reasonable; however it must be pursued in such a way to avoid collateral effects that could bring more drawbacks than advantages.

On load tap changers (OLTC) for MV/LV transformers have been identified as a technical solution to support higher penetration levels of PV and other renewables. This type of transformers has intrinsically higher losses as a consequence of having an OLTC; based on that, the Ecodesign Regulation defines lower levels of efficiency in 2015 for MV/LV transformers equipped with OLTC (implying an allowance of 20 % for no load losses and 5 % for load losses) compared with conventional components, but such concessions will be gradually phased out resulting in a maximum efficiency reduction of 10% for no load losses in 2021.

It must be noticed that 2021 targets are very ambitious for conventional transformers as well as for those equipped with OLTC, representing a very challenging objective: notwithstanding it would be possible to build today an MV/LV OLTC transformer within the 2021 loss limits, the cost would be prohibitive for the transformer itself and for its integration into the grid (due to the extra size and weight).

As the presence of OLTC inevitably affects the overall performance of the transformer and OLTC system, it can be expected that also in the future these components, which must in turn become more and more efficient, will have increased levels of losses compared with conventional transformers.

It is already foreseen that in the review of the Regulation, which shall take place in 2017, an assessment will be made about the possibility to separate the losses associated to the core transformer from those associated with other components performing voltage regulation functions; a specific mandate on that has been already given to CENELEC. The PV GRID Consortium strongly supports this approach, which will help transformers with OLTC complying with the Ecodesign Regulation; building on this approach, PV GRID recommends considering the overall energy balance of systems in addition to pure efficiency factors.

4.1.4. Debate on Curtailment

Current EU and National Legislation

Three European Directives refer to desirable or mandatory priority/guaranteed access and priority dispatch of electricity produced from renewable energy sources (and of other types of electricity, e.g. combined heat and power and, under certain conditions, electricity produced using indigenous primary energy fuel sources): Directive 2009/28/EC on the promotion of the use of energy from renewable sources [4], Directive 2009/72/EC concerning common rules for the internal market in electricity [2] and Directive 2012/27/EU on energy efficiency [6]. Unfortunately, these pieces of legislation do not provide a clear definition of and distinction between the concepts of access and dispatch and present some discrepancies.

Article 16 of Directive 2009/28/EC mentions the obligation for Member States to provide for **either priority access or guaranteed access to the grid of renewable electricity.** Recital 60 of the same Directive clarifies that:

> *“Priority access to the grid provides an assurance given to connected generators of electricity from renewable energy sources that they will be able to sell and transmit the electricity (…) in accordance with connection rules at all times, whenever the source becomes available. In the event that the electricity from renewable energy sources is integrated into the spot market, guaranteed access ensures that all electricity sold and supported obtains access to the grid, allowing the use of a maximum amount of electricity from renewable energy sources from installations connected to the grid.”*

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[7] European Commission, DG Enterprise and Industry website

No other piece of legislation regulates priority/guaranteed access of renewable electricity. Directive 2012/27/EU, while providing priority/guaranteed access also to high-efficient cogeneration, reassures that priority access for energy from variable renewable energy sources is not endangered (article 15).

Article 16 of Directive 2009/28/EC reinforces the RES priority/guaranteed access rule by also stating that:

> *"Member States shall ensure that transmission system operators and distribution system operators in their territory guarantee the transmission and distribution of electricity produced from renewable energy sources".*

No other existing piece of legislation refers to or contradicts this provision.

As regards priority dispatching for RES, no clear definition is provided by the relevant EU legislative texts and discrepancies exist among them. Article 16 of Directive 2009/28/EC asks Member States to require that transmission system operators, when dispatching electricity, give priority to electricity produced from renewable energy sources. It asks Member States to take measures to minimise curtailment and to require transmission system operators to inform their respective national regulatory authority when they curtail RES electricity and to indicate corrective measures they will take in the future to "prevent inappropriate curtailment". The Directive is silent about distribution system operators' dispatching obligations. Directive 2009/72/EC, while confirming the obligation for TSOs to grant priority dispatching to renewable electricity (and putting forward the possibility to grant dispatch priority also to combined heat and power and installations using indigenous primary energy fuel sources), affirms in article 25 that:

> *"A Member State may require the distribution system operator, when dispatching generating installations, to give priority to generating installations using renewable energy sources or waste or producing combined heat and power".*

This apparent discrepancy among EU pieces of legislation on priority dispatching at distribution grid level may be explained by the fact that in some EU Member States dispatching falls exclusively under the scope of TSOs' prerogatives. Hence, an EU piece of legislation obliging DSOs to grant priority dispatching to a certain type of electricity technology may be interpreted as if at the same time DSOs were provided with the right to dispatch. However, the sharing of tasks between TSOs and DSOs is regulated at national level.

Possible Conflicts between Technical Solutions and Current Legislation

PV GRID has identified a set of technical solutions that could help increase the hosting capacity of distribution grids or limit network investments to accommodate PV systems. Some of these solutions involve interference with the natural production pattern of PV installations (especially curtailment, but direct voltage control is also concerned). The relationship among these technical solutions, their usability to support distribution grids and the general philosophy of the RES Directive and of national laws with regards to RES priority dispatch involve a certain element of conflict. In what follows, this conflict is described from the viewpoint of PV GRID. This description is then used to discuss the case for an increased use of curtailment, albeit under strict restrictions.

Priority dispatch has an important positive influence on the business case of RES operators as they do not face the risk of not being able to inject their production into the grid because of network bottlenecks.

Curtailment without some form of compensation for the lost revenues is a measure that entails considerable risks for the planning security of RES investors and hence a high potential of slowing down the growth of PV installations. Furthermore, curtailing RES electricity means abandoning the principle of harvesting as many kilowatt-hours of CO_2 neutral power as possible.

On the other hand, curtailment can make sense from a technical point of view as the real production of a PV system, similarly to the one of any other variable generator, only seldom reaches values that are close to its installed capacity: even a significant reduction of the generated power (kW) causes only a small loss of energy production (kWh).

Power versus Energy

The situation described above is due to the variable nature of the electricity produced by PV. The amount of electricity produced depends inter alia on the time of year (i.e. the angle of incidence of the sunlight), the cloudiness of the sky and the temperature of the PV modules which in turn is weather dependent itself. A PV system normally reaches its production peak on a mild, somewhat cloudy day, for instance in spring or early summer when times of cloudy and sunny skies change frequently. Under these weather conditions the production spikes frequently for some minutes, even reaching the maximum capacity. On a sunny and warm day instead a PV system shows a much steadier production with almost no spikes. Under these weather conditions PV does not reach its production maximum because the modules are too warm. A PV system only seldom produces close to capacity peak: the energy that is produced close to the capacity peak is only a fraction of the energy produced overall.

Curtailment could be organized in a fixed manner (i.e. the meter or the inverter would stop injecting electricity into the grid once a predefined cap, e.g. 70% of the peak power at the PCC, is reached) or in an active manner (the active power is reduced based on the voltage at the PCC). Alternatively, the active power at the PCC could be limited by the DSO only in critical situations, which would reduce energy curtailment to a minimum but would require additional communication devices. All these solutions enable an increase in the DER capacity that can be installed in distribution grids, hence an increase in the distribution grid hosting capacity, and a higher degree of utilization of the public grid. Why this is the case will become clear after a short description of the investment triggers in public distribution electricity grids.

Peak Power as the Major Driver for Network Investments

The main driver for network investments is the peak power at connection point and grid segment levels: the network is generally dimensioned in a way that enables the DSO to cope with all demand withdrawn from and production injected into the grid at any time throughout the year and at any point while still adhering to all (security and technical) parameters. It is important to notice that a peak in demand or production will only occur during a few hours of the year. For instance in northern Europe a demand peak might occur in a living area when it is very cold, as a lot of auxiliary heating systems running on electricity would be used. In southern Europe a demand peak might occur in the middle of the day in summer, when many air conditioning units would be on. A PV production peak might be registered on a mild spring or early summer day during which clouds and sun alternate frequently. PV production peaks can trigger investment needs in distribution grids if: 1) voltage parameters are violated at local level and if 2) PV production remaining after demand in the same grid segment has been met is higher than the demand peak the segment was planned for (leading to congestion issues). A large-scale PV expansion in a specific distribution network segment is therefore clearly a driver for investments.

Against this background, the question arises on whether, and if so, how and under which conditions, curtailment – understood in this case as PV peak shaving – could be used to increase distribution network hosting capacity and delay or even avoid PV-driven network investments. From the DSO's point of view, PV curtailment would be beneficial in many circumstances, even if PV agents are reimbursed for the losses of income that result from the curtailment, i.e. the avoided expansion costs could be higher than the amount of money spent on reimbursements.

Benefits of Peak Shaving: A Theoretical Example

Imagine the following simple example: Five PV installations of equal size feed into a single network segment. As an assumption, a coincident production spike in these five installations should have the potential to equal the network capacity or would still be just inside of voltage restrictions. Now, under these circumstances a sixth PV connected to the network segment would lead to a necessity of network expansion as the existing grid could not be sufficient any longer. Now, if all five existing PVs were curtailed at e.g. 70% of capacity this would yield the capacity for an additional 140% of such PV installations (i.e. one PV of the same size would easily fit into the network) without expansion. But as new PVs would also be curtailed at 70% of capacity it would be possible to fit even two new PVs into the segment without causing any necessity to invest. Now, as the major part of the energy produced by the PV systems, the energy that is lost due to curtailment will be overcompensated by the energy provided by the new installations which would not have fitted on the network segment without curtailment.

PV GRID Discussion about Curtailment

From the viewpoint of the PV GRID project the questions raised by DSOs and other parties has no clear-cut and easy answer. Firstly, there is a clear relation between the presumed advantage of curtailment and the existence of spikes from PV: if PV spikes less due to its erection in easterly and westerly direction, curtailment is less advantageous. Secondly, if PV self-consumption regulations are put in place so that it is guaranteed that PV peak electricity is not injected into the grid but consumed at the customer's premise, curtailment is not needed. Thirdly, as already mentioned, curtailment has the potential to jeopardize the PV investment climate. Fourthly, curtailment will only delay grid reinforcement if the number of PV systems continues to grow. Nevertheless, PV GRID considers an EU-wide, fair and informed discussion on the issue to be worthwhile and in markets with high PV penetration levels even necessary. PV GRID has formulated some recommendations on boundary conditions for the use of curtailment that could serve as guidance to dialogue among all partners and to EU and national lawmakers. These recommendations will be presented in section 4.2.4.

4.1.5. The Impact of European Network Codes on PV Integration in Distribution Grids

Introduction

European Network Codes (NCs) aim to contribute to the implementation of Europe's main energy policy pillars: competitiveness, security of supply and sustainability. EU Regulation 714/2009/EC on conditions for access to the network for cross-border exchanges in electricity mandates the European Network of Transmission System Operators (ENTSO-E) to draft European network codes in electricity [7]. Under the mandate of the European Commission and according to the Framework Guidelines of the Agency for Cooperation of Energy Regulators (ACER), ENTSO-E is now in the process of drafting such NCs. Once adopted, NCs requirements will complement and/or replace national rules. NCs in electricity are divided into three main groups: grid connection, system operation and markets. NCs are meant to address cross-border issues and are therefore focused on transmission grids. Yet, they may also have a strong impact on distribution grids. NCs represent an important opportunity for grid and market integration of distributed energy technologies, such as PV. However, their implementation will only be successful if economic signals sent by DSOs, TSOs and wholesale markets to distributed generators to influence their behaviour are properly coordinated.

Requirements for Generators (NC RfG)

NC RfG [8] was among the first developed network code. Even if it addresses cross-border issues, the RfG is one of the NCs with the highest impact on PV integration in distribution grids. Indeed, it sets some requirements that PV plants, as well as other generators, have to meet in order to be connected. The NC divides generators into different categories according to their type of interface with the grid (synchronous, inverter based, etc.), connection levels and size (see Table 4.1.1).

Synchronous Area	Maximum capacity threshold from which on a Power Generating Module is of Type B	Maximum capacity threshold from which on a Power Generating Module is of Type C	Maximum capacity threshold from which on a Power Generating Module is of Type D
Continental Europe	1 MW	50 MW	75 MW
Nordic	1.5 MW	10 MW	30 MW
Great Britain	1 MW	10 MW	30 MW
Ireland	0.1 MW	5 MW	10 MW
Baltic	0.5 MW	10 MW	15 MW

Table 4.1.1 - Thresholds for Type B, C and D Power Generating Modules

As the generator size increases, TSOs have the faculty of requiring more support in a more discretional way at national level. In this document we will divide requirements set by the NC RfG into three groups: technical capabilities, operational notification and compliance, and communication. In summary:

- Some technical capabilities set in the NC can have a general negative impact on PV deployment as they can lead to increased equipment costs and to lengthier connection procedures. Furthermore, the use of certain technical capabilities to support transmission grids can have negative side-effects on distribution grids;
- Operational notification and compliance procedures set in the NC can have a general negative impact on PV deployment because their complexity and lengthiness represent a burden for PV generators;
- Communication devices to be installed on PV generators can have a positive impact on PV integration in distribution grids, as they can be used not only for support to transmission networks as intended by NC but also for distribution network management if the DSO has access rights to the communication devices. However, the rollout of communication devices could lead to a significant cost increase for small-scale PV generators.

Technical Capabilities

NC RfG establishes general requirements for Power Generating Modules and for Power Park Modules[8]. Generators will have to comply with additional requirements compared to today’s situation. This NC will give rise to additional costs, smaller or greater according to the rated power of the generator, notwithstanding the connection solution adopted. In case prescribed capabilities are not technically implementable in a short time period, the NC may give rise to delays in the erection of PV power plants.

With regard to the rate of change of frequency withstand capability, NC RfG establishes that a Power Generating Module shall be **capable of staying connected to the network** and of operating at rates of change of frequency up to a value defined by the Relevant TSO. The enlargement of the frequency bandwidth within which generators must stay connected, required by ENTSO-E, increases the probability of uncontrolled islanding in distribution networks. This could lead to damaging appliances connected to the same network. The Frequency Sensitive Mode functionalities required by ENTSO-E for overall system stability may amplify the phenomenon as well. In case of islanding, a risk exists that generation operators experience damages to their equipment and are held responsible for accidents and damages to those of final customers.

NC RfG establishes that the Power Generating Module shall be capable of activating the provision of **Active Power Frequency Response** at a frequency threshold between and including 50.2 Hz and 50.5 Hz with a droop in a range of 2 – 12 %. The actual frequency threshold and droop settings shall be determined by the relevant TSO. The Power Generating Module shall be capable of either continuing operation at Minimum Regulating Level when reaching the frequency threshold or of further decreasing Active Power output.

With regard to **Reactive Power capability**, according to the NC RfG (in Art. 15.2 a), the Relevant Network Operator shall have the right to define the capability of a Type B Power Park Module to provide Reactive Power [8]:

- The relevant DSO shall have the right to define capabilities for a Power Park Module to provide Reactive Power (Q) (e.g. Q=Q(U)) in case it is agreed at national level that those capabilities are needed.
- The relevant TSO shall have the right to define capabilities for a Power Park Module to provide fast reactive current injection in case it is agreed at national level that those capabilities are needed.

The latter prescription does not have technical sense according to DSOs, particularly at MV level, but could theoretically be implemented for type B PV plants. In this case, as an inverter is generally not able to provide more than the nominal current, fulfilling the requirement could imply over-sizing and could be difficult and costly depending on the settings defined at the National Level.

Operational notification and compliance

NC RfG establishes provisions for Power Generating Modules, regarding the **operational notification procedure**. Operational notification procedures for connection will be more complex than the existing ones, in particular for type B generators (larger than 1 MW in Continental Europe).

NC RfG establishes that the Power Generating Facility Owner shall ensure that a Power Generating Module is compliant with the requirements under this Network Code. This compliance shall be maintained throughout the lifetime of the facility. More complex compliance monitoring procedures for verification of fulfilment of requirements during generation plants' lifetime will be introduced, in particular for type B generators (larger than 1 MW in Continental Europe). For type A generators, type testing (using third party product

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[8] Cf. Art. 8, 9, 10, 11, 15, 16 and 17 in the NC RfG

certificates) is allowed but without defining the procedure itself. Without the development of a proper national or, preferably, European standardised approach, this will create an additional burden for type A owners and for the relevant DSO.

Communication

The NC RfG establishes that the Power Generating Modules shall be equipped with a **logic interface** (input port) in order to cease Active Power output within less than 5 seconds following an instruction from the Relevant Network Operator. The Relevant Network Operator shall have the right to define the requirements for further equipment to make this facility operable remotely. This requirement can be a driver for the use of interactive solutions identified by PV GRID, as the logic interface can be used not only for support to transmission networks as intended by NC but also for distribution network management. However, the rollout of communication devices could lead to a significant cost increase for small-scale PV generators.

Other Network Codes

Other NCs currently under development can facilitate active PV participation in the electricity system. For example, the draft Load Frequency Control and Reserves (LFC & R) and the Electricity Balancing(EB) NCs potentially allow PV to offer balancing services [9], [10]. The provision of balancing services by PV generators will have an impact on distribution grids. Hence, proper coordination is required among signals sent to generators by DSOs, TSOs and markets.

According to the draft **Network Code for Load Frequency Control & Reserve**, additional requirements in capabilities and/or operational behaviours may be required to new generation or existing generation in case the generation plant owner is interested to access the Frequency Containment Reserves (FCR), the Frequency Restoration Reserves (FRR) or Replacement Reserves (RR) market. However, access to this market is not mandatory (and even forbidden for intermittent generation in some countries) and can eventually represent an opportunity for RES generation.

PV participation in the electricity system will require more information from generators. This is why the draft **Network Code on Operational Security** (OS NC) mentions that generators of type B, C or D may be asked to provide to their DSO real-time information about the status of the switching devices and the circuit breakers at the Connection Point and active and reactive power flows, current, and voltage at the Connection Point [11]. This on one hand will require further investments for installation of specific equipment, on the other hand may ease the delivery of interactive solutions for increasing hosting capacity.

4.1.6. The Key Role of Technical Standards

Introduction

Distributed generators have an important impact on system operation (both at distribution and transmission levels and even, due to their important share, on overall EU system stability). Therefore, they must behave in well-defined ways in certain circumstances. This behaviour has to be described using a set of functional requirements (i.e. what DER have to do), which are further detailed in technical requirements (i.e. how DER have to behave).

The majority of national grid codes, as they are presently drafted, do not define requirements for and characteristics of generators in a sufficiently detailed way so as to be used as the basis for the development of specific standards. For instance, grid codes cannot be used as a basis for testing of equipment as they do not define in details the requirements and the testing procedures.

Having in mind that the DER market is global and that the hundreds of thousands future decentralised generators will use mass-produced equipment or components (like PV inverters), the availability of well- designed standards is a “must have”.

Standardization is the most effective way to deal with the technical details especially at the LV and MV levels because of necessary adaptation to local particularities and rapid evolution of the needs and opportunities to use new functionalities.

Furthermore, some of the functionalities are required at the system level and are therefore common to an interconnected network. The NC RfG describes the minimum functionalities a power plant must have to be connected. However, the lack of standards is a major barrier to the implementation of this network code at the national level. In particular, the need for testing methods for product development and manufacture and connection procedures should be properly addressed.

The use of European standards will be crucial in providing guidance for a progressive alignment of the national legal frameworks avoiding product variance and facilitating further deployment of DER by a better use/understanding of DER capabilities. Standards have to be improved or developed *ex nihilo*, providing specification to manufacturers and system operators for the connection (including protections functions), the communication with and the operation of DER.

Official Standardization Bodies

Electrical standards are developed by official bodies at the international level – International Electro-technical Commission (IEC) – and at the European level – CENELEC (CLC). National standardization committees (such as the CEI in Italy) are directly involved in the IEC or the CLC and develop national standards that can sometimes be based on the international/European ones. IEC and CLC are composed of Technical Committees (TCs) dealing with a particular subject. For instance CENELEC TC8X is developing several standards for the system aspects of electrical energy supply. TCs are composed of several Working Groups (WG), which focus on specific aspects. For instance CLCTC8X WG 3 is developing standards for the requirements for connection of generators to distribution networks, which are discussed in the following section.

Standards and Technical Specifications for the Connection and Operation of Distributed Generators

When functional requirements are translated into exact figures, a set of technical requirements is specified. Generating units have to respect these requirements when working in parallel with a distribution grid. Although they are not in a final state yet, these technical requirements are already quite developed considering the evolution of the standard for micro generators (EN50438) and the technical specifications for LV and MV connected generators (TS50549-1 and -2) developed by CENELEC TC8X/WG3.

EN50438 specifies technical requirements for connection and operation of micro-generators and their protection devices, irrespective of their primary source of energy [12]. Micro-generation refers to equipment rated up to and including 16 A per phase (single or multi). This European standard is intended for installations mainly in the domestic market. This standard, which is under revision, should be adopted as soon as possible and the synergy between this standard and NC RfG should be improved as standardization is absolutely required in case of small mass products generators connected at the LV level.

There is no existing standard for generators connected to the low voltage (> 16 A) and medium voltage level but technical specifications exist.

pr TS 50549-1 and pr TS 50549-2 are applicable to all individual generating units or cluster of generating units with a common point of connection connected to the LV (and rated at more than 16A per phase) or MV level respectively [13], [14]. These technical specifications define the requirements for the generators intended to operate under normal network operating conditions. Island operation of the generating unit and the safety of personnel are out of the scope of these documents.

These documents recognize the existence and must comply with national standards and network codes. The requirements specified in these technical specifications can consequently be applied in the absence of a national framework (standards and codes) for the connection of the LV and MV generators or as long as they are not in conflict with existing national framework. The two technical specifications should eventually be approved by the end of 2014.

Further work should be conducted to develop, on the basis of these technical specifications, two European standards. The evolution of these technical specifications into EU standards should be speeded up as it will trigger harmonization and will facilitate further DG deployment.

Tests and Compliance Procedures with Standards and Grid Codes on Grid Connection

Clear test methods and evaluation criteria for the functional requirements defined in a grid code or a standard are missing in most cases. For distributed generation, a two-step approach is needed and should be developed:

- As a first step, the relevant technical requirements to be tested should be identified and a general approach about the testing method should be defined.
- As a second step, the approach should be translated into the specific domain of the generating unit defined by its technology and primary source.

In the case of small generators, certifying the compliance of the components (e.g. inverter certificates) rather than ensuring the compliance of the unit during the connection process is essential for the good functioning of the distribution system. It is the best (and only) assurance that the generating unit will behave in line with the functional requirements because generally DSOs do not test directly the unit and the circumstances for which a specific behaviour is requested might be rare.

An efficient test procedure should demonstrate DER capabilities while not being too burdensome for manufacturers. Test procedures for grid compliance and certification of products are missing and should be developed by the relevant technical committees of CENELEC as soon as the existing and futures EU standards / network codes for connection are finalised.

Standards for the Communication and Device Automation

Previous standardization needs were related to the capabilities of DER (among them PV systems), which are necessary for a proper implementation of prosumer solutions. For this type of solution, the device (a battery or a PV system) behaves in an autonomous way.

Interactive solutions rely on the concept of advanced distribution automation involving communication between the prosumer and the DSO.

Advanced distribution automation will facilitate and improve the management and operation of distribution networks hosting a high share of DER evolving from a passive/semi-automated status to a fully automated one.

A series of standards (**IEC 61850**) specifying the design of electrical substation and external devices automation exists [15]. Although IEC 61850 was originally developed to address communications and applications within the substation, some work has been recently initiated in order to extend the applicability of the standard to distribution grids automation. For instance IEC 61850-7-420 deals with the peculiarities of communication systems for distributed energy resources [16]. This work could be further extended to DER, possibly enabling the concept of Virtual Power Plant.

Further improvement and development of this series of standards will allow for "better/real-time communication" between all components and devices of the grid (including DER).

Support should be provided to WG17 working on communication systems for DER and to other technical committees involved in equipment standardization (TC38, TC95, etc.…) related to the development of interfaces for smart grids. These developments should take into account inherent capabilities and the size of distributed generators to avoid too complex protocols.

In order to facilitate communication between prosumers and system operators/market participants, data exchange via web services and existing infrastructures could possibly be an effective way. But a particular attention should be paid to cyber security (not only for web based services). TC 57 should be supported in the development and improvement of standards describing the communication networks and associated information exchange for power systems.

A modern network control architecture is the final step for the achievement of the integration of prosumers and energy management systems (EMS) in the current system allowing market participants/system operators to develop new services. **IEC 61968**, **61970 and 62325** series define standards for data models in electrical networks [17]–[19] and **IEC 62786** specifies the Smart Grid User Interface [20]. DER integration will be facilitated by a harmonised prosumer interface with the grid and data exchange models.

Even if they are not necessary to achieve large scale PV integration into the distribution grids, these standards, if properly developed taking into account DER particularities and capabilities, will ensure the widest possible harmonization across Europe and enable effective market based participation of DER to system operation.

In order to enhance VPP capabilities, support should be provided to WG17 working on communications systems for DER and others TCs involved in equipment standardization (TC38, TC95, etc.…) related to the development of interface for smart grids. These developments should take into account inherent capabilities of small generators in views of avoiding to complex protocols.

Protective Equipment and Electromagnetic Compatibility of DER

Protective functions and equipment for DER connection to the grid are essentials for a safe deployment of DER. Following the increasing integration of DER and the use of new capabilities, further work has to be conducted to identify new protection functions, particularly when it comes to unintentional islanding detection. Islanding risks are going to increase as grid codes are requiring more and more stabilizing behaviour by distributed generation in case of system disturbances. These new capabilities may create undesired effects – for instance may sustain isolated portion of the network in an uncontrolled way – exposing generation operators and final customers to electrical hazards.

CENELEC/TC95 works on measuring relays and protection equipment [21]. A new standard : e.g. “protective functions and equipment for DER connection to the grid” should be developed based on research conducted to identify new protection issues.

For a number of smart appliances like DER, EVs and smart meters, Electro Magnetic Compliance (EMC) will be a major issue. The smart grid concept must be designed with careful consideration for electromagnetic emissions and immunity for various electromagnetic phenomena. It is therefore critical that EMC is addressed effectively to achieve Smart Grid potential and providing benefits when deployed.

The structure of the **IEC 61000** series reflects the subjects dealt with by basic EMC publications [22]. They include terminology, descriptions of electromagnetic phenomena, measurement and testing techniques, and guidelines on installation and mitigation.

Within current standards the requirements for emission and immunity are set for single equipment on a clean grid. In the future the possible interaction of different devices connected to the same grid should also be covered. Revised standards are needed to ensure that power quality requirements will be met in an automated and de-centralised environment. Support should be provided to the EMC committees and products committees defining EMC requirements in their products standards in their effort of reviewing existing standards.

4.2. Recommendations

4.2.1. Recovery of DSO Investments and Costs

Investment Recovery Schemes

- In the context of an evolving electricity system accommodating more and more distributed generation, DSOs' investment costs and cost structures are changing. National regulators should therefore adapt and where necessary transform DSOs' investment recovery schemes. Guidance on European level could be helpful to foster the transformation of national systems into a more smart grid-oriented regulation that respects national peculiarities.

Grid Connection Charges and Network Tariffs

- Grid connection charges for PV systems are set differently in terms of type and level across Europe as the result of different political choices. National policy makers should take into account the fact that the level of PV grid connection charges and the level of grid connection costs spread over all consumers' bills (socialisation) are indirectly proportional and that high grid connection charges have a detrimental impact on PV profitability. They should also consider whether PV systems, when installed behind an already existing connection point, may not trigger additional costs on the part of the DSO;
- Connection charges are usually lump sums. They do not correspond to the exact connection costs incurred by the DSO; they are calculated on the basis of a price list of typical grid investments. National policy makers should make sure that such price lists are transparent and easily accessible to PV developers, so that the latter can factor in their business plan an accurate estimate of their connection charge.
- When considering a move from volumetric- to capacity-based distribution grid tariffs, policy makers should take into account that such a move:
    - has redistributive effects on consumers based on their actual consumption behaviour: in other words, in a capacity-based tariff scenario consumers that fully exploit their contracted capacity are treated the same way as those that only exploit it less frequently;
    - can have an important negative impact on the profitability of existing PV systems;
    - may discourage energy conservation behaviours (if the network tariff constitutes a large part of the consumer's bill) and penalise consumers not using their full connection capacity.

4.2.2. Moving towards "Smart Grids"

- A "smart grid" can bring about many advantages, such as a more sustainable, efficient and secure electricity supply to customers. However, these benefits are accompanied by significant costs related to the purchase, operation and maintenance of the required components. Careful consideration of both costs and benefits will be required;
- National regulators should discuss with all relevant stakeholders the adaptation of national regulatory frameworks in order to concretely promote smart grid investments;
    - A stable and transparent regulatory framework (avoiding frequent changes), and an ex-ante approach should also be established in order to favour such evolution;
- If the conclusion of careful analysis suggests the implementation of smart grids to support integration of renewables and where necessary, explicit (pecuniary) incentives should also be established:
    - Incentives can apply to innovative projects in smart grids, approved by the national regulators;
    - In case that these incentives are to be generalised it would be required to clearly define a smart grid in terms of what the services are it has to provide, its architecture and components.

4.2.3. The Ecodesign Regulation for Transformers

- A balance should be struck between energy efficiency and integration of distributed energy resources in distribution grids.

4.2.4. Debate on Curtailment

- A fair debate on the use of curtailment of PV electricity would require the determination of 1) a national cost-benefit analysis methodology, 2) boundary conditions and 3) adequate compensation rules to the PV agent. It should be noticed that the economics of curtailment on the part of the PV agent are also influenced by: 1) the options and the relative savings / investment costs of PV self-consumption and of PV storage 2) and by whether national regulation foresees that the PV agent is in any other way engaged in the financing of the grid;
- DSO driven curtailment should only be allowed when congestion or voltage problems arise in the local network and all other available measures have been evaluated and utilised if possible;
- Curtailment should be kept as low as possible (e.g. ≤ 5% of the annual production);
- As a general and overriding rule, the annuitized savings in avoided investments from curtailment should be larger than the compensation paid to the PV agent. Otherwise the network should be expanded;
- As it was already mentioned, curtailment can put RES market growth at risk, bringing investment insecurity. Therefore, it should only apply to new installations.

These recommendations should also be considered at national level, taking into account the characteristics of each national context as exemplified in the national case studies, which can be found in Annex I and II of this document (available for download at: http://www.pvgrid.eu/results-and-publications.html).

4.2.5. The Impact of European Network Codes on PV Integration in Distribution Grids

All relevant Network Codes

- EU network codes, especially the Requirements for Generators, the Electricity Balancing, the Load Frequency Control& Reserves and the Operational Security ones, are designed in order to address cross-border issues; yet, they may have a strong impact on distributed generation, such as PV, and on distribution system operators. Such impact should be taken into account both at the design and implementation phase of network codes;
- These NCs can have a positive influence on PV grid and market integration; however, they can imply high compliance costs for PV generators, thus slowing down the potential growth of the PV technology;
- As many prescriptions contained in EU NCs are non-exhaustive, details should be agreed upon at national level within an EU-wide process involving DSOs and PV (RES) associations;
- It should be understood that PV systems are made up of mass-produced components; therefore, the implementation of these network codes will only be cost-efficient if relevant standards exist and are fully used.

Network Code on Requirements for Generators

- Technical capabilities defined in the NC RfG should be further defined in standards developed within the TC8X WG03. Such standards should applied by all Member States when implementing the NC RfG;
- Some RfG NC requirements affect the Active Power output of PV systems to support transmission grids, while some technical solutions identified within PV GRID involve a variation of the PV Active Power output to support distribution networks; discrepancies should be avoided;
- Some NC RfG requirements may lead to negative side effects in distribution grids, such as islanding. As possible anti-islanding defence actions may differ according to the operational criteria and protection schemes of MV and LV network, a scrutiny of present prescription set by each national regulatory authority at national level might be appropriate;
- Operational notification procedures for type B should be based on standardised documentation in a similar way than type A, as far as it is possible, so as to ease the implementation of NC RfG;
- PV compliance with the NC RfG should rely on testing and compliance methods defined in future standards;

Network Code on Operational Security (OS NC)

- OS NC already foresees that the information exchanges between TSOs and DSOs and the provision of data related to generators of Type B, C and D shall be governed by the principles of efficiency and proportionality.
- In order to pursue those principles, duplications of communication channels and information flows must be avoided. In case of DN-connected generators of Type B and C, it can be expected that information exchanges only involve a PV plant owner and the relevant DSO, who must therefore be provided with operational tools which can ensure the fulfilments of local as well as system performances, preventing direct orders are sent by TSOs to the PV installation.

4.2.6. The Key Role of Technical Standards

For mass-marketed equipment like inverters or other DER components, standardisation is the most effective solution to address the challenges related to grid integration of distributed generation while minimizing costs by avoiding products variance. Attention should be paid to the lack of appropriate standards and support should be provided to the relevant CENELEC technical committees, particularly in the working areas listed below.

Grid Connection of DER

Further work should be conducted as soon as possible to develop proper standards for the connection of generators to LV and MV levels:

- Standard EN 50438, which is under revision, should be adopted as soon as possible and the synergy between this standard and the NC RfG should be improved as standardization is absolutely required in case of small mass-produced generators rated up to and including 16 A per phase;
- Further work should be conducted to develop, on the basis of two almost finalised technical specifications (TS 50549-1 and -2), two European standards for small generators rated above 16 A per phase. This will trigger harmonization and will facilitate further DER deployment.

DER Compliance with Connection Grid Codes and Standards

- As soon as the above-mentioned standards for the connection of generators are finalised, CENELEC TC82/TC8X should be requested to develop testing and compliance methods. Adequate testing and compliance methods are a prerequisite for the proper implementation of the ENTSO-E NC RfG for small-scale generators. Certifying the compliance of the components makes more sense than ensuring the compliance of the unit during the connection process.

Communication and Grid Devices Automation

- Current standards are inadequate for the communication and data exchange with prosumers and distributed generation. Relevant standards should be revised and extended to integrate lighter communication protocols. As the number of access points to the communication infrastructure will increase in the future, a particular attention should be paid to cyber security.

Protection Functions and Electromagnetic Compliance

- With the increasing integration of electronic devices and new grid integration functions, the relevant standards dealing with protection and electromagnetic compliance series should be urgently reviewed taking into account new developments into the grid.

5. IMPLEMENTATION OF TECHNICAL SOLUTIONS AT NATIONAL LEVEL : CHALLENGES AND RECOMENDATIONS

While discussing the implementation of the identified technical solutions, the PV GRID consortium has recognised a series of general (affecting all solutions identified) and/or specific (affecting mainly one or a few of the solutions identified) challenges in the four focus countries (Germany, Spain, Italy and Czech Republic).

In the next sections, these challenges are illustrated together with concrete examples in PV GRID focus countries. In the final section, a series of general, national recommendations are provided.

5.1. General Challenges

5.1.1. Recovery of DSO Investments and Costs

Investment Recovery Schemes

As mentioned in section4.1.1, the technical solutions proposed by PV GRID determine an impact on DSO costs and cost structures. Therefore, the question to be addressed is whether DSO remuneration schemes should be adapted so as to ensure that DSOs are encouraged to implement these technical solutions when these can be considered efficient. If the answer to that question were affirmative, the responsibility for the due changes would fall on the national competent authorities.

For details regarding the discussion on recovery of DSO investments and costs, refer to section 4.1.1.

Grid Connection Charges and Distribution Network Tariffs

As discussed in section 4.1.1, the connection to the grid of PV installations can entail a certain amount of network costs, both at the point of connection and, in some cases, in the upstream network. In order to compensate DSOs for these costs, at least partially, PV operators generally have to pay an initial one-off connection charge – deep, shallow or shallowish.

The connection charging approach has great relevance both for PV producers and for DSOs. Compared to the other types of charges, deep connection charges provide stronger incentives to PV developers to design new systems (size and location) taking into account the local grid configuration. However, shallow or shallowish charges facilitate the grid connection of new generators, especially small units for which deep charges could be a major economic burden. Deep charging can involve a discriminatory treatment of generators : the generator triggering the network reinforcement could have to bear all the costs while the next generators coming on-line would not pay any.

Shallow charging has been advocated for in previous EU projects such as DG-GRID, SOLID-DER or IMPROGRES, at least for small-sized units. In fact, shallow or shallowish connection charges are the most common approach among EU countries, with the exceptions of Spain, Austria and Slovakia. Furthermore, some countries generally apply deep charges, but have defined a “shallower” approach for small generators : in the Netherlands, shallow charges apply only to generators smaller than 10 MW, whereas in Spain shallowish charges apply to generators below 100 kW (only reinforcements within the voltage level at which the generator connects have to be paid for). Connection charges are calculated by DSOs themselves in many countries.

In case of shallow or shallowish charges, NRAs ought to make sure that the remaining connection costs are recovered by DSOs via distribution network tariffs paid by consumers (including PV system owners for the electricity still withdrawn from the grid) and/or distribution network tariffs paid by generators when injecting their electricity into the grid.

Distribution tariffs for consumers are calculated by the corresponding NRAsat least in Czech Republic, France, Italy, Portugal or Spain. However, DSOs are responsible forthis task in many other countries including the Netherlands, Poland, Estonia, Germany, Finland, Sweden, and the United Kingdom [23]. Note that this does not imply absence of regulatory control; in most cases the tariff structure[9] and its elements are described in a special law or ordinance and the calculated tariffs are reported to the NRA before they enter into force.

5.2. Specific Challenges

5.2.1. Rules Forbidding RES Energy Curtailment except For Security Issues

Priority access and dispatching rules embedded in the RES Directive foresee the possibility to curtail renewable energy only for system security and security of supply reasons. Hence, the RES Directive does not allow DSOs to curtail PV electricity for distribution grid planning and/or managing purposes.

Despite this, PV GRID found that there are circumstances under which DSOs should be allowed to curtail the energy output of PV installations when it proves convenient for both PV agent and the DSO. Such circumstances involve the implementation of the following technical solutions:

- Curtailment of power feed-in at PCC;
- Active power control by PV inverter P(U);
- SCADA + PV inverter control (Q and P);
- Wide area voltage control

These technical solutions involve a control of the PV system, at any voltage level. For these solutions to be applied, an evolution of the regulatory framework is necessary. The relationship among these technical solutions, their usability to support distribution grids and the general philosophy of the RES Directive and of national laws with regards to RES priority dispatching involve a certain element of conflict.

Curtailment can make sense from a technical point of view as the real production of a PV system only seldom reaches values that are close to its installed capacity. The peak power (of consumption and production) is the main driver for network investments. As peaks in consumption or production will only occur during a few hours of the year, curtailment of these peaks may imply significant savings.

However, without some form of compensation for the loss of revenues, curtailment is a measure that entails considerable risks for the planning security of RES investors and hence has high potential to slow down the growth of PV installations. From the DSO's point of view, PV curtailment would be beneficial in many circumstances, even if PV agents are reimbursed for the losses of income that result from the curtailment.

In Spain, the curtailment of power generated from non-controllable RES installations is possible only for installations with an installed total power higher than 10 MW, and is used by the TSO only in situations that would otherwise imply a risk for the quality and continuity of supply. This is only applicable when there are no other solutions available either in real time or with some anticipation.

In Italy, generation from renewable energy sources follows the rules of priority dispatching. Curtailment is only available for transmission system security reasons. It is potentially applicable only for scenarios with low demand and very high production. It cannot be used in case of local voltage or load constraints, which are the usual cases in distribution network. The legislative and regulatory framework does not allow DSOs to use curtailment or limit the injected active power or generators, even for a limited percentage of yearly hours.

In the Czech Republic, curtailment is only accepted to guarantee the safety or stability of the grid. Power plants can be requested to adapt their production in steps of 100%, 60%, 30% and 0%. The active power control is obligatory only for PV systems over 100kWp and compensation is paid only if it is not an emergency (or emergency prevention) situation.

In Germany, curtailment can only be used for system security reasons by TSOs. DSOs may also use curtailment in case of local congestion, i.e. if the necessary network enhancement is lagging behind the PV rollout, and the responsible DSO must compensate for the curtailment. However, in line with the directives, DSOs are still expected to reinforce their network to dissolve the bottleneck that caused the curtailment.[10] Therefore, curtailment is only accepted as a temporary solution.

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[9] As already discussed in section , a debate is currently on-going on the modification of the existing tariff system in order to more fairly redistribute the costs of DG Between consumers and producers/prosumers, including the transition towards a system more relying on capacity-based tariffs. The PV GRID consortium acknowledges this discussion, but does not wish to take a position as this requires a different analysis than the one in the scope of this project.

[10] cf. the relevant part of the preamble of EEG 2012.

5.2.2. Insufficient Self-consumption Framework

A private citizen or a company may install a PV system and use the electricity produced by the system directly to offset on-site load (meaning consumption needs) in real time while only injecting the excess production to the grid. At the same time, when PV-generated electricity is insufficient to cover on-site load, electricity can still be drawn from the grid.

However, in several European countries[11] it is currently not allowed to instantaneously self-consume the electricity produced by a PV system operated in the same premises by a consumer. Therefore the entire electricity produced has to be injected into the grid, while keeping the full consumption contract. In other countries, proper incentives or obligations for self-consumption are not set, therefore not exploiting the potential of this solution.

Net-metering Support Schemes

Net-metering support schemes are quite diffused means of incentivising PV and DG across the world, sometimes in combination with feed-in tariffs or quota systems. With net-metering we mean a regulatory framework under which the excess produced electricity injected by a prosumer can be used to later offset his consumption during those times when the production of his PV (or DG) system is absent or insufficient. Net-metering consists, in practice, of the use of the grid as a backup system, allowing a recovery of the investment in a PV or DG system, by valorising also the electricity that is injected into the grid. While in some cases the offsetting is done in energy terms (i.e. 1 kWh injected gives a right for 1 kWh to be later retrieved) in other cases the offsetting can be done in economical terms and associated with a cost for the prosumers. In these cases, the electricity injected into the grid and later retrieved will have a lower value than the retail price of electricity, based on the different market values of electricity and the fact that using the grid as a “storage“ device implies participating in its costs.

An example of a net-metering scheme based on such a partial economic compensation is the Italian *“Scambio sul posto”* managed by GSE, a government-owned company set up for the purpose of managing all RES incentives. With *scambio sul posto* a prosumer normally pays consumption electricity bills to its supply company for all the electricity withdrawn from the grid (except the one instantaneously self-consumed from its PV system production), while GSE receives the excess injected electricity, sells it on the market, and periodically pays back a contribution to the prosumer based on injections and withdrawals of electricity in a given calendar year and on their respective market values. As a consequence such a scheme still provides an incentive for self-consuming as much as possible of the prosumers’ instantaneous PV (reducing PV peak power flows), while it also represents an incentive to install PV systems.

In any case, it has to be considered that the implementation of net-metering requires addressing a series of practical issues at national level, especially with regards to electricity billing, trading and balancing. As explained above, in Italy these issues are managed by GSE as the third party responsible for both paying the economic compensation to the prosumers and dealing on the market with the electricity injected into the grid by prosumers. These issues have been so far addressed differently in other European countries. For instance, in Belgium the net-metering scheme available for owners of small PV systems (PV capacity smaller than 10 kVA) more simply consists in “reversing the meter”, i.e. the injection of PV electricity into the grid directly offsets the energy withdrawal of the prosumer. At the end of each yearly billing period, only the difference between withdrawal and injection is due to the electricity supplier, on top of fixed charges. If the difference is negative (withdrawal smaller that injection), the prosumer will not receive any credit, tough.

As a consequence of the net-metering scheme, Belgian electricity suppliers currently face an increasing economic loss caused both by the reduced demand of PV prosumers and by the difficulties of correctly forecasting the load/injection profiles of small PV prosumers in the residential and commercial segments. In fact, the standard consumer Synthetic Load Profiles (SLP) currently used for forecasting the profiles of PV prosumers’ feed-in lead to an error in the day ahead market bidding positions of suppliers, that results in deviation in their balance groups, i.e. lead to a “demand” for balance energy and finally to penalties to be paid to the TSO. These issues could be solved by the developing of better forecasting tools for PV prosumers, but it is also likely that they could result in electricity suppliers offering PV prosumers more expensive supply contracts in the future, as the delivery of electricity to a prosumer may have a different risk profile than the delivery to a “normal” consumer.

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[11] Assessment based on PV GRID survey results, completed by national PV associations. Survey results are available in Annex III of the European advisory paper: http://www.pvgrid.eu/results-and-publications.html. Also refer to EPIA‘s Position Paper on Self-consumption of PV Electricity: http://www.epia.org/uploads/tx_epiapositionpapers/Self_and_direct_consumption_-_Final_version_of_the_Position_Paper_02.pdf

On top of reducing a prosumer's electricity bill, self-consumption can bring benefits to the whole system, since it may reduce the peak power that needs to be distributed or transmitted through the grid. These benefits are at their best if the overall peak power demand is reduced locally or (to a lesser extent) globally, since distribution and transmission networks have to be sized for the peak scenario. In order to ensure that there is a reduction in peak power it may be convenient that the size of PV does not exceed local demand. For this reason, in some countries such as Cyprus or Portugal, self-consumption is constrained, by setting limits to the size of the PV system.

However, self-consumption on a voluntary basis cannot lead to a simplification of connection solutions at local level, due to the unpredictability of user consumption behaviours. Therefore, this also means that a widespread self-consumption implementation scenario will not significantly enhance the grid connection process, unless it is opportunely combined with the obligation not to inject within the grid a significant part of the PV production. In particular, boundary conditions for self-consumption obligations should be aimed at reducing the peaks of electricity injection in order to ease the grid connection and overall grid capacity requirements.

Technical solutions affected by this barrier include:

- Curtailment of power feed-in at PCC;
- Self-consumption by tariff incentives.

Self-consumption, in some cases in conjunction with net-metering support schemes, is already a mature concept proven in certain European countries such as Italy, Belgium, Denmark, Netherlands, and Germany. However, in other European countries the situation is not so positive. In Spain, while possibilities for instantaneous self-consumption are limited to PV systems below 100 kW, a legal framework that regulates self-consumption with net-metering is still missing, and the current debate is centred on the introduction of a distribution grid tariff that would also apply to self-consumed electricity produced by the PV system. In the Czech Republic there is a similar situation, with a standby tariff to be paid even on the portion of electricity consumed from own production and not withdrawn from the grid.

5.2.3. Insufficient DSO Access to Advanced PV Inverter Capabilities

Modern inverters are able to provide many functionalities to support network stability. Although some of these solutions are already available from a technical point of view, in many countries (such as Bulgaria, Denmark, Ireland, Spain) DSOs cannot exploit such functionalities, as they do not have access to PV inverters. In other countries in which DSO access is allowed, other barriers may be the lack of experience and of clear rules, as well as the absence of standards. All technical solutions implying any kind of DSO control on PV inverters are affected, namely:

- Reactive power control by PV inverter Q(U) Q(P);
- Active power control by PV inverter P(U);
- Curtailment of power feed in at PCC;
- SCADA + PV inverter control (Q and P);
- Wide area voltage control.

In Spain, telemetry of the DG installations is provided to the TSO for installations greater than 1 MW, but DSOs do not receive such metering and have no other control on these installations. Installations greater than 10 MW may receive instructions by the TSO for the temporal modification of the power factor range, according to necessities of the system, receiving an economical compensation for compliance.

The lack of control of photovoltaic installations by the DSO is also experienced in Italy. Italian technical standards specifically prescribe that the national regulating authority must define how these advanced PV capabilities can be exploited.

In the Czech Republic, DSOs may require remote control functionalities for all inverters installed since 2012. Therefore, DSOs may have some form of access to PV inverters in all new installations, but have no control over installations below 30kWp installed until the end of 2011, which, in quantity, still constitute the majority of installations in the country.

In Germany, defined options for the power factor control of DG inverters (cos φ regulation) exist and are used by an increasing number of DSOs in order to cope with voltage problems. Additionally, DSOs who are responsible to upgrade inverters connected to their grid regarding the 50.2 Hertz problem have set up the necessary processes and the changeover of existing inverters has already been started. Nevertheless, some other issues are still under discussion.

In addition, PV GRID recognises that in the future other ancillary services may be provided by DG operators. However, further details still need to be defined in order to provide a sufficient regulatory framework for such services.

5.2.4. Insufficient Framework for Prosumer Storage Solutions

Preamble 57 in Directive 2009/28/EC on the promotion of the use of energy from renewable sources states that there is a need to *"support the integration of energy from renewable sources into the transmission and distribution grid and the use of energy storage systems for integrated intermittent production of energy from renewable sources"* [4]. In particular, article 16 establishes that *"member states shall take the steps to develop, among others, storage facilities"*.

PV electricity production has fluctuations associated to weather phenomena, such as cloud coverage and its changes, air temperature and others. These fluctuations result in a situation where the power output of these installations is not predictable and subjected to spikes. From the market's point of view storage integrated with PV generators increases the ability of the PV to "produce" a predictable profile even in rapidly changing weather conditions.

From the network's point of view, storage may be a means to control the maximum load that any PV will actually deliver to the network i.e. production spikes above a certain power threshold are not delivered to the network but kept in the storage. The implementation of these solutions would allow increasing PV penetration in some areas, deferring investment in other equipment. Other technical solutions such as demand response, curtailment of power feed-in at PCC and wide area voltage control could also use some kind of storage to facilitate the objective of integrating more PV. If used in one of these grid supportive ways, the installation of a storage system may help to increase hosting capacity for newly connected PV systems.

Generally, prosumer storage solutions are allowed in most European countries. Though, in Spain there are certain cases (if a royal decree applies) where the application is explicitly forbidden. However, even in those cases where prosumer storage is allowed, it is not very spread, both because of economical profitability issues and lack of clarity on the connection and operation requirements in conjunction with existing DG[12]. In Italy, due to growing prosumer interest in storage solutions, the national regulator has been recently asked to clarify the conditions for their installation and operation.

In Germany, an incentive program for storage that could be a reference for other countries has recently been launched. KfW Bankengruppe's renewable energy storage program (program 275) offers low-interest loans and repayment subsidies for PV installations that incorporate a fixed battery storage system. In order to ensure that there is a benefit to the system, the storage has to achieve a permanent limitation to 60% of the maximal power output of the PV system.

5.2.5. Insufficient Framework for DSO Storage Solutions

In principle, storage solutions can be used by DSOs to address the variability of DG. However, the concept of unbundling implies that DSOs are not allowed to own, operate or use storage. This is currently under discussion in several countries. The reason is that DSO use of storage solutions would have (positive or negative) implications in the electrical market due to the difference in prices between the instant of charging and the instant of discharging. The indirect access to storage capacities via a service provider is possible, but economically and technically questionable.

In order to play a major role in the operation of the distribution grid, storage technologies would need to be directly connected to the LV or MV grid. In certain LV systems with a heavy PV penetration, DSO controlled storage could help to avoid upgrading transformers or even to control current on certain lines. Also, as studies show, the question of whether storage is beneficial for the network depends to quite a large extent on whether DSOs can exercise some control over it [24].

Currently in Germany, Spain and the Czech Republic, DSOs are not allowed to own storage as it is considered to be in conflict with the unbundling of the generation activity.

In Italy, while it is similarly considered that the process of charging and discharging of a storage system has implications on the electricity market, there are a few interesting developments. In fact, a set of transmission level storage demonstration projects have already been approved by the Italian National Regulatory Agency and launched by the TSO. At distribution level however, even if similar demonstration projects are already running, no specific regulation is yet in place, despite the fact that a 2012 Decree of the Ministry of Economic Development has introduced the possibility for DSOs to install and manage storage facilities in primary substations in order to support RES production.

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[12] Assessment based on PV GRID survey results, completed by national PV associations. Survey results are available in Annex III of the European advisory paper: http://www.pvgrid.eu/results-and-publications.html.

5.2.6. Insufficient Framework for Demand Response

Basic demand response services are available in several countries (e.g. United Kingdom, Italy, Spain, and Germany[13]) in the form of tariffs with time-block discrimination. However, this type of demand response is only useful to reduce system peaks, and not for local violations of the technical constraints. Additionally, from the point of view of integrating PV installations, it is usually more useful to have the ability to increase demand rather than to reduce it. This requires more advanced and dynamic services of demand response including the necessary processes and market rules, especially in unbundled electricity markets. A detailed regulation on demand response is still not present in several countries, given the complexity of the topic and the strong connection with the future “Smart Grid” implementation.

In order to provide these services, DSOs would have to exchange information about energy-related economics with final customers and their supply companies. However, distribution network-related services and their economical treatment have not yet been defined for passive customers. Besides, these services should only be applied to customers voluntarily accepting to adjust their demand. In this case, the economic compensation they would receive also has to be determined. For low voltage customers the concept would also be possible through the concept of aggregators.

In several European countries (such as Austria, Belgium, United Kingdom and Germany), existing national regulations allow DSOs to contract load curtailment services with the customers. In other cases (such as in Spain), load curtailment is usually only allowed for system security reasons and not depending on local network conditions. Therefore, even if so-called “interruptible” customers exist, their services are only available to TSOs. These issues affect several technical solutions, namely:

- Demand response by local price signals
- Demand response by market price signals
- SCADA + direct load control
- Wide area voltage control

In Germany, special network fees and technical measures are used to shift the demand of approx. 3 million domestic heating appliances into the night hours using fixed switching times provided by the DSO. Also, simple time-of-use tariffs exist. Besides, DSOs are obliged to offer a reduction of the network fee to LV network users that guarantee the controllability of their loads. However, this provision still has to be clarified and is not yet ready for a massive application.

The Italian National Regulating Authority (NRA) has defined since the 2000s the right for TSO to require load curtailment to passive customers with an installed power larger than 1 MW. The price of this service for the customers is fixed by a unique bid auction in which all interested customers are involved. No such provisions are presently operating at DSO level. Besides, the Italian NRA has defined in 2011, in a recommendation document for the Parliament [25], Demand Response as a possible intervention to facilitate RES integration in the electric system. In this country, different pilot projects led by DSOs are aimed at making additional metering information available to electricity traders and their customers in order to allow market players to build out advanced price signal services.

Direct load control has been in place in Spain for about 20 years. The Spanish TSO can request industrial customers to curtail the load with the condition of informing them in advance. This way these industries may receive a discount according to the number of requests received to reduce demand. These mechanisms are intended to compensate imbalances between supply and demand. Besides, there have been price-led programmes for some time, with time of use tariffs providing economic signals for demand response. The TSO can determine the hours corresponding to the most expensive period. The time of use rates divide the 8760 h in a year into several periods, having a different rate for each component of the tariff in each period.

In the United Kingdom, industrial and large commercial consumers are able to agree interruptible contracts with suppliers. The System Operator can contract with such large users directly as part of their network balancing activities. Besides, about 4.5 Million customers make use of multi-rate energy tariffs. This involves programmes for obtaining discounted electricity rates at night [26].

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[13] Assessment based on PV GRID survey results, completed by national PV associations. Survey results are available in Annex III of the European advisory paper: http://www.pvgrid.eu/results-and-publications.html.

5.2.7. Incoherent Metering Framework

Smart meters are electronic devices that can measure the consumption of energy, adding more information than a conventional meter, and can transmit data using a form of electronic communication [27]. The European Commission in four Directives and in a recommendation paper mentions these devices:

- Directive 2006/32/EC on energy end-use efficiency and energy services explicitly mentions the need of smart meters in article 13 [28];
- Directive 2009/72/EC concerning common rules for the internal market in electricity establishes that by 2020 at least 80 % of consumers shall be equipped with intelligent metering systems [2]. However, it also establishes that member states might run a cost benefit analysis (CBA) evaluating all potential costs and benefits associated to smart meters (including effects on DG) in order to take a decision on the scale of their national roll-out;
- Directive 2012/27/EU on energy efficiency explicitly mention smart meters in articles 9 (metering) and 10 (billing information) [6];
- Additional recommendations on smart meters are summarised in 2012/148/UE, regarding data protection, security considerations, and the methodology for the economic assessment of the long-term costs and benefits for the roll-out of smart metering systems [29].

The importance of smart meters is therefore explicitly recognised at European level, with an ambitious 2020 80% target. While this target is even increased in some countries (e.g. Spain set an objective of 100% smart meters by 2018), in other countries the mentioned CBA process may result in a smaller-scale deployment. While legally all member states that decided to carry out a CBA are obliged to be finished by now, some results are still unknown. Besides, most smart meters roll-outs in Europe so far have been focused on consumption meters only (such as in France, Greece, Hungary, Ireland and others), and therefore it is by no means clear that all PV systems to be installed in the coming years will automatically be equipped with a smart production meter. Smart meters could also be interesting for other DG technologies, so they should be installed on existing or new DG where the economics turn out to be positive.

As discussed, an incoherent or insufficient deployment of smart meters may negatively influence the deployment of the following technical solutions:

- SCADA + PV inverter control (Q and P);
- SCADA + direct load control;
- Demand response by local price signals;
- Demand response by market price signals.

Hence, the deployment of smart meters is connected with the ability of the distribution network to host more DG. However, it must be recognised that, while smart meters are convenient for some solutions, they are not sufficient. They need to be complemented with other equipment that for example allows remote controlling, and with new business models that turn the available data into business opportunities. Furthermore, DSOs can operate "smarter" without a large-scale roll-out of intelligent metering systems. That said, it appears clear that any consideration about mandatory introduction of intelligent metering systems is out of the scope of this project and should be assessed carefully within a more general system framework. It may be the case that installing the required intelligent infrastructure is only viable with large-scale PV installations.

5.2.8. Regulatory Frameworks discouraging "Smart Grid" Development

As previously discussed, Directive 2009/28/EC establishes that Member States shall take the steps to *"develop intelligent networks"*, i.e. network structures that are commonly referred to as "smart grids".

These networks are vital for a transition to a low-carbon economy, being also required to integrate DER such as electric vehicles and DG. Smart grids are an evolution of current networks with more advanced system services, online monitoring of grid operating conditions, including an intensive use of communication systems and technologies. Therefore they require new investments in communication technologies to serve as the basic infrastructure for developing smart grid applications.

The aim to develop smart grids at a European level is often in conflict with national regulations, which establish the specific conditions under which DSO recover their investments. Basically, the national frameworks tend to implement regimes that include elements of incentive regulation, which has the main objective of promoting only efficient investments, with the aim that this reduction in investment and/or operational expenditure will ultimately imply a reduction of prices for the consumer. The most common methods for this incentive regulation are price cap and revenue cap, depending on whether a restriction on prices or on revenues is set. As opposed to standard cost-of-service regulations, with incentive regulations there tends to be a decoupling between the real investments of the companies and their revenues.

These types of regulations are adequate for promoting efficiency. However, as incentive regulations decouple the revenues from the real investments, they are a disincentive to investment; in addition they are mostly inefficient in steering investments into certain technologies. In fact, smart grid solutions typically rely on electronic components that have shorter useful lives and/or are not fully proven yet. Consequently, DSOs could discard their implementation due to the technological uncertainties. Under these conditions, national regulators should consider setting specific incentives to adopt and test innovative solutions. As described in [30], some countries have already set this kind of incentives such as Italy or the United Kingdom.

In many circumstances, when the incentive regulation is based on a regulatory period of four or five years, the period may not be sufficient to perceive the benefits of these installations, and for this reason they can also be discouraged. According to a EURELECTRIC report on regulation for smart grids [31], other major problems are sub-optimal rates of return and regulatory instability, delayed roll-out or partial application of smart meters, and a narrow view of the regulators for evaluating cost efficiency, penalising research on innovation projects.

On a different topic, the enactment of smart grid solutions may also require the improvement of voltage measurement and monitoring practices on MV and especially on LV networks, of which DSOs often have a much lower amount of information. Even if metering devices are nowadays often in place in these portions of the network, these devices are most likely not equipped with digital communication capabilities. As a consequence, voltage values are usually not known, unless faults or disservices are first revealed and consequently the interested part of the grid is inspected.

In the past, it was deemed suitable not to collect extensive measurement data in lower network levels due to the fixed load flow, but in recent times due to the growth of DG this practice has become less appropriate. The lack of automated network measurements may cause that the DSO obligation of maintaining the maximum specified voltage limits cannot be properly verified. For instance, with smart meters in place it would be possible to periodically measure the voltage values in these portions of the network. These measurements could contribute to let the DSOs take corrective measures in case that the planning of the network does not guarantee an adequate level of voltage values under certain operating conditions. Also, without knowledge about a specific local situation a DSO would not be able to apply, for example, SCADA functionalities or direct access to loads and inverters.

Technical solutions affected by the barriers discussed above include:

- SCADA + PV inverter control (Q and P)
- Advanced voltage control for HV/MV transformer
- SCADA + direct load control
- Wide area voltage control
- Advanced Closed-Loop Operation
- Demand response by local price signals
- Demand response by market price signals

In most countries, the support of the smart grid concept depends only on the DSO. In Italy, although there is an explicit incentive for smart grids since 2007, in practice this incentive is not applied because the NRA has not yet stated which kind of installations can be considered as smart grids, and therefore it has only applied to specific innovation projects individually selected by the NRA.

In order to address deficiencies of the regulatory frameworks, specific incentives can be set for investments in smart grids in countries. This is the case for example of the low carbon networks fund (LCNF) in United Kingdom [32]. With £500 million over five years, this program encourages distribution companies to carry out ground-breaking projects to develop smart grids, and assisting in the creation of a low carbon economy. This program aims to efficiently connect DG, meet the needs of small-scale and intermittent generation, increase the use of electric vehicles, use smart meters to improve the network performance and incentive customers to manage their demand. An independent panel of experts is in charge of evaluating all bids against common criteria.

5.3. Recommendations at National Level

5.3.1. Recovery of DSO Investments and Costs

DSO Investment Recovery Schemes

- The following regulatory principles should be followed [33]:
  - sustainability, guaranteeing the timely recovery of costs efficiently incurred so that the electrical power sector is economically viable;
  - economic efficiency, maintaining the service at lowest cost possible while meeting prescribed quality standards – both with a longer term perspective;
  - transparency, they should be based on a well-defined and clearly explained methodology;
  - stability in the methodology to reduce the risks of regulatory uncertainty;
  - simplicity, as far as possible.
- In order to diminish DSOs' risks, the delay between the moment in which an investment in equipment is made and the moment in which the cost incurred for the investment is recovered via allowed revenues should be shortened;
- Regulatory frameworks should be adapted so as to equalize the incentives between CAPEX and OPEX.

Grid Connection Charges and Distribution Grid Tariffs

- The methodology used to calculate connection charges and distribution grid tariffs should be as transparent as possible, This is also important for PV investors' security;
- There are pros and cons in all types of grid connection charges. National policy makers should strike a balance between PV owners' responsibility vis-à-vis the financing of distribution grids and PV profitability. The smaller the PV system size, the more difficult high charges become.

5.3.2. Rules Forbidding RES Energy Curtailment except for Security Issues

- The European level recommendations given in chapter 4.2.4 should also be considered at national level, taking into account the characteristics of each national context.

5.3.3. Insufficient Self-consumption Framework

- For those countries that do not have it in place, legislation allowing for self-consumption of PV generated electricity should rapidly be approved;
- A favourable regulatory framework should be created, stimulating PV electricity self-consumption to contribute to network operation (reducing peaks);
- Reasonable self-consumption obligations may be introduced for newly-connected DG, in order to ensure transparent and non-discriminatory planning criteria;
- Boundary conditions for self-consumption obligations should be aimed at reducing electricity injection peaks in order to ease the grid connection and overall grid capacity requirements.

5.3.4. Insufficient DSO Access to Advanced PV Inverter Capabilities

- Boundary conditions for DSOs' access to advanced PV inverter capabilities should be defined by the competent national authorities;
- The trade-off between requested capabilities (grid codes) and capabilities that are offered on a voluntary basis needs to be recognised and analysed further by stakeholders;
- Mechanisms to avoid conflict of interests with the TSOs and energy providers shall be put in place.

5.3.5. Insufficient Framework for Prosumer Storage Solutions

- Prosumer storage solutions should be allowed by national regulatory frameworks;

- The connection and operation requirements currently under discussion, should ensure that prosumer storage does not pose a security problem to the system or interfere with the metering of DG production;
- Explicit mechanisms should be established for supporting prosumer storage solutions, when these are applied to reduce the peaks of PV installations.

5.3.6. Insufficient Framework for DSO Storage Solutions

- Within each national regulatory framework, given the network operation benefits that can be made available by DSO storage, there should be a reflection on how to activate this potential without affecting the unbundling principle;
- Roles, rights and limitations of DSOs (and TSOs) in the use of storage must be clearly defined by the national regulating authorities;
- Local security-related capabilities should be made available to DSOs.

5.3.7. Insufficient Framework for Demand Response

- Technical features and market models for Demand Response should be assessed taking into account that they are related to wider objectives than the mere integration of DG, including system/flexibility services at the distribution level for management of local grid constraints. While they may have important side effects on DG hosting capacity, the main focus of Demand Response must be on the benefits on the customers' side;
- Market model-neutral enabling factors, such as the communication between DSO and final customers, can and should be defined as soon as possible;
  - For instance, the "traffic light concept" as it is currently discussed throughout Europe is a good starting point;
- DSOs should be allowed to manage load reduction and activation services in order to fully utilise any demand-side management potential;
- A compensation scheme for users participating voluntarily in demand response and load reduction services should be discussed and put in place.

5.3.8. Incoherent Metering Framework

- A cost-benefit analysis on the deployment of smart meters, as demanded by European Directive 2009/72/EC, should be rapidly performed at national level;
- In countries where the roll-out of smart meters has so far been focused on consumption meters, it should be analysed whether DG installations should also be equipped with these devices;
- For smart meters deployed on DG, it should be ensured that their potential is used for implementing telemetry and other applications increasing the hosting capacity of the distribution network.
- Mandatory introduction of intelligent metering systems should be assessed carefully. It may be the case that installing the required intelligent infrastructure is only viable with large-scale PV installations.

5.3.9. Regulatory Frameworks discouraging "Smart Grid" Development

- A smart grid can bring about many advantages, such as a more sustainable, efficient and secure electricity supply to customers. However, each of these benefits is accompanied by significant costs related to the purchase, operation and maintenance of the required components. Careful consideration of both costs and benefits will be required;
- National regulators should discuss with all relevant stakeholders the adaptation of national regulatory frameworks in order to concretely promote "smart grid" investments;
  - A stable and transparent regulatory framework (avoiding frequent changes), and an ex-ante approach should also be established in order to favour such evolution;
- If the conclusion of careful analysis suggests the implementation of smart grids to support integration of renewables and where necessary, explicit (pecuniary) incentives should also be established:
  - Incentives can apply to innovative projects in smart grids, approved by the national regulators;
  - In case that these incentives are to be generalised it would be required to clearly define a smart grid in terms of what are the services it has to provide, its architecture and components.

6. APPLICATION AT NATIONAL LEVEL

In this section we provide an initial framework that can be used to apply the barrier analysis and recommendations presented in the previous sections to a given national context.

6.1. Introduction

The main goal of the project PV GRID is helping to reduce barriers to large-scale integration of PV systems in electricity distribution infrastructures across Europe. Concerning this goal the present European advisory paper has analysed the current situation and the regulatory and normative barriers that might stem from current legislation and other regulatory and normative framework conditions.

While PV LEGAL, as a predecessor to this work, was focused on barriers resulting from legal-administrative processes, the work of PV GRID focuses on the relation between certain legislative, regulatory and normative frameworks and the identified technical solutions available to increase distribution grid hosting capacity. Even though the project's main focus is PV, the PV GRID consortium believes that the reduction of identified barriers and the implementation of the identified technical solutions could be beneficial also to other RES, such as wind or biomass.

It is the purpose of this chapter to foster the knowledge transfer between European Member States, especially with regards to how they can apply what was described in chapters 4 and 5 of this paper on the national level. Even though the focus is on applying PV GRID results on the national level, this chapter will not focus on any particular member states. Rather, it will give general ideas and advice on how to structure the analysis and then find a course of action, if the national strategy does indeed call for a (strong) increase in the penetration of PV or of other RES in the distribution networks.

PV GRID is built upon two underlying assumptions, which are important for the discussion of this chapter and thus, will be explained below. Furthermore, different PV support schemes and the market design options they include are introduced as a background for the following discussion. On this basis, the chapter focuses on some general, though important relations between certain support schemes and the applicability of the technical solutions identified by PV GRID towards certain types of installations. Based on these discussions, a roadmap for "Increasing PV Penetration" is introduced. It is one of the most important results of this advisory paper. The roadmap aims at providing guidance and advice to member states that either anticipate a significant increase in PV penetration or are planning for such an increase. Together with the technical solutions identified by PV GRID with regards to MV and LV networks the roadmap can be used to identify gaps in the national regulatory and normative frameworks. To this end, it will support member states in their PV and overall RES strategy as it gives an indication whether the technical solutions to increase the hosting capacity of existing grids should be exploited.

6.2. The PV GRID Roadmap

General Assumptions

One of the main purposes of the PV GRID project is to identify and help to reduce barriers to large-scale integration of PV into current European distribution networks. Following this mission, the entire project is based on two general assumptions. These assumptions are neither discussed nor analysed any further here, as such an analysis and discussion (especially in relation to other possible paths of action) would be out of the scope of the project. Those two basic assumptions are:

- A (large-scale) increase in the penetration of PV is a given political goal (cf. the applicable European Directives and national legislations).
- PV is granted priority access to the grids and priority dispatching (again in compliance with current EU legislation).

Design options of a RES support scheme

The second assumption stated above, i.e. granting priority access and dispatching to PV installations and other RES, has been a major driver for increasing levels of RES in Europe in the past ten years. However, priority access is not the only element in a national PV support scheme that influences the PV business case. On the contrary, it can be assumed that the investment behaviour of private agents towards PV is heavily influenced by a large number of (interdependent) political decisions. Figure 6.2.1 provides a non-exhaustive set of examples of important policy dimensions that also need to be considered when planning for an increase in the installed PV capacity and that inter alia might also influence the usefulness and applicability of the technical solutions identified by PV GRID.

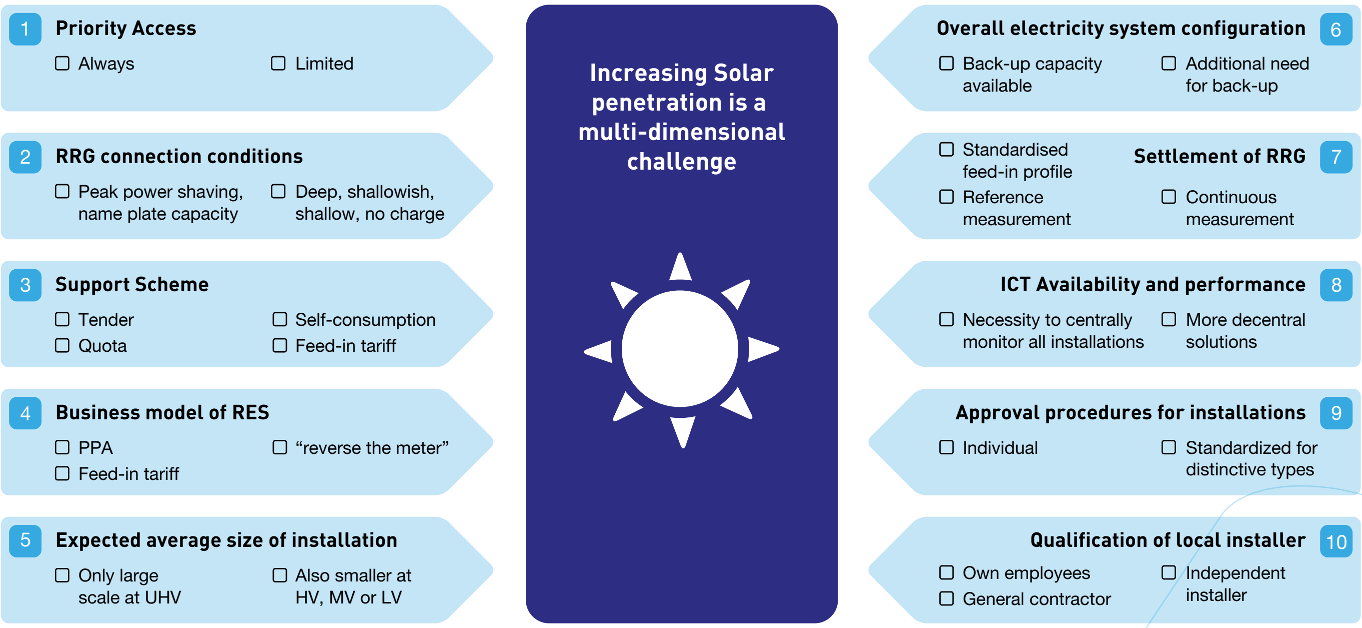

Figure 6.2.1: Important dimensions for large-scale PV development. Source: RWE Consulting

As Figure 6.2.1 shows, most policy dimensions are multi-optional. For instance, there is more than one way of organising an access regime for PV – even though the EU has taken a decision on this issue by opting for priority access. While the access regime is a very important factor, other issues are also important and may influence the usefulness of priority access directly, i.e. the different dimensions shown in Figure 6.2.1 are not independent from one another.

For example, connection charges will have a direct impact on the PV owner's business case and may thus support the right to access even further or effectively qualify it. But even if a PV system's connection charge were rather high, it might still be balanced by the support scheme itself.[14] For instance a feed-in-tariff could be designed in a way that is able to cope with higher connection charges without jeopardizing the PV business case.

Also some of the design options might not effectively work with one another. As an example, an individual approval procedure for every single installation would have some direct and significant consequences in terms of the amount of qualified staff that would be required to perform such approval procedures. If those personnel were not readily available, approval procedures would most probably become a major bottleneck for PV deployment, as shown by PV LEGAL. Furthermore, as some technical solutions for increased PV penetration require enhanced information and communication technologies (ICT) that are centrally monitored, the first question is whether those technologies have been deployed and second, whether enough qualified staff to operate those ICT technologies are available.

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[14] PV is not the only possible connectee in the market. Hence, the connection rules that exist for other parties / installations / power stations might to a certain extent determine the rules used for PV.

It is important to realise that multiple design options exist. Furthermore, they influence each other, and their interaction has the potential to determine the overall performance of the support scheme.[15] Hence, analysing and understanding existing support schemes, thereby determining which incentives they provide, is therefore almost an aim in itself. In addition, as it will be argued in the following section, some design arrangements of support schemes will make the case for using the technical solutions identified by PV GRID and thus replace or delay traditional grid expansion even stronger. Therefore, knowing and understanding the current or future support scheme may be helpful in analysing which technical solutions might be needed when and where.

Important dimensions of support schemes and their relation to PV Grid's technical solutions

With regards to the technical solutions identified by the PV GRID project and the barriers these might be facing, some interrelations between certain dimensions of a support scheme are more important than others. First and foremost, it should be recognised that there is a general correlation between the type of support scheme established and the type, technology and size (load) of PV and/or RES installations that will be generated. Some important correlations are shown in Table 6.2.1.

Type of investor Regime	**Large Investor (mostly institutional investors)**	**Small Investor (mostly private investors)**	**Electricity Supply Company**
Tender	Industrial ground-mounted PV systems[16]	--	--
Quota	Industrial ground-mounted PV systems / Commercial PV systems	--	Industrial ground-mounted PV systems / Commercial PV systems
Feed-in Tariff[17]	Industrial ground-mounted PV systems / Commercial PV systems	Commercial PV systems / Residential PV systems	--
Net Metering	--	Commercial PV systems / Residential PV systems	--

Table 6.2.1 - Correlation between RES support schemes and RES development. Source: PV GRID[18]

The relation is described by the term "correlation" to indicate that it is not a "consequential" relationship. To wit, policymakers are not able to exactly "steer" the type and size of installations that will finally be realized (*inter alia* because technological developments might increase the advantage of certain technologies that were originally not planned for). However, due to the different investment risks that are inherent to certain RES support schemes, these correlations exist and hence, certain support schemes will support peculiar types of installations "better" or "more" than others.

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[15] In very general terms the European Parliament recognized these and other dependencies in its resolution of 14 March 2013 on the Energy roadmap 2050, a future with energy [2012/2103(INI)]. The Parliament mainly stressed that support schemes in general and especially the changes to them can strongly influence investor confidence.

[16] cf. the PV GRID database for an exact definition of industrial ground mounted systems, commercial system and residential systems per country.

[17] With a Feed-in-tariff a lot depends on the actual design of the tariff. Real world examples (cf. Germany) most often include a differentiation of the subsidy between different sizes of installations, i.e. smaller PV systems receive higher subsidies per kWh than larger ones. Thus, smaller PV systems become more attractive.

[18] This PV GRID appraisal is based on general observations by consortium members. Furthermore, the EU-project Beyond 2020 argues in its October 2012 review report on interactions between RES-support instruments and electricity markets that "…the type of support scheme can influence the ownership structure. Depending on the risk involved in investments in renewables, smaller or bigger actors will become active…" (page 65)

The important point is that a certain support scheme will not only attract certain types of investors, but it will also largely determine the (average) size of PV installations that is to be expected. Using a simple example that is also presented in the table, one might argue that running a tender scheme implies (higher) transaction costs, which in turn implies larger tranches and larger (more capital intensive) types of investors. Altogether, it is therefore more likely that a tender regime will lead to rather large or very large PV systems. In the same way net-metering regimes tend to create a certain advantage in self-consuming PV produced electricity and probably imply somewhat smaller systems, i.e. systems whose size is "related" to amount of energy used on-site. As a final example, electricity supply companies would probably be most interested in direct and indirect PV investments if a quota system with technology targets was in place, forcing them to have certain amounts of green electricity in their portfolios.

Due to the technical characteristics of electricity networks in general, another issue arises from the aforementioned correlations: the type and size (i.e. maximum capacity) of any RES installation will to a large extent determine the network level it will be connected to. The network level of connection determines the applicability and relative advantage of the technical solutions that were identified by PV GRID. As a direct consequence of these assumptions, it should also be possible to analyse in advance of any roll-out whether network structures exist that are either especially suitable for hosting an increased number of PV installations without any further action, or whether certain grids that are less suitable due to their technical set-up can be identified already at the outset.

In general terms the following relations should hold true[19]:

- **Very Large ground-mounted PV systems** are typically installed in high voltage (HV) and, to a lesser extent, in medium voltage (MV) networks. In these cases, most typically a new connection is needed and built.
- **Commercial PV systems** in most cases are installed in MV networks. In this case, either a new connection is built or an existing one is enlarged.
- **Residential PV systems** are typically installed in low voltage (LV) and sometimes MV networks. If the PV system's peak production capacity is not larger than the connection of the premise it is built upon, the existing connection might also be used for the purposes of the PV feed-in. Otherwise, the connection needs to be enlarged or a new connection needs to be built.

Summing up, a large-scale increase in PV will not happen independently from the overall policy framework for supporting renewables. The implemented policy is, among other things, affecting the size of installations and their maximum load. And certain sizes of load, in turn, effectively determine network levels of connection.

Other issues like the geographical set-up of the country will be decisive for the full-load hours reached in different regions and also for the network infrastructure in place today (i.e. some rural areas have a lot of space available and might also be very attractive in terms of solar radiation, but their networks tend to be less strong than the ones found e.g. in inner cities).

Therefore, it is generally possible and useful to analyse the current (and future) set-up of the RES support scheme and the network infrastructure as well as the regulatory and normative framework to determine (in advance) whether the technical solutions as identified by PV GRID are:

- useful in the current or upcoming situation (as they might help to avoid or delay network expansion);
- applicable in the current regulatory and normative framework (as they might be hindered by some of the barriers that were identified by PV GRID).

In order to structure such an analysis further, the PV GRID consortium developed a roadmap that may be used as an exemplary blueprint by any national authority or stakeholder in order to identify barriers early on, and thus direct PV investments into suitable regions or foster an increase of the grid hosting capacity where necessary.

The PV GRID Roadmap

The roadmap that is developed and explained in detail below aims at giving policy makers and other stakeholders a first and easy indication on where their country is positioned and what needs to be done to actually help increasing the penetration levels of PV. In order to use the roadmap, we strongly suggest policy makers and other stakeholders familiarise themselves with PV GRID's technical documents (D3.1: Prioritisation of Technical Solutions available for the Integration of PV into the Distribution Grid) in order to clarify which technical solutions might be useful in their particular situation – they will probably end up with a combination of these measures, as in fact none of the technical solutions identified allows for resolving all issues by itself.

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[19] Actually the situation might be somewhat different from country to country or in between support schemes, but for technical reasons higher loads (kW) will generally be connected to higher network levels. This generally holds true for demand and production sites.

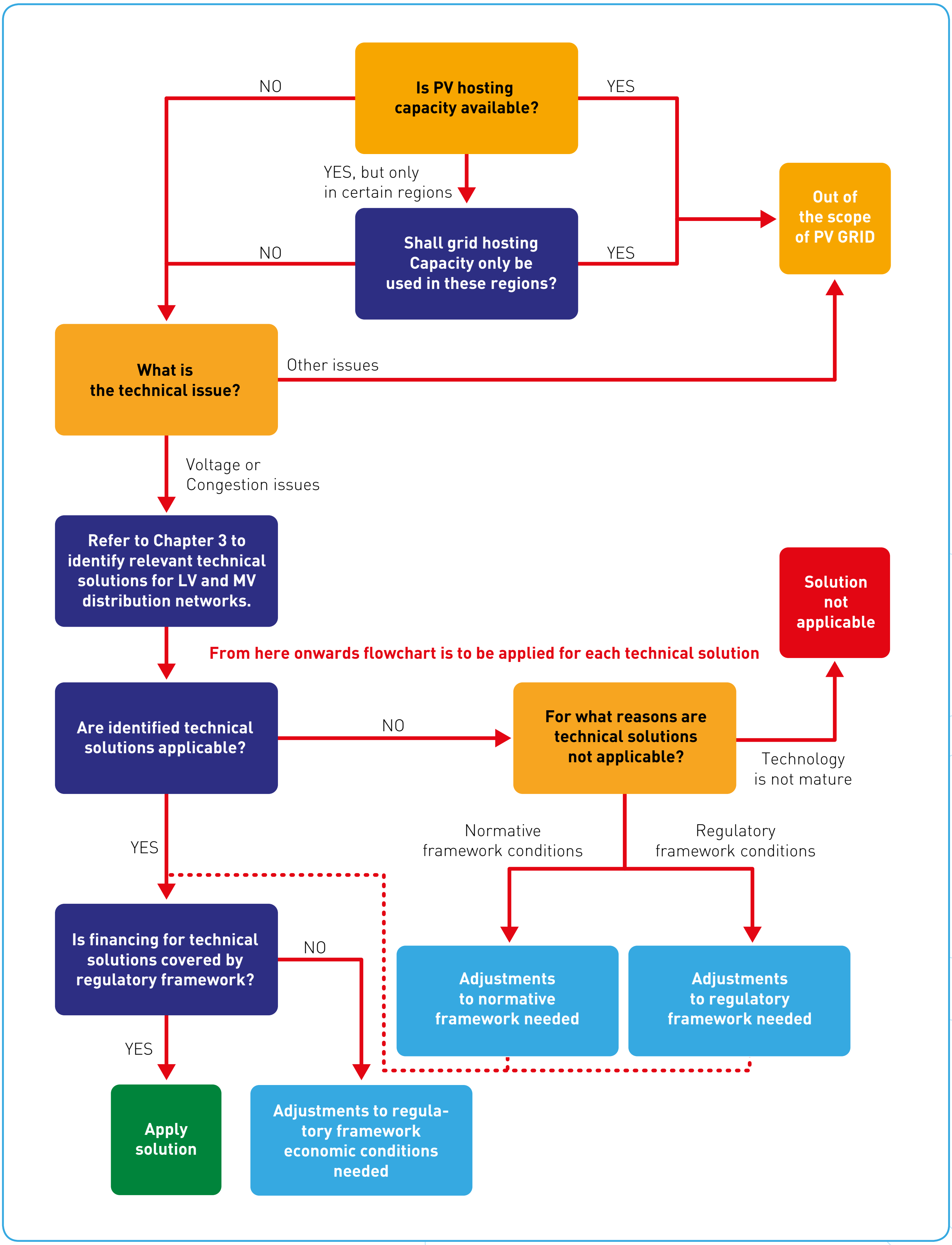

Figure 6.2.2 - Roadmap for Increasing PV Penetration on the Distribution Grid

The roadmap does not focus on any single technical solution, it rather uses a flowchart to indicate which questions should be analysed at first and which questions should be addressed in a second step, to be analysed later or after the answers to the questions on the first level have been clarified. Furthermore, the roadmap is somewhat simplified, as in reality issues are more complex and interdependent, including processes happening in parallel. Just as this whole chapter, the roadmap assumes a situation where large-scale integration of PV is either already the case or will become reality in the near future.

The roadmap offers a course of action for policy makers, regulators, DSOs, PV associations and other important stakeholders. However, in order to reach satisfying results, the process of analysing the current situation and identifying suitable technical solutions as well as barriers in the regulatory and normative framework that may have to be overcome will need to be carried out together by all stakeholders. Applying this inclusive approach will allow for reaching common ground, developing mutual understanding and helping to implement the needed changes to the framework conditions.

Based on a country's RES goals and policies for increasing PV penetration, is there a need for action regarding the distribution grid hosting capacity? If so, policymakers need to determine whether PV is supposed to be installed uniformly distributed, or only in certain regions. It is highly recommendable to base this decision upon broad stakeholder input. In case available regional hosting capacities should be used first, it may be necessary to introduce regulatory and normative steering instruments offering incentives for PV systems in those regions with hosting capacity available.

If not enough grid hosting capacity is available, stakeholders need to identify why capacity is limited and on what voltage level. PV GRID is addressing two main problems: voltage and/or congestion. Other problems are out of the project's scope and hence, not addressed here.

Successively, DSOs in collaboration with other stakeholders need to check which of the technical solutions identified by PV GRID best suits the task of handling the particular situation in a certain region or country, thereby identifying the optimal mix of solutions to address the problems. It needs to be checked whether those solutions are actually applicable. This step involves the analysis of barriers (as discussed in Chapter 4 (European level) and Chapter 5 (national level) to determine whether technical solutions are easily applicable or not. If not, necessary changes in the normative and/or regulatory framework conditions need to be identified and all stakeholders should work together towards implementing them. The final test is whether the most suitable solutions identified above can be financed, either by DSOs or by other stakeholders (e.g., Prosumer storage solutions by consumers). Are existing financial incentives sufficient to stimulate the application of technical solutions? If not, stakeholders should work together towards adjusting the regulatory framework setting the economic conditions in order to allow for adequate financing to apply the optimal mix of technical solutions.

6.3. Status of PV Integration and Barriers in Participating Countries

In order to assess the urgency of adopting PV GRID recommendations in the different national contexts, the PV penetration ratio may be indicative. However, this is only a rough indication, as it doesn't take into account the actual grid topography of each country, the distribution between PV and load as well as the distribution of other DG technologies and the distinction between distribution and transmission levels. Hence, this indicator must be treated with some reservation and caution.

PV Penetration Ratio

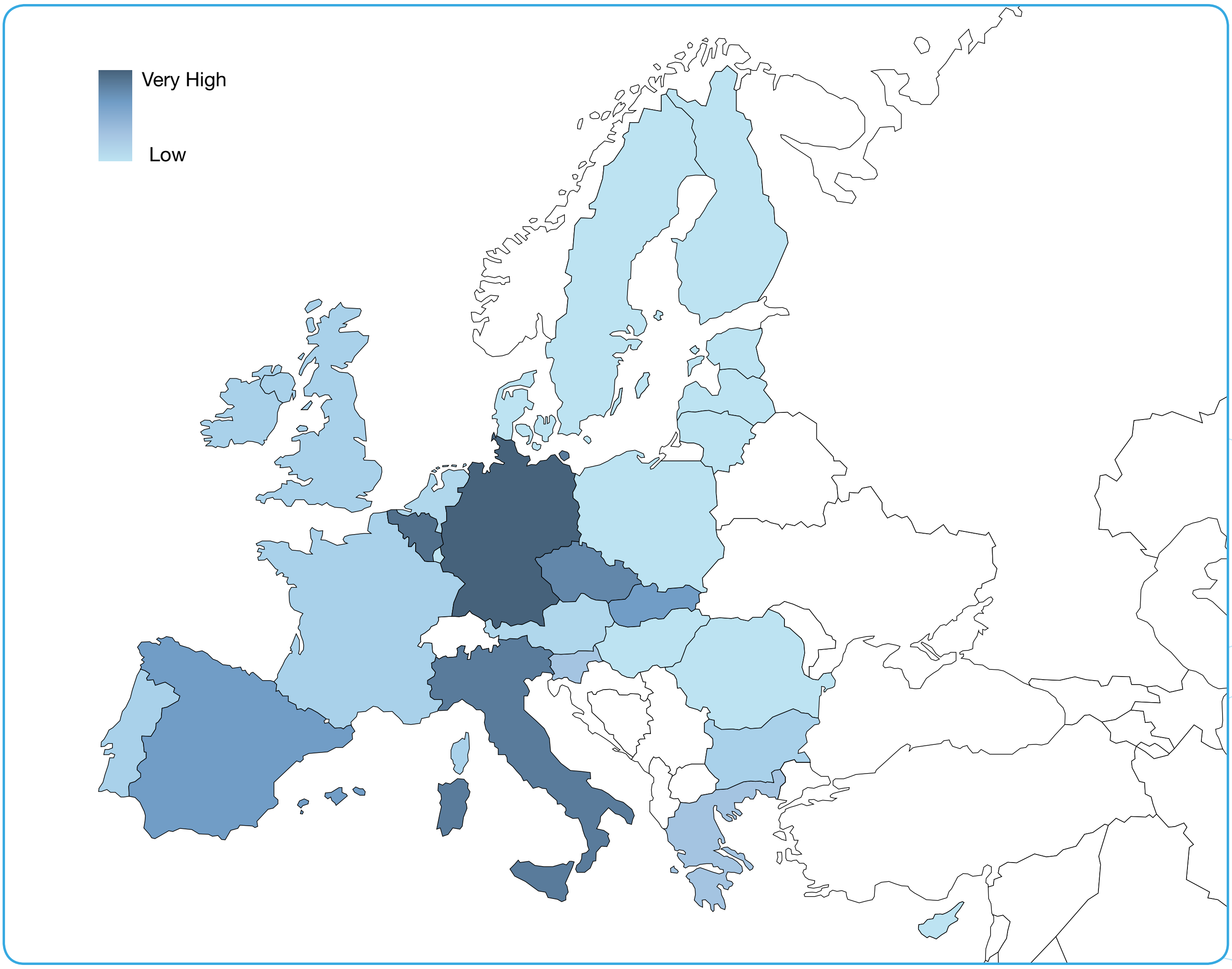

Figure 6.3.1 – Clustering based on PV penetration ratio

The PV penetration ratio is calculated for each country as the quotient of the total installed PV generation capacity in 2012[20] and the total installed electricity generation capacity[21], expressed in %. In our analysis, the PV penetration ratio is considered very high when it is greater than 14%, high when it is greater than 8% and low when it is lower than 1%. The limits are arbitrary, but there is a clear separation between the medium and high penetration ratios, as Slovakia has a penetration of 5.74%, and the immediate higher penetration ratios correspond to Czech Republic, Italy and Belgium with a penetration ratio of 9.67%, 10.86% and 11.04% respectively.

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[20] Obtained from the 2013 EPIA "Global Market Outlook"

[21] Total Electricity Capacity in 2011 obtained from Eurelectric Power Stats and Trends 2012

Country	PV capacity scenarios [MW] (2012)	Total Electricity Installed Capacity [MW] (2011)	PV Penetration (%)	PV Penetration
Austria	176	22.019	0,80%	Low
Belgium	2.018	18.284	11,04%	High
Bulgaria	135	12.228	1,10%	Medium
Cyprus	9	1.689	0,53%	Low
Czech Republic	1.959	20.250	9,67%	High
Denmark	16	13.540	0,12%	Low
Estonia	0,2	2.441	0,01%	Low
Finland	1	16.813	0,01%	Low
France	2.659	126.462	2,10%	Medium
Germany	24.678	167.820	14,71%	Very high
Greece	631	17.659	3,57%	Medium
Hungary	4	9.497	0,04%	Low
Ireland	3	8.459	0,04%	Low
Italy	12.754	117.490	10,86%	High
Latvia	0,2	2.576	0,01%	Low
Lithuania	0,3	3.672	0,01%	Low
Luxembourg	30	1.728	1,74%	Medium
Malta	12	572	2,10%	Medium
Netherlands	103	26.733	0,39%	Low
Poland	3	34.688	0,01%	Low
Portugal	183	19.819	0,92%	Low
Romania	3	16.460	0,02%	Low
Slovakia	468	8.152	5,74%	Medium
Slovenia	81	3.146	2,57%	Medium
Spain	4.400	101.613	4,33%	Medium
Sweden	15	36.447	0,04%	Low
United Kingdom	875	89.261	0,98%	Low

Table 6.3.1 - PV penetration ratios. Source: PV GRID calculations based on EPIA and Eurelectric data.

The penetration ratios indicate that, compared to other countries, in Germany a very high, and in Belgium, Italy and the Czech Republic a high PV penetration is occurring. Therefore, these countries should pay special attention to the technical solutions described in chapter 3, as it is expected that they will be the first ones facing challenges in the distribution networks as far as PV is concerned. In other words, the PV penetration ratio gives a rough indication of the urgency of adopting PV GRID recommendations.

Occurrence of Barriers at National Level

In order to establish which of the barriers identified in chapter 5 occur in participating European countries, the PV GRID consortium has undertaken a basic research of existing studies at European level, and conducted a short barrier assessment survey. The survey has been completed by national PV associations, often with support from regulators, DSOs, TSOs and consultancies in the concerned countries. Furthermore, each survey has been vetted with participants of national consultation workshops and was adjusted according to the feedback received. All survey results are accessible and publicly available in Annex III, which can be downloaded at: http://www.pvgrid.eu/results-and-publications.html.

Based on their careful preparation and the following review process, the survey results shown in Table 6.3.2 - Occurrence of identified barriers in PV GRID countries. can serve as indicators for assessing changes needed in regulatory and normative frameworks in order to increase PV hosting capacities in individual countries.

Barriers / Country	**Recovery of DSO Investments and costs**	**Rules forbidding RES energy curtailment except for issues**	**Insufficient self-consumption framework**	**Insufficient DSO access to advanced PV inverter capabilities**	**Insufficient framework for prosumer storage solutions**	**Insufficient framework for DSO storage solutions**	**Insufficient framework for Demand Response**	**Incoherent metering framework**	**Regulatory frameworks that do not incentivise smart grids development**
Austria	□	■	□	□	▨	■	■	□	▨
Belgium	▨	▨	□	▨	▨	■	▨	▨	■
Bulgaria	▨	□	▨	□	■	■	▨	■	■
Czech Republic	▨	■	▨	□	▨	□	■	□	■
France	■	■	▨	□	■	■	▨	□	□
Germany	▨	▨	□	□	□	■	▨	▨	▨
Greece	■	■	□	■	■	■	▨	■	■
Italy	□	■	▨	▨	■	■	■	□	▨
Netherlands	▨	■	▨	■	■	■	■	▨	▨
Poland	▨	□	▨	■	▨	■	■	▨	■
Portugal	▨	▨	■	□	■	■	■	□	■
Slovakia	■	□	▨	■	■	■	▨	□	■
Spain	■	■	▨	■	■	■	■	▨	■
Sweden	▨	■	□	■	▨	■	▨	□	■
U.K.	▨	□	▨	■	▨	■	▨	■	□

■ Several barriers detected

▨ Few barriers detected

□ No barriers detected

Table 6.3.2 - Occurrence of identified barriers in PV GRID countries.

In Annex I, the four focus country case studies are presented. The PV GRID consortium members in the respective four initial focus countries (Germany, Italy, Czech Republic and Spain) have conducted a thorough analysis of PV integration into the national distribution grids, including a detailed regulatory and normative barrier analysis with respect to the adoption of technical solutions and recommendations on how to overcome those barriers. The case studies serve as a blueprint for the overall analysis of barriers and recommendations in the European advisory paper. At the same time, they also offer an example for stakeholders in other participating countries interested in carrying out a more detailed analysis based on the PV GRID roadmap. Annex I is publicly available and can be downloaded at : http://www.pvgrid.eu/results-and-publications.html.

Furthermore, four additional case studies have been prepared based on national consultation workshops with respect to the PV GRID project results in the following countries : France, Greece, Netherlands and United Kingdom. Those additional case studies are publicly available in Annex II and can also be downloaded at : http://www.pvgrid.eu/results-and-publications.html.

7. OUTLOOK AND CONCLUSIONS

7.1. PV GRID National Consultation Process

Between February and May 2014, fifteen national consultation workshops took place in the countries participating in the project. During these events, PV GRID project results have been presented to key national stakeholders, including DSO and TSO representatives, regulators, policy-makers and other electricity sector experts. Some of the workshops were performed as bilateral meetings in order to accommodate for sensitive situations in particular countries. In these cases, bilateral meetings were providing for a more productive and solution-oriented discussion atmosphere due to different levels of interests and sometimes diverging visions of various stakeholders on the topic of enhancing hosting capacity in the distribution grids. Other workshops were followed or accompanied by additional bilateral meetings.

In most countries that didn't already have a national case study available, the potential for applying technical solutions as identified by PV GRID and their effectiveness in the respective countries was assessed and discussed amongst workshop participants. Specific challenges and barriers encountered in the respective countries along with recommendations on how to overcome them derived from PV GRID were presented and discussed. Barrier assessments previously undertaken by national PV associations were vetted with participants and adjusted according to the feedback received.

In the so-called PV GRID focus countries, a more detailed analysis on technical solutions and barriers hampering their application had already been undertaken and was previously published in the national case studies. The respective results were reviewed and discussed at the national workshops in those countries, namely Czech Republic, Germany, Italy and Spain. In these cases, detailed feedback from workshop participants was used to further enhance the case studies.

All national PV associations that organized a PV GRID consultation workshop reported that fruitful discussions amongst participating key stakeholders took place, enhancing and deepening mutual understanding of the challenges faced from all parties concerned. Furthermore, the workshops in many cases also facilitated collaboration on finding answers to the tough questions regarding the integration of solar into the larger energy delivery system. Many associations report that they plan to stay active and engage in national discussions beyond the PV GRID project and contribute to enhancing the current or developing new regulatory frameworks in their respective countries.

7.2. Conclusions

With reference to the implementation of the set of technical solutions identified within the PV GRID project, categorized in DSO, prosumer and interactive solutions, a number of conclusions can be drawn as a result of the discussions that took place. In the case of interactive solutions, the necessity of allowing the DSO some kind of control over PV generation appears. This control can range from more invasive solutions, such as direct control, to more moderate approaches, such as allowing the DSO to set or impose functions to the PV inverters. In any case it appears necessary that, if advanced technical solutions are available in the PV inverter[22], the DSOs shall have access to them, so that they can be really used for solving congestions or voltage issues in the distribution grids. In this case, the boundary conditions for using these solutions must be clearly defined by the competent national authority. There is a trade-off between the mandatory requested capabilities that can be imposed on the PV inverter (set by grid codes) and the capabilities that can be offered on a voluntary basis in exchange for an economic compensation. For example, as commented in the Spanish case study, it should be avoided that this technical requirements turn out to be a barrier to small PV installations. So it may be the case that small size PV installations (for which the benefits of this control are lower) could be exempt from this obligation and provide it instead on a voluntary basis. On the other hand, the control of the PV inverter could also be useful to TSOs and energy providers, so, when defining this control, it is also essential to avoid conflicts of interest among all these agents.

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[22] This is often the case nowadays as inverter series are produced for a continent and the grid functions are disabled based on the requirements at the national level.

The current European directives limit the possibility of curtailment to system security or security of supply reasons, and force grid operators to take grid measures to minimize the curtailment of electricity produced from renewable energy sources. However, one of the results of the discussions in this project is that curtailment is a technical solution which can make sense from a global economic point of view if the compensation to the PV agent for curtailment is lower than the cost of the reinforcements required for preventing it, otherwise the network should be expanded or reinforced. For this solution to be applied it is necessary to open a fair debate on the use of curtailment of PV electricity. This debate should cover the determination of 1) a national cost-benefit analysis methodology, 2) boundary conditions and 3) adequate compensation rules for the PV agent. DSO driven curtailment should only be considered when congestion or voltage problems arise in the local network and when all other available measures have been evaluated and utilized if possible. In any case curtailment should be kept as low as possible. An example of a quantitative indicative measure is that for instance it should not exceed 5% of the annual production of each single installation. Although identified as a technical solution, it is possible that curtailment can put RES market growth at risk, bringing investment insecurity. To prevent this, it should only apply to new installations.

The implementation of curtailment as a technical solution should be considered at national level, taking into account the characteristics of each national context as exemplified in the national case studies, which are presented in Annex I and II of this document.

A revision of EU network codes (NC) has been carried out to evaluate their consequences on the technical solutions, as they may affect most of them. It has been concluded, that as many prescriptions contained in EU NCs are non-exhaustive, details should be agreed upon at national level within a coordinated EU-wide process involving DSOs, PV and other RES/DG associations. Besides, technical capabilities defined in the NC RfG should be further defined in standards developed within CENELEC. Such standards should be applied by all Member States when implementing the NC. Also, the following details have been highlighted:

- The revision of the standard on technical requirements for connection and operation of micro-generators and their protection devices up to and including 16A should be accelerated;
- Technical specifications for connection and operation of micro-generators and their protection devices above 16A should be turned into standards;
- Standards for testing and product certificates should be developed ex-nihilo as soon as possible;
- As possible anti-islanding defense actions (triggered by the use of certain PV capabilities prescribed in the NC RfG) may differ according to the operational criteria and protection schemes of MV and LV networks, scrutiny of present prescriptions set by each national regulatory authority at national level might be appropriate.

Another common topic to be addressed for all the technical solutions is that the DSO has to be remunerated for their investments in implementing these technical solutions. In particular, general regulatory principles suggest that DSOs should be efficiently remunerated for their incurred investments. Although this is not easy to determine, it should be the objective we should aim for. National regulators should adjust DSOs' investment and cost recovery schemes so as to encourage the investments needed for the decentralisation of the energy system and the roll-out of technical solutions enhancing grid integration of PV and other smart grid investments. In order to diminish DSOs' risks, the delay between the moment in which an investment in equipment is made and the moment in which the cost incurred for the investment is recovered via allowed revenues should be shortened. In particular, the evolution of the existing grids involving more distributed energy resources is demanding an increasing use of communication infrastructures, reducing the costs that conventional reinforcements would otherwise require. In this case the DSO revenue framework is critical. While preserving national specificities, guidance at European level should foster the transformation of national schemes into more smart grid-oriented frameworks.

A "smart grid" can bring about many advantages, such as a more sustainable, efficient and secure electricity supply to customers. However, each of these benefits is accompanied by significant costs related to the purchase, the operation and maintenance of the required components, and the management of the information and communication infrastructure associated with them. Careful consideration of both costs and benefits will be required. National regulators should discuss with all relevant stakeholders the adaptation of national regulatory frameworks in order to concretely promote "smart grid" investments. A stable and transparent regulatory framework (avoiding frequent changes), and an ex-ante approach should also be established in order to favor such evolution. If the conclusion of careful analysis suggests the implementation of smart grids to support integration of renewables and where necessary, explicit (pecuniary) incentives should also be established. Incentives can apply to innovative projects in smart grids, approved by the national regulators. These incentives in pilot projects can be useful for making the technology ready for broad adoption, but they are not sufficient for achieving the recovery of this type of investments by the DSO. In case that these incentives are to be generalized, it would be required to clearly define a "smart grid" in terms of what are the services it has to provide, and (in the cases in which such a fixed list of equipment exists) its architecture and components.

In particular, deploying and using smart meters can be seen as a first stage towards smart grids. Although smart meters are not considered as a technical solution by themselves, they are at least an enabler to some of the technical solutions identified within PV GRID. Where a cost-benefit analysis on the deployment of smart meters has not been carried out yet, as foreseen by the European Directive 2009/72/EC, it should be rapidly performed at national level. The consortium has also raised the potential benefits of having smart meters installed at PV plants and not only for consumers. In countries where the roll-out of smart meters has so far been focused only on consumption meters, it should be analyzed whether DG installations could also be equipped with these devices. For smart meters deployed on DG, it should be ensured that their potential is used for implementing telemetry and other applications, increasing the hosting capacity of the distribution network. However, mandatory introduction of intelligent metering systems should be assessed carefully. It may be the case that installing the required intelligent infrastructure is only viable with large PV installations.

Two other technical solutions identified are demand response by either local price signals or by market price signals. When demand response is triggered by market price signals, a global price signal for all prosumers will not allow distinguishing between the different local situations in the distribution grid. Therefore demand response by local price signals is more appropriate for grid integration issues. Technical features and market models for Demand Response should be assessed taking into account that they are related to wider objectives than the mere integration of DG. While they may have important side effects on DG hosting capacity, the main focus of Demand Response must be on the benefits on the customers' side. Market model-neutral enabling factors, such as the communication between DSO and final customers, can and should be defined as soon as possible. For instance, the "traffic light concept" as it is currently discussed throughout Europe is a good starting point. When focusing on DG integration, load activation is more useful than load interruption, although less common. DSOs should be allowed to manage load reduction and activation services in order to fully utilize any demand-side management potential. In any case, a compensation scheme for users participating voluntarily in demand response and load reduction services should be discussed and put in place.

An alternative to demand response for reducing the power flows is self-consumption. Self-consumption can bring benefits to the whole system, since it reduces the electricity that needs to be distributed or transmitted through the grid. These benefits are at their best if the overall peak power demand is reduced either globally or locally, since distribution and transmission networks have to be sized for the peak scenario. However, it has to be pointed out that self-consumption only allows reducing the local peaks to the extent that generation is encouraged to be located closer to the load points. Once the DG is installed, the physical power flows are the same regardless of the metering scheme (unless prosumer storage is installed or demand response is applied). Countries that do not have a self-consumption framework in place, should consider legislation for allowing it. In addition, economic incentives stimulating PV electricity self-consumption to contribute to network operation (reducing peaks) should be assessed.

From the PV GRID perspective, connection solutions and processes for individual PV agents can be simplified if, and only if, "dependable" self-consumption behaviour is available. In this respect, self-consumption obligations should be introduced with the aim of reducing electricity injection peaks in order to ease the grid connection and overall grid capacity requirements.

As commented, the benefits of self-consumption are at their best when the peak power demand is reduced. In order to ensure this, storage could be a rather interesting option, when the costs turn affordable for these uses. Theoretically, there could be at least two alternatives. The storage could be installed on the prosumer side or on the DSO side. Where they are currently forbidden, national regulatory frameworks should allow prosumer storage solutions. In order to avoid technical problems, the connection and operation requirements currently under discussion should ensure that prosumer storage does not pose a security problem to the system or interfere with the metering of DG production. Explicit mechanisms should be established for supporting prosumer storage solutions, when these are applied to reduce the peaks of PV installations. For the other alternative, DSO storage, there is currently an enormous barrier represented by the unbundling of activities, which prevents the DSO from using storage, as it is usually considered a market interfering activity. Although recognizing the importance of such a restriction, a solution should be found so as to allow DSOs to make use of such a technical solution. Given the network operation benefits potentially brought about by DSO storage, national regulators should reflect on how to activate this potential. Roles, rights and limitations of DSOs (and TSOs) in the use of storage must be clearly defined by the national regulating authorities.

7.3. Open Issues to explore in the Future

PV GRID has focused on identifying technical solutions to solve voltage and thermal issues in distribution networks. In the context of applying those solutions, one important aspect to be researched, defined and developed further is the overall future role of the DSO, including the coordination between DSOs and TSOs under new requirements set by high penetration of RES and DG. However, while several issues related to the role of DSOs (access to DG capabilities, Demand Response facilitation, Smart Grid functionalities, etc.) have been treated in PV GRID and have eventually given rise to recommendations, the latter has also surfaced at various points within the project, for example when discussing the EU Network Codes, but wasn't addressed in more detail as it was out of the scope of the project, and therefore needs further investigation. Another relevant topic with additional need for further work is the national implementation of EU Network Codes. In light of the new role of DSOs, it will be important to align and adapt the education and training for the DSO workforce in order to equip staff with the required competences to master the future challenges of system operations.

A detailed technical analysis, including modelling of different options, as well as a detailed cost benefit analysis focussing on the different technical solutions and the recommendations provided by PV GRID, is still to be undertaken. With the limited resources available in the project, this immense task couldn't be carried out and has to be delivered by future endeavours. In addition, it is highly recommendable to check whether the existing barrier assessment is also broadly valid for other RES technologies, such as wind.

A consistent and detailed regulatory and economic framework for using Demand Response, Storage Solutions, Metering and Smart Grids needs to be further developed, especially if the potential provided by DSO Storage should be exploited on a broader scale. The current ancillary services market design should be advanced and adjusted in order to accommodate for new products delivered by RES generators and storage devices.

8. GLOSSARY

Booster Transformer is a transformer of which one winding is intended to be connected in series with a circuit in order to alter its voltage and the other winding is an energizing winding.

Capacity of PV plant is the peak DC power as specified by the module manufacturer for standard test conditions.

Closed-Loop Operation (or Closed Ring Operation) is the method of operation where each point of a given part of a network is fed from two sources along two distinct paths.

Curtailment is a planned reduction of the power production.

Dump load is a device (usually an electric heating element) to which PV generator power flows when the grid cannot accept more feed-in power.

DSO is the abbreviation for distribution system operator

EHV is the abbreviation for extra high voltage (> 230 kV according to IEC)

Fast Voltage Deviations are defined as the variations that occur instantaneously in a network in case a generation plant suddenly disconnects.

Feeder is a power line transferring power between distribution substations and consumers.

Grid hosting capacity is the maximum DER penetration for which the power system operates satisfactorily.

Impedance is the measure of the opposition that a circuit presents to the passage of a current when a voltage is applied.

NRA is the abbreviation for National Regulatory Authority.

Meshed grid includes redundant lines, which are in addition to the main lines and organised as backups for the purpose of rerouting power in the event of failure to a main line.

On-Load-Tap-Changer (OLTC) is a device for changing the tapping connections of a winding, suitable for operation while the transformer is energised or on load.

Point of common coupling (PCC) is the point on the public electricity network at which customers are connected.

Priority access to the grid provides an assurance given to connected generators of electricity from renewable energy sources that they will be able to sell and transmit the electricity from renewable energy sources in accordance with connection rules at all times, whenever the source becomes available. In the event that the electricity from renewable energy sources is integrated into the spot market, guaranteed access ensures that all electricity sold and supported obtains access to the grid, allowing the use of a maximum amount of electricity from renewable energy sources from installations connected to the grid." (Directive 2009/28/EC on the promotion of the use of energy from renewable sources).

R/X is the ratio resistance divided by reactance for a power line.

RES is the abbreviation for renewable energy source

Slow Voltage Deviations are defined as the variations which occur in voltage during normal operation, due to the behaviour of generation and load connected to a given network.

Static VAR Compensator (SVC) is an electrical device which provides fast-acting reactive power in an electrical network under various system conditions.

Supervisory control and data acquisition (SCADA) usually refers to centralised systems which monitor and control entire sites, or complexes of systems spread out over large areas (anything from an industrial plant to a nation).

TSO is the abbreviation for transmission system operator.

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10. ANNEXES

Annex I offers a deeper analysis for the four PV GRID focus countries: Germany, Italy, Czech Republic and Spain.

Annex II offers a deeper analysis of 4 additional countries: France, United Kingdom, Greece and the Netherlands.

Annex III offers an overview of the national barriers assessment process and its results that was carried out in all 15 countries participating in PV GRID.

All Annexes are available at: http://www.pvgrid.eu/results-and-publications.html.

PV GRID

Reducing barriers to large-scale integration of pv electricity into the distribution grid

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