The Cyber Physical System for the Energy Transition

Digitalisation Challenges, Opportunities and Projects from TSOs and ENTSO-E

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Introduction to this report

How can we enable the integration of an increasing share of variable renewables into our power system, to empower customers and facilitate the integration of different sectors? The answer is digitalisation.

The "digital grid" is a physical grid that is completed by an emerging ICT layer, enabling efficiency gains and new functionalities while simultaneously posing challenges for the power system. It is a combined grid, and not a grid where one replaces the other: this is why ENTSO-E proposes the term "cyber-physical grid".

ENTSO-E and its member transmission system operators (TSOs) strive towards implementing this cyber-physical grid to ease the transition to the next generation power system: smarter, cleaner, secure, more connected and, of course, with the customer as a key player.

This report sheds light on the cyber-physical grid by conducting an extensive analysis on the current situation of digitalisation at the TSO and pan-European level. The report considers more than 100 Research & Development (R&D) and operational projects within the TSOs and ENTSO-E. It explores the technical features of digitalisation and shows how digital technologies are being deployed by TSOs to capture opportunities and overcome the challenges of the energy transition as they begin to deliver the Digital Grid.

The report examines digitalisation as a tool for TSOs in their response to the current overhaul of the energy system. It is focused on the role of TSOs in the transition towards the Digital Grid; other actors have also published reports and positions on digitalisation and their respective roles, for instance DSOs' European associations[1]. ENTSO-E and its members are committed to exchanging information and engaging in discussion with all the stakeholders of the energy system on this matter, to share and build a vision together.

This report has been developed by ENTSO-E and TSOs in conjunction with Pöyry Management Consulting.

1 **DSOs' reports:**
E.DSO for smart grids, 'Digital DSO – a vision and the regulatory environment needed to enable it'
Eurelectric, 'Where does the change start if the future is already decided?'

Other reports:
ETIP Wind, 'When wind goes digital'
SolarPower Europe, 'When solar policy went digital

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Executive summary

Digitalisation is central to Transmission System Operators (TSOs) as they have to manage a fast-evolving power system 24/7 while keeping the lights on. Today, they are required to overcome a variety of new challenges, such as the increased amount of variable generation, sector coupling, power and transport connected through e-mobility, increasing electrification and, in particular, heating and cooling, as well as the rise of the Energy Internet of Things and the many flexibility opportunities and needs. Digitalisation also contributes to further market facilitation and enables new actors and new roles, centred around prosumers and active system management.[2]

A cyber physical grid is in the making. This is composed of the physical part on the one hand – towers, cables, wires, substations etc. – and the increasing Digital Grid on the other. The Digital Grid will allow for the integration of models, tools, platforms and information. It will enable not only automated and coordinated decision-making inside the business units of TSOs and between them, but also enable it in the future with Distribution System Operators (DSOs) and all the other parties that constitute the electricity value chain.

ENTSO-E and its TSOs' members decided to investigate the cyber physical grid, along with its challenges, opportunities and projects that have already been undertaken on a national, regional and European level by TSOs and their organisations. This work was undertaken by ENTSO-E's Research Development and Innovation Committee (RDIC) and supported by Pöyry Management Consulting.

The present report provides a state of play based on real world examples and next step requirements. It is a unique effort, as more than 100 digital projects within the TSOs and ENTSO-E have been gathered and discussed. It focuses on the role of TSOs in the transition towards the Digital Grid; other actors have also published reports and positions on digitalisation and their respective roles, such as DSOs' European associations. ENTSO-E and its members are committed to exchanging information and engaging in discussions with all the stakeholders of the energy system on this matter, in order to share and build a vision together.

Key findings and 100 projects

The analysis has shown that the European TSOs are already widely using digitalisation technologies. We have organised the projects according to the TSO activity area – here referred to as a layer – that they relate to. The contribution of the digitalisation is explained layer by layer.

Of the 100 projects, more than half address the physical layer and data management layer, while the same proportion is deployed for system operation purposes. Only a small number of projects consider the market layer, and even fewer the sector coupling layer.

1 **Physical layer:** The impact of digitalisation on the asset management function leads to reduced maintenance costs and extending the lifetime of high voltage assets. Digitalisation could also lead to increased reliability and lower outage times.

2 **Data layer:** TSOs have already been gathering data during operation for years, but nowadays digitalisation enables improvements in the forecast and the opening-up for additional sources of data.

2 TSO-DSO report: An integrated approach to active system management. https://www.entsoe.eu/Documents/Publications/Position%20papers%20and%20reports/TSO-DSO_ASM_2019_190416.pdf

3 **System operation layer:** Digitalisation will enable the development of a new set of tools in control rooms that can offer the operator a whole new level of hyper-vision and automation, from two days ahead up to real time, to face a context of an increasing number of uncertainties and interlinkages.

4 **Market layer:** With more digital additions to the grid and the system, more information can be gathered from more parties (including consumers and prosumers), processed and shared much more efficiently and securely using a range of digital technologies. The TSOs therefore need to play a leading role in the digitalisation of power markets.

5 **Sector coupling layer and cross border dimension:** Sector coupling requires digitalisation so as to connect across two currently largely disconnected energy sectors. Meanwhile, the cross-border dimension is not only addressed by neighbouring TSO countries or Regional Security Coordinators (RSCs) but also at the pan-European level, which is why ENTSO-E has been driving numerous parts of the digitalisation agenda.

What are the challenges, risks and opportunities related to digitalisation?

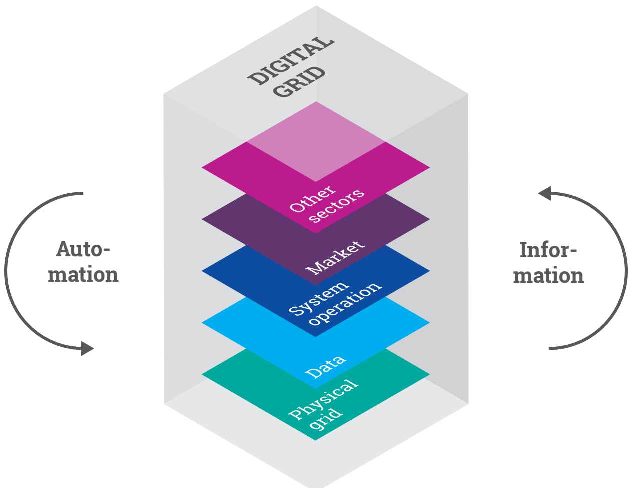
Our survey sheds light on how TSOs see the risks and opportunities associated with digitalisation. The most relevant challenges for TSOs are design strategy and regulation, but also market design, cost effectiveness and cyber security.

Opportunities provided by digitalisation are the overall system and grid cost efficiencies, risk management, system security and sector coupling.

New technologies are game changers for the TSOs, and this includes in particular artificial intelligence, machine learning, digital twin, the Internet of Things and 5G.

The way ahead: More R&D, more projects everywhere and a regulatory framework incentivising the cyber physical grid

The report shows that TSOs consider all the dimensions when developing projects: local, national, regional/cross-border and pan-European. However, the results of the survey indicate that not all **TSOs** are **actively** pursuing digitalisation projects. A further reason for this is a **regulatory framework that does not incentivise** them to **seek low-risk** long asset lifetime solutions. ENTSO-E therefore urges the policy makers and regulatory agencies to use their tools to support the rise of the cyber physical grid. It goes without saying that to achieve the vision of the Digital Grid, R&D **investments need to increase** substantially.



The 5 layers of the Digital Grid concept

1. Digitalisation and Power System Transformation

1.1 Policy objectives

General societal policy objectives (e.g. decarbonisation) drive the **EU Energy Strategy's policy targets**: sustainability, competitiveness and security, which in turn introduce many changes to the power system. The **2030 climate and energy framework**, which builds on the 2020 climate and energy framework, sets three key targets for the year 2030:

- at least 40% cuts in greenhouse gas emissions (from 1990 levels)
- 32% share for renewable energy
- 32.5% improvement in energy efficiency
- The framework helps drive progress towards a low-carbon economy and build an energy system that:
- ensures affordable energy for all consumers
- increases the security of the EU's energy supplies
- reduces dependence on energy imports and increases the RES (renewable energy sources) integration
- creates new opportunities for growth and jobs

The present ENTSO-E analysis of more than 100 projects in the TSO and ENTSO-E domain concludes that digitalisation is a tool that contributes to reaching the aforementioned policy targets.

1.2 Characteristics of the future power system

To achieve the EU energy policy targets, the future power system must address the following **characteristics** and limitations:

a) Ensuring an **increased level of RES integration** while considering the impacts on:

- The traditional way of operating the system due to the reduced use of dispatchable/load following generation units (e.g. large thermal plant)
- ensuring sufficient levels of reserve due to growing **imbalance** volumes and the associated cost of energy balancing
- network congestion in the DSO and TSO grids
- Public acceptance of the deployment of new power lines, which is much harder to achieve and progressively more challenging due to the difficulty in **obtaining the permits for overhead lines**

b) Further developing the pan-EU markets

- There is a need to adapt or develop network codes and guidelines to build the European power system and single **pan-EU market**
- **new roles** might appear within the system including, for example, small-scale producers (**prosumers**) and demand-side **aggregators'** impact on the system operation
- **cross-border trading**, driving increased data transparency, as well as modifying the pattern of power flows and changing energy balancing costs
- The high level of power electronics with **different technical characteristics** will produce subsequent changes to system dynamics and inertia, and will therefore require the development of new technical services

c) Ensuring transparency and communication

- greater **data transparency** and market facilitation requirements; the growing presence of **microgrids** and **peer-to-peer** energy exchange
- the growth of high-capacity connections (e.g. to support **EVs** and the **electrification of heat** and cooling)

Digitalisation is intrinsically crucial for the TSOs' unit to manage all these evolutions that result from the energy transition.

Additionally, there are external requirements coming **directly** from regulation as mandates or **indirectly** from the implementation of the network codes, the requirement for optimising the use of assets.

Some examples from existing regulation are in the **post notes** below:

- Commission Regulation (EU) 217/1485 Article 114 describes the General provision for ENTSO-E for the Electricity Operational Planning Data Environment, which mandates ENTSO-E to implement and operate an ENTSO-E operational planning data environment for the storage, exchange and management of all relevant information.

OPDE

TITLE 7

ENTSO FOR ELECTRICITY OPERATIONAL PLANNING DATA ENVIRONMENT

Article 114

General provisions for ENTSO for Electricity operational planning data environment

1. By 24 months after entry into force of this Regulation, ENTSO for Electricity shall, pursuant to Articles 115, 116 and 117, implement and operate an ENTSO for Electricity operational planning data environment for the storage, exchange and management of all relevant information.

- Commission regulation (EU) No 543/2013 on the submission and publication of data in the electricity markets: establishment of a central information Transparency Platform.

TP

Article 3

Establishment of a central information transparency platform

1. A central information transparency platform shall be established and operated in an efficient and cost effective manner within the European Network of Transmission System Operators for Electricity (the 'ENTSO for Electricity'). The ENTSO for Electricity shall publish on the central information transparency platform all data which TSOs are required to submit to the ENTSO for Electricity in accordance with this Regulation.

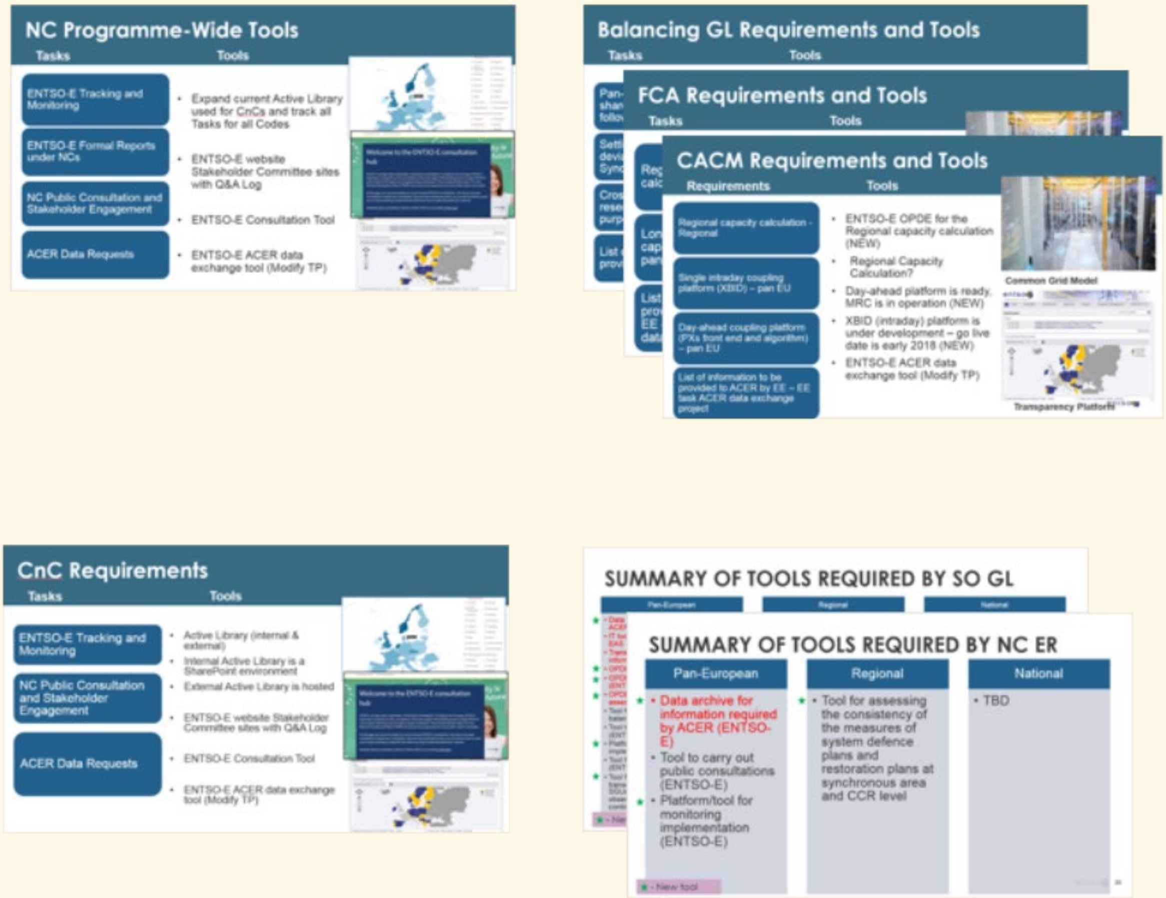
- The Current Clean Energy Package (CEP) considers specific provisions for digitalisation, as shown in the following table:

new CEP Art 27.1.(fb) El Reg	Promote the digitalisation of transmission networks including the deployment of smart grids, efficient real time data acquisition and intelligent metering systems.
new CEP Art 27.1.(jb) El Reg	Promote cyber security and data protection in cooperation with the relevant authorities and regulated entities.
new CEP Art 27.1.(ha) El Reg	Contribute to the establishment of interoperability requirements and non-discriminatory and transparent procedures for accessing data, as provided for in Article 24 of the [Electricity Directive].

Some examples calling indirectly for the use of digitalisation are related to the need to strengthen cooperation within existing players (inter TSO- and X-border tools, TSO & DSOs), new market actors (EVs, Distributed Energy Resources -DER), microgrids and coupling with other sectors.

TSOs are tasked with the requirement to handle the technical consequences of the energy transition. Digitalisation presents challenges and opportunities for TSOs in handling and facilitating this change.

Often implicitly required …



1.3 Power system transformation: Digital Grid

TSOs have come together to **define digitalisation** as "the increased use of information and communication technology (ICT) and data to deliver value to the customers and stakeholders, maintain and improve the security of supply, utilise the grid in a cost efficient manner, facilitate new and existing markets and contribute to energy sector transformation".

The **"Digital Grid"** concept is ENTSO-E and the TSOs' vision of the power grid for 2030 and beyond. It refers to the emerging ICT layer on top of the physical grid, complementing and enhancing it, but not replacing it. The Digital Grid is a precondition to enable transparent information to the end users. It will also enable the delivery of an optimal and integrated system approach and ensure the data flow among the power system layers: 1) physical grid, 2) data, 3) system operation, 4) market and 5) other sector layers and actors. Automation will be the key to addressing the complexity of managing a system of systems optimally. Digital platforms will ensure cooperation between the value chain players, and between the different energy sectors, in a cross-border and optimal manner.

ENTSO-E and TSOs will work to enable this Vision, together with stakeholders.

The Digital Grid common cyber-physical space will enable the integration of models, tools, platforms and information. This will be useful for the automated and coordinated decision-making at different levels:

- inside the business units of TSOs
- between TSOs and DSOs such as in Active System Management for activating ancillary services, and
- between TSOs and all the parts of the electricity value chain – whether they are entities trading in the wholesale market or acting on a peer-to-peer basis – and creating new consumer products or with other sectors.

The concept of the Digital Grid should not be a centralised tool or platform for managing the electricity system, but a new space in which interoperability criteria between new solutions and legacy solutions predominate, together with transparency, to facilitate the exchange of data, and optimisation through the integration of information from different areas of interest.

The Digital Grid will provide, through neutral market facilitators such as system operators, the data platforms and interfaces necessary to implement an inclusive digital architecture, where market parties and customers can participate and shape the market. The Digital Grid will also increase the value of existing assets by extending their lifetime and making the power system more resilient, using smart sensors and automation.

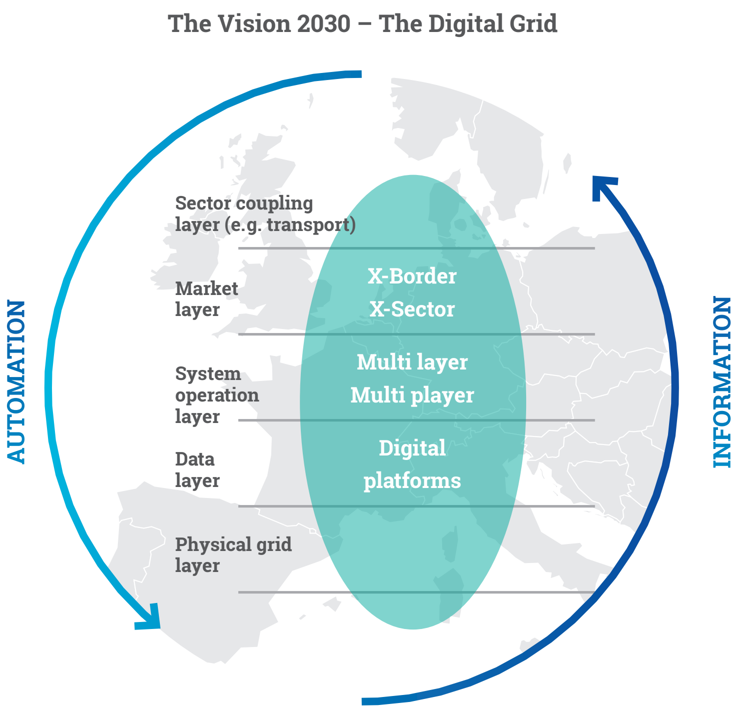


Figure 1: The Digital Grid Concept

2. Opportunities, Impact and Challenges

2.1 The opportunities presented by digitalisation

A survey of the TSO community shows that most of the opportunities digitalisation brings are focused on increasing the overall system efficiencies (e.g. due to expanding a market or reducing constraints). Figure 2 demonstrates that digitalisation opportunities can be found in the grid cost efficiencies, in terms of improving asset management and reducing related costs, and increasing the performance of assets. System risk management, security of supply and safety have been identified as opportunity niches where digitalisation could bring added value. This is not to forget the possibilities derived from the cooperation and building of the pan-EU energy system, which includes the sector coupling and cooperation with other operators and stakeholders.

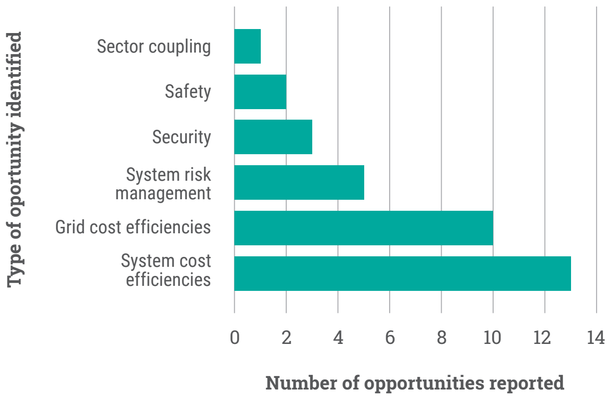


Figure 2: Digitalisation opportunities

A deeper, detailed analysis is provided in the figure 3:

SYSTEM COST EFFICIENCIES

- Reduction of operating costs
- Market improvement by developing new trading algorithms
- Optimise calculations by considering TSOs and DSOs information
- Enabling the transition from customer to prosumer
- Optimise calculations by considering TSOs and DSOs information
- Exploit the use of available data to increase system flexibility

GRID COST EFFICIENCIES

- Use dynamic network management models based on real time data
- Reduce grid development costs by implementing smart power flow and voltage control
- Allow full observability of the grids and unlocking of grid connected resources
- Automation of engineering and improved planning due to more and accurate data
- Increase networks utilisation

SYSTEM RISK MANAGEMENT

- Data availability for better risk assessment
- Increase quality of service and RES integration due to availability of larger amount of data
- Increase security of supply by implementing preventive measures and assessing the grid condition
- Automation of engineering and improved planning due to more and accurate data
- Increase networks utilisation through digitalisation

SECURITY AND SAFETY

- Increase resiliency supported by decision support tools.
- Ensuring connectivity of all assets and resources, ensuring a proper management.
- Increasing personnel safety by using robotics and virtualisation.
- Improving the sustainable development of the grid.

COOPERATION AND BUILDING THE PAN EU ENERGY SYSTEM

- Enabling sector coupling
- Fostering TSO-DSO cooperation
- Active system management
- Improving cross border cooperation
- Connecting the customer

Figure 3: Opportunities of digitalisation from the TSO perspective

2.2 Impact of digitalisation in the TSO Digital Grid

Nowadays, digitalisation has a significant impact on every TSO function. Digital technologies have been implemented to grasp the opportunities in the system. The following analysis illustrates what the impact of digitalisation is in the different areas.

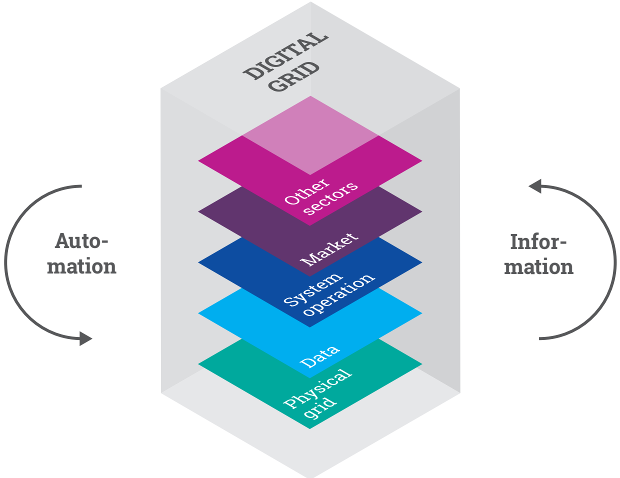


Figure 4: The 5 layers of the Digital Grid concept

2.2.1 Impact of digitalisation in the physical layer

Cutting-edge **predictive maintenance** techniques, using artificial intelligence **(AI) and big data**, are providing much better insight for outage management, improving the resilience, availability and capacity of the grid. The installation of multitudinous sensors also enables a much greater level of observability of the network components. Thus, maintenance activities can be based on the collection of much more granular data sets than have traditionally been available.

However, some digitalisation projects begin to interact with other layers – using data and information, and/or providing useful output. For example, projects such as MANINT (which is focused on reducing maintenance costs and improving grid availability by using predictive maintenance) cross the boundaries between the five layers (MANINT not only uses data from the physical devices but combines it with data from the system operation layer), and provide a useful example of how the Digital Grid is being created.

In a general industrial context, the impact of digitalisation on the asset management function is to reduce costs and extend operational lifetimes. For a TSO, whereas direct maintenance costs may be expected to decrease, adjusting and expending the lifetime of high voltage assets can lead to even more significant savings. Moreover, additional benefits in terms of increased reliability and lower outage times can ultimately provide greater social welfare benefits.

2.2.2 The data layer

Data is crucial for running the electrical system in a secure way. Exogenous data, such as meteorological data (wind, solar, rays and snow…) and seasonal environmental data (water, etc…) are required to optimise the operation, in addition to forecasted and real time data from demand and generation, together with data from assets in the field and network topology. TSOs have been gathering these data already for years and storing them in platforms, but nowadays digitalisation enables improvements in the forecast and enables additional sources of data (e.g. Digital substation based on IEC61850).

Digitalisation projects are developing new added value data platforms and opening access to this wider set of data sources, for example the ESTFEED and Transparency Platform (TP) projects.

The impact of the data-layer related digitalisation projects is therefore not only to provide the direct benefits for which they were intended (for example, ESTFEED enabling the development of new supplier services, and TP enabling the communication of market data), but also, through common platforms and open Automated Programming Interfaces (APIs), to provide indirect benefits by enabling value to be found across the energy system.

2.2.3 The system operation layer

Digitalisation will enable the development of a new set of tools in control rooms that can offer the operator a whole new level of hyper-vision and automation from two days ahead up to real time, to face an increasingly strained context with more uncertainties and interlinkages. They also need to cope with new usage patterns (new behaviour of players, new components on the system, etc.), and this complexity leads the TSOs' operation activities to switch from a reaction-oriented management of the system to a complete predictive scheduling.

Thus, the impact of digitalisation on system operation extends not only to the direct cost savings of system operation through optimisation and a faster response, but the more efficient procurement of services also increases social welfare by allowing more service providers to access a wider market. For example, the COORDINET project will develop innovative network services for TSO-DSO through demand response, storage and small-scale distributed generation, impacting on the overall power system coordination.

2.2.4 The market layer

Digitalisation will enable changes to market facilitation – more information can be gathered from more parties (including consumers and prosumers), processed and shared much more efficiently and securely using a range of digital technologies.

Other newer technologies such as Blockchain may be used for secure micro transactions of both information and payments in new market platforms and systems involving end users. AI and automation may remove the need for human interaction between assets, markets and actions, such that markets become much more efficient and able to cover a larger set of functions.

With smaller consumers and producers playing an increasingly important role in the power system, it is important to ensure that these smaller players' assets are available to and can access the relevant market. This can be achieved with better information flow, simplified access, proper incentives and new market structures. To avoid potential costs and delays, functionality will need to be developed which facilitates the coordination and harmonisation of activities. The TSO therefore needs to play a leading role in the digitalisation of power markets both as a central and neutral part of the power system, as well as an important stakeholder. Aware of this, ENTSO-E and TSOs have already made an effort to develop a Common Grid Model (CGM) to facilitate the market and enable the capacity calculation among TSOs.

Another example is the INTERRFACE H2020 project, which, with the participation of ENTSO-E and at least six DSO-TSO couples, is developing the next generation TSO-DSO cooperation model to enable added value services for the customer based on data management strategies. The project aims to develop a pan-European Grid service architecture (market and services design), including services for congestion management and local flexibilities.

2.2.5 Sector coupling layer and cross-border dimension

Sector coupling requires digitalisation to connect across two currently largely disconnected energy sectors. For example, Electrical Vehicles (eVs), via vehicle-to-grid can provide balancing services to the electricity market, while hybrid heat-pumps enable trade-offs between heat-pumps and conventional heating equipment in the building sector. Heating and cooling networks may also be used as storage systems. All these use cases will require proper communication links and be enabled by digital platforms. Digitalisation projects such as TenneT's collaboration with The New Motion are testing some of these concepts.

The X-border dimension is not only addressed by neighbouring TSOs countries and RSCs. ENTSO-E has been driving many parts of the digitalisation agenda. Three notable early examples are the Transparency Platform to manage pan-EU market data and the CGM to enable pan-EU planning, ECCO-SP as a secure platform for TSOs to exchange data.

2.3 Challenges of digitalisation faced by TSOs

2.3.1 Today challenges

The TSOs survey indicated that among the 42 challenges associated with digitalisation, the most relevant categories of themes for TSOs are those presented in Figure 5 - Digitalisation challenges" below.

2.3.1.1 Design strategy

"Design strategy" is defined as the overarching strategy for designing an ICT solution for a situation. Specific challenges identified by TSOs in questionnaires/interviews include:

- Ensuring the complementarity of systems – which can include interoperability and compatibility of systems. This includes interoperability between actors (RSC, TSO, DSO, market participants etc) and interfacing with legacy systems and process. This can be mitigated through proper digitalisation strategies, a clear understanding of the existing systems and a global forward-looking strategy. It requires solutions which facilitate future interconnection and the coupling between systems. **The Digital Grid will become a 'system of systems' within which these problems could be contained.** The ECCO-SP project is aimed at creating a platform that allows TSOs and RSCs to exchange data in a cyber secure way.
- Preventing failures of systems – some systems will need to be resilient to failure, with specific recovery timeframes, failover or redundancy arrangements. Again, this can be mitigated through appropriate digitalisation and IT strategies, especially business continuity plans, and is strongly related to the wider need for overall system security. The digital layer of the electricity network becomes an integral part of the cyber-physical system; the security of the digital layer becomes as important as the security of the physical grid. **Resiliency of the network becomes dependent on the resiliency of the ICT systems that underpin the Digital Grid.**

These two design strategy considerations point directly to the requirement to develop a system of systems. These issues underline the need for continued research and development to bring together existing and new systems – the development of a multi-layer, multi-player, cross-border and cross-sector platform – and the need to properly investigate and consider the resilience and the cybersecurity of these systems.

Further specific challenges:

- the increasing demand for data provisioning/publication/sharing. There are a series of subsequent design considerations associated with the increasing requirements for transparency: reliability of access, speed of access, data storage volume, access and security and interface requirements. As a greater number of assets connect and use the digital grid, it will be especially important to conceive **scalable systems** with an **open-data** orientation to meet the growing volume of data and interactions.
- ensuring compliance with **GDPR** and related data laws.

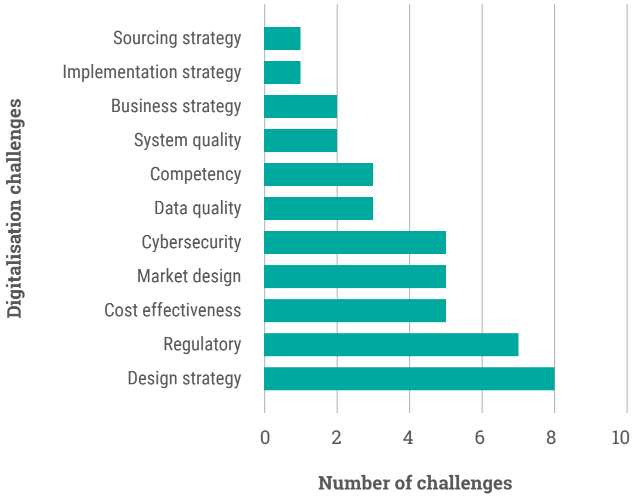


Figure 5: Digitalisation challenges

2.3.1.2 Regulatory

Regulatory challenges refer to the ability to finance digitalisation projects and activity, and the mechanisms for doing so. For example, how major IT investment should be treated in the regulatory accounts and what is the regulatory approval process.

It will be important to establish that any digitalisation strategy or project is economically beneficial in a wider system sense. Digitalisation provides new alternatives to extend the asset lifetime and performance.

2.3.1.3 Cost effectiveness

Specific challenges mentioned by TSOs, such as the time required to process huge amounts of data or the physical space required for hosting computing equipment (data centres) are perhaps solvable through e.g. accessing greater processing power, cloud hosting, etc, but this also needs to be reflected in the project economics and regulatory arrangements alongside related challenges:

- the frequency of device maintenance and servicing (e.g. where devices are required to maintain system stability)

› the asset life of system components

2.3.1.4 Structure/market design

Several specific challenges relate to the structure of the industry or 'market design' of the wider system – as this evolves, so the requirements for digitalisation will evolve too. A clear and obvious example is that ICT solutions might depend on who is responsible for the re-dispatch of distribution connected assets. The challenges within this category connect more with the policy-related concepts of digitalisation:

› The increasing need for sector coordination introduces interoperability challenges, but understanding how sector coupling might evolve is important in knowing how to deploy digitalisation to facilitate rather than hinder evolution.

› Decentralised ideas of how to control/balance the future energy system may re-define the roles/responsibilities.

› With the continuous increase of distributed renewable generation and storage, and the expected rise of active customers engaging in demand response, it is important to understand how to integrate the flexibility services provided by these new assets and players into the ancillary services market, in order to maximise the value for customers and distributed flexibility resources providers. To facilitate this, it is necessary for TSOs to increase the observability and controllability of distributed energy resources.

2.3.1.5 Cybersecurity

Cybersecurity was mentioned as a specific challenge by five of the responding TSOs, however, cybersecurity has also been discussed as a challenge in several other forums.

As a concept, cybersecurity has not changed with the advent of digitalisation, however the challenge has been exacerbated by several factors:

› strong integration of ICT within the power system

› strong reliance on digital systems

› increased use of public networks and internet-based technologies

› connection of many different types of devices

› increased number of parties connected to the digital grid (i.e. consumers, market agents)

› greater requirements for transparency of system design, etc., to enable collaboration

The energy system is a key strategic asset and an important target for nefarious actors, making it particularly vulnerable to attack compared to other industries. Where access to the relevant ICT is only possible through direct physical interface, the energy systems did not necessarily need to be so well-protected. Historically, therefore, nefarious actors were unable to impact the power system. Connection, although indirect, of these systems to a publicly accessible network will require a significant hardening of the measures to be implemented.

There are a variety of countermeasures that can be employed and a series of standards relating to managing cybersecurity (e.g. ISO/IEC27001, NIST CSF, etc.) Although these may mitigate many of the issues associated with cybersecurity, there are emerging technologies that either may not be sufficiently well protected against advanced cybersecurity threats or enable new attack vectors. Therefore, a key factor for mitigation is to understand cybersecurity requirements generally and ensure that any digitalisation strategy accommodates them.

Cybersecurity for the EU is the primary subject of the Network and Information System (NIS) Directive[3] and has been transposed into Member States' national laws by 2018. This identifies electricity TSOs, DSOs and suppliers as being providers of essential services and will require Member States to ensure that they take appropriate measures regarding cybersecurity. It also requires Member States to establish a NIS authority and appropriate response teams, as well as to cooperate and exchange intelligence. Cybersecurity is essentially a combination of processes and controls, as well as some specific underlying software and systems, which try to prevent attacks, minimise and mitigate the risks arising from attack, and minimise the damage should an attack occur. Many TSOs already pay specific attention to the role of cybersecurity: the challenge for the digitalised future is that there is a greater need to rely on public-interfacing communication channels, and so the volume of cybersecurity work increases. Ultimately, cybersecurity can never deliver an absolute defence: the protocols must extend to contingency planning, mitigation (e.g. island operation) and recovery. Such planning is in its infancy in the context of the distributed energy world.

2.3.1.6 Other challenges

Other challenges raised by TSOs include:

› Business strategies and sourcing and quality strategies (dependence on niche/unique suppliers, bug fixing and development requirements) and implementation strategies (related to security and reliability requirements)

› withholding of commercially owned data could reduce the opportunities available

› understanding of requirements for and the provision of quality, dependable and accurate data

› retraining the workforce to make use of the new tech, to redeploy and/or downsize the workforce, and to employ specialists to maintain the ICT and/or manage ICT contracts

3 Directive (EU) 2016/1148 of the European Parliament and of the Council of 6 July 2016 concerning measures for a high common level of security of network and information systems across the Union

3. Where are we?

TSOs are on the right track, however additional effort is necessary to build an efficient and effective Digital Grid. This report shows an extensive analysis – but not an exhaustive one since the digital activity is continuously evolving – of existing digitalisation projects.

3.1 Digital technologies in TSOs' businesses

Digital technologies emerge and evolve faster than technologies used in the power system (Transformers, switches, etc…). Gartner has plotted the key digital technologies in the hype-cycle curve, to enable an assessment of the expectations of these technologies.

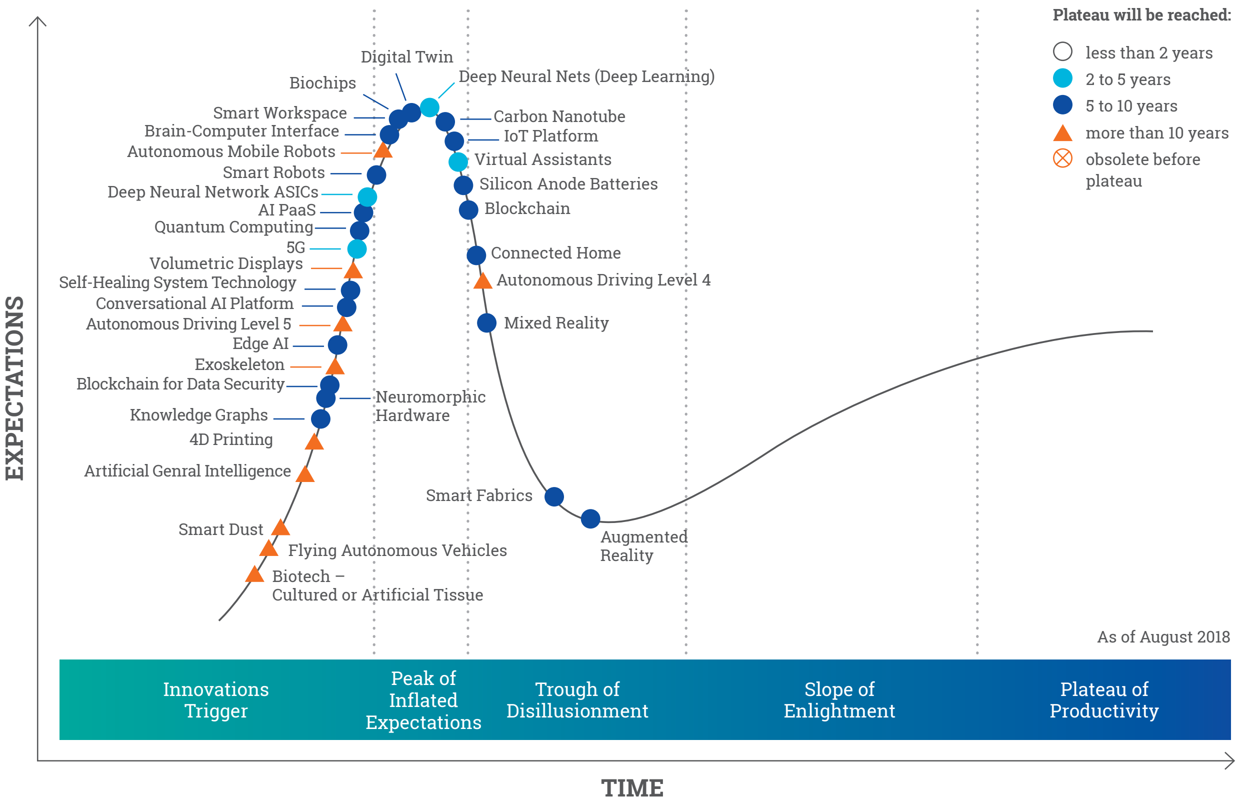


Figure 6: Gartner Digital technologies hype cycle August 2018

TSOs have assessed these technologies and identified the following as the most impactful in the power system:

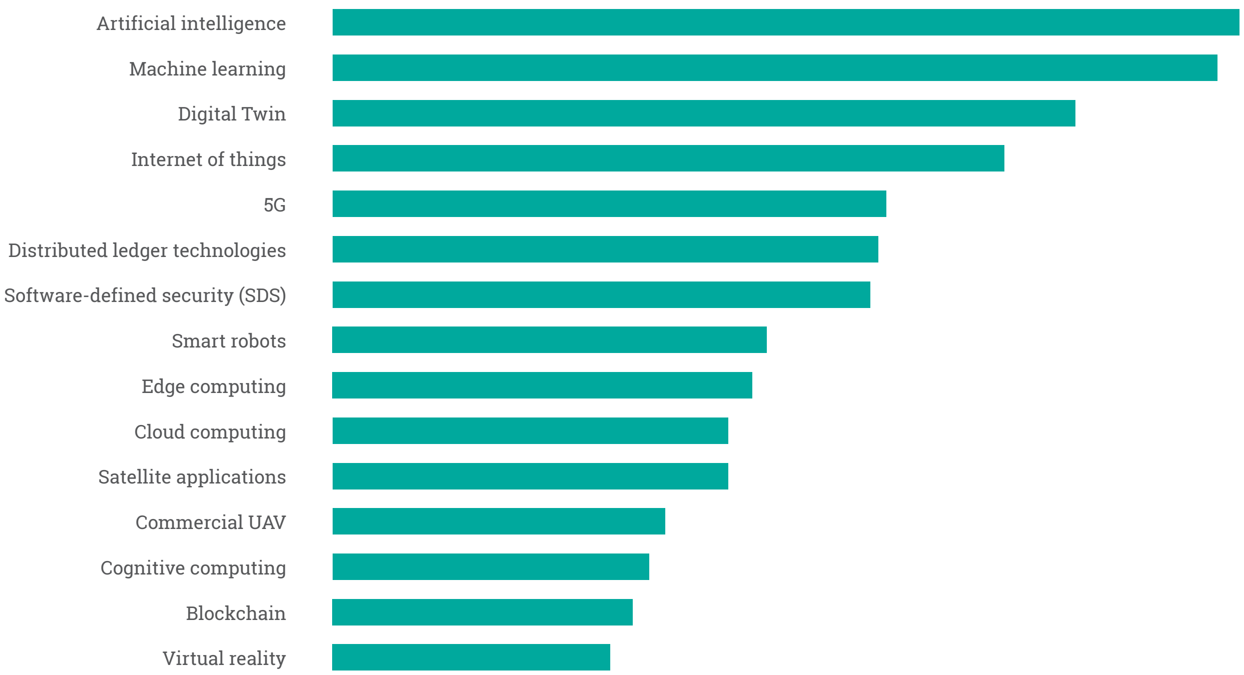


Figure 7: Top 15 Digital Technologies prioritisation

More than 140 innovation projects have been skimmed through by scanning the R&D sections of TSO websites, from TSOs' questionnaires responses, and from news and articles. These projects have been subjectively assessed by POYRY and only 100 plus have been considered as digitalisation projects. These projects have been assessed across several dimensions including technology type, geographic scope, the challenges they address for TSOs, the policy-level objectives they address or facilitate for society, how advanced they are, and their potential impact.

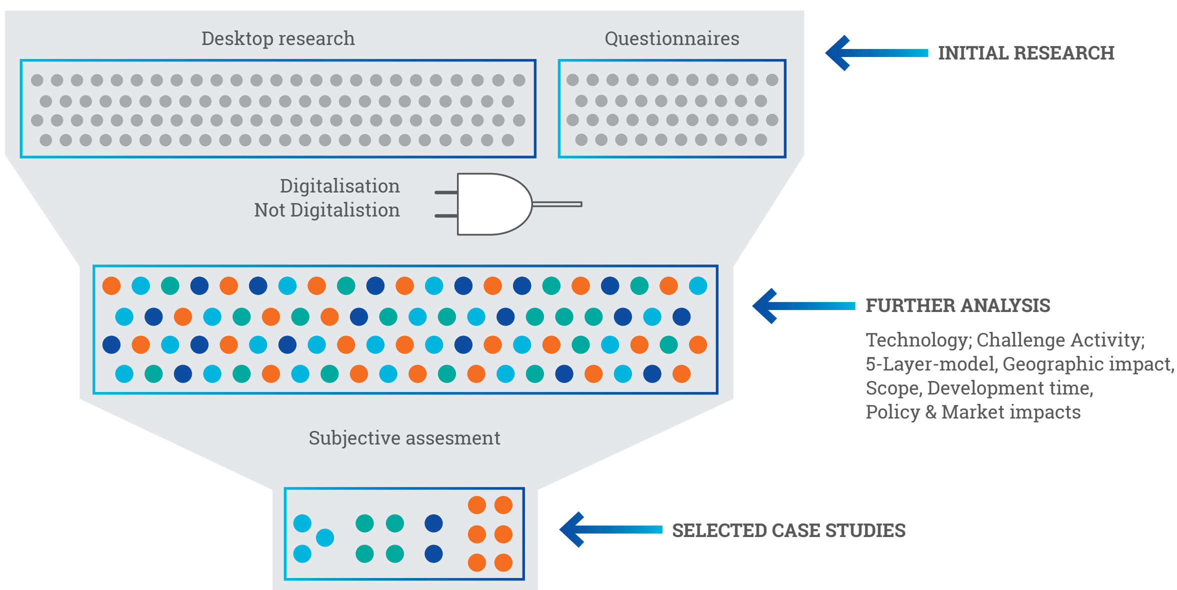


Figure 8: Project assessment and case study selection

3.2 Number of projects along the Digital Grid

The projects have been assessed along the dimension of the Digital Grid concept for the TSO that is shown in the five layers (physical, data, system operation, market interaction and an emerging sector coupling layer), as well as the automation and information dimensions (Figure 9).

Figure 10 shows that some projects address more than one layer, which indicates that interaction across layers of the digital grid is happening and the journey to accomplish the Digital Grid – a multi-layer, multi-player, cross-border and cross-sector digital platform – has already begun. However, a bigger impact could be achieved if the interaction were to increase.

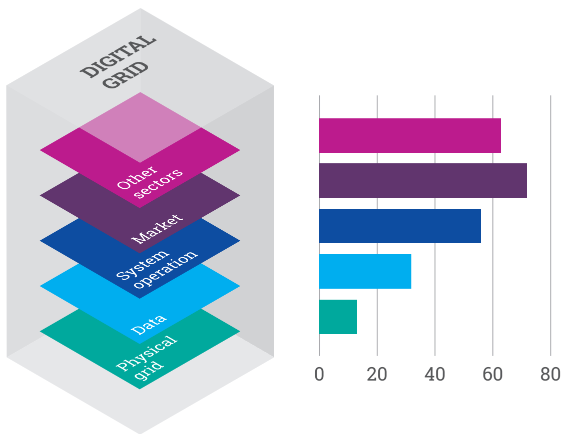


Figure 9: Number of digitalisation projects per layer of the Digital Grid

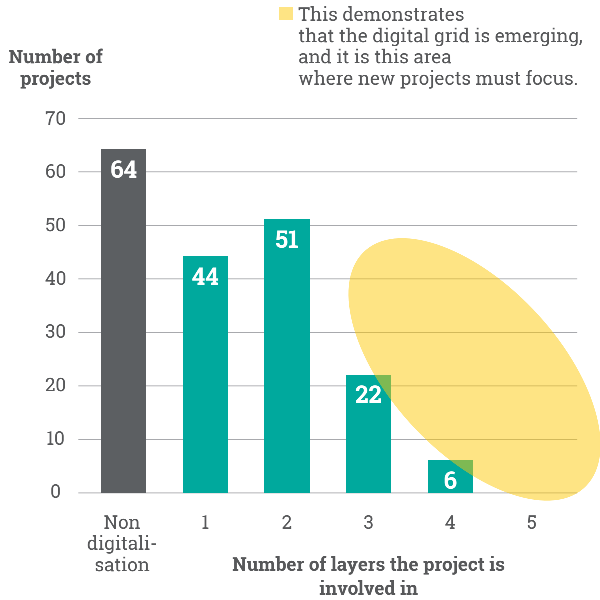


Figure 10: Number of digitalisation projects across Digital Grid layers

Analysis has revealed that over half the European TSOs are already investing in and engaging with a wide variety of digitalisation technologies and projects use cases, such as:

- projects that are truly pan-EU
- cross-border projects that involve more than one TSO
- collaborative projects that involve a variety of other parties both from the energy market but also from technology providers and new business models
- projects focused on the operational deployment of new systems, as well as projects focussed on research and piloting new technologies
- projects that span both different types of technologies and technology readiness levels
- projects that span national boundaries

Thus, the journey towards a system architecture – as proposed by the Digital Grid concept – has already begun.

3.3 Projects in the Physical layer

Sixty three digitalisation projects dealing with the physical layer have been identified. These projects are all listed in Table 1. As is evident, many projects in the physical layer have a link to the data and/or system operation layers. However, there are several projects linking the physical with the market or sector coupling layers. One possible reason for this is that the physical layer is indirectly coupled to the market layer via the system operation layer. It must be further investigated whether this indirect coupling is sufficient, or whether R&D/digitalisation projects should address both worlds – physics and the market – in a more direct manner.

Project code	Project Name	Use case	Layer				
			Physical	Data	Sys. ops.	Market	Sec. cpl.
1	SPANDEx	Improving real-time grid operation	1	1	1		
2	SAMBA	Asset management using Big Data	1	1	1		
6	SOVN	Market model for future investment decisions	1	1		1	
11	Real-Smart	Circuit protection	1	1	1		
17	Humber Smart Zone	Circuit protection	1				
20	EFCC	Improving real-time grid operation	1		1		
22	PV_Live	Intermittent power prediction	1	1			
23	Virtual Synchronous Machine	Adapting system to handle more DER	1		1		
26	AI to process drone data on Transmission assets	Improved transmission system maintenance	1				
27	FITNESS	Standardised (and secure) communication	1				
28	VISOR	Circuit protection	1	1			
30	Flexible Networks	Improved transmission system maintenance	1				
32	Bellrock Lumen-Condition Monitoring Decision Support	Predictive maintenance	1				
34	Maintenance Management 2020	Predictive maintenance	1				
35	Condition Monitoring System	Improved transmission system maintenance	1				
36	ELVIS	Coordinated asset management	1				
38	Demand Respone Pilots	Accessing distributed flexibility sources	1		1	1	1
39	Virtual Workshop	Online collaboration/training	1	1			
41	Orchidea	Online collaboration/training	1	1			
42	Estfeed	Metering data hub	1	1			
50	Stability FACTS	Adapting system to handle more DER	1				
58	Digitisation of the Swiss extra-high-voltage grid	Improved inspection of transmission system	1				
59	Digital Transformation	Customer portal for trading guarantees of origin	1			1	
65	Derig	Adapting system to handle more DER	1	1	1		
66	Knowfut	Online collaboration/training	1	1			
72	Blockchain as virtual power station	Virtual power plant for batteries	1		1		1
75	C/Sells	Other (multiple)	1	1			
77	Migrate	Adapting system to handle more DER	1				
79	Platform Digital Energy World	Understand and evaluate sector-wide digitalisation initiatives	1	1			
90	Smart Grids	Other (multiple)	1	1	1		
91	Callia	Accessing distributed flexibility sources	1			1	
96	Innovative Data Exchange Portal	Data sharing	1	1			
97	CHPCOM	Standardised (and secure) communication	1			1	
100	Smart Grid Innovation hub	Other (multiple)	1			1	
101	STAR (short term active response)	Shorter balancing period services from flexible demand	1		1	1	1

Project code	Project Name	Use case	Layer				
			Physical	Data	Sys. ops.	Market	Sec. cpl.
102	Powersave	Shorter balancing period services from flexible demand	1		1	1	1
103	Smart Valve	Shorter balancing period services from flexible demand	1	1			
104	Sumo	Improving real-time grid operation	1	1	1		
105	Sincro.Grid	Adapting system to handle more DER	1		1		
106	Poste Intélligent	Automation and substation digitalization	1	1	1		
108	GARPUR	Probabilistic risk assessment	1		1		
112	Twenties	Adapting system to handle more DER	1				
116	IT technology for plant maintenance	Predictive maintenance	1	1			
117	Space4Energy	Improved inspection of transmission system	1	1			
120	GE WAMS Project	Improving real-time grid operation	1	1	1		
126	BigDataOcean	Intermittent power prediction	1	1			
127	Digital line box	Standardised (and secure) communication	1				
129	WAMS Project	Circuit protection	1	1	1		
132	MANINT	Improved transmission system maintenance	1	1			
138	RINGO	Improving real-time grid operation	1	1	1		
142	Drones for inspection and maintenance of electricity lines	Improved inspection of transmission system	1				
143	Phasor measurement project	Circuit protection	1	1	1		
146	Drones for asset inspection	Improved inspection of transmission system	1				
149	Condition-/risk-based maintenance – 4 Imaging	Improved transmission system maintenance	1	1			
151	IoT for Dynamic Line Ratings	Improving real-time grid operation	1	1			
154	Substation digital twin	Improved transmission system maintenance	1		1		
156	LiDAR surveying	Improved inspection of transmission system	1				
161	Smart Wires Smart Valve	Improving real-time grid operation	1				
162	Smart Wires Powerline Guardian	Improving real-time grid operation	1				
163	Power off Save	Improving real-time grid operation	1				
164	Phasor Monitoring System	Improving real-time grid operation	1				
165	TSCNET	Probabilistic risk assessment	1	1	1		
176	3D Decision Support System	Improved inspection of transmission system	1				

Table 1: List of projects in the physical layer

3.4 Projects in the Data layer

Seventy-two projects deal with the data management layer, as can be seen in Table 2. The table shows that only a few projects delivering market platforms consider the data from the physical layer or the system operation layer. This could be interpreted as an opportunity for the R&D development of market tools and platforms, considering the use of the data from the physical grid and the system operation processes.

Project code	Project Name	Use case	Layer				
			Physical	Data	Sys. ops.	Market	Sec. cpl.
1	SPANDEx	Improving real-time grid operation	1	1	1		
2	SAMBA	Asset management using Big Data	1	1	1		
3	EarlyWarn	Predictive maintenance		1	1		
6	SOVN	Market model for future investment decisions	1	1		1	
11	Real-Smart	Circuit protection	1	1	1		
12	Elhub	Metering data hub		1		1	
13	Datahubs in the Nordic Regions	Metering data hub		1		1	
14	Deepmind	Improving real-time grid operation		1	1	1	
19	Power Potential	Adapting system to handle more DER		1	1	1	
22	PV_Live	Intermittent power prediction	1	1			
25	Blockchain balancing pilot	Accessing distributed flexibility sources		1	1	1	1
28	VISOR	Circuit protection	1	1			
37	Control Hub	Accessing distributed flexibility sources		1	1	1	
39	Virtual Workshop	Online collaboration/training	1	1			
41	Orchidea	Online collaboration/training	1	1			
42	Estfeed	Metering data hub	1	1			
53	ANEMOS	Intermittent power prediction		1	1		
65	Derig	Adapting system to handle more DER	1	1	1		
66	Knowfut	Online collaboration/training	1	1			
67	Ownership	Accessing distributed flexibility sources		1	1	1	1
70	EDSN	Metering data hub		1		1	
74	NEW 4.0	Other (multiple)		1		1	1
75	C/Sells	Other (multiple)	1	1			
76	enera	Other (multiple)		1		1	
78	mobile sensoring	Intermittent power prediction		1	1		1
79	Platform Digital Energy World	Understand and evaluate sector-wide digitalisation initiatives	1	1			
82	Gridcast	Intermittent power prediction		1	1		
83	ORKA 2	Intermittent power prediction		1	1		
86	WindNODE	Other (multiple)		1	1	1	
90	Smart Grids	Other (multiple)	1	1	1		
94	Information security	Cybersecurity		1			
95	Wholesale Model	Metering data hub		1		1	
96	Innovative Data Exchange Portal	Data sharing	1	1			
103	Smart Valve	Shorter balancing period services from flexible demand	1	1			
104	Sumo	Improving real-time grid operation	1	1	1		
106	Poste Intélligent	Automation and substation digitalization	1	1	1		
110	éCO2mix	Data sharing		1			
116	IT technology for plant maintenance	Predictive maintenance	1	1			
117	Space4Energy	Improved inspection of transmission system	1	1			
118	Bits&Watts	Other (multiple)		1			

Project code	Project Name	Use case	Layer				
			Physical	Data	Sys. ops.	Market	Sec. cpl.
120	GE WAMS Project	Improving real-time grid operation	1	1	1		
122	Renewable Energy Dispatch Tools	Intermittent power prediction		1	1		
125	Power System Sumulation	Improving real-time grid operation		1	1		
126	BigDataOcean	Intermittent power prediction	1	1			
129	WAMS Project	Circuit protection	1	1	1		
132	MANINT	Improved transmission system maintenance	1	1			
133	Platform for Operation Services	Data sharing		1		1	
135	Data governance	Data sharing		1			
137	NAZA	Accessing distributed flexibility sources		1	1		
138	RINGO	Improving real-time grid operation	1	1	1		
143	Phasor measurement project	Circuit protection	1	1	1		
144	TSO-DSO information exchange platform	Accessing distributed flexibility sources		1		1	
147	Condition-/risk-based maintenance - 2 Big Data	Asset management using Big Data		1			
148	Condition-/risk-based maintenance - 3 Data Analytics	Improved transmission system maintenance		1			
149	Condition-/risk-based maintenance - 4 Imaging	Improved transmission system maintenance	1	1			
151	IoT for Dynamic Line Ratings	Improving real-time grid operation	1	1			
152	Digitalization for workforce management	Improved inspection of transmission system		1			
153	Big Data for PMU/WAMS	Improving real-time grid operation		1	1		
157	Smart Grid Dashboard	Data sharing		1		1	
165	TSCNET	Probabilistic risk assessment	1	1	1		
166	Baltic CoBA Balancing Dashboard	Data sharing		1		1	
168	INTERRFACE	Accessing distributed flexibility sources		1	1	1	1
169	TDX-Assist	Data sharing		1			1
171	XBID	Cross border balancing/redispatch		1		1	
172	MARI	Cross border balancing/redispatch		1		1	
177	OPDE	Data sharing		1	1		
183	Transparency platform	Data sharing		1	1		
184	Network Codes application tool	Data sharing		1			
185	Common Grid Model	Data sharing		1			
186	Terre	Data sharing		1	1	1	
187	IGCC	Data sharing		1	1	1	

Table 2: List of projects in the data layer

3.5 Projects in the System operation layer

Many of the digitalisation projects (56 projects) are deployed for system operation purposes. This emphasises the importance of this layer and how it functions as a bridge between the physical layer and the market layer. Ultimately, system operation is the backbone for the further development of the Digital Grid.

At EU level this is remarkable, and demonstrates that the current regulation and the implementation of the network codes are key drivers.

Project code	Project Name	Use case	Layer				
			Physical	Data	Sys. ops.	Market	Sec. cpl.
1	SPANDEx	Improving real-time grid operation	1	1	1		
2	SAMBA	Asset management using Big Data	1	1	1		
3	EarlyWarn	Predictive maintenance		1	1		
11	Real-Smart	Circuit protection	1	1	1		
14	Deepmind	Improving real-time grid operation		1	1	1	
19	Power Potential	Adapting system to handle more DER		1	1	1	
20	EFCC	Improving real-time grid operation	1		1		
23	Virtual Synchronous Machine	Adapting system to handle more DER	1		1		
25	Blockchain balancing pilot	Accessing distributed flexibility sources		1	1	1	1
37	Control Hub	Accessing distributed flexibility sources		1	1	1	
38	Demand Respone Pilots	Accessing distributed flexibility sources	1		1	1	1
49	EntreREDes	Online collaboration/training			1		
53	ANEMOS	Intermittent power prediction		1	1		
65	Derig	Adapting system to handle more DER	1	1	1		
67	Ownership	Accessing distributed flexibility sources		1	1	1	1
68	Gredor	TSO/DSO interaction for coordinated control of flexibility			1		
69	Dynamic dimensioning of the FRR needs	Lowering cost of procuring reserves			1		
72	Blockchain as virtual power station	Virtual power plant for batteries	1		1		1
73	The New Motion	Accessing distributed flexibility sources			1		1
78	mobile sensoring	Intermittent power prediction		1	1		1
82	Gridcast	Intermittent power prediction		1	1		
83	ORKA 2	Intermittent power prediction		1	1		
86	WindNODE	Other (multiple)		1	1	1	
87	SwarmGrid	Adapting system to handle more DER			1		
90	Smart Grids	Other (multiple)	1	1	1		
98	EcoGrid EU	Shorter balancing period services from flexible demand			1		
99	FutureFlow	Cross border balancing/redispatch			1	1	
101	STAR (short term active response)	Shorter balancing period services from flexible demand	1		1	1	1
102	Powersave	Shorter balancing period services from flexible demand	1		1	1	1
104	Sumo	Improving real-time grid operation	1	1	1		
105	Sincro.Grid	Adapting system to handle more DER	1		1		
106	Poste Intélligent	Automation and substation digitalization	1	1	1		
108	GARPUR	Probabilistic risk assessment	1		1		
111	iTesla	Probabilistic risk assessment			1		
120	GE WAMS Project	Improving real-time grid operation	1	1	1		
122	Renewable Energy Dispatch Tools	Intermittent power prediction		1	1		

Project code	Project Name	Use case	Layer				
			Physical	Data	Sys. ops.	Market	Sec. cpl.
125	Power System Sumulation	Improving real-time grid operation		1	1		
129	WAMS Project	Circuit protection	1	1	1		
137	NAZA	Accessing distributed flexibility sources		1	1		
138	RINGO	Improving real-time grid operation	1	1	1		
139	Dynamo	Improved power system simulation			1		
143	Phasor measurement project	Circuit protection	1	1	1		
145	Elia blockchain	Improving real-time grid operation			1		
153	Big Data for PMU/WAMS	Improving real-time grid operation		1	1		
154	Substation digital twin	Improved transmission system maintenance	1		1		
155	Fast reserves from Evs	Accessing distributed flexibility sources			1		1
160	Control centre tools	Improving real-time grid operation			1		
165	TSCNET	Probabilistic risk assessment	1	1	1		
167	OSMOSE	Accessing distributed flexibility sources			1		1
168	INTERRFACE	Accessing distributed flexibility sources		1	1	1	1
170	EU_SysFlex	Accessing distributed flexibility sources			1		
174	MAD (Models for Aggregation and Disaggregation)	Intermittent power prediction			1		
177	OPDE	Data sharing		1	1		
183	Transparency platform	Data sharing		1	1		
186	Terre	Data sharing		1	1	1	
187	IGCC	Data sharing		1	1	1	

Table 3: List of projects in the system operation layer

3.6 Projects in the Market layer

There are thirty-two projects addressing the market layer. The majority of projects facilitating and expanding the market layer interact with one or more of the other layers, as shown in the list.

Project code	Project Name	Use case	Layer				
			Physical	Data	Sys. ops.	Market	Sec. cpl.
6	SOVN	Market model for future investment decisions	1	1		1	
12	Elhub	Metering data hub		1		1	
13	Datahubs in the Nordic Regions	Metering data hub		1		1	
14	Deepmind	Improving real-time grid operation		1	1	1	
19	Power Potential	Adapting system to handle more DER		1	1	1	
25	Blockchain balancing pilot	Accessing distributed flexibility sources		1	1	1	1
37	Control Hub	Accessing distributed flexibility sources		1	1	1	
38	Demand Respone Pilots	Accessing distributed flexibility sources	1		1	1	1
59	Digital Transformation	Customer portal for trading guarantees of origin	1			1	
67	Ownership	Accessing distributed flexibility sources		1	1	1	1
70	EDSN	Metering data hub		1		1	
74	NEW 4.0	Other (multiple)		1		1	1
76	enera	Other (multiple)		1		1	
86	WindNODE	Other (multiple)		1	1	1	
91	Callia	Accessing distributed flexibility sources	1			1	
95	Wholesale Model	Metering data hub		1		1	
97	CHPCOM	Standardised (and secure) communication	1			1	
99	FutureFlow	Cross border balancing/redispatch			1	1	
100	Smart Grid Innovation hub	Other (multiple)	1			1	
101	STAR (short term active response)	Shorter balancing period services from flexible demand	1		1	1	1
102	Powersave	Shorter balancing period services from flexible demand	1		1	1	1
133	Platform for Operation Services	Data sharing		1		1	
144	TSO-DSO information exchange platform	Accessing distributed flexibility sources		1		1	
157	Smart Grid Dashboard	Data sharing		1		1	
166	Baltic CoBA Balancing Dashboard	Data sharing		1		1	
168	INTERRFACE	Accessing distributed flexibility sources		1	1	1	1
171	XBID	Cross border balancing/redispatch		1		1	
172	MARI	Cross border balancing/redispatch		1		1	
173	PICASSO	Cross border balancing/redispatch				1	
175	ECCO-SP	Data sharing				1	
186	Terre	Data sharing		1	1	1	
187	IGCC	Data sharing		1	1	1	

Table 4: List of projects in the Market layer

The market is already an important part of today's TSO operations, and is being directly facilitated by the implementation of network codes and transparency obligations. Network codes' implementation will require the development of market places, which will be supported by tools and apps. Moreover, there is a need to cover new functions such as grid congestion management and balancing services from various flexibility to ensure the security of supply and to increase the RES integration.

In addition, the development of the pan-EU single market leads to the development of specific tools for market integration: XBID, COBA, FutureFlow, Mari, Terre and Picasso are covering the different products and time horizons in the market design.

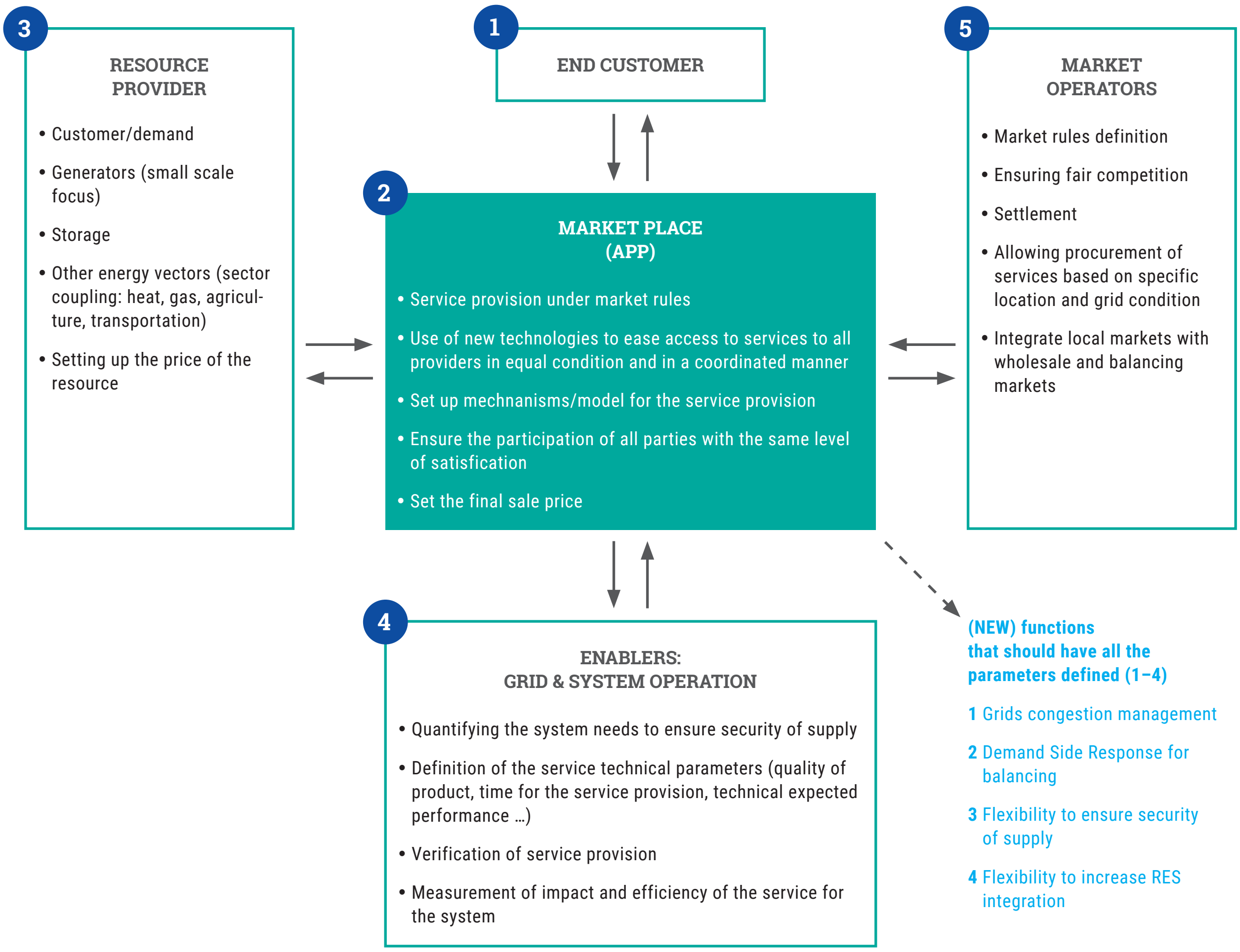


Figure 11: The market place and functions that will require new tools and apps

3.7 Projects in the sector coupling layer

There are projects being undertaken by TSOs, or involving TSOs, which are directly aimed at providing for sector coupling and addressing its challenges.

Many of these are directly concerned with the integration of electric vehicles and/or the electrification of the heat sector, leading to further impacts on the power system but also providing access to flexibility and services from those markets. Most of the projects are also associated with the System Operation layer, where the immediate impact will be first observed and handled.

The projects are largely pilot projects, aimed at exploring the potential for technologies to provide solutions which enable the concept of sector coupling. Although they consider common elements of delivering sector coupling, there are different underlying technologies and market and system designs being explored.

This relatively small set shows that the TSOs are already beginning to deliver the Sector Coupling layer, although more could be done to integrate it with the Physical and Data layers.

Project code	Project Name	Use case	Layer				
			Physical	Data	Sys. ops.	Market	Sec. cpl.
25	Blockchain balancing pilot	Accessing distributed flexibility sources		1	1	1	1
38	Demand Respone Pilots	Accessing distributed flexibility sources	1		1	1	1
67	Ownership	Accessing distributed flexibility sources		1	1	1	1
72	Blockchain as virtual power station	Virtual power plant for batteries	1		1		1
73	The New Motion	Accessing distributed flexibility sources			1		1
74	NEW 4.0	Other (multiple)		1		1	1
78	mobile sensoring	Intermittent power prediction		1	1		1
101	STAR (short term active response)	Shorter balancing period services from flexible demand	1		1	1	1
102	Powersave	Shorter balancing period services from flexible demand	1		1	1	1
155	Fast reserves from Evs	Accessing distributed flexibility sources			1		1
167	OSMOSE	Accessing distributed flexibility sources			1		1
168	INTERRFACE	Accessing distributed flexibility sources		1	1	1	1
169	TDX-Assist	Data sharing		1			1

Table 5: List of projects in sector coupling

3.7.1 Pan-EU dimension and X border

From the set of 100 analysed projects, approximately 32 % embrace the pan-EU or cross-border dimension. It is interesting to note that most of them are R&D EU funded projects. That shows that the European Commission is succeeding in promoting the EU integrated approach and that TSOs are responding positively to these calls.

ENTSO-E has been driving many parts of the digitalisation agenda. Two notable early examples are the TP and the CGM.

Beyond this, ENTSO-E is proposing ECCO-SP – a secure platform for TSOs to exchange multitudinous data, CGM and the TP. It is essential that this platform is robust and highly secure, thus cybersecurity is a cornerstone for each development.

Common Grid Model

The CGM finds its legal basis in three of the network codes: the SOGL (Art. 64), the CACM Regulation (Art. 17) and the FCA Regulation (Art. 18). The CGM, and its data exchange system the Operational Planning Data Environment (OPDE), are a prerequisite for several processes harmonised in the network codes, including coordinated capacity calculation, operational security analysis, outage planning coordination and adequacy analysis.

The CGM compiles the individual grid model of each TSO, covering timeframes going from one year before real time to one hour before real time. TSOs' individual (in most cases, national) grid models are picked up by RSCs, who, following a quality assessment and pan-European alignment process, merge them into a pan-European CGM and feed the merged CGM back into the system.

Project code	Project Name	Use case	Layer				
			Physical	Data	Sys. ops.	Market	Sec. cpl.
6	SOVN	Market model for future investment decisions	1	1		1	
11	Real-Smart	Circuit protection	1	1	1		
53	ANEMOS	Intermittent power prediction		1	1		
65	Derig	Adapting system to handle more DER	1	1	1		
68	Gredor	TSO/DSO interaction for coordinated control of flexibility			1		
77	Migrate	Adapting system to handle more DER	1				
86	WindNODE	Other (multiple)		1	1	1	
91	Callia	Accessing distributed flexibility sources	1			1	
99	FutureFlow	Cross border balancing/redispatch			1	1	
100	Smart Grid Innovation hub	Other (multiple)	1			1	
105	Sincro.Grid	Adapting system to handle more DER	1		1		
108	GARPUR	Probabilistic risk assessment	1		1		
111	iTesla	Probabilistic risk assessment			1		
112	Twenties	Adapting system to handle more DER	1				
118	Bits&Watts	Other (multiple)		1			
157	Smart Grid Dashboard	Data sharing		1		1	
160	Control centre tools	Improving real-time grid operation			1		
165	TSCNET	Probabilistic risk assessment	1	1	1		
166	Baltic CoBA Balancing Dashboard	Data sharing		1		1	
167	OSMOSE	Accessing distributed flexibility sources			1		1
168	INTERRFACE	Accessing distributed flexibility sources		1	1	1	1
169	TDX-Assist	Data sharing		1			1
170	EU_SysFlex	Accessing distributed flexibility sources			1		
171	XBID	Cross border balancing/redispatch		1		1	
172	MARI	Cross border balancing/redispatch		1		1	
173	PICASSO	Cross border balancing/redispatch				1	
174	MAD (Models for Aggregation and Disaggregation)	Intermittent power prediction			1		
175	ECCO-SP	Data sharing				1	
177	OPDE	Data sharing		1	1		
183	Transparency platform	Data sharing		1	1		
184	Network Codes application tool	Data sharing		1			
185	Common Grid Model	Data sharing		1			
186	Terre	Data sharing		1	1	1	
187	IGCC	Data sharing		1	1	1	

Table 6: List of projects in the Pan-EU and X border dimension

Setting up the CGM requires three building blocks: ENTSO-E's OPDE; a physical communication network (PCN); and TSOs' individual grid models (IGM) and methodologies which describe how they should be merged into CGMs.

ECCo SP

ECCo SP – ENTSO-E Communication and Connectivity Service Platform – is a value-added platform enabling communications between business applications. It is currently made of two main functional blocks: EDX and ECP. EDX is a distributed messaging system that allows the transfer of messages between EDX network participants. EDX defines the network configuration, which allows for the introduction of the concept of services, service providers and consumers. ECP provides message delivery capabilities with the following features: (a) security, (b) reliability, (c) integration, (d) transparency and (e) portability.

OPDE

OPDE is the ICT solution supporting the process delivering the European electrical CGM. It is designed as a distributed application made of a set of applications communicating together through EDX/ECP messaging. This communication (connectivity layer) will be further enhanced with semantic enrichment following international standards (e.g. IEC 61698-100) to create plugins of various data exchange protocols and allow for a plug-n-play connection of more assets on the platform.

Electronic Highway

The electronic highway is a meshed router network (separate from the internet) connecting the European TSOs, and is designed for real-time and non-real-time data exchange between them. Today, the electronic highway covers the fields of the exchange of real-time data and non-real-time data related to grid operation, and to market. The Electronic Highway is outdated and will need to be upgraded to accommodate new data and messages requirements.

ENTSO-E Awareness System (EAS)

Launched in April 2013, and building on decades of TSO cooperation, the EAS is an important collaborative tool for ENTSO-E TSO members across 35 European states. The EAS allows TSOs to monitor real-time information on the transmission systems across Europe, and react quickly with assistance or system measures if an area appears to be under stress, both in the prevention and resolution of disturbances. All TSOs' interconnections are connected and there is an EAS display in the control room.

EDICT – ENTSO-E Disturbance and Incident Classification Tool

EDICT will be a web-based tool for all TSOs for reporting incidents according to the Incident Classification Scale. The project includes data gathering environment for recording incidents through screen-based data entry with predefined standardised choices for details, reporting functions providing the required visualisation and data needed for ICS annual reports, and facilitating the creation of ad hoc reports, charts and graphs.

3.7.2 Building the digital grid

The digital grid that is emerging is creating platforms, enabling the information to be shared among the different sectors. There are only a few tools and platforms enabling this exchange:

Only some tools (most of them in the R&D/Pilot domain) link three or more layers together.

Project code	Project Name	Use case	Layer				
			Physical	Data	Sys. ops.	Market	Sec. cpl.
1	SPANDEx	Improving real-time grid operation	1	1	1		
2	SAMBA	Asset management using Big Data	1	1	1		
6	SOVN	Market model for future investment decisions	1	1		1	
11	Real-Smart	Circuit protection	1	1	1		
14	Deepmind	Improving real-time grid operation		1	1	1	
19	Power Potential	Adapting system to handle more DER		1	1	1	
25	Blockchain balancing pilot	Accessing distributed flexibility sources		1	1	1	1
37	Control Hub	Accessing distributed flexibility sources		1	1	1	
38	Demand Respone Pilots	Accessing distributed flexibility sources	1		1	1	1
65	Derig	Adapting system to handle more DER	1	1	1		
67	Ownership	Accessing distributed flexibility sources		1	1	1	1
72	Blockchain as virtual power station	Virtual power plant for batteries	1		1		1
74	NEW 4.0	Other (multiple)		1		1	1
78	mobile sensoring	Intermittent power prediction		1	1		1
86	WindNODE	Other (multiple)		1	1	1	
90	Smart Grids	Other (multiple)	1	1	1		
101	STAR (short term active response)	Shorter balancing period services from flexible demand	1		1	1	1
102	Powersave	Shorter balancing period services from flexible demand	1		1	1	1
104	Sumo	Improving real-time grid operation	1	1	1		
106	Poste Intélligent	Automation and substation digitalization	1	1	1		
120	GE WAMS Project	Improving real-time grid operation	1	1	1		
129	WAMS Project	Circuit protection	1	1	1		
138	RINGO	Improving real-time grid operation	1	1	1		
143	Phasor measurement project	Circuit protection	1	1	1		
165	TSCNET	Probabilistic risk assessment	1	1	1		

Table 7: List of projects impacting in multiple layers of the digital grid

Six projects cover 4 layers – the sector coupling, market and system operations layers, with half of these also relating to the data layer, and half relating to the physical grid layer. For example, one of the projects is the Ownership project being undertaken by Elia with Enervalis which, although it is linked to the development of the market for flexibility, does not consider the integration of measurements from the field.

Project code	Project Name	Use case	Layer				
			Physical	Data	Sys. ops.	Market	Sec. cpl.
25	Blockchain balancing pilot	Accessing distributed flexibility sources		1	1	1	1
38	Demand Respone Pilots	Accessing distributed flexibility sources	1		1	1	1
67	Ownership	Accessing distributed flexibility sources		1	1	1	1
101	STAR (short term active response)	Shorter balancing period services from flexible demand	1		1	1	1
102	Powersave	Shorter balancing period services from flexible demand	1		1	1	1
168	INTERRFACE	Accessing distributed flexibility sources		1	1	1	1

Table 8: List of projects impacting 4 layers of the Digital Grid Detailed

3.8 Detailed analysis

The identified digitalisation projects have been assessed across a number of different dimensions to demonstrate the range of application across European TSOs. A series of visualisations were used to explore the ~100 digitalisation projects. The following dimensions have been considered:

- geographic scope, including assessment of pan-EU or cross-border application
- digitalisation activity applied to the functions of the TSO
- use of digitalisation technologies
- policy level objective (competitiveness, security, sustainability)
- market-based challenge (cost, new products, improved service)
- technology
- ENTSO-E Digital Grid layer (as defined in Figure 4)
- primary form of digitalisation (i.e. data, machine learning, decision support, automation and control, other)
- technology readiness/research scope
- potential impact on social welfare
- time to completion/adoption
- a larger list of over 30 identified TSO challenges faced by TSOs

These dimensions originated from intense internal discussions and debates regarding the potential ways in which digitalisation projects could be assessed, with the aim of trying to identify areas where further research or investment might be necessary. The dimensions and high-level conclusions from their examination are discussed below.

Challenges caused	Primary technology	TSO Activity	Geographic Scope	Digitalisation types	Scope of project	Time of project completion	Policy level objective	Market based challenges	Particular TSO challenges
Design strategy	AI	Asset Management & System development	Local (Pilot)	New data sources	R & D	< 2 years	Sustainable	Cost savings	RES
Regulatory	Automated control	Market Facilitation	National	Decision support	Pilot	2–5 years	Secure	Improved existing products/ services	New demand
Cost effective-ness	Bid Data	System Operation	Regional (wide area)	Automation	Demonstration	5–10 years	Competitive	New market offerings	Cyber threats
Market design	Blockchain	Asset M, System development & SO	Pan European		Full scale	> 10 years			NEW XB rules
Cybersecurity	Commercial UAVs (Drones)	Asset M, System development & Market							Acceptance
Data quality	Common platform	Market & SO							
Competency	Data analytics	Asset M, System devel-opment & SO & Market							
System quality	Hardware								
Business strategy	Human input/ social media								
Implementa-tion strategy	Imaging								
Sourcing stratgy	Internet of Things								
	Knowledge sharing/ social media								
	Machine learning								
	Other								
	WAMS								

Figure 12: TSO activity intersection.

3.8.1 Geographic reach

The analysis of the geographic reach of the identified digitalisation projects shows that TSOs consider all the dimensions when developing projects: local, national, regional/cross-border and pan-European. Fourteen of the projects are pan-European in scope; there are 25 projects which are regional/cross-border (but not pan-European) in scope, with 61 being national and 28 being sub-national (local) in scope.

The pan-European and cross-border4 dimensions are clear in many of the projects examined.

Detailed analysis, presented in the table below observes that there are a number of regional and cross-border digitalisation initiatives which are driven by EU-level initiatives, such as Horizon 2020, while others are driven by increasing the cooperation at the regional level (RSC) and within the value chain.

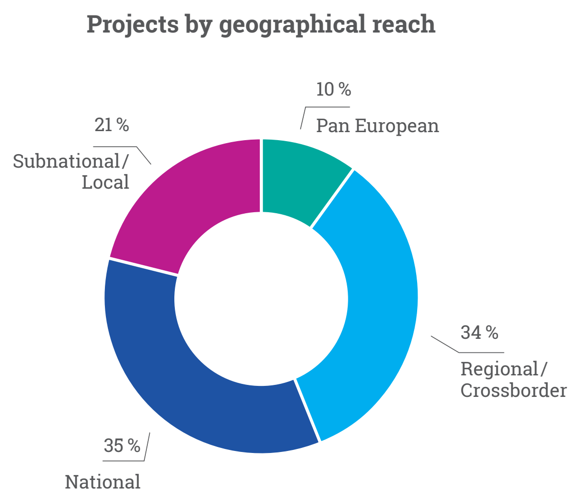


Figure 13: Geographical reach of the digitalisation projects

4 "cross-border" means belonging to more than one European country, whereas pan-European refers to a complete EU coverage.

REGIONAL PROJECTS – COORDINATION WITH DIFFERENT PLAYERS IN THE VALUE CHAIN	REGIONAL PROJECTS – EC FUNDED PROJECTS (H2020 AND OTHER FPS)	REGIONAL PROJECTS – REGIONAL CONTROL CENTERS
1 Promaps (related to Garpur)	1 MERGE	1 SCC – regional control center
2 HDVC Inertia provission	2 INSPIREgrid	2 SEE – Thessaloniki RSC
3 Gridfut	3 RealisGrid	3 Baltic RSC
4 Opfut	4 GridTech	4 Nordic RSC
5 Resman	5 H2020 SOGNO	5 CORESO (RSC)
6 NETZ:KRAFT	6 ANEMOS	6 TSCNET
7 ISEM	7 Powertech	
8 PRIBAS	8 Migrate	
9 SOVN	9 FutureFlow	
10 MAD	10 Sincro.Grid	
11 HILP	11 Optimate	
12 Coordinated Secure Timing for the Smart Grid	12 GARPUR	
13 Real-Smart	13 iTesla	
14 Datahubs in the Nordic Regions	14 Twenties	
15 WAMS Project	15 OSMOSE	
16 Derig	16 EU_SysFlex	
17 Gredor	17 MAD (Models for Aggregation and Disaggregation)	
18 WindNODE	18 INTERFACE	
19 Callia	19 TDX-Assist	
20 Bits & Watts		
21 Smart Grid Dashboard		
22 Baltic CoBA Balancing Dashboard		

Table 9: Characteristics of regional/cross border digitalisation projects

Focusing on the local, national and regional dimensions[5], Figure 14 on the following page shows activity in all three major TSO functions (system operation, market facilitation, asset management) and across three of these three geographical dimensions. As markets are currently regional/cross-border or national, there is little activity to be expected on a local level; similarly, as there are no assets with common cross-border ownership, so there are fewer cross-border digitalisation projects looking at improving asset management. The analysis shows that:

1. The focus for regional projects is centred on system operation functions.
2. Market facilitation tends to focus on the national level, but it is starting to develop the regional and pan-European activity, building the pan-EU market.
3. System operation functions lend themselves to trialling local solutions, so pilot projects are often low regret decisions, which if successful can be scaled nationally.

5 "Regional" refers to pan-European and cross-border projects; "National" refers to projects that are being undertaken on a specific transmission system; "Local" refers to a project that is being applied in a sub-national context. Projects not associated with a specific TSO (e. g. ENTSO-E projects) are excluded.

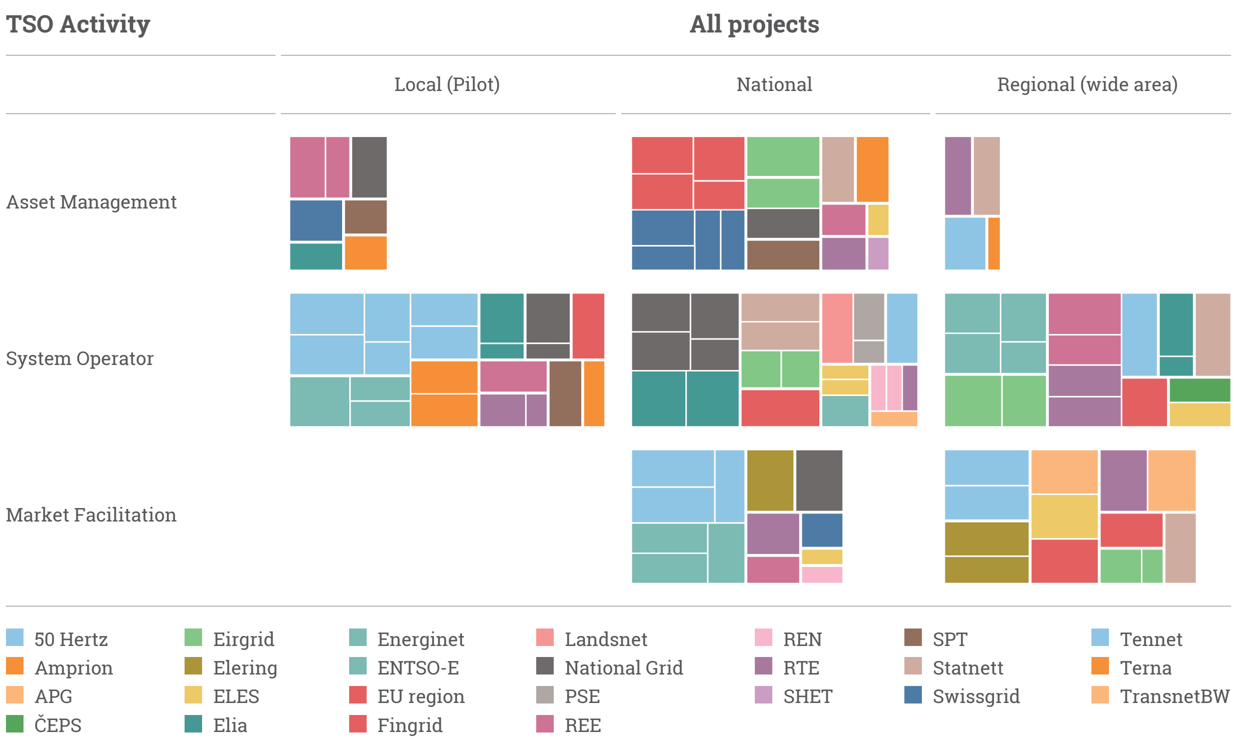


Figure 14: Geographic scope of projects

3.8.2 Digitalisation activity applied to the functions of the TSO

Figure 16 identifies the predominant digitalisation activity (Information/decision support/Automation) in the TSO function (Asset management/System operation/ Market facilitation).

It also indicates the maturity and relevance of each activity.

For example, the total weight of the projects considering new data sources that impact on system operation is the greatest, however this is closely followed by the projects applying decision support to the system operation function. We can see that the automation is not applied at all for the market facilitation and applied in a very limited way for the asset management.

There are only a few projects in the system operation domain using the most advanced technologies, represented by the darkest blue colour. However, the majority of the projects are in a R&D and pilot state. The clear blue in asset management and system operation show that there are many projects using relatively straightforward digitalisation technologies.

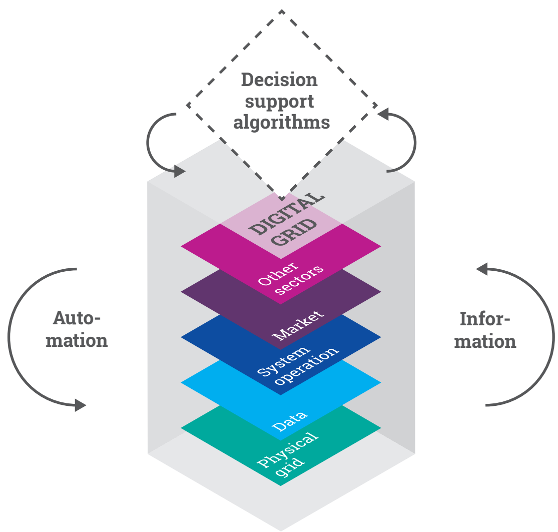


Figure 15: Decision support algorithms influence the Digital Grid

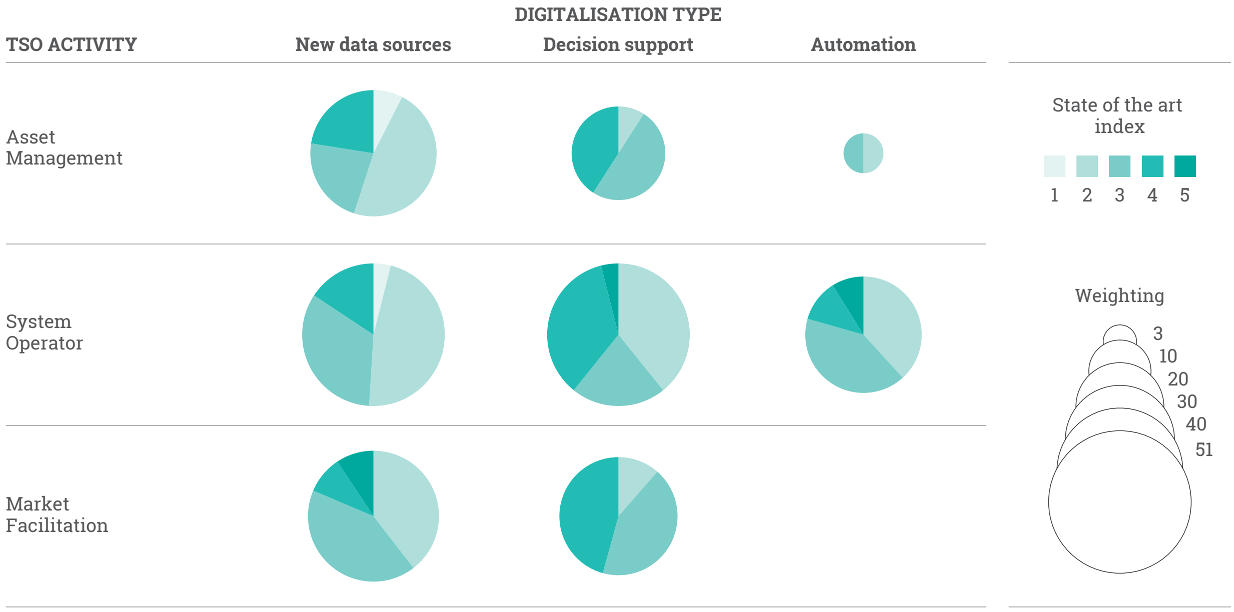


Figure 16: TSO activity intersection

This visualisation also demonstrates that there is considerable activity centred on obtaining and using new data sources across most of the roles of the TSO, which leads to the conclusion that TSOs are providing an increasingly important data-layer within their activities. Such a layer is a vital prerequisite to being able to unlock the wider digitalisation benefits of decision support and automation

In this way, it demonstrates that TSOs are beginning to use decision support and automation within their processes, especially within the System Operation function, to automate the operation of the power grid, and certainly at the local level for providing voltage control, dynamic thermal rating systems, etc. The lack of projects concerning the intersection of Market Facilitation with Automation is not surprising. Since this function would be expected to also be driven by market participants rather than TSOs (e.g. algo-trading), new balancing guidelines and ancillary services will require the greater involvement of TSOs.

3.8.3 Use of digitalisation technologies by TSOs

Figure 17 on the following page shows that over half the European TSOs are actively engaged in digitalisation projects (while also noting that the desktop research is not necessarily exhaustive), across a range of different type of technologies. This provides evidence to support the observation that the Digital Grid is already beginning to emerge.

However it also indicates that many TSOs may not actively be pursuing digitalisation projects, possibly because their regulatory framework incentivises them to seek low-risk, long asset lifetime solutions. Where this is the case, it directly supports the conclusion that regulatory structures need to be adapted to become more dynamic and to integrate the development of the physical grid together with the Digital Grid.

As discussed in section 3 above, a number of the digitalisation projects extend to the cross-border realm. Many of the projects also span across the value chain, involving DSOs, suppliers, consumers, prosumers and producers. There are a number of smaller projects also beginning to handle and facilitate solutions to cross-sectoral issues (e.g. TenneT's Blockchain pilot with Vanderbron, which seeks to use flexibility from EVs).

This graphic plots the projects according to the primary technology, referenced in Figure 12. **Colours reflect** the proportion of digitalisation type (new data sources, analysis & evaluation, automation) of each TSO's projects. **Each column** represents a single TSO. **The first column** demonstrates that the relevant TSO is involved in at least one project that is primarily concerned with Big Data technology, and that the relevant project(s) are involved relatively equally in providing/accessing a new source of data, analysing and evaluating data, and providing some level of automation. **The final column** shows that the relevant TSO has one (or more) project(s) which are primarily concerned with data analytics technologies, which is/are more focused on analysis and evaluation than on automation or new data sources. Some projects involve more than one TSO, but have only been included in the analysis associated with one TSO so as to avoid double-counting.

Figure 17: TSO digitalisation

3.8.4 Digital technologies enhancing TSOs functions

When examining the primary technology or conceptual approach underlying the individual projects to assess where, in the three-role function of a TSO, efforts are being focused (shown in Figure 18), some interesting observations can be made.

› The development of common data/system platforms dominates the market facilitation role of the existing TSO functions. For example:

– Elering's Estfeed project provides a data exchange platform for the consumption data of electricity, gas, a commercial register and forecast data that also allows for third parties to build applications and services based on the data.

– Energinet.dk's CHPCOM project – a cooperation with the Danish CHP owners and market participants to produce a standardised communication platform, develop new business cases, and reduce uncertainty and transaction costs.

– TDX-Assist, an ENTSO-E participated project, is a platform to facilitate scalable and secure information systems and data exchange between TSOs and DSOs.

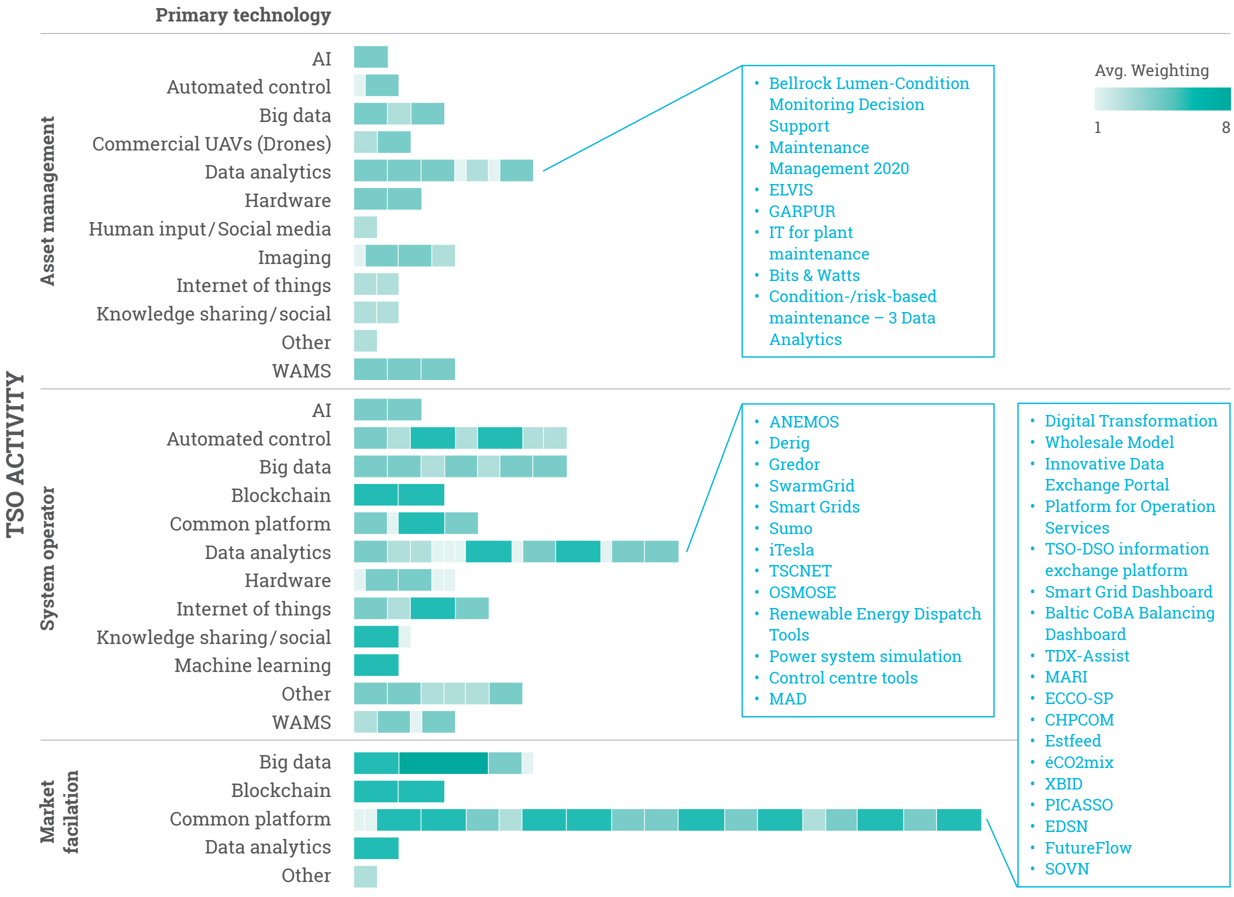
› Data analytics, big data and automation are key areas being invested in to improve system operation functions. For example:

– Eirgrid's Powersave project, which enables an automatic demand response.

– Statnett's Spandex project, which provides new methods and solutions based on real-time data from Phasor Management Units (PMUs), the establishment of an ICT platform and the development of new applications.

– EDP Nester's Power System Sum project, which provides a real-time power system digital simulator as well as advanced grid monitoring and control capabilities for the planning and operation of power grids.

– Within the asset management function, emphasis is placed on data analytics. RTE's Garpur project examines probabilistic power system reliability criteria and transmission system reliability management strategies, on a pan-European basis, for reducing costs associated with n-1 criterion.



The 'other' identification in primary technologies indicates projects for which it is not obvious what the main underlying technology is, or are aimed at developing or investigating non-technology solutions (e.g. cybersecurity) – for example, Energinet.dk's Information Security project.

Figure 18: Technologies for TSO activity.

3.8.5 Digitalisation ambition and R&D&I

The project portfolio is balanced between pilot and full-scale projects.

A further analysis was undertaken of how "cutting edge" typical digitalisation projects undertaken by TSOs are. A subjective assessment of how close to "the state of the art" (referring to the level of technological advancement of the project – the higher the number, the more advanced the underlying technology) each project appears to be, indicates that TSOs have a tendency to invest in established technologies that deliver clear benefits in the near-term, however the analysis shows that TSOs are also involved in the early stages of developing new technologies through involvement in research and development activities. The analysis is shown in Figure 20. The methodology used to build-up the graph uses a combination of project types (R&D, Pilot, demonstration full scale), assigns the Technology Readiness Level or state of the art index to each project, and finally assigns the estimated time to completion.

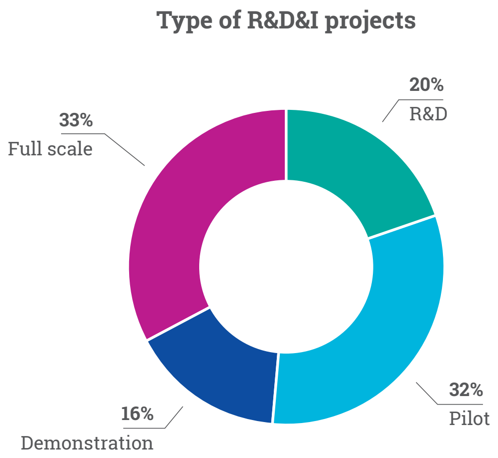
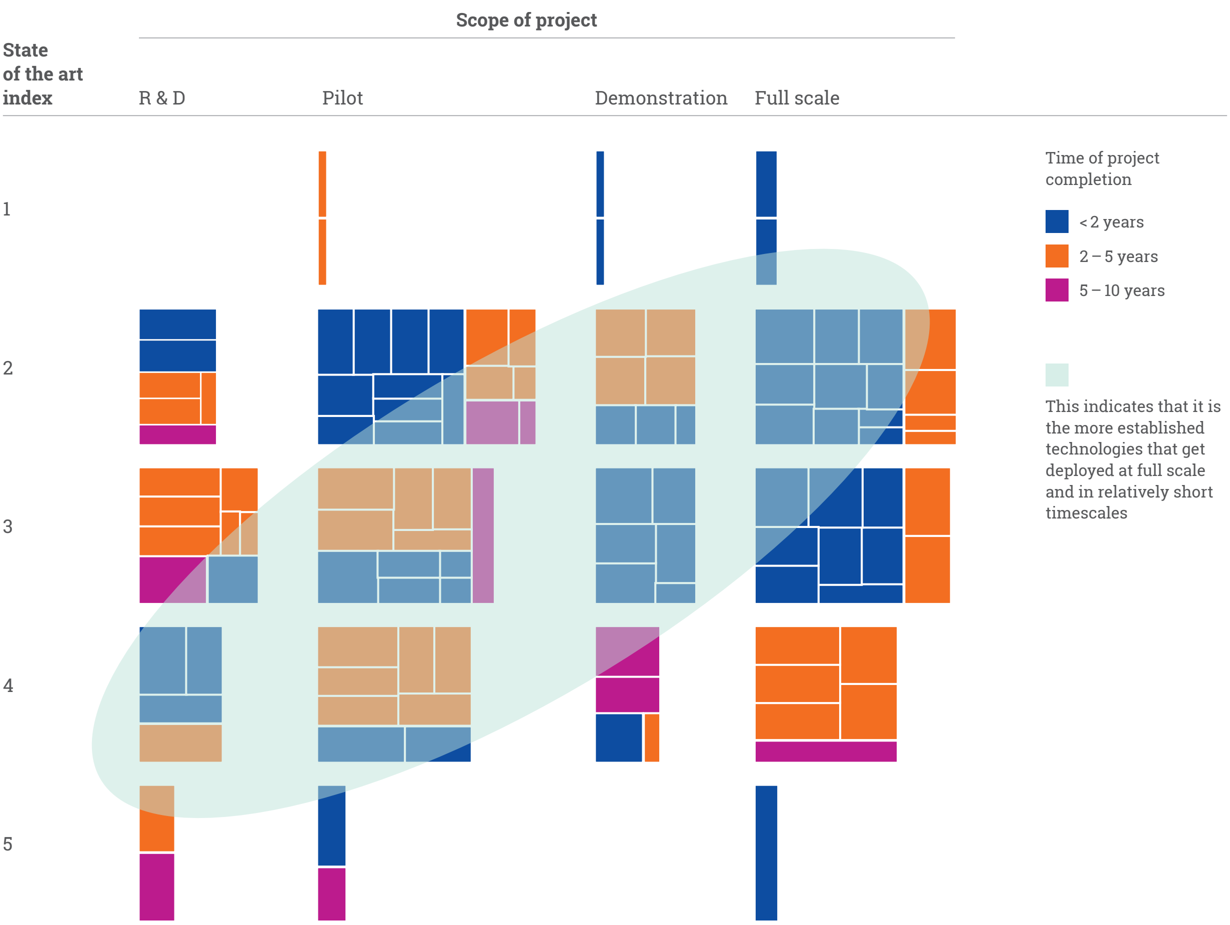


Figure 19: Type of projects

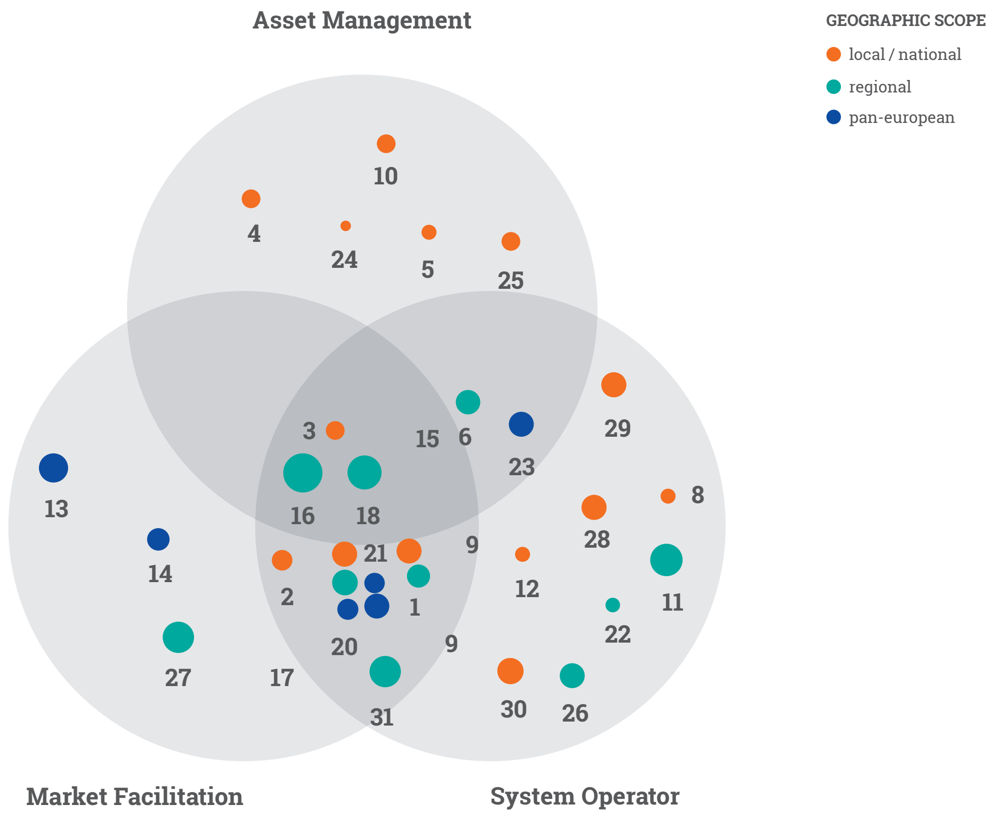


'State of the art' refers to the level of technological advancement of the project – the higher the number the more advanced the underlying technology. It is a simplification of the TRL levels. (TRL1- TRL9). The size of the rectangle reflects the POYRYS subjective weighting of the project, which considers the risk and rewards of the project.

Figure 20: Ambition and research

3.8.6 Impact of projects in layers of the digital grid

Digitalisation impacts the responsibilities of a TSO – asset management, system operation and market facilitation – allowing the boundaries between these responsibilities to be redefined and paving the way for sector coupling. Thirty-one projects have been selected to demonstrate the impact in each of these responsibilities, while highlighting geographical scope. The selected case studies are shown in Figure 21.



PROJECT

1. Callia
2. Power Potential
3. Estfeed datahub
4. Various (drones)
5. MANINT
6. GARPUR
7. Blockchain as virtual power station
8. Dynamic dimensioning of the FRR needs
9. EcoGridEU
10. SAMBA
11. FutureFlow
12. Poste Intelligent
13. Network Codes application tool
14. Transparency platform
15. Common Grid model
16. INTERFACE project
17. TDX-Assist
18. EU_SysFlex
19. XBID
20. MARI
21. PICASSO
22. MAD (Models for Aggregation)
23. ECCO-SP
24. 3D Decision Support System
25. SUMO
26. COBA
27. Swarmgrid
28. Elia – Blockchain for tertiary ...
29. Project The New Motion
30. OSMOSE

Note: The size of marker indicates the (subjective) importance of each project, although these are not to a standardised scale: Local/national means within a country, usually involving a single TSO. Regional means cross-border but not pan-European.

Figure 21: Digital grid integration projects.

3.8.7 Current use cases per country

Digitalisation activities are unevenly distributed across Europe.

Asset management and market facilitation are the main functions supported by digitalisation at national level (left hand panel of figure 22). System operation is the dominant function for cross-border and pan-European projects (right hand panel of figure 22). Further market facilitation and cross border system operation are supported by digitalisation at the pan-European level, through the projects promoted by RSC (not represented in the graphic).

The spread of the projects considering the regional scope and pan-European dimension show the compromise of the whole EU countries in digitalisation projects.

National projects only **All projects**

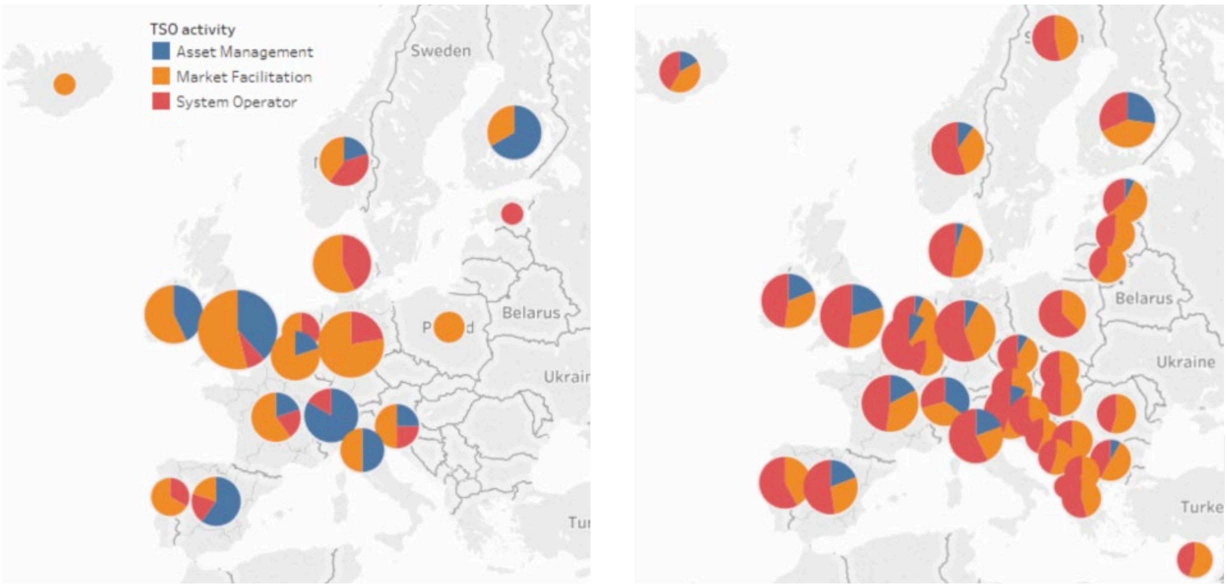


Figure 22: Digitalisation effort per TSO function: geographical distribution studies on policy objectives

3.8.8 Impact of digitalisation in the policy objectives

The following figure illustrates the direct relationship of the impact of digitalisation on the policy objectives: Competitiveness, Security of supply and Sustainability.

Most of the case studies aim to improve the competitiveness of the businesses. The TSOs are acting in a regulated framework and innovation funds are usually not covered by a specific regulation, so it makes sense that most of the case studies aim to increase the competitiveness of the business in order to maximise the revenue.

For each of the selected projects and their use cases, Figure 23 shows the primary policy objective supported (many use cases support more than one policy objective).

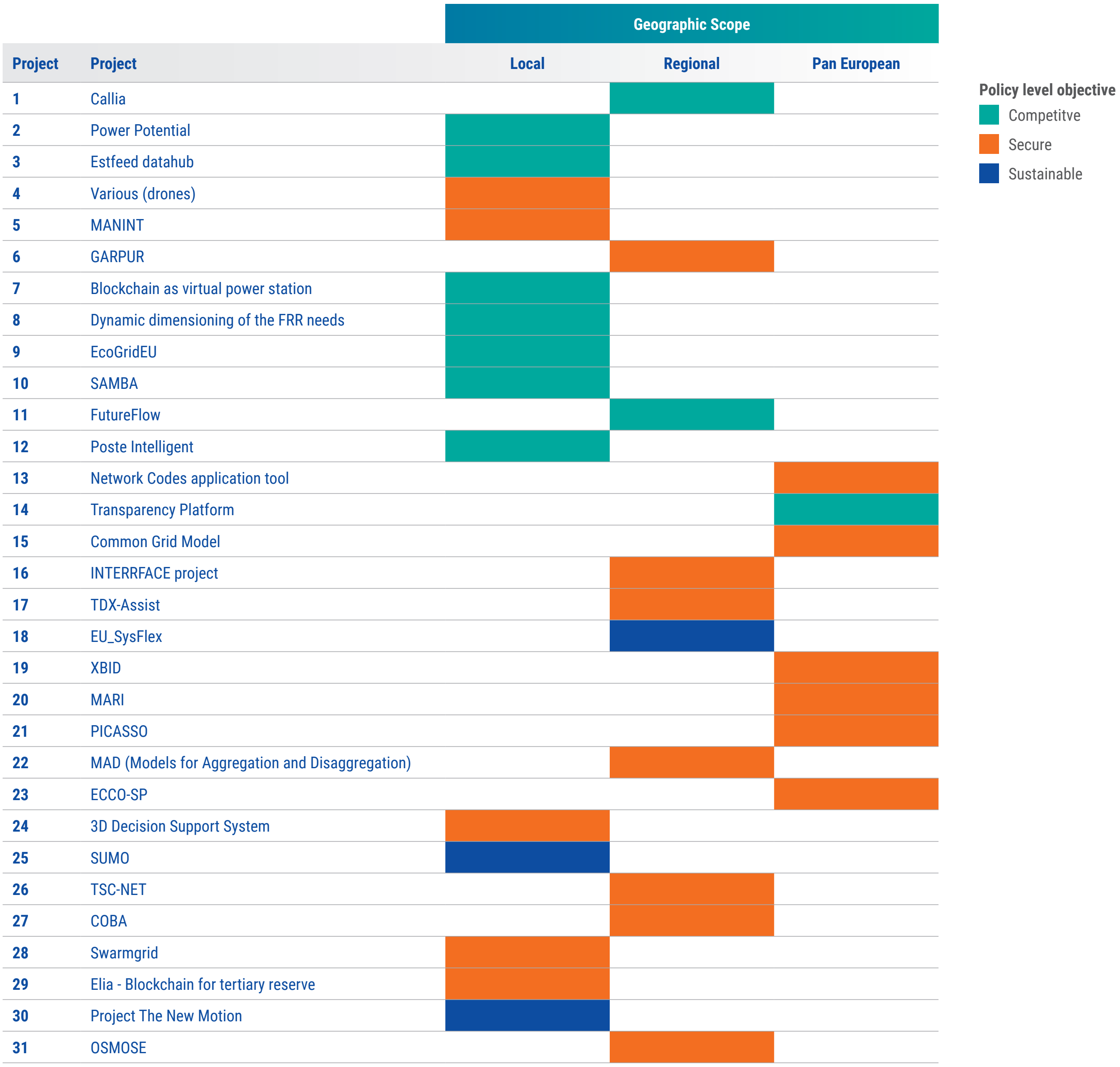


Figure 23: Impact of the 31 case studies on policy objectives

3.8.9 Meeting challenges

TSOs are employing digitalisation projects to meet some of the characteristics presented in section 1. The analysis shown in Figure 24 considers the sum of the weightings of projects at the intersections between policy and market based challenges and the challenges faced by TSOs. It therefore summarises where TSOs are focused on delivering an impact to meet the policy targets.

	Policy level objective/Market-based challenge								
	Competitve			Secure			Sustainable		
Characteristic	Cost savings	Improved existing products/ services	New market offering	Cost savings	Improved existing products/ services	New market offering	Cost savings	Improved existing products/ services	New market offering
Acceptance of transmission build		2		3					
Cost efficiency	41	12	5	14	27		2	2	2
Cyber threats				2	3				
New demands			21	3	4			4	
New XB rules	25	20	25	2	6			8	1
RES	16	3	4	16	19	3	1	26	5

List of challenges:

- Access to distributed resources
- balancing, closer to real-time control
- common cross-border protocols
- communication transmission owners
- coordination with industrial sector
- cost savings
- cross-border trading
- curtailment of RES
- cybersecurity
- decentralisation
- education of users
- EV charging
- growing imbalance volumes
- growing penetration of power electronics
- impact of weather
- acceptance of new power lines
- increased flexibility
- increased intermittency
- investment decisions
- labour intensity, data transparency
- use of new technology
- multi-vendor substations
- new satellite data
- promoting innovation
- risk of outage
- smarter maintenance
- standardising processes with external parties
- using data & smart meter data.

The number of projects at each intersection is included in each cell. The darker the colour, the bigger the product of project weighting and number of projects.

Figure 24: Characteristics of power system, policy objectives and TSOs projects

4. From promise to reality – The need for R&D

To achieve the vision of the Digital Grid, RD investments need to increase substantially. TSOs are already cooperating with DSOs, market players and stakeholders in developing market and system operation platforms and solutions (e. g. Interrface, Coordinet, Gopacs).

4.1 Incentives

Where so incentivised, TSOs invest in new technologies such as digital technologies that increase network capabilities and therefore lower the CAPEX burden associated with the energy transition. The digital technologies have shorter lifetimes than traditional power infrastructure. They also imply changes towards OPEX such as buying services from consumers. The analysis in section 3 demonstrates that although many TSOs are directly incentivised to innovate (e. g. RTE, National Grid, Statnett) and some TSOs are directly instructed to implement specific digitalisation projects (e. g. Elering's ESTFEED), many TSOs are unable to make trade-offs between CAPEX and OPEX. This potentially hinders the effectiveness and ambition of their digitalisation projects.

There is a need to understand how to enable CAPEX-OPEX trade-offs, facilitated by digitalisation and the Digital Grid concept, as this will lead to more efficient outcomes and support the energy transition.

4.2 Developing the Digital Grid: Multi-layer, Multi-player, cross-border, cross-sector digital platforms

Current developments show that progress is registered on each layer and, to an extent, a combination of a couple of layers. However, the Digital Grid aims at integrating all layers, players and geographical scope (from local to regional to European).

There is a need to create cross-border connectivity between data hubs and clear regulation on how to manage them. ESTFEED and ECCoSP projects are making progress in achieving these goals in order to make all the relevant information available at the cross-border and cross-sector to different agents and users.

4.2.1 Unknown challenges

All these developments will need to be complemented by finding solutions for known challenges as well as some unknown ones:

- The complexity of the system will increase. Power systems are becoming increasingly dependent on digital solutions up to the point where the physical system and the IT layer will merge into a cyber-physical system where real-time computing and physical systems interact seamlessly.
- Cybersecurity and Critical Infrastructure Protection need to be addressed. The systems will be ubiquitously accessed; they will rely on different communication infrastructures more, including public internet, and therefore entail new risks.
- Data privacy for consumers as well as secure data access will have to be ensured, and governing rules will need to be developed. Market information and data necessary to operate the system should be managed, applying the neutrality rules.
- Interoperability and rules for the integration of the different platforms will have to be put in place.
- Building new capacities and digitalisation skills in people to manage all the layers (physical, market system operation, and sector coupling) with the IT and data layer.
- Different lifecycle for investments in the physical grid and digital developments:
  1. long term grid planning for lasting infrastructures in the power system
  2. shorter term planning for digital developments which by nature require continuous software and hardware updates and upgrades
- Emergence of new services not yet identified and driven by the Digital Grid concept implementation will have to be assessed and implemented.

4.2.2 Requirements for R&D

There are several areas which require further research and innovation. They can be clustered into five topics: data access and acquisition; data processing, integration of SW and platforms, interoperability and standards; automation; critical information infrastructure protection; and cybersecurity.

Much of the cutting-edge research will produce insight into what might be achievable by wide-scale deployment. However, this research is often isolated to the specifics of the technology or situation that is being examined.

Traditional approaches to system development lead to the creation of clearly defined individual systems. In a power system context, these systems are often designed as closed systems with strictly controlled access and interfacing to ensure security – this hampers the emergence of multi-layer, multi-player, cross-border and cross-sector interfacing. Where there is a need to interface to other systems, interfaces are designed and created based on contemporaneous specifications, which can lead to the need for cascaded re-engineering as the older systems are changed or replaced. Without coordination, there are numerous, disparate and difficult-to-interface systems that emerge, reducing overall system security as well as increasing costs and complexity.

Possible and typified system arrangements are shown in Figure 26

There is, therefore, a need for coordination to ensure that activity within each sector's value chain, across the sectors and across borders does not lead to:

- cumbersome incompatibility (e.g. helping to produce appropriately secure cyber-physical systems);
- lost opportunity due to technology lock-in
- inefficient repetition of study

There is a recognition[6] that many digitalisation projects should or could be considered as projects of common interest (PCI). Being designated as a PCI would enable wider stakeholder engagement and could provide additional funding to ensure that cross-border issues are properly addressed in system design.

There is a need to understand the particular inputs and outputs of digitalisation efforts, and to map these to the benefits and potential benefits available because of the Digital Grid. This will provide further and more detailed insight into the particular needs for digitalisation in different contexts.

6 Mark van Stiphout (DG Energy), Innogrid 2020+ conference, May 2018

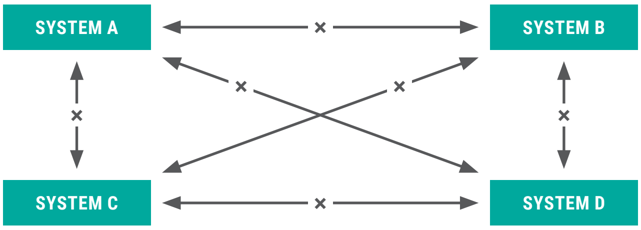
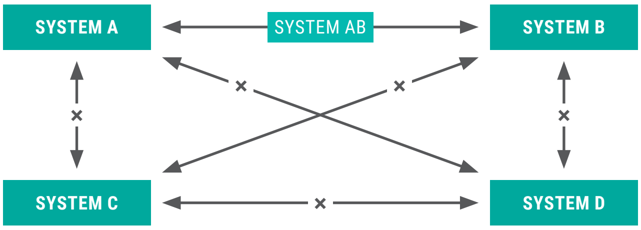
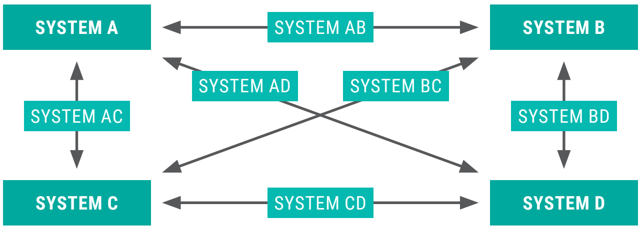
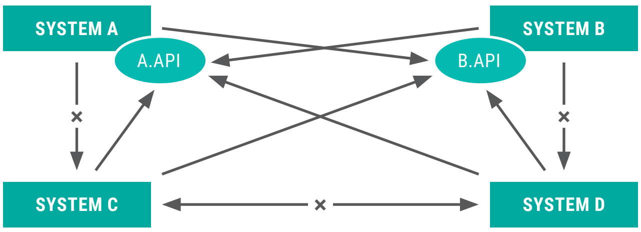
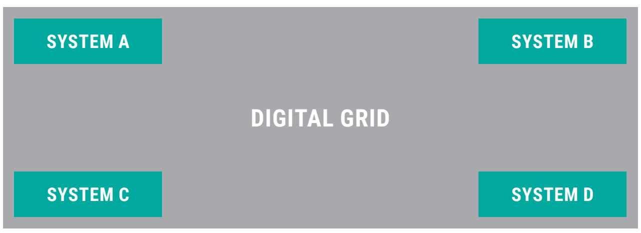
ELEMENT	DIAGRAM	DESCRIPTION
0		Systems developed in isolation – no interfacing ('×' indicates no interface)
1		Specific interfacing developed between two systems
2		…ultimately leading to a very large number of system interfaces
3		APIs can be developed, but this does not avoid the cascade re-engineering problem
4		With a pan-EU, coordinated approach, the emerging Digital Grid (via projects such as ECCO-SP) will at first deliver common secure interfacing and communication
5		…ultimately leading to a system of systems

Figure 25: Typified system interfacing approaches

5. Conclusions

The analyses have demonstrated that not only is there a wide variety of technologies being experimented across a wide geography, but also that TSOs are, collectively, at the cutting edge of the digitalisation agenda. However, further work is required to unleash the potential of an integrated system approach, to release the flexibility available across the system and to enable real time markets coupled with system operation.

Innovation is required to explore and demonstrate the potential of emerging technologies and assess their impact in the performance on the cyber-physical system as well as the impact on the business models.

The development of common data platforms and systems for data and information exchange – in both horizontal (i.e. cross-border) and vertical (i.e. market facilitating) dimensions – **demonstrates the emergence of the Cyber physical system**. This becomes a new core function of TSOs' activities, which is important to facilitate not only the efficient operation of the electricity networks and markets, but also the efficient development of cross-sectoral solutions.

These results inspire a series of key messages and recommendations:

1. Digitalisation is an enabler of the energy transition.
2. We need an appropriate implementation of policy and recognition of costs by regulators, so as to deploy the cyber physical grid.
3. The setting of the new cyber-physical power system, which emerges with the digital grid on top of the physical, requires determined pro-active action on cybersecurity, starting with an appropriated risk assessment. New rules should be developed together with relevant stakeholders.
4. Digital grids and the interoperable associated platforms require research, development and innovation, and therefore appropriate incentives.
5. Multi-layer, multi-player, cross-sector and cross-border data management coordination interoperability rules need to be established.
6. Innovation incentives are required to facilitate the demonstration of new technologies and assess their impact on the Digital Grid construction.

By addressing these, TSOs will provide an even stronger contribution to a successful energy system transformation.

About ENTSO-E

ENTSO-E, the European Network of Transmission System Operators for Electricity, represents 43 electricity transmission system operators (TSOs) from 36 countries across Europe.

ENTSO-E was established in 2009 and was given legal mandates by the EU's Third Legislative Package for the Internal Energy Market, which aims to further liberalise the gas and electricity markets in the EU.

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