Assessing, monitoring and future proofing European grids[1]: Increasing transparency on the performance of electrical grids within the framework of the European Green Deal

Reflection Paper by T&D Europe

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[1] Formerly titled “A smartness indicator for grids”, renamed because of broadening the concept.

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1. Introduction: Why monitoring and assessing grids in a Green Deal equation?

For many years the European Union has been committed to the reduction of carbon dioxide emissions and to increasing the share of renewable energies in its energy mix. An important milestone in this long process of legislative initiatives is the package Clean Energy for all Europeans proposed by the European Commission in November 2016.

From 2020, we must look at how we produce, transport, distribute and use energy within the framework of the European Green Deal. Electricity networks are the backbone of Europe's energy system. Electricity has become an essential and critical resource of the daily life of Europeans. A temporary or prolonged disruption in our electricity supply touches virtually every part of our society and economy. Without electricity, everyday life is severily disrupted, creating massive impacts on essential services such as transportation, water and food supply, communications, security and health services. Given its criticality, the EU has designated electricity generation and transmission as European critical infrastructure[2].

As we move on from traditional energy systems, new, smarter solutions will be required to manage the changing generation mix, whilst maintaining affordability and ensuring security of supply. This means that not only the generation sector has to undergo a fundamental transformation, but that we also need to future-proof the European transmission and distribution network and improve its resilience by ensuring the quality of service and the continuity of supply under different circumstances. Digitalisation is one of the key enablers for a successful energy transition towards a carbon emission free energy supply and data sharing will be one of the key prerequisites to make the energy system ready for the decarbonized future. This must be accompanied with a robust, effective and agile cybersecurity approach.

Electricity grids connect and coordinate all elements of power systems to serve their end users. Grids will play a crucial role in facilitating and enabling the energy transition to incorporate increasing levels of distributed generation, changing demand patterns and the implementation of new technology and solutions. As we move on from traditional energy systems, new, smarter solutions will be required in order to manage the changing generation mix, whilst maintaining affordability and ensuring security of supply. This means that not only the generation sector will have to undergo a fundamental transformation, but also the grids will have to change and develop accordingly in order to ensure value for money, a successful transition and to deliver value and quality of supply to consumers.

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[2] COUNCIL DIRECTIVE 2008/114/EC of 8 December 2008 on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection

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Moreover electricity grids are long-term investments. We expect grid components to be in place, serving their purpose in good quality over several decades. Europe's electricity grids have a particular ageing structure, as they are all originating from the time after World War II. Therefore many of their components are close to end of their life time. Steady re-investments are very important in such situation to avoid reduction of reliability of supply because of synchronous failures of outdated equipment in future.

Both aspects can be summarised under the umbrella "state of the grid": On one side this term addresses the state of existing installations as a basis of reliability of supply in future and on the other side it addresses the future preparedness of grids in a transitional period resulting in new tasks and challenges.

Today's regulation does not reflect neither of these two topics. Regulation is primarily or in many cases even exclusively focusing on cost-efficiency of the grids and quality of supply. These output-oriented criteria are reflecting today's tasks of the grids and their current solution. They do not reflect the technical quality of grids nor do they address the preparedness for changes of these tasks resulting from the energy transition. Thus, today's regulatory schemes do not reflect the active contribution of grids to a successful (including cost-efficient) energy transition. There is a need to broaden this regulatory view on electricity grids in two directions:

- **Monitoring the current state of the grid:** In addition to measuring the current quality of service a monitoring process for the technical state of grids is needed. Its main purpose is ensuring continuous re-investments and avoiding accumulation of outdated equipment. Infrastructures can be operated over a long time with insufficient investments while maintaining quality of service, but beyond a tipping point quality of service may collapse and it takes a long time to restore it in such situation. A pragmatic approach for monitoring the technical state of grids would be looking at the age distribution of grid components. This part of monitoring the state of grids will not be elaborated in this paper, but it should be acknowledged as integral part of the proposed approach nevertheless.

- **Monitoring the future preparedness:** This part is by far the more difficult one, as it somehow requires monitoring and regulating an unknown future, based on the fact that all new developments are connected to the grid (electric mobility, all types of distributed energy resources (DER), storage etc), and this X-to-Grid brings uncertainty to the electrical network, and may fragilize it from the transmission and distribution angle or from the "last mile" perspective. However, as explained already, there is a need of a continuous and structured discussion on what needs to be done in order to make today's investments in grids as future-proof as possible. Ideas on realising this additional element of regulation are the main subject of this paper. Moreover, all

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future investments have to be viewed and assessed within the framework of an increasingly circular economy approach.

Expert Group 4 (EG4, Smart Grid Infrastructure Deployment) within the Commission's Task Force Smart Grid has dealt with the second of these extensions of regulatory schemes regarding projects proposed under the framework of Projects of Common Interest (PCI). A more detailed discussion how the framework for assessing projects proposed by this expert group[3] is linked to the approach proposed in this paper is subject of a separate chapter at the end of this document. What can be summarised here is, that the assessment proposed by EG4 is addressing projects to be built. Our proposal is complementing this by monitoring the status of smart grid deployment in the installed base. In addition, it covers all investments in grids outside the scope of PCI. We propose the introduction of grid smartness monitoring process as an additional element of regulation schemes for the grids. This new methodology would create transparency on the transition to smarter grids in Europe, increase the awareness of smart technologies and their potential and promote the use of best practices. By doing so it is expected to help Member States investing to reach their emissions reduction and energy efficiency targets while incentivising investments in innovative technologies. While our proposal is focussing on innovative solutions, it is important to keep in mind, that it is primarily addressing new functionalities expected to be required in future. Different from that, innovative solutions can also help improving present performance of grids. Improving the regulatory framework with this regard is not subject of our proposal. The impact of the regulatory schemes on innovation in European grids as a means for performance improvement has been analysed for instance in a study for the European Commission published in March 2019[4].

Introducing such a smartness monitoring process requires using the knowledge of all relevant stakeholder groups. T&D Europe therefore has drafted a first set of ideas on how such an indicator could be created. This is presented by this paper, which we propose to serve as a starting point for a development process to be launched by the European Commission and involving the relevant stakeholder groups. These should at least include grid operators, grid users (generators and consumers) and regulators.

3 Definition of an Assessment Framework for Projects of Common Interest in the Field of Smart Grids under the EC 'Proposal for a regulation of the European Parliament and of the Council on guidelines for trans-European energy infrastructure and repealing Decision No 1364/2006/EC' (COM(2011) 658), Brussels, July 2012

4 Do current regulatory frameworks in the EU support innovation and security of supply in electricity and gas infrastructure? Final report, European Union, ISBN: 978-92-76-03384-4, 2018

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2. What should Grid Smartness Monitoring address and what does this mean?

2.1 Objective of the Green Deal monitoring smartness indicators of grids

The Grid Smartness Monitoring Process should provide information on the ability of a grid to serve its purpose in a changing environment. Traditionally there has been a triangle of expectations on power systems and on grids as an integral part of them. They should ensure cost-efficient, reliable and sustainable provision of electrical energy.

These three expectations are still in place, but they are applied in a different environment today.

Monitoring the smartness should therefore reflect the ability of the grid to enable the entire power system to ensure cost-effectiveness whilst supporting the energy transition and security of supply as well as the participation for all users known today and in the future (e.g. generators, consumers, prosumers, aggregators, etc.).

2.2 Breakdown of the objective and the expectations on grids

Although expectations on power systems and grids seem to be the same as in the past from an end user point of view, the conclusions may be different in the context of the energy transition. This chapter therefore discusses the different elements of the objective more in detail.

Cost-effectiveness, **support of the energy transition and security of supply** are representing the traditional triangle of requirements, with the energy transition covering sustainability and security of supply addressing reliability and resilience.

However, **cost-effectiveness** in the context of the energy transition translates into other challenges and solutions than in traditional power systems. Wind and solar power as well as new types of load, in particular EV charging infrastructures, are rapidly evolving and are challenging the grids with high and rare peaks. Traditional design of the grid based on the peak load would result in decreasing utilisation due to changing demand patterns and projected increases in peak demand affected directly by consumer charging behaviour. Deferring investments in primary equipment and reinforcement by smarter operation of the grids therefore gains importance.

Future investments need to be assessed regarding their contribution to a more circular economy and their carbon footprint all over their life cycle.

Some examples of smarter operation are:

a) Dynamic loading of components

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b) Increased ability to accommodate DER (generation and new types of load, such as EV charging infrastructures) by dynamic voltage control

c) Reasonable curtailment of rare peaks of RES feed-in or load - such as Active Network Management

d) Advanced asset health management, for a better life cycle management

e) Minimization of fuel and carbon cost of conventional generation by maximizing accommodation of renewables - increasing network capacity and headroom using smart techniques such as reactive power compensation

Examples for equipping and using the grids for supporting **sustainability and the energy transition** are:

a) Loss reduction by increasing energy-efficiency of the grids

b) Accommodating increasing levels of renewable generation

c) Support of electrification of new sectors based on sector coupling optimisation, e.g. electric vehicles (EV) charging and heat

d) Optimization of the grid load at all voltage levels including phase balancing, to increase the energy efficiency of the grid

e) Circular economy offers, based on end of-life management, recycling, for instance

f) Greener components, e.g. more efficient transformers or SF_6 free switchgear, to contribute to climate neutrality of networks

Ensuring **security and quality of supply as well as resilience** of the system has become a quite different and much more challenging task in an environment with much more stochastic, volatile processes and significantly increased complexity due to highly distributed, active resources both on generation and consumption side.

Examples for approaches for the grid to more effectively manage this are:

a) Advanced planning procedures and tools, reflecting distributed resources and new loads, in particular EV charging infrastructures, and consideration of operational measures (e.g. peak shaving) when assessing and planning the infrastructure.

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b) Advanced asset management, reflecting condition and importance of assets and ensuring that critical components are identified and prioritised: Such approaches are becoming more relevant in a rapidly evolving environment, in which grid enforcements and extension have to be implemented much faster than in the traditional, quite stable European environment. Prioritization of limited investment and maintenance resources is a key success factor under such circumstances. Future asset management has also to consider a circular economy framework and end of life management and recyclability.

c) Real-time dynamic security assessment on transmission level: Historically, the European interconnected power system has been engineered to share reserves and to allow portfolio optimisation in a regionally balanced power system. Additionally, the majority of generation was provided by large rotating machines, stabilizing the grid by their mechanically inertia. Today, with increasing regional imbalances caused by geographically constrained sources of renewable energy mainly connected via power electronics, the pan-European transmission grids are facing a fundamentally different task. The traditional way of operating the systems with strong focus on preventing emergencies and much less attention on curing such efficiently, which resulted in high reserve capacities in the transmission grid, is not adequate for this task any more. Instead, more real-time monitoring and network management should be applied to ensure best utilisation of the infrastructure, while at the same time maintaining security of supply. In doing so, also new grid elements based on power electronics need to be considered.

d) Self-healing or re-configuring distribution networks: Rapidly changing load situations caused by volatile distributed generation are requiring more operational flexibility even in the secondary distribution level, which traditionally has not been controlled or monitored. This will contribute bot to the ability of networks to accommodate production from distributed sources and reliability of supply for citizens.

e) Fast outage clearing: Reliability of supply can be improved not only by avoiding outages, but also by shortening the time of interruption of supply. Increased application of remote control and monitoring can support this and at the same time even lower costs.

f) Increased resilience provided by on-grid micro- or nanogrids: Distributed generation, if equipped with adequate microgrid controllers, can run independent from the grid in case of regional or system-wide blackouts. Using this opportunity given by distributed generation would reduce the negative impacts of such blackouts significantly.

g) Demand response programmes helping to avoid critical situations: Such programmes may help to balance load and generation, they may help accommodating renewable generation, but they may also give relief to the grids in critical situation, and help the grid to manage changing demand patters and increasing connected loads in a more effective and efficient way.

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h) Cyber security assessments: All the items above imply the use of more digital control and communication technologies. Moreover, integrating and coordinating highly distributed resources means a quantitatively much broader exposure of the system to cyber crime. Cyber security and cyber security assessments are therefore crucial for ensuring security of supply in future power systems.

Empowerment of all types of users of the grids and letting them participate more actively is a new, additional requirement complementing the traditional triangle. An important pre-requisite for such participation is transparency of the user's influence on the service received and on the system, both for the user and for service providers. Examples for implementation are:

a) Smart metering infrastructure and services providing information to users and grid operators

b) Time-of-use tariffs (enabled by time-based metering or smart meters)

c) Differentiation between applications with guaranteed supply and such, which may be switched off under certain conditions and get another (cheaper) tariff therefore

d) Facilitation of participation of all players - even very small ones - in markets by efficient and functional regulation for registration, qualification and settlement

e) Allowance for the grid operator to use reasonable curtailment of rare peaks as an alternative to grid extension based on economic decisions

There are two more elements in the objective summarised earlier, which suggest a broadening of the traditional triangle of requirements and a need for different solutions in future than in the past: The first is the requirement to serve all types of users of the grids. In addition to the classical users – bulk power plants and passive consumers – this addresses for instance distributed generators, prosumers and new service providers, such as aggregators. The second is to be accessible to all of these new users known already today, but also to those that may evolve in future and are not known yet. This accessibility requires concepts that are capable of evolution and adaptation. Digitalisation, if properly applied, can be expected to be a key enabler to address this requirement.

3. First ideas on monitoring smartness Indicators of grids

3.1 The general concept

A Grid Smartness Monitoring process addressing the objective as outlined in the previous chapter would ideally deliver figures clearly measuring the contribution of a particular grid to

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the energy transition, e. g. by quantifying accommodated renewable generation, utilisation of assets, reliability of supply or curtailed generation from renewables. However, these outcomes will not only depend on the smartness of the grid, but at least as much on its structure inherited from the past, the situation of load and generation and many other factors.

Therefore, we propose another view: Monitoring the smartness of grids should reflect the feasibility that a grid is prepared to support the objective defined above. It should not be a precise measurement of what a particular grid is delivering by using smart technologies and solutions. With other words: We propose to measure the capabilities of the grids do deal with tasks, which may evolve in future, and not their current performance. Therefore, it may be sufficient to accumulate obviously supportive technologies weighted based on their role out in the grid or availability to the grid user, without the need for quantifying their contribution in a particular grid. This makes the process simple, robust – and will always allow the addition of new solutions in the future.

It should also be noted that there is not a one and only smart grid. Differences in the geographical structure of load and generation as well as different combinations of technologies and solutions may result in grids equally serving the requirements, although being quite differently equipped. This also means that some of the solutions proposed to be monitored may be overlapping, defining more a menu of alternatives than one consistent set of complementary solutions. This implies that not all monitored solutions need to be in place in a certain grid to make it smart.

We therefore understand the proposed monitoring process as a principle defining a general direction of development but leaving freedom for its users (e.g. regulators) to be adopted to national requirements and to support national goals. With other word: We are not asking for the same path for all, but for a common direction with local freedom.

Looking at technologies and solutions to be monitored, we propose to structure them in three technological groups:

I. **Smart grid infrastructure** (field devices, remote monitoring and control): Assuming that a common denominator of most, if not all smart solutions is to operate grids in a more precise and adaptive manner, getting information from the field and being able to control the grid remotely is a pre-requisite for increased smartness. This would be reflected by this first group: a smart grid infrastructure that supports cost-efficiency as well as reliability and - by increasing the capability to accommodate RES generation – sustainability. Moreover, smart devices at the edge of the grid are the basis for all types of new consumer-oriented services and for consumer empowerment.

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II. **Smart grid functions** (operational features on network level, software):
Using information provided by the infrastructure addressed by the first group is the second building block of smart grids, which contains primarily out of software functions applied on network level – either on parts of a network, such as lines (i.e. underground cables, overhead lines, gas insulated lines), or to entire grids.

III. **Smart actuators** - new non-conventional components to operate the network:
Combining the first two groups means to operate conventionally equipped grids with more monitoring and remote control more smartly. This is an important first step towards smart grids. However, there are more opportunities if non-conventional elements are added, allowing faster adaptation of the grid to new situations and by that to increase utilisation without reducing reliability of supply. Such solutions are frequently based on power electronics.

3.2 Technologies and solutions contributing to the three areas of smartening grids

3.2.1 Smart grid infrastructure

Examples of technologies and solutions representing the smart grid infrastructure are listed in the following table. The two right columns are indicating the areas of impact: Some solutions are relevant for the transmission level, others for the distribution level and some for both. Moreover, some are contributing to improved operation of the grids, while others are supporting consumer services and engagement. However, it should be recognized that advanced network operation in general is expected to improve the service quality for consumers, meaning that in the end all of the listed solutions are consumer oriented.

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Examples	T/D[5]	g/c[6]
Percentage of substations remotely monitored and controlled in real-time, itemised as transmission, HV/MV and MV/LV substations	T, D	g
Percentage of substations ready for predictive maintenance, itemised as before	T, D	g
Percentage of energy efficient transformers	(T), D	g
Percentage of underground and overhead lines remotely monitored in real-time, itemised as HV, MV and LV	T, D	g
Percentage of underground lines ready for predictive maintenance, itemised as before	T, D	g
Percentage of LV lines with efficiency monitoring (phase imbalance detection)	D	g
Percentage of smart meters installed (supporting transparency and time-of-use tariffs)	D	c
Percentage of smart meters with building automation gateways installed (supporting remotely controlled flexibility)	D	c, g
Percentage of the grid connected to smart buildings (according to the Smartness indicator for buildings)	D	c

3.2.2 Smart grid functions

Smart grid functions are complementary modules to the smart grid infrastructure, these help to manage grid planning, operation and maintenance more effectively and efficiently.

[5] T: transmission (extra-high/high voltage, EHV/HV), D: distribution (high, medium and low voltage, HV/MV/LV)

[6] g: supporting grid operation, c: supporting consumer services

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Examples	T/D	g/c
Percentage of the number of underground and overhead lines operated under dynamic line ratings	T	g
Asset health monitoring, supporting controlled, temporary overloading	T, D	g
Percentage of networks prepared by local automation for remote reconfiguration through advanced distribution management systems	D	g
Number of micro- or nanogrids being able to operate autonomously during grid outages	D	c
Use of real-time dynamic security assessment on transmission level	T	g
Flow-based allocation of interconnector capacity in market processes	T	g
Share of load under demand response programmes	T, D	c
…		
…		

3.2.3 Smart actuators - new non-conventional components to operate the network

Traditional grid operation focusses primarily on prevention of critical situations rather than curing them. As a consequence, most of the active grid elements, such as transformers, are not prepared to influence load-flow quickly, resulting in the need of reserving significant grid capacity as reserve for emergency situations. In truly smart grids this approach needs to be challenged. Non-conventional (but in many cases already proven) components can support this.

Examples	T/D	g/c
HVDC lines embedded into the AC grid being able to influence load flow	T	g
Fast (i.e. power electronics based) FACTS, optionally including storage	T, (D)	g
Smart distribution transformers with actuators or other equipment for distribution voltage control (e.g. line voltage regulators)	D	g
..		

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3.3 Contribution of smart solutions to enabling grids to serve their purpose

Smart technologies and solution have been grouped using technical categories in the previous sections in order to reflect the technical structure of a grid. Doing so ensured that each solution could be counted only once. However, eventually it is also important to understand, to which of the objectives of a grid discussed in the chapter before the different solutions can contribute. The following table therefore maps solutions to objectives.

Smart technology or solution	**Cost-effectiveness**	**Energy transition**	**Security of supply**	**Empowerment**
Smart grid infrastructure				
Percentage of substations remotely monitored and controlled in real-time, itemised as transmission, HV/MV and MV/LV substations	•	•	•	
Percentage of substations ready for predictive maintenance, itemised as before	•			
Percentage of energy efficient transformers	•	•		
Percentage of underground and overhead lines remotely monitored in real time itemised as HV, MV and LV	•	•	•	
Percentage of underground lines ready for predictive maintenance, itemised as before	•		•	
Percentage of LV lines with efficiency monitoring (phase imbalance detection)	•	•		
Percentage of smart meters installed		•		•
Percentage of smart meters with building automation gateways installed		•	•	•
Percentage of the grid connected to smart buildings (according to the Smartness indicator for buildings)	•	•		•
Smart grid functions				
Percentage of number of underground and overhead lines operated under dynamic line ratings	•	•	•	
Asset health monitoring, supporting controlled, temporary overloading	•	•	•	
Percentage of networks prepared by local automation for remote reconfiguration through advanced distribution management systems		•		
Number of micro- or nanogrids being able to operate autonomously during grid outages			•	•
Use of real-time dynamic security assessment on transmission level	•	•	•	
Flow-based allocation of interconnector capacity	•	•		
Share of load under demand response programmes	•	•		•

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Smart technology or solution	**Cost-effec-tiveness**	**Energy transition**	**Security of supply**	**Empower-ment**
Smart actuators				
HVDC lines embedded into the AC grid being able to influence load flow		•	•	
Fast (i.e. power electronics based) FACTS, optionally including storage		•	•	
Smart distribution transformers with actuators or other equipment for distribution voltage control (e.g. line voltage regulators)	•			

4. Links between monitoring the smartness of grids and other initiatives

4.1 Link between smart grids and smart buildings

In the Energy Performance of Buildings Directive (EPBD) the European Commission has proposed to develop a Smartness Indicator for Buildings. Such indicator shall reflect the ability of buildings to

a) Adjust to the needs of the user and empower building occupants providing information on operational energy consumption (complementing the energy performance information provided in the EPCs);

b) Ensure efficient and comfortable building operation, signal when systems need maintenance or repair; and

c) Readiness of the building to participate in demand response, charge electric vehicles and host energy storage systems.

In particular the first and the third bullet points address topics related to electricity consumption. These need to be reflected and supported by the grid infrastructure accordingly. There is a fundamental link between smart buildings and the grid they are connected to. Smart buildings can only deploy their potential if they are connected to a smart grid to ensure the building and its residents participate in the energy flexibility by mechanisms such as DSR, time of use tariffs and new energy services.

The smartness indicator for buildings, as currently being developed in the framework of the revision of the Energy Performance of Buildings Directive, therefore needs to be consistent with the smartness provided by grids and monitored as proposed in this paper. We believe the

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connection to a grid with (smart) digital functionalities should form an integral part of the buildings indicator. In the same spirit, the existence of smart buildings connected to the grid is reflected by our proposal of monitoring the smartness of grids as buildings play an important role as load and energy resources for the grid.

4.2 Complementarity with the assessment framework for Projects of Common Interest in the Field of Smart Grids

In July 2012 Expert Group 4 (Smart Grid Infrastructure Deployment) of the Task Force Smart Grids of the European Commission finished its work by proposing an assessment framework for Projects of Common Interest with regard to using smart grid solutions[7]. The following table is listing the requirements for the assessment worked out by this group.

Smart grid project evaluation criteria	Assessment tool
1) Fulfil minimum technical requirements	Checklist
2)Contribute significantly to the specific target functions defined in Article 4.2.c (of the report of EG1[8] of the Commision Task Force)	Evaluation against six policy criteria: key performance indicators (KPI) and corresponding metrics
3) Benefits outweigh costs	Cost-benefit analysis (CBA) and qualitative impact analysis of additional impacts that cannot be reliably monetized

Analysing these requirements very clearly shows an important different between the assessment framework proposed in the report of EG4 and the indicator proposed in this document. The assessment framework is meant to give decision support for individual projects to be implemented. Therefore, it is focussing on measuring the particular benefit provided by each individual project. By doing so it is assessing the performance of a planned project.

In difference to that, monitoring the smartness of grids shall not measure the current performance of the installed base, but instead give an indication on the capabilities of the grid to deal with future challenges. Therefore, it is not even trying to assess the impact of installed solutions in a particular environment. Nevertheless, when selecting the smart grid solutions and functions to be monitored, a thorough analysis is required, why it can be assumed that these technologies are able to contribute to requirements on grids. This analysis should be

7 Definition of an Assessment Framework for Projects of Common Interest in the Field of Smart Grids under the EC 'Proposal for a regulation of the European Parliament and of the Council on guidelines for trans-European energy infrastructure and repealing Decision No 1364/2006/EC' (COM(2011) 658), Brussels, July 2012

8 European Commission Task Force for Smart Grids, 2010. "Expert Group 1: Functionalities of smart grid and smart meters", available from http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/expert_group1.pdf

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consistent with the KPI and methods proposed by EG4 in order to make the two approaches truly complementary.

In its report, the expert group has introduced six smart grid functions and related key performance indicators (KPI). These are listed in the table below and discussed with regard to the smartness indictor for grids as proposed in this paper.

Key performance indicator as introduced in the assessment framework for PCI	Relation to monitoring the smartness of grids
Level of sustainability	Sustainability is explicitly mentioned as one of the objectives to be supported by electricity grids. The contribution to this objective of each solution proposed to be monitored is analysed and indicated.
1) Reduction of greenhouse emissions	This is addressed both by increasing the energy efficiency of the grid infrastructure itself and by facilitating accommodation generation from renewables and all types of services helping to increase energy efficiency on the consumer side.
2) Environmental impact of electricity grid infrastructure	There is not much focus on this KPI yet, this should be added in a future step.
Capacity of transmission and distribution grids to connect and bring electricity from and to users	
1) Installed capacity of distributed energy resources in distribution networks	As monitoring the smartness is expected to give an indication of the capability of a grid to deal with situations that may occur in future, the current situation is less relevant and thus not reflected.
2) Allowable maximum injection of electricity without congestion risks in transmission networks	This task is explicitly mentioned in the analysis, why which solutions are supportive for the overall objectives (in this case both sustainability and overall cost-efficiency).
3) Energy not withdrawn from renewable sources due to congestion or security risks	Same as before. As monitoring the smartness is not performance based, it cannot refer to the current performance, but It does address, which solutions proposed to be monitored will support this KPI.

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Key performance indicator as introduced in the assessment framework for PCI	Relation to monitoring the smartness of grids
Network connectivity and access to all categories of network users	Openness to all types of known and future users of the grid is the core justification for the proposal of the new smartness monitoring process.
1) Methods adopted to calculate charges and tariffs, as well as their structure, for generators, consumers and those that do both	The issue of network tariffs is not in the focus of the smartness monitoring proposal but mentioned. In any case, a smart metering infrastructure and demand response programmes are listed as solutions to be monitored. Both are technical pre-requisites for this KPI.
2) Operational flexibility provi-ded for dynamic balancing of electricity in the network	This is clearly addressed by the solutions listed both in the smart grid infrastructure and in the smart grid functions sections.
Security and quality of supply	Security and quality is acknowledged as one of the three main objectives for electricity supply.
1) Ratio of reliably available generation capacity and peak demand	As the intention of monitoring the smartness of grids is to get indications on the preparedness of grids, a KPI addressing assets outside the grid naturally cannot be considered.
2) Share of electricity generated from renewable sources	Same as before.
3) Stability of the electricity system	For all solutions listed in the current proposal their contribution to reliability and quality of supply is discussed, System stability is one item covered by that.
4) Duration and frequency of interruptions per customer, including climate related disruptions	As the monitoring process is not performance based, it can only discuss how solutions can help improving this KIP (and does so).
5) Voltage quality performance	Same as before – solutions to improve voltage quality are listed, the issue is addressed.

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Key performance indicator as introduced in the assessment framework for PCI	**Relation to monitoring the smartness of grids**
Efficiency and service quality in electricity supply and grid operation	Efficiency and service quality are not explicitly mentioned, but implicitly addressed by sustainability and consumer empowerment.
1) Level of losses in transmission and distribution networks	Energy efficient components (and also ways to structure and operate grids most efficiently) are covered by the monitoring process. I addition, we also need to be aware of indirect contributions of grids to overall efficiency.
2) Ratio between minimum and maximum electricity demand with in a defined time period	Cannot be addressed by the monitoring process, as it is not specific to the grid itself – it is part of the task the grid is facing.
3) Demand side participation in electricity markets and in energy efficiency measures	Presence of demand side programmes is proposed to be monitored.
4) Percentage utilisation (i.e. average loading) of electricity network components	As this is a performance based indicator, it cannot be directly linked to the proposed smartness monitoring. However, many of the solutions listed there are expected to help operating assets closer to their limits without threatening reliability of supply.
5) Availability of network components (related to planned and unplanned maintenance) and its impact on network performances	Not directly addressed (but maybe indirectly by asset health monitoring).
6) Actual availability of network capacity with respect to its standard value	Same as under KPI number four in this section.

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Key performance indicator as introduced in the assessment framework for PCI	Relation to monitoring the smartness of grids
Contribution to cross-border electricity markets by load-flow control to alleviate loop-flows and increase interconnection capacities	This section seems to be very strongly linked to transmission network development and PCI resulting from the TYNDP. The smartness monitoring process is not focussing on such particular part of the grid. However, the report of the Commission Expert Group on electricity interconnection targets[9], published on November 9, 2017, is addressing this issue and is proposing a monitoring process for interconnectors in order to trigger decisions on additional interconnector capacity. This approach is very similar to the concept of monitoring the smartness, as it creates transparency on the current situation in order to trigger more detailed analysis.
1) Ratio between interconnecttion capacity of a Member State and its electricity demand	The report of the Commission Expert Group proposes to complement this by a similar indicator considering installed capacity of renewable generation, reflecting that high installed RES capacities result in a need of temporary exports.
2) Exploitation of interconnection capacities	Highlighted in the report of the Expert Group as well.
3) Congestion rents across interconnections	The Expert Groups requests a positive CBA as condition sine qua non.

Summarising the detailed comparison of the key performance indicators defined in the report of EG4 as assessment framework for Projects of Common Interest with the objectives, which solutions listed under the newly proposed Smartness Monitoring for (existing) grids are expected to support, it can be sad, that there are no conflicts and gaps between the two approaches. There is, of course, a principal difference in the approach: As the assessment framework is expected to support decisions on individual projects, it is focussing on the forecasted performance of these. Smartness Monitoring on the other side shall increase transparency on the capabilities of existing grids to support objectives – the same objectives

9 Towards a sustainable and integrated Europe. Report of the Commission Expert Group on electricity interconnection targets, Brussels, November 2017

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as behind the PCI assessment framework. This transparency shall result in in-depth analysis of possible differences between grids and may eventually result in investment proposals.

With this consistency in the objectives and the methodological difference resulting from the need of decision-making on one side and the objective to increase transparency on the status quo on the other side the two approaches are perfectly complementary.

To complete this picture, the recently published report of the Commission Expert Group on electricity interconnection targets, “Towards a sustainable and integrated Europe”, should also be referred to. In this report the experts are proposing to replace the interconnection target of 15% of installed generation capacity by a monitoring process assessing the existing interconnection capacity and triggering further, more detailed analysis on need for enforcement in case the indicator is below certain thresholds. Eventually this process will lead to new proposals for Projects of Common Interest, which then are subject to the assessment as proposed by the report of Expert Group 4 of the Commission Task Force Smart Grids.

This means that both monitoring the smartness of grids and the interconnection targets process are monitoring and analysing the status quo in order to identify future needs. After having translated these into concrete project proposals, these will either be assessed by the method proposed by EG4 (in case of Projects of Common Interest) or within the regulatory frameworks of the Member States.

4.3 Consistency with the Toolbox for Electricity DSOs

On February 27, 2018 the four trade associations representing DSOs in European policies, CEDEC, EDSO, Eurelectric and GEODE, presented a toolkit for DSOs to adapt to energy flexibility[10]. This toolkit lists various means to enhance the ability of DSOs to provide flexibility in order to deal with the increasing volatility caused by increasing shares of distributed generation and new types of load, e.g. charging infrastructures for electric vehicles.

The toolkit presents a comprehensive overview of options DSOs have in order to provide the required flexibility to the system. They are clustered in five main groups:

a) Enabling technologies

b) Tariff solutions

c) Connection agreement solutions

[10] Flexibility in the Energy Transition. A Toolbox for Electricity DSOs. CEDEC, EDSO, Eurelectric, GEODE, Brussels, February 2018

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d) Rules based solutions

e) Market based solutions

Monitoring he smartness of grids is meant to analyse the technical preparedness of grids to support evolving future tasks primarily caused by changes in the context of the energy transition. The DSO toolkit addresses the same changes. Therefore it can be assumed that conclusions should be similar, at least as far as technical aspects are concerned. Among the five groups identified by the DSO associations this applies for the first one, enabling technologies, but not for the other four, as these are dealing with DSO processes and business environment. The following table is taken from the DSO toolkit report (table 1, page 23) and extended by an additional column discussing links to monitoring the smartness of grids as proposed in this paper.

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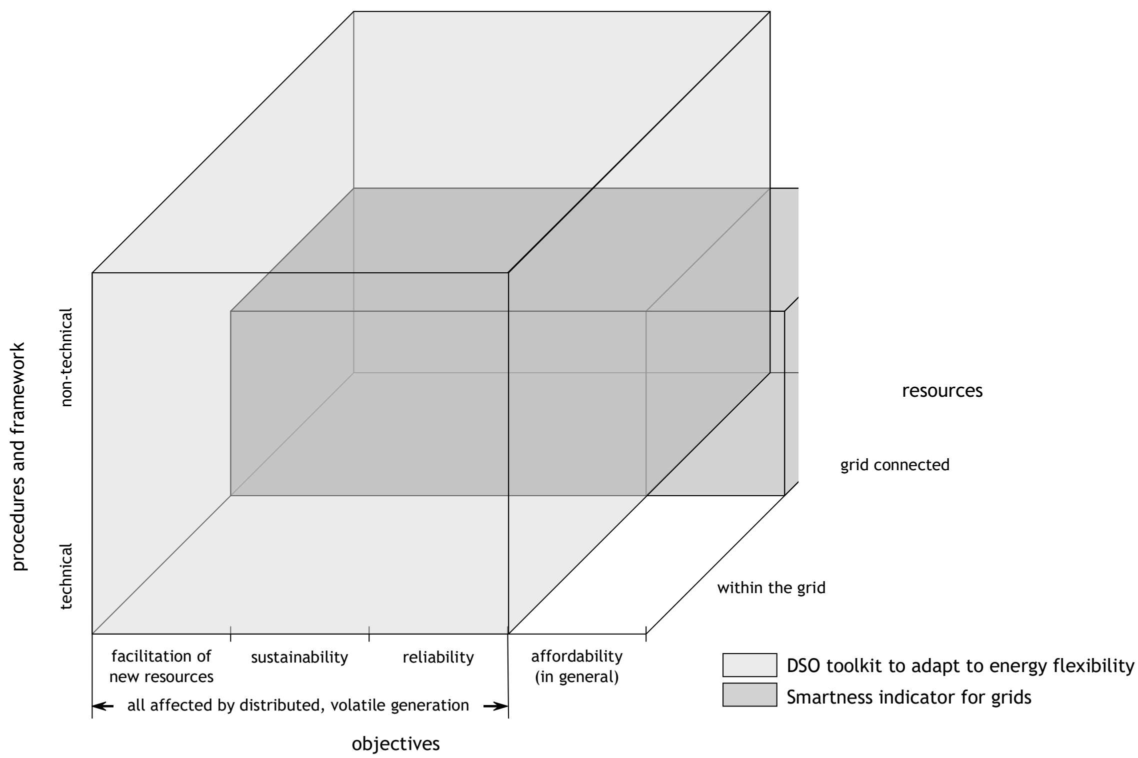
Category	Technology	Voltage	Current	Reactive power	Link to smartness indicator
Core IT components	Metering/sensors	basic requirement			This group is similar to the technological group “smart grid infrastructure” proposed as part of smartness monitoring.
	Communication				
	Control center (SCADA)				
	Database				
Local smart components	Adjustable local grid transformers	X			This group can be linked to the technological group “smart actuators” of smartness monitoring.
	MV-on-load tap changer	X			
	Reactive power compensation unit			X	
	Battery storage	X	X		
Advanced smart grid control	Agent based intelligent P-Control	X	X		Although the title of this section suggests to be close to “smart grid functions”, the examples given here are a mix of field devices and control functions.
	Wide area control for transformer stations	X			
	Steady State transformers	X			
	Q-Control based on FACTS	X		X	
	Low Impact Operation Mode	X			

Source: First five columns: Toolkit for DSOs to adapt to energy flexibility[11]; last column: T&D Europe

Before discussing the conclusions from this table, it should be acknowledged, that the objectives of monitoring the smartness of grids and the DSO toolkit are not identical. Monitoring the smartness of grids is meant as a means to monitor and discuss grid technologies supporting network operators – both in distribution and transmission – to meet all the expectations on grids, i. e. facilitating affordable, reliable and sustainable power to all people while at the same time allowing all types of known and future resources to be connected to the grid. The DSO toolkit on the other side is focussing on all types of solutions, processes or elements of the legal and regulatory framework of DSOs supporting them in providing the flexibility required to deal with more distributed and volatile resources connected to their

[11] Flexibility in the Energy Transition. A Toolbox for Electricity DSOs. CEDEC, EDSO, Eurelectric, GEODE, Brussels, February 2018

grids. The intersection of both objectives are technical solutions within the grids helping DSOs to deal with new types of assets. Neither components outside the grids nor non-technical solutions are part of this intersection. Moreover solutions primarily improving economic efficiency, e. g. by improved asset management, are not in the focus of the DSO toolkit, but they are a core element of the smartness indicator. The following graph illustrates this relationship between the two approaches in the area of power distribution.



Based in this initial analysis the three categories being defined within the DSO toolbox approach and listed in the table above can be discussed with regard to monitoring the smartness of grids:

a) **Core IT components:** This category covers smart metering, communication infrastructure, databases and SCADA and is declared to be the basic requirement for all types of (new) flexibility. There is some similarity to the technological group "smart grid infrastructure" introduced in the smartness indicator concept. However, the DSO toolkit focusses on the entire IT infrastructure here, including SCADA systems, which are not explicitly mentioned in the smartness monitoring concept as they are assumed to be standard. At that point it has to be mentioned that there is one more difference between the smartness monitoring concept, which intends to identify new solutions only, and the DSO toolbox, which wants to give the full picture of tools helping DSOs to realize flexibility.

b) **Local smart components:** In this category the DSO toolbox focusses – in difference to the first one – on non-conventional solutions only. Therefore this group of solutions is the one closest to one of the groups defined within the smartness monitoring concept, namely the one called "smart actuators". In principle the listed solutions are very similar, with the exception of battery storage, which is part of the DSO toolkit, but only mentioned as an optional extension of FACTS in the smartness indicator. This difference is motived by the stronger focus on solutions within the grids (i. e. without active power contribution) in the smartness monitoring approach.

c) **Advanced smart grid control:** This category is again, like the first one, a mix of non-conventional grid components and solutions supporting advanced grid operation, which are covered by the technological group "smart grid functions" in the smartness monitoring paper. However, the focus of operational solutions is more on local operating principles. With the exception of FACTS all the solutions listed in this group of the DSO toolkit have not been explicitly mentioned in the smartness monitoring concept but could be easily added.

In addition to the technologies listed as part of the DSO toolkit also grid reconfiguration is mentioned as a contributor to flexibility. The DSO toolkit documents describes much more in detail procedural pre-requisites and consequences of this approach, but in principle there is consistency with the smart grid functions mentioned as part of monitoring smartness. However, there is one exception from this statement: While the smartness monitoring approach proposes to monitor micro- or nanogrids being able to run on their own, the DSO toolkit for flexibility does not mention these. This makes sense with regard to the intention of the toolkit to show possibilities a DSO has to contribute to flexibility in the system.

Summarizing the comparison of the technology related part of the DSO toolkit with the smartness monitoring process for grids proposed in this paper, it can be said, that the two approaches show a very high level of consistency in the area, in which the they are covering the same topic, i. e. provision of flexibility in order to deal with increasing shares of distributed, volatile generation. Particularly, the level of granularity of the two approaches is very similar, meaning that on one side only a limited number of solutions is mentioned, but on the other side these are sufficiently differentiated in order to identify their individual contributions to the system. There are no conflicting elements, only a few solutions, which might need to be mentioned more explicitly in the smartness indicator proposal.

As the DSO associations are highlighting the importance of the solutions listed in their toolkit, monitoring the smartness of grids, as proposed by T&D Europe and Europacable, would be a tool creating transparency on the current state of deployment of the elements of the toolkit. By that it would increase awareness of the technological elements of the toolkit and support their deployment.

4.4 Similar initiatives outside Europe

4.4.1 Grid Modernization Index (GridWise Alliance, USA)

In Northern America the GridWise Alliance (https://gridwise.org) runs and publishes the Grid Modernization Index. The GridWise Alliance is a membership organisation of network operators, system operators and technology providers (see https://gridwise.org/members/).

The rationale of the Grid Modernization Index (https://gridwise.org/grid-modernization-index/) is very similar to the one of the Smartness Indicator for Grids: As there is a broad need for re-investment in Northern American grids due to the age of the assets, the GridWise Alliance wants to offer a factual basis for discussing, whether the opportunity of modernizing grids during this re-investment cycle is used sufficiently. The Grid Modernization Index (GMI) is published on an annual basis and uses data inputs and publicly-available information to evaluate and rank the status of grid modernization efforts across all 50 US states and the District of Columbia.

The GMI has become widely recognized across the industry as a resource that benchmarks states on a wide range of grid modernization policies, practices and investments; providing insights into the progress and various approaches. The GMI takes a comprehensive view, tracking dozens of specific changes in each state and highlighting several of the most significant changes in the industry. The following picture shows the summary from the 2017 report (GMI4).

As the GMI is analysing the use of modern solutions, assuming these are more future oriented than traditional ones, it is not only focussing on the current situation of grids, but also future-oriented. From that perspective it is very similar to the monitoring process proposed in this paper.

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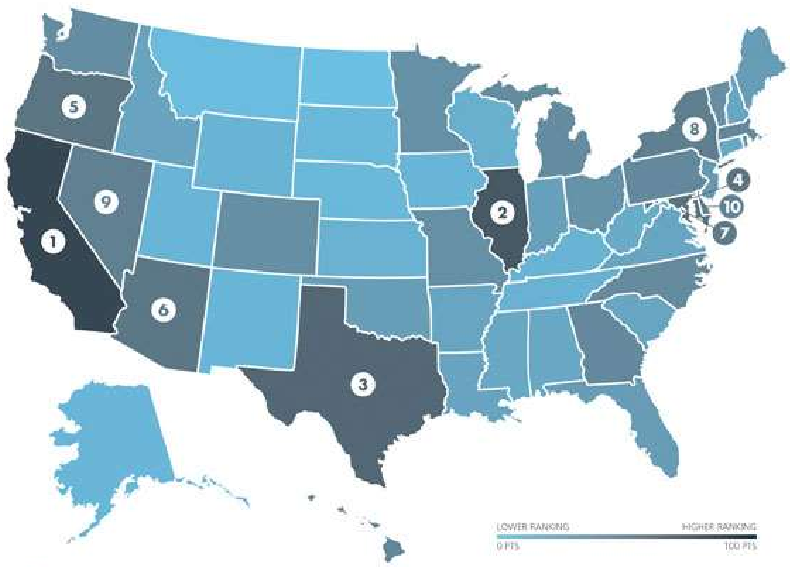
OVERALL RESULTS



RANK	+/-	STATE	LEADERSHIP SCORE
1	0	California	81.5
2	0	Illinois	73.0
3	0	Texas	64.6
4	0	Maryland	57.5
5	2	Oregon	56.8
6	3	Arizona	55.5
7	-2	District of Columbia	53.5
8	8	New York	51.0
9	5	Nevada	50.1
10	-4	Delaware	48.5
11	1	Hawaii	46.0
12	8	Massachusetts	44.8
13	-5	Pennsylvania	44.0
14	-4	Georgia	43.5
15	-4	North Carolina	43.3
16	-1	Michigan	41.7
17	12	Washington	40.5
18	17	Colorado	40.0
19	-6	Vermont	39.6
20	2	Missouri	39.0
21	-2	Minnesota	38.8
22	3	Ohio	36.8
23	25	Rhode Island	34.0
24	2	New Jersey	32.3
25	-8	Florida	30.1
26	-5	Maine	29.5
27	-9	Oklahoma	29.0
28	-4	Indiana	27.0
29	4	Louisiana	24.4
30	2	Idaho	23.9
31	8	Virginia	23.4
32	-2	Arkansas	23.2
33	1	South Carolina	23.1
34	-6	New Hampshire	21.6
35	-4	Connecticut	21.4
36	7	Mississippi	21.3
37	-10	Alabama	21.0
38	-1	West Virginia	19.0
39	1	Wisconsin	15.1
40	-4	Kansas	14.4
41	3	Tennessee	13.2
42	-3	Wyoming	11.9
43	2	Kentucky	11.6
44	3	New Mexico	11.0
45	1	Iowa	10.7
46	-8	Utah	10.5
47	0	Alaska	10.3
48	-6	South Dakota	9.0
49	1	Nebraska	8.5
50	-1	Montana	6.3
51	0	North Dakota	3.3

GRIDWISE ALLIANCE

10

4.4.2 Smart Grid Index of the Singapore Power Ltd. (SP Group)

The Smart Grid Index by the SP Group from Singapore (https://www.spgroup.com.sg/what-we-do/smart-grid-index) is another index using publicly available data. It measures the electricity grid of major utilities globally, in seven key dimensions.

- Monitoring & control
- Data analytics
- Supply reliability
- DER integration
- Green energy
- Security
- Customer empowerment & satisfaction

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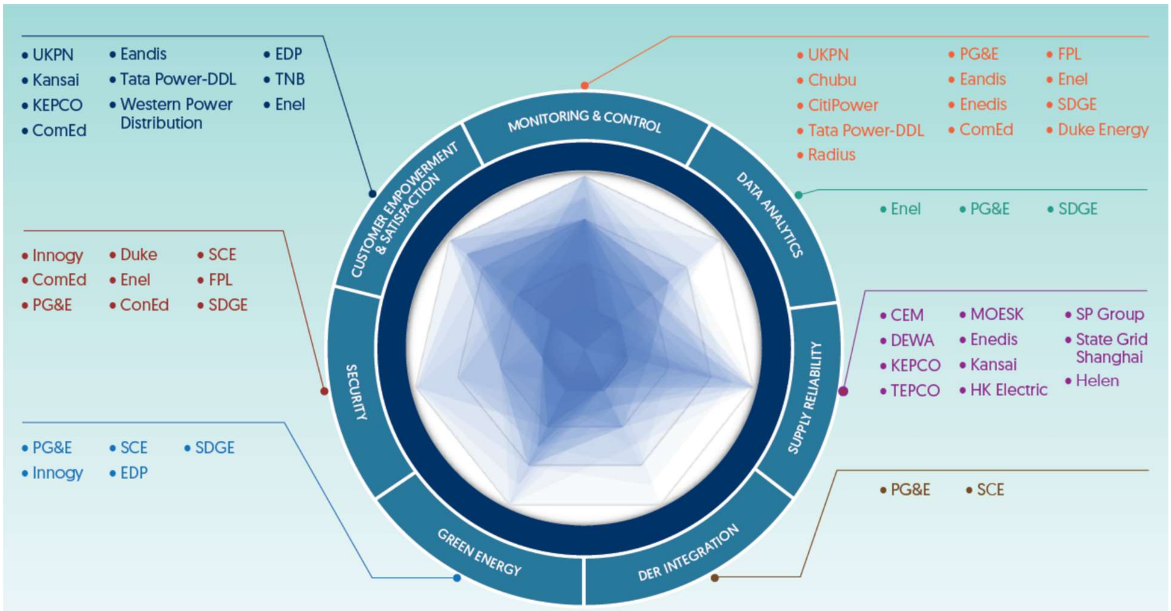
The benchmarking results also identify best practices to drive smart grid advancement. The index currently covers 45 utilities from 30 countries. The following picture shows a summary clustering best practices by the seven dimensions listed above.



Although the objective of this index is to identify best practices to drive smart grid deployment, there is an important difference to the monitoring process proposed in this paper: Some of the dimensions of the Smart Grid Indicator of SG Power are looking at particular technologies, such as monitoring and control or data analytics, while others are output or task oriented, for instance share of green energy, DER integration or customer empowerment. This means that the SG Power index is not addressing future readiness, but current performance of grids. On the other side, as the index is monitoring the same technologies as addressed in this paper, it may provide valuable information on the correlation between technologies on one side and challenges for grid operators on the other side.

5. Glossary

AC	alternating current
CBA	cost-benefit analysis
DER	distributed energy resources
EHV	extra high voltage (namely above 110 kV)
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
EV	electric vehicle(s)
FACTS	flexible AC transmission systems
HV	high voltage (namely between 72 kV and 110 kV)
HVDC	high voltage direct current
KPI	key performance indicator
LV	low voltage (namely up to 1 kV)
MV	medium voltage (namely between 1 kV and 72 kV)
PCI	project of common interest
RES	renewable energy sources
TYNDP	ten-year network development plan

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