

From Legacy to Leadership: Europe's Digital Grid Transformation

Why smart regulation is key to ensuring digital grids deliver value to all stakeholders

Final report

Developed for:

T&D
& europe

Foreword

Europe is facing the challenge of providing Europeans with an affordable, resilient and sustainable energy system. This T&D Europe Digitalisation Study was commissioned to analyse how digital solutions can transform the continent's electricity grid—making it smarter, more flexible, and better equipped to integrate renewable energy and manage new patterns of demand. It explores the regulatory and operational changes needed to unlock the full potential of digitalisation for all stakeholders. The result is a vast amount of expert content that can help policymakers, regulators, network operators, and technology providers to take the right decisions in building the modern electrical system that Europe needs.

This study, conducted by Compass Lexecon, is the result of close collaboration among T&D Europe members, with valuable input and review from experts whose comments and suggestions have helped shape the study's direction and clarity. It is, however, grounded in real world experiences from practitioners, which adds to the richness and strength of the study. The dedication and the efforts of all contributors has ensured a comprehensive and actionable analysis.

Special thanks go to Christiane Mann, chair of the T&D Europe working group Grid Digitalisation, who was the initiator and driving force behind the study, and Hyeonji Hwang and Federica Bottacin, policy advisers in T&D Europe, who have tirelessly supported the project.

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Diederik Peereboom
T&D Europe Secretary General

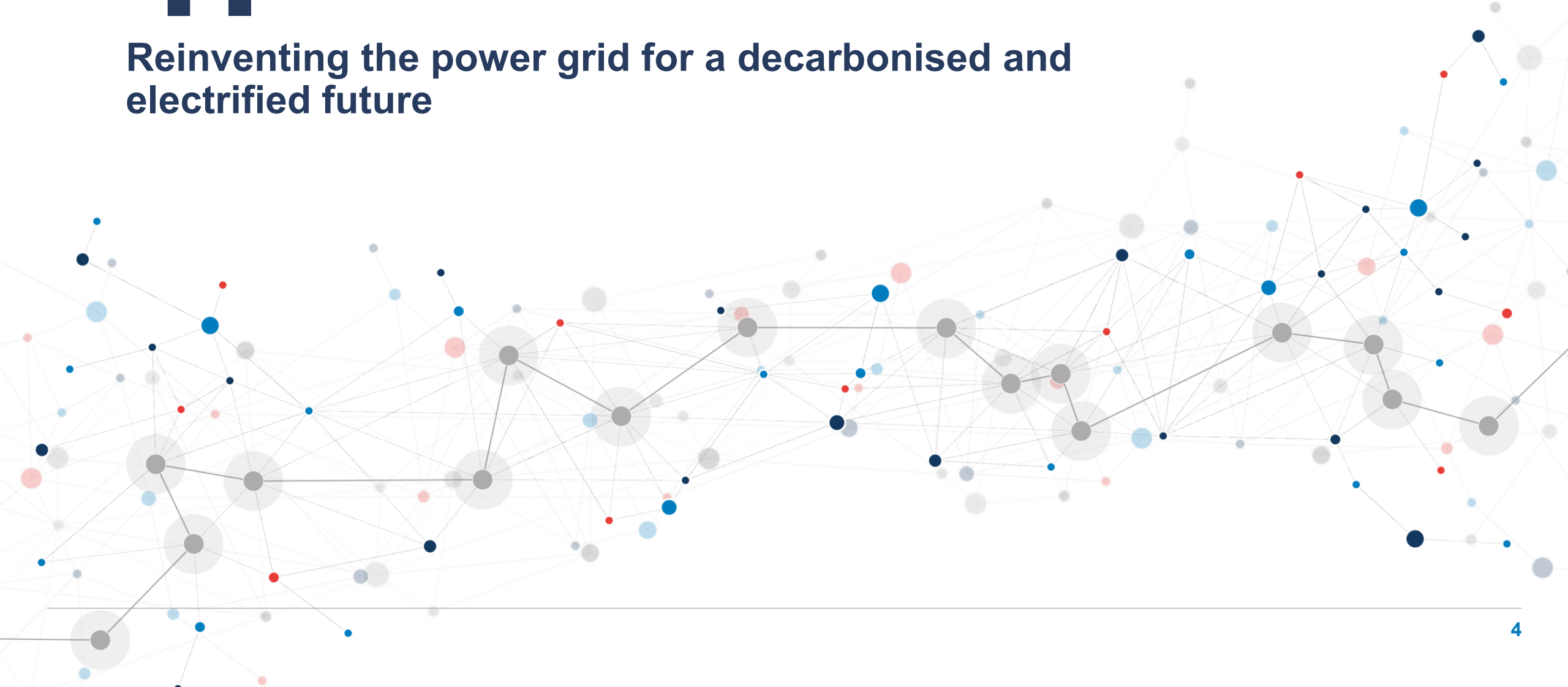


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1.

Reinventing the power grid for a decarbonised and electrified future



Today's power grids were not designed to support the energy transition

Power grids are the backbone of the energy transition. The three dimensions of the Energy Trilemma - resilience, affordability, and sustainability – continue to guide every policy decision

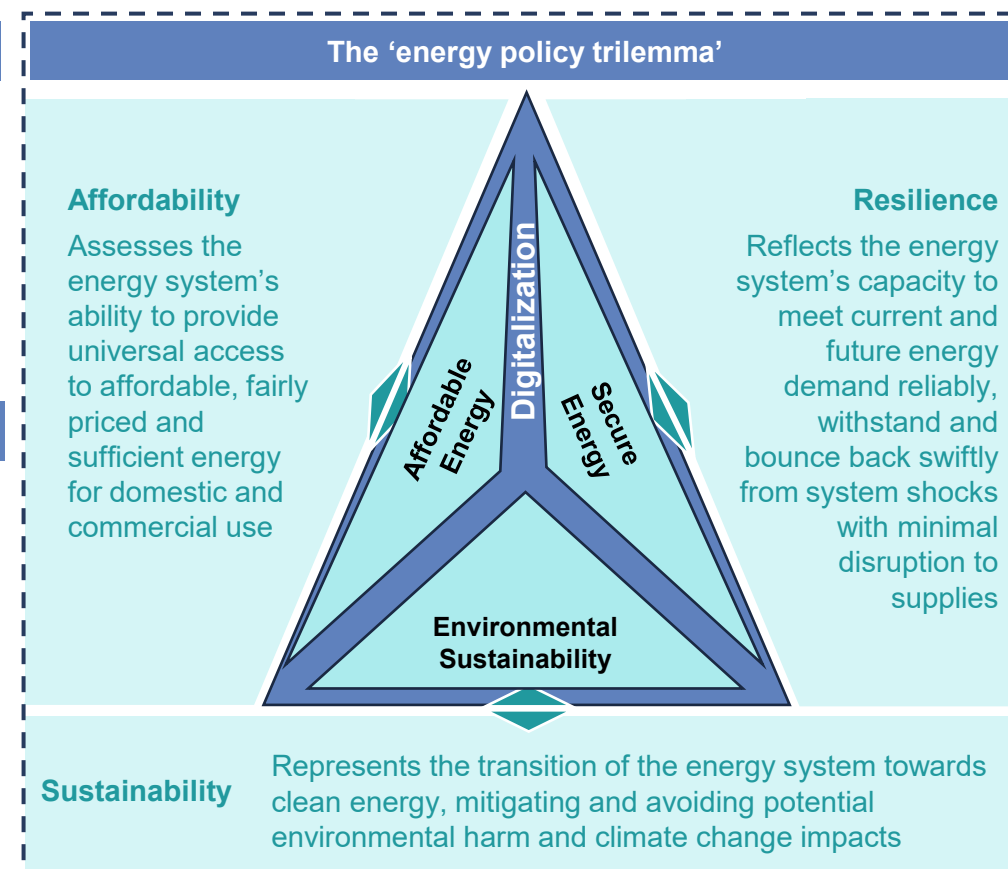
The electricity grid lies at the heart of Europe's decarbonisation

Delivering clean, reliable and affordable energy at scale requires significant investment in a modernized network.

- In 2023, the European Commission launched its *Grid Action Plan*, identifying over €584 billion in investment needs by 2030 to expand and upgrade EU grids. This figure could rise to €1.87 trillion by 2050, according to the European Court of Auditors.^{1,2}
- The *Draghi report* warns that electricity networks must be built 3 to 20 times faster than historical rates to meet Europe's net-zero targets.³

Economic and administrative factors exacerbate the upgrade challenge

- **Supply Chain Impacts:** Grid development depends on critical components, including transformers, cables, and essential raw materials like copper and rare earth elements
- **Permitting Bottlenecks:** Permitting processes for new grid infrastructure are often long and fragmented, many projects taking around seven years to gain approval
- **Skills and Workforce Challenges:** Labor shortage impacts installation capacities
- **Sustainability Requirements:** Grid projects are increasingly subject to strict environmental standards, including requirements for biodiversity protection and climate resilience
- **Financing and Investment Gap:** Achieving Europe's grid modernization goals will require massive investment, particularly DSO often face challenges accessing capital
- **Ecosystem:** New stakeholders are adding to the complexity of the energy business



The existing grid infrastructure is at the core of today's electricity system

The power grid is a unique, complex structure, built over the last 100 years, connecting thousands of stakeholders. The necessary transition is not a single day's job but requires a thorough evolution.

The electricity grid is unique in its physical specifications

- The electrical grid must always be physically balanced to maintain stability.
- Grid operations cannot be turned off, unlike e.g. railway tracks that allow periodic shutdown for infrastructure upgrades.

The European electricity grid is the largest machine in the world – it took 100 years to build

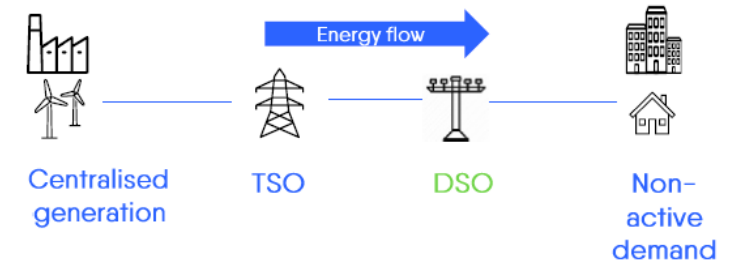
- The grid connects millions of consumers and generators simultaneously.
- A large part of the installed grid infrastructure (c. 40%) is already over 40 years old, reflecting decades of use of traditional grid technologies.
- The European grid infrastructure is interconnected across Member States, adding operational complexity.

Changes to the grid take time – they are often gradual and require detailed preparation

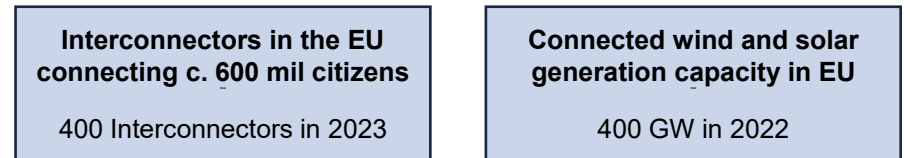
- End customers continuously require electricity, which is a critical aspect of energy security.
- The existing grid infrastructure cannot simply be replaced like upgrading to a new "e-car" or "smart TV."
- Project lead times for transmission lines typically range from 8 to 13 years, including planning, permitting and construction.

Conceptual outline of the existing grid's connection flow.

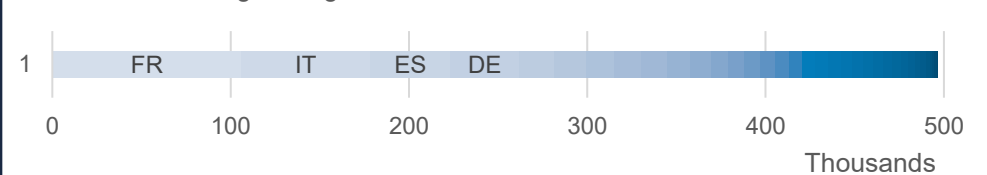
From a uni-directional model...



Selected data signalling the size and relevance of today's grid



Transmission grid length in thousand km



The grid infrastructure must be updated and expanded for the transition

Network capacity must be increased to enable the connection of new demand and supply assets.

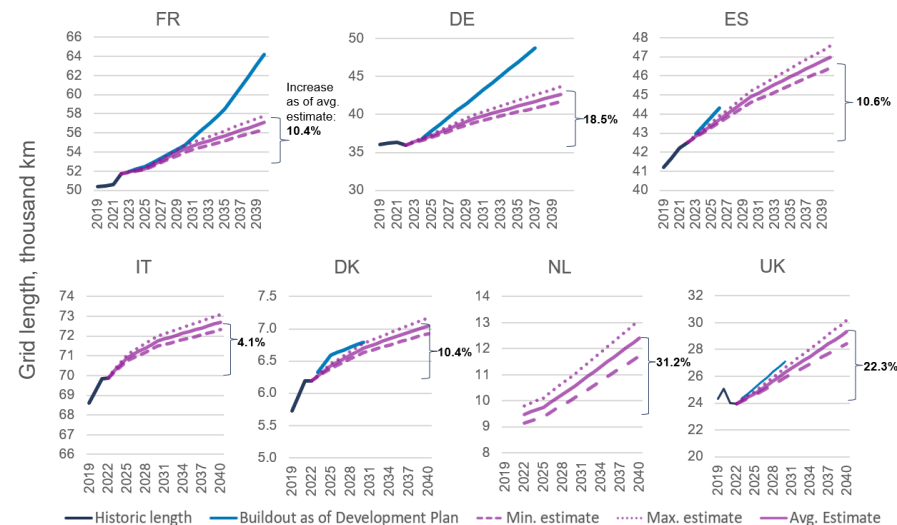
The energy transition significantly impacts the grid infrastructure

- Variability of RES increasingly pose challenges for grid stability and energy supply. Electrification is driving an increase in demand, leading to more connection requests, bottlenecks, and congestion in the grid.
- DER and electrification shift the previously central grid structure towards a more decentralized structure, where feed-in and out are distributed across all voltage levels, Multidirectional electricity flows are increasing.
- New dimensions for demand-side flexibility are driven by new stakeholders, business models, and technologies (both hardware and software).

Economic challenges further exacerbate the challenge to adapt and upgrade the grid

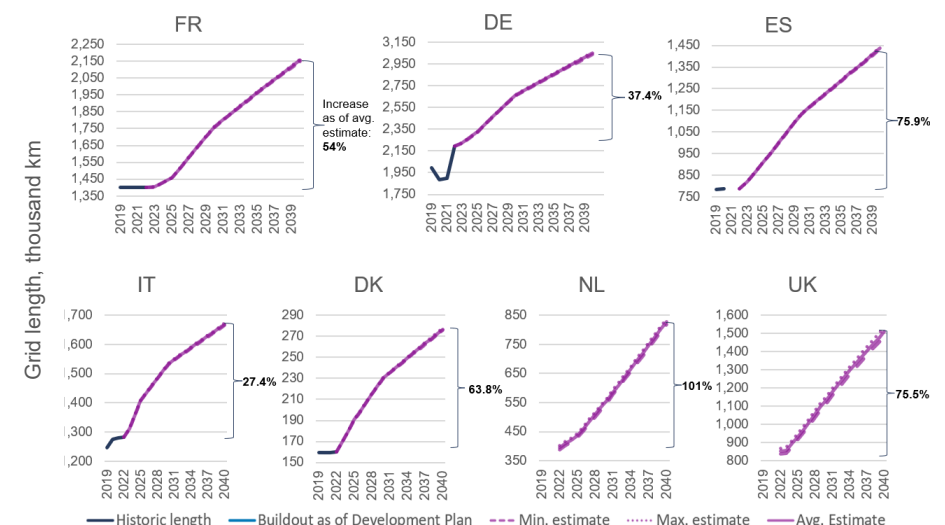
- The aging grid infrastructure requires upgrades to meet modern demands and technological advancements.
- Additional factors include supply chain challenges, extended permitting times, personnel changes and a lack of skilled workers, as well as issues related to financing and sustainability requirements (see next page).

Grid length expansion in selected countries – transmission grid ('000 km)



The increasing share of variable RES (esp. wind, solar) requires enhanced long-distance and cross-border transmission capacity to transport electricity from generation hubs to demand centres, while ensuring system stability.

Grid length expansion in selected countries – distribution grid ('000 km)



The rapid electrification of sectors (e.g., heating, mobility), the decentralization of generation (e.g., solar, batteries) and bi-directional power flows demand significant reinforcement of distribution networks.

Economic and administrative factors exacerbate the upgrade challenge

Challenges include supply chain constraints, lengthy permitting times, personnel changes and insufficient skilled workers, as well as issues related to financing and sustainability requirements.

Supply Chain Impacts

- Grid development depends on critical components, including transformers, cables, and essential raw materials like copper and rare earth elements
- Many of these components are sourced from outside the EU, creating vulnerabilities due to geopolitical tensions and market disruptions.
- Manufacturing and logistics delays, compounded by the aftermath of the pandemic and international developments, continue to strain project timelines.

Permitting Bottlenecks

- Permitting processes for new grid infrastructure are often long and fragmented, many projects taking around seven years to gain approval.
- Differences in permitting procedures across EU member states complicate coordination, particularly for cross-border transmission projects.
- A lack of administrative capacity and digitalisation in some regions further contributes to inefficiencies and delays. Files cannot be exchanged in a digital format.
- Insufficiently harmonized DSO technology **specifications** cause fragmentation and additional resources to adjust e.g. the requirements for compact substations

Skills and Workforce Challenges

- Labor shortage impacts installation capacities
- A significant portion of the current grid workforce is nearing retirement, potentially impacting institutional knowledge and technical expertise.
- The industry is struggling to attract and retain new talent, particularly in specialized roles such as high-voltage engineering and grid planning.
- Rapid technological changes are creating demand for new skillsets, but education pipelines have not kept pace with these evolving needs.

Sustainability Requirements

- Grid projects are increasingly subject to strict environmental standards, including requirements for biodiversity protection and climate resilience.
- Developers must now conduct comprehensive environmental impact assessments, which can extend project timelines.

Financing and Investment Gap

- Achieving Europe's grid modernization goals will require massive investment, estimated at €584 billion by 2030.
- Particularly DSOs often face challenges accessing capital.
- There is a strong need for clear policy direction and stable regulatory frameworks to unlock private investment and enable long-term planning.

Current infrastructure cannot deliver the required functionalities

Using only conventional grid solutions will be limited at some point, because of a) the limited speed of network expansion that would allow; b) the new targets for the energy sector and new task for the grid.

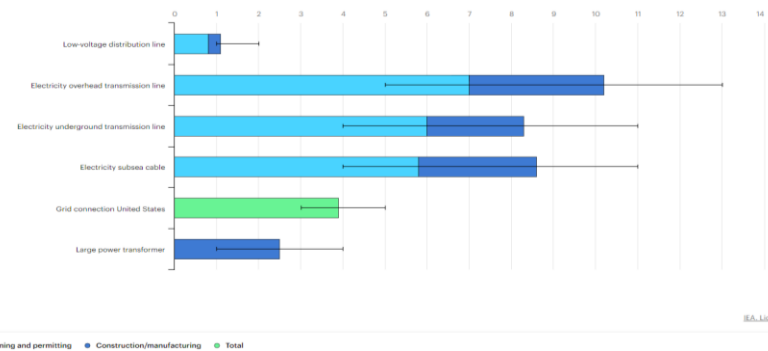
Expanding the grid as done historically is not feasible with the speed and at the scale required due to several challenges

- Permitting processes are slow, delaying grid expansion.
- Supply chain challenges further complicate expansion efforts.
- Costs of expansion are extremely high.

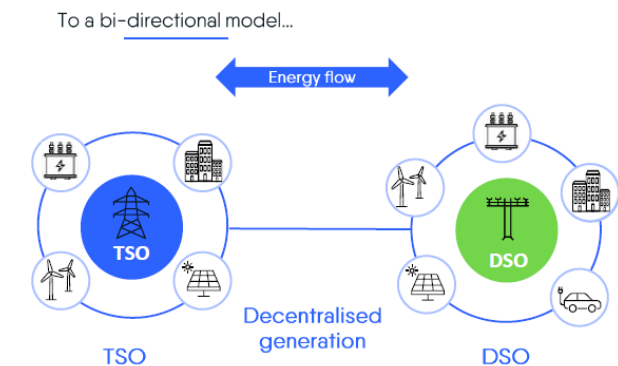
Grids will become larger, more distributed, and more inter-connected, but the historically high reliability of networks should be maintained

- Peak load occurs rarely which implies that lines are typically utilized at a reduced rate. Estimates range between 20-30% and 60-70% of their capacity, depending on grid and usage patterns. This creates a substantial opportunity to better distribute the load and enhance the efficiency of the existing grid infrastructure. Also, PV/wind farm connections may not need the same level of availability as required in a city.
- Historic achievements regarding security of supply and resilience must be maintained, irrespective of changes to the capacity mix, the types of demand, and innovation facilitating the transition. License conditions prescribe security of supply standards and connection speeds.
- Electricity flow will become increasingly bidirectional due to decentralised generation assets, including power flows between TSOs and DSOs. This implies rethinking how grid communicate and coordinate with other network and connected assets.

Average Lead Times to Build New Electricity Grid Assets, Europe & U.S., 2010 - 2021



Conceptual presentation of tomorrow's grid planning and operation



New stakeholders are adding to the complexity of the energy business

Integrating new technologies requires adapting communication protocols and market structures – but may facilitate the use of innovative solutions and new capabilities that may be aligned with network needs.



New technologies require technical change for coordination

- The grid must interact with a broader range of distributed technologies including RES, EV charging, battery storage, and smart home devices. This **increases the complexity** of real-time coordination and planning.
- New **coordination protocols** and digital infrastructure are essential to manage these decentralized technologies efficiently.
- Energy **data structures** must evolve to support real-time communication, seamless integration, and interoperability across varied devices and platforms.
- Advanced **forecasting, automation, and energy management systems** are required to optimize grid utilization and integrate demand-side resources effectively.



Market design must be adapted to include new stakeholders

- Historically, consumers became prosumers (consuming + generating). Now, the rise of **flexumers** – participants providing flexibility – is reshaping grid dynamics.
- These engaged stakeholders require streamlined **access to markets** and grid services. Current market frameworks often lack incentives or mechanisms for active participation by flexumers.
- Residential and industrial flexumers have different requirements; industrial flexumers typically have larger individual potential per stakeholder.
- There is a need to **develop adequate markets** and value streams for flexibility, congestion, and demand response – reflecting not just TSO level dynamics, but also local grid conditions at the DSO level.
- Electricity markets remain heavily regulated, but new entrants (e.g., smart buildings, energy communities) operate in **less-regulated environments**, demanding a hybrid regulatory approach that encourages innovation while maintaining grid reliability.

New technologies and stakeholders present a massive opportunity to support grid operation and the wider energy system – their successful integration relies on the deployment of digital network capabilities and adequate market structures

Digitalisation can help manage the complexity of future grid operations and unlock more capacity from new and existing network infrastructures

Networks are a core part of the transformation of the power system and need to handle rising complexity.

1 Systemic Drivers of Power System Transformation

	Description	What it means for the grid
Decentralisation	Electrification and distributed generation move most of the generation and flexibility providers to the lower voltage levels of the grid – making a formerly highly centralized system highly distributed.	New approaches to grid management and grid expansion are needed to address new topology and rapidly changing flows on system, and more complex network planning and operation
Rapid expansion of renewable energy	A system increasingly depending on weather conditions will entail highly dynamic patterns of generation and prices.	
New and more stakeholders	Electrification of heating, transport, and industrial processes means that new stakeholders need to be integrated into the system for the first time. Load patterns will also evolve with more stakeholder engagement (flexumers) and sector coupling.	
(New) regulatory framework conditions	Sustainability goals lead not only to new reporting requirements but also tight alignment between the stakeholders	

2 Related challenges and constraints

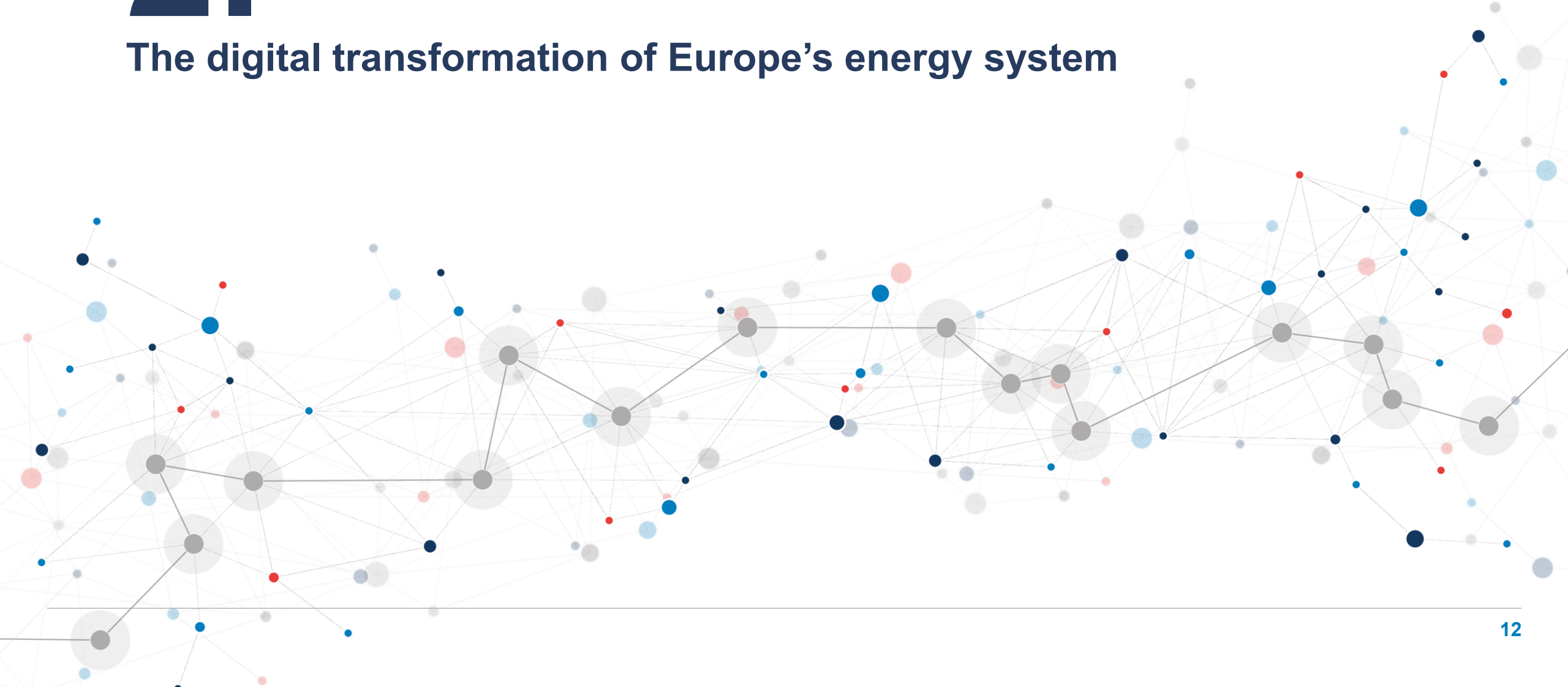
	Description
Supply chain impacts	Component availabilities impact supply chain
Skill and labour constraints	Skill, knowledge, and labour constraints limit available qualified workforce
Continued operation	Continued operation with constant electricity supply throughout the transformation creates challenges
Administrative burden	(Manual) reporting requirements; lack of digital file exchange

Digitalisation is more than just a support tool – Digitalisation impacts the whole electrical system, from individual processes, to the way the grid can be managed, right up to facilitating the transition from prosumers to flexumers.

Digital Grid Technologies have the potential to address the requirements / mitigate the challenges

2.

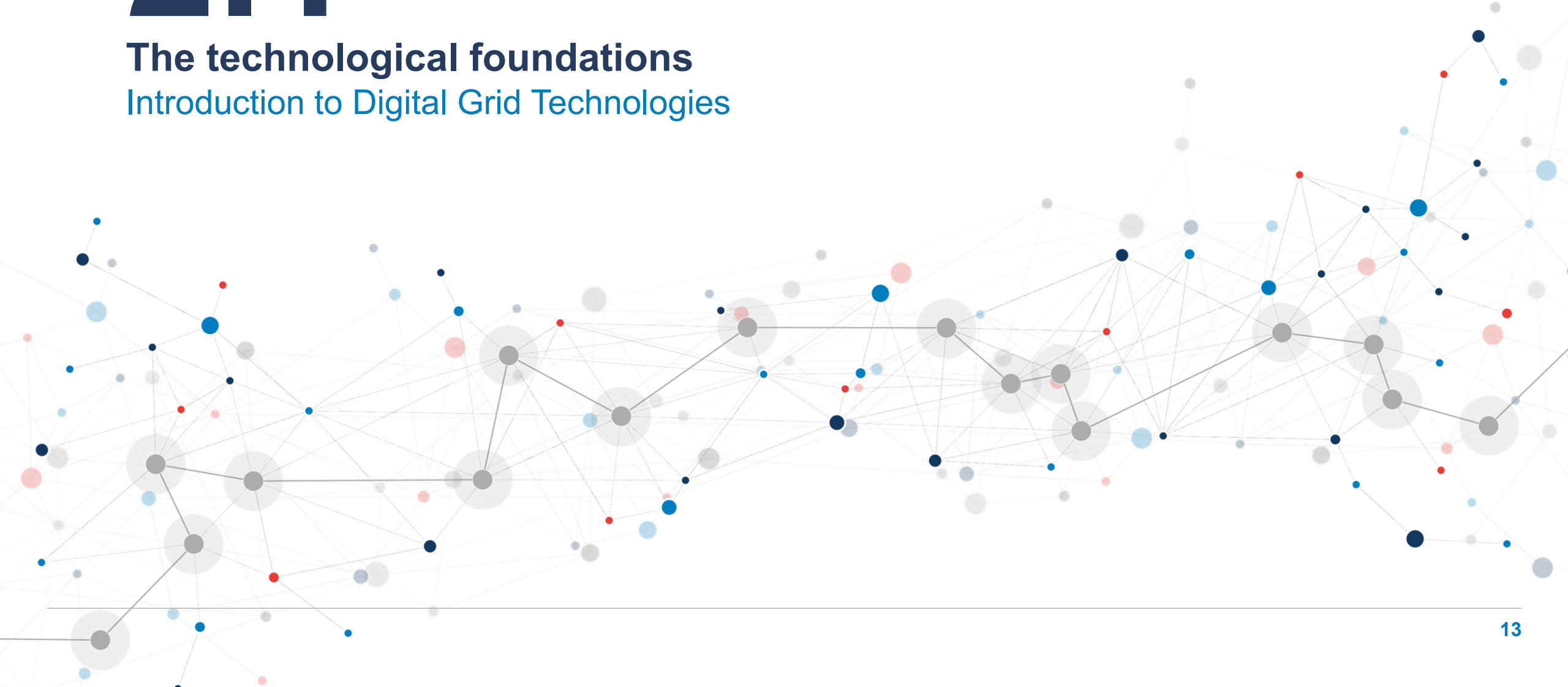
The digital transformation of Europe's energy system



2.1

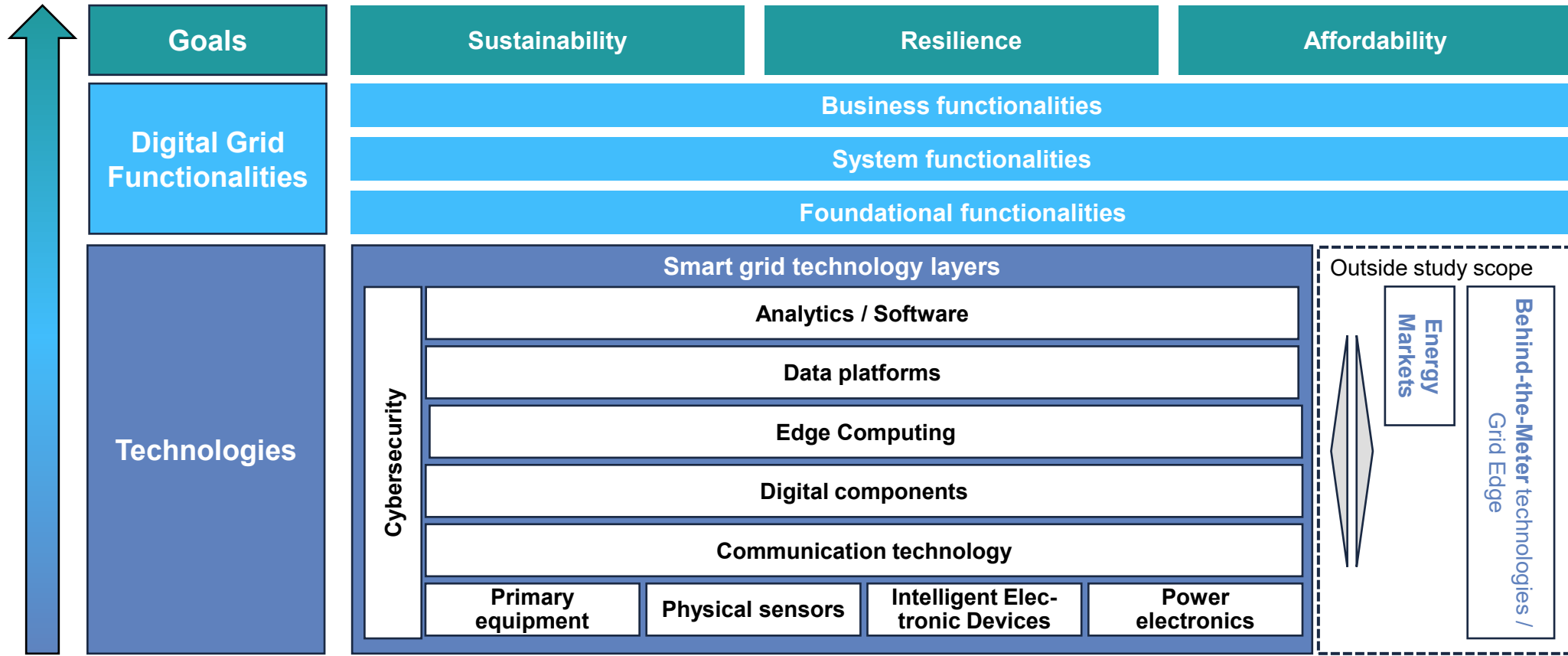
The technological foundations

Introduction to Digital Grid Technologies



Technological fundament of the digital grid of the future

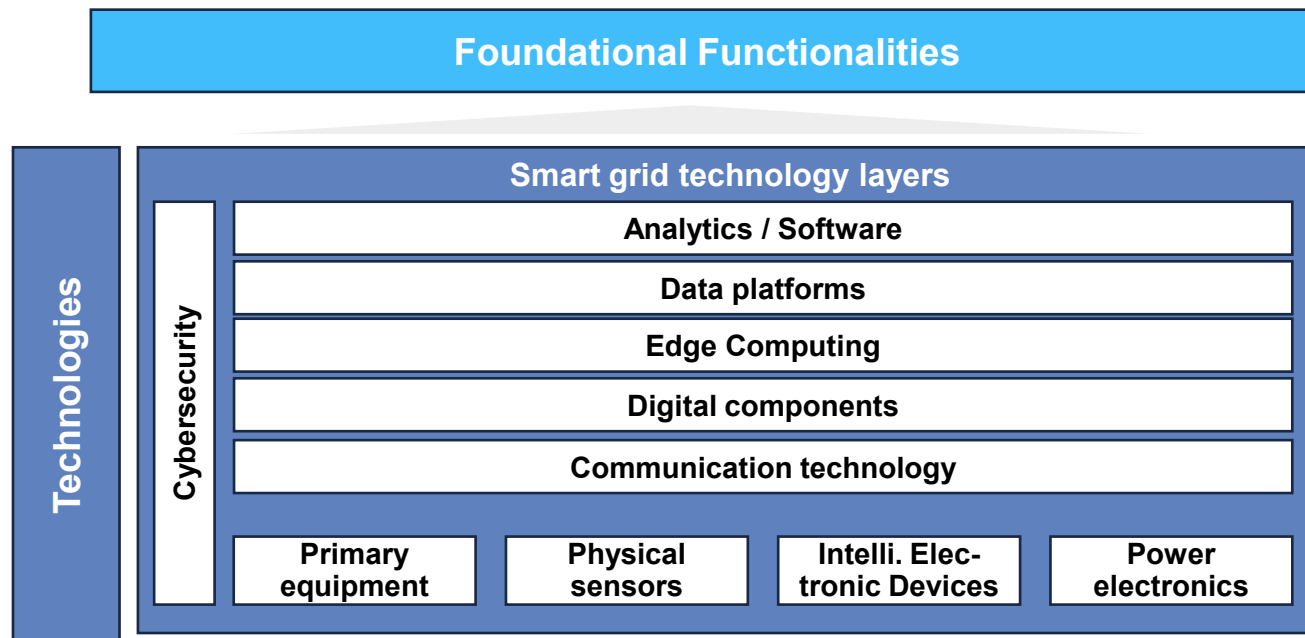
Digital grid functionalities serve important role in achieving goals of the energy trilemma. They are enabled by a combination of the technologies in the smart grid technology stack



Simplified schematic; will differ per TSO / DSO

Digital Grid Technologies (DGTs) allow for a more effective use of grid infrastructure

Grid digitalisation needs holistic implementation across all layers and respective technologies



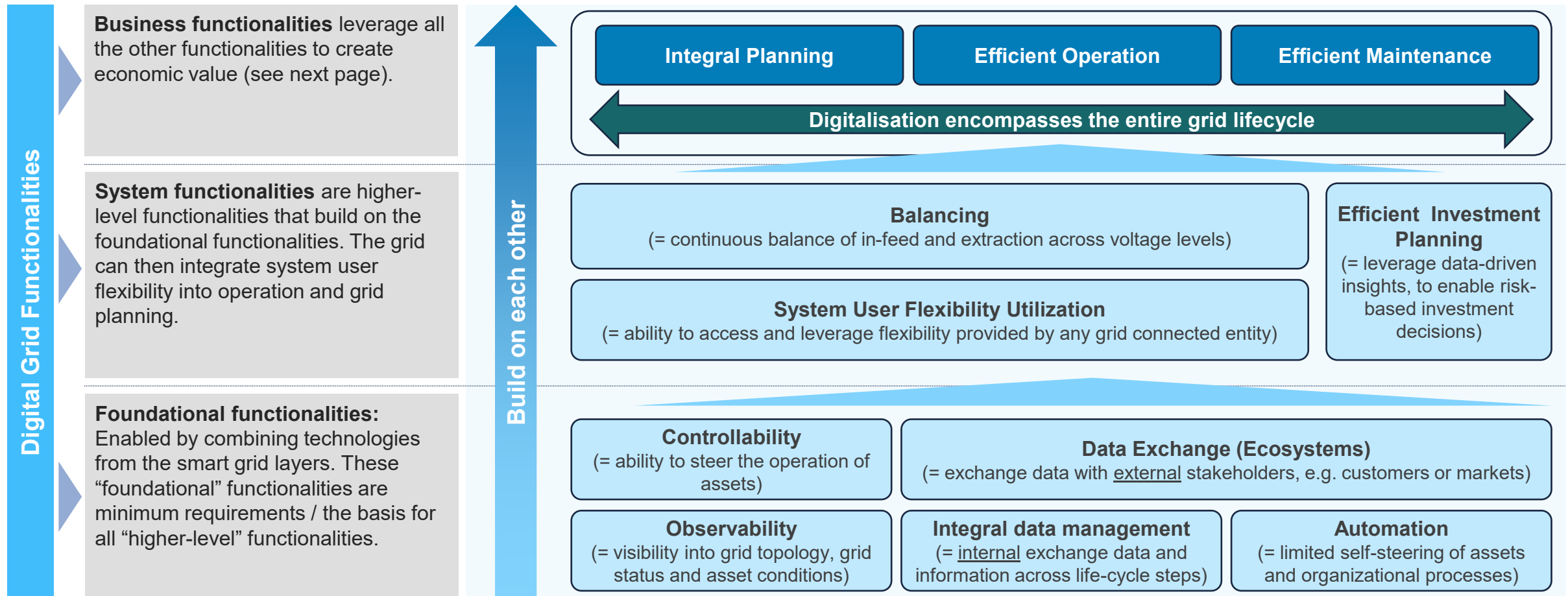
“**Smart grid technologies**” are the result of **smart layering of traditional and digital technologies**

Example: e.g. “passive” transformer/ switchgear + IED + sensor + communication = digitized transformer / switchgear (provides data) + connectivity = monitored transformer + analytics = smart transformer / switchgear

- There is **no single “silver bullet”**; grid digitalisation requires a mix of hardware and of software solutions.
- **Holistic implementation** across all layers and integration with respective technologies is key.
- Grid digitalisation begins with establishing a **technology stack that enables foundational functionalities**. These are prerequisites for enabling higher-level system and business functionalities like flexibility utilization and system balancing.
- Digitalisation must be treated as an **integral part of grid evolution**, not an add-on.
- Success depends on a **system-wide perspective** that includes lifecycle views, sector coupling and cross-border harmonization to ensure scalability, interoperability, and efficiency. It must include permitting and procurement processes.
- Software systems must **integrate seamlessly** with all layers and underlying technologies for optimal performance.

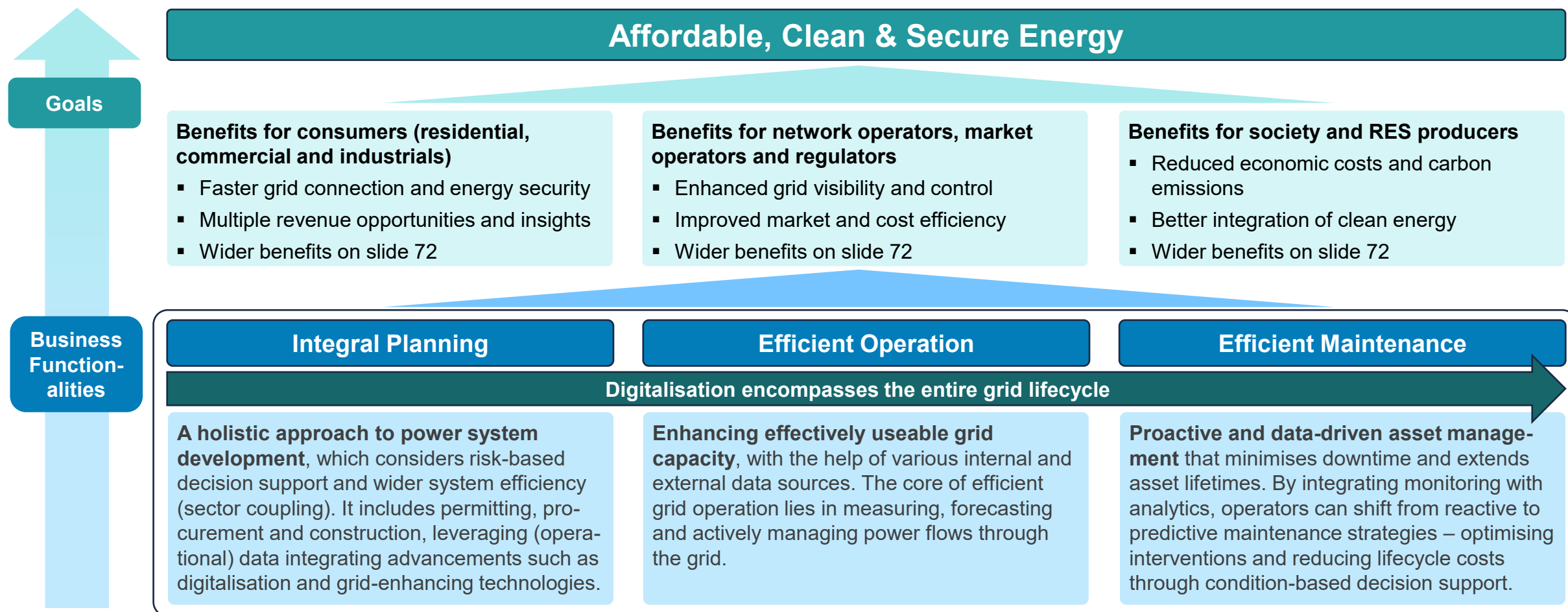
Digital Grid Technologies enable advanced functionalities necessary to plan, build and manage the Grid of the Future

Laying the foundational groundwork is essential before higher-level functionalities can be accessed



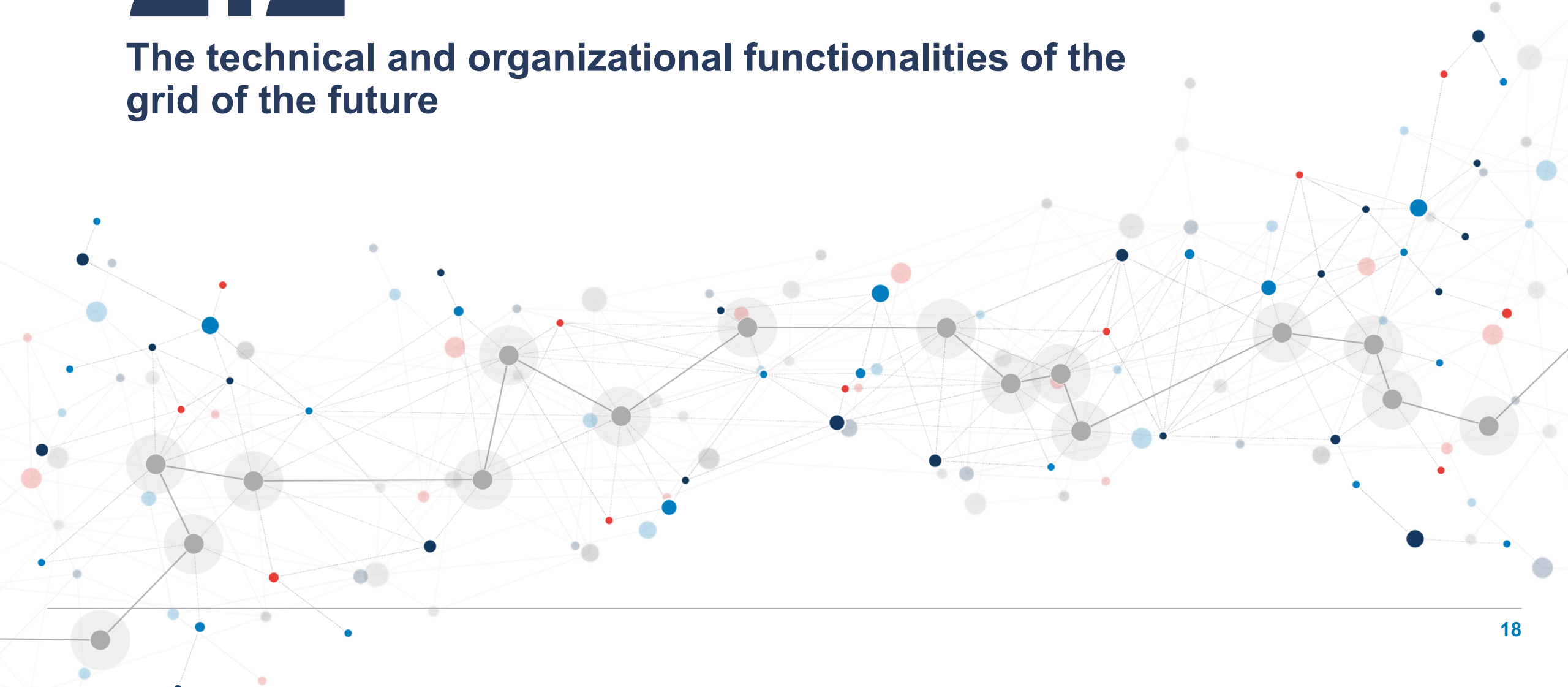
Digital grid functionalities uniquely support the energy trilemma dimensions across the grid value chain and across other sectors

Grid digitalisation enables more than smart grids



2.2






The technical and organizational functionalities of the grid of the future






The functionalities unlocked by a digitalised grid (1/2)

Digitalisation enables to leverage advanced grid functionalities (or improve existing ones)

Foundational functionalities

Functionality	Definition
 Observability	The ability of the grid operator to observe, i.e. have visibility into grid topology, grid status and asset conditions, providing the data basis for informed decision-making across all voltage levels – achieving grid transparency .
 Controllability	The ability to actively control, i.e., adjust and influence grid parameters and assets remotely . Allows faster, direct action, more flexible response options, saves travel time and resources. Contributes to quality of supply by shortening or avoiding disruptions of supply.
 Automation	The ability to manage complexity by automating processes. Integrating automation, intelligent algorithms, and AI enables the grid to act as a co-pilot for planning, operation, or maintenance tasks. From individual manual decisions with failure risk to accurate automated processes. Supports decision-making and increases efficiency in processes, services and network planning. Basis for autonomous grid.
 Integral data management	The ability to easily exchange data and information between grid planning, operation, and management teams of one system operator. Overcoming operator internal data silos ; from single user to multi-user import and exchange of data between teams and departments, reduces inefficiencies, enhances workforce efficiency, and enables continuous improvement in grid management.
 Data Exchange (Ecosystem)	The ability to seamlessly exchange data and information , via robust digital communication systems, using standardised interfaces with external stakeholders , such as customers, market and grid operators.

System functionalities

Functionality	Definition
 System user flexibility utilisation	The ability to access and leverage flexibility provided by any grid connected entity (i.e., the system user); e.g., by addressing individual grid connection points (EVs, heat pumps, industrials, distributed RES-infeed, ...) via market and flexible connection agreements to manage peak demands
 Balancing	The ability to continuously balance in-feed (supply) and extraction (demand) across and between all voltage levels involving all decentralized energy resources ensuring system wide power quality
 Efficient investment planning	The ability to leverage data-driven insights, to enable risk-based investment decisions across the flexible energy system prioritizing cost-effective investments in functionalities in the right locations at the right point in time

The functionalities unlocked by a digitalised grid (2/2)

Digitalisation enables to leverage advanced grid functionalities (or improve existing ones)

Business functionalities

Functionality

Definition



Efficient Operation

Enhancing effectively usable grid capacity, with the help of various internal and external data sources, building on and interacting with other functionalities including maintenance and planning, by measuring, forecasting and managing power flows through the grid.



Efficient Maintenance

Proactively using grid assets, reducing downtime and extending asset lifetimes with data-driven insights. Using data and information in software models that provide decision support for predictive analytics, condition-based monitoring.



Integral Planning

Power system development should be a holistic approach which considers risk-based decision support, energy system efficiency and sector coupling. This approach combines grid expansion and optimisation, market design, and technological advancements, such as grid enhancing technologies, to support long-term energy transition goals and system resilience. Crucially, it also includes permitting, procurement and construction work.

Business functionalities

System functionalities

Foundational functionalities



The digital grid needs: Observability

Observability across all voltage levels forms a key foundation for downstream functionalities

Definition

Observability refers to the ability of the grid operator to observe, i.e. have visibility into grid status and asset conditions, providing the data basis for informed decision-making across all voltage levels – in other words, this is about **achieving grid transparency**.

Technical requirements

Required functionalities: Observability is a foundational functionality

Required technologies:

Data acquisition: sensors within the grid

Data transfer, communications systems and networks

Power electronics (HDVC, FACTS, etc.)

Data processing, aggregation with compatible data formats

Software/interfaces to visualize

Status Quo

- Variation in smart meter rollout across Europe regarding penetration and functionality, leading to discussions on alternative BTM measurement devices.
- Different regional legislation with respect to access of meter data by network operators
- No clear goals for use of measurement devices (smart meters and others) within grid operators.
- Variety of data formats in measurement devices entails complexity in integrating different data streams for analytics and steering purposes.

What needs to happen

- Broad roll-out of measurement devices, such as any grid or IOT device, in substations / ring main units, or smart meters. Develop roadmap and role of grid measurement devices
- Clear minimum requirements for the functionalities of smart meters and dedicated measurement devices
- Incentivising the deployment of measurement technology in the regulatory framework.
- Investments in software systems to analyse data and incorporate results into operations
- Clearly define and delineate the rights to use smart meter data for grid operators and third-party service providers.

Examples of stakeholder benefits

Network Operator

- Enhanced grid visibility and control
- Improved asset management and maintenance prediction

Regulator

- More granular energy market in-/oversight
- Improved data for policy making
- Enhanced monitoring of compliance
- More accurate performance metrics
- Enhanced transparency in grid operations



The digital grid needs: Controllability

Controllability forms a foundational prerequisite for any optimized utilization of assets

Definition

Controllability refers to the ability to actively control, i.e., **adjust and influence grid parameters and assets remotely**. This allows faster action, more flexible response options and saves travel time and resources.

Technical requirements

Required functionalities:

Observability

Required technologies:

Congestions calculation; decision supporting, and measure triggering software

Automation/remote control of grid devices/ components

Status Quo

- Deployment of remotely controllable grid components is at the discretion of each network operator, with no mandatory standards.
- Existing digital stations often have non-harmonized, system operator specific functionalities, making integration challenging.
- Lack of standardized, automated onboarding processes for new assets into grid management systems, complicating interoperability.
- Communication infrastructures and system maturity levels vary, limiting full remote-control functionalities.

What needs to happen

- Define and harmonize technical requirements and interfaces for remotely controllable grid assets across system operators.
- Incentivize and embed digital, remotely controllable infrastructure in the regulatory framework.
- Standardize asset onboarding processes (e.g., through Asset Administration Shells and Thing Description standards).
- Promote investment into advanced communication systems and software capable of managing and integrating diverse asset types.

Examples of stakeholder benefits

Network Operator

- Enhanced grid visibility and control
- Improved asset management and maintenance prediction
- Better outage management and faster restoration
- Improved power quality management
- Reduced technical losses
- Increase internal digital maturity of network operators



The digital grid needs: Automation

Today, it drives efficiency and manages complexity; tomorrow it powers the autonomous grid

Definition

The ability to **manage complexity** by automating processes. Integrating automation, intelligent algorithms, and AI enables the grid to act as a co-pilot for planning, operation, or maintenance tasks. From individual manual decisions with failure risk to accurate automated processes. Supports decision-making and increases efficiency in processes, services and network planning. **Basis for autonomous grid (AI powered automation)**

Technical requirements

Required functionalities:

Integral data management

Required technologies:

Harmonized processes, roles, responsibilities

Digitalizing processes and documents

Status Quo

- Internal processes are often undocumented, inconsistent, and not digitalised – many still rely on manual steps.
- Digitalisation efforts are siloed within departments, leading to fragmented systems and duplicated work.
- Low incentive to optimise processes due to limited competitive pressure and lack of cost drivers.
- Knowledge about automation potential and best practices is limited and rarely shared across teams.

What needs to happen

- Establish transparency of internal workflows through standard process modelling (e.g. BPMN) to identify automation potential.
- Standardise and digitise core business processes, assigning clear responsibilities and KPIs.
- Promote a cultural shift toward digital thinking and efficiency, supported by leadership and training.
- Incentivise cross-departmental collaboration to align digital tools and break down silos.

Examples of stakeholder benefits

Network Operator

- Improved asset management and maintenance prediction
- Reduced operational costs

Energy Market Operators

- Improved market efficiency and in the long run liquidity
- Faster and more granular alignment of market and grid

Society/Environment

- More efficient resource utilization

↔ The digital grid needs: Integral data management

Breaking down silos within network operators is a crucial step to build a sector data economy

📋 Definition

The ability to **easily exchange data and information** between grid planning, operation, and management teams of one system operator. Overcoming **operator internal data silos**; from single user to multi-user import and exchange of data between teams and departments, reduces inefficiencies, enhances workforce efficiency, and enables continuous improvement in grid management.

! Technical requirements

Required functionalities:

Automation

Required technologies:

Data storage across units and tasks (cloud)

Accessibility, and if possible, comparability of information - data and software

Software to bring together data products (future readiness), e.g. planning and operational data

Access right for company members, "Share unless"-principle

🕒 Status Quo

- Limited strategic focus and expertise to design and implement enterprise-wide knowledge and data strategies.
- Network operator/department specific IT architectures limit interoperability and integration possibilities.
- Lack of company-wide data access policies and/or harmonized interfaces slows down collaboration.
- Data systems are dispersed and siloed across departments. Cross team data sharing/exchange is limited. Manual efforts create redundant and frequently inconsistent data.
- Overall slow data updates and additions. A systematic challenge starkly contrasting the needs of the rapid transformation of the power system.

💡 What needs to happen

- Define and implement unified requirements for software interfaces and data accessibility across departments.
- Develop a company-wide data and knowledge management strategy linked to an overarching software architecture.
- Incentivise investments into integrated IT infrastructures that promote interdepartmental data sharing.
- Foster a cultural shift towards transparency and collaboration beyond departmental boundaries.

👥 Examples of stakeholder benefits

Network Operator

- Increase internal digital maturity of network operators
- Optimized grid planning and investments

Regulator

- More granular energy market in-/oversight
- Improved data for policy making
- More accurate performance metrics
- Enhanced transparency in grid operations

Society/Environment

- More efficient resource utilization



The digital grid needs: Data exchange (Ecosystems)

A shared data space enables efficient, standardized information exchange

Definition

The ability to **seamlessly exchange data and information**, via robust digital communication systems, using standardised interfaces with **external stakeholders**, such as customers, market and grid operators.

Technical requirements

Required functionalities:	Integral data management	Automation
Required technologies:	Data exchange platform(s) (data space) to interact with external stakeholders: standardized data sets with linked access rights	Bi-directional communication for flexibility mechanisms and activation: Cloud, market, grid connection point (≠ controllability of grid devices!)
	Traceability of data and single source of truth	

Status Quo

- Beyond electricity market trading, few centralized or standardized external data platform exist; data exchange is largely proprietary or ad-hoc (e.g., email, phone).
- Different processes and tools exist per country and per use case, driven by fragmented legal and regulatory frameworks.
- Limited interoperability across organisations, leading to delayed or incomplete information sharing (e.g., construction project changes).
- Limited harmonized technical requirements for secure and efficient communication between entities.

What needs to happen

- Establish a regulated, interoperable Energy Data Space for structured data exchange across all relevant stakeholders.
- Mandate usage of the Energy Data Space by network operators and other municipal or sector-specific organisations.
- Harmonize technical and interface requirements for communication systems at both national and European levels.
- Gradually implement use cases within the Energy Data Space to build momentum and demonstrate benefits beyond pilot projects.

Examples of stakeholder benefits

Network Operator

- Increase internal digital maturity of network operators

Consumers (residential, commercial, industrials)

- Better energy consumption insights
- Enhanced customer service
- Greater choice in energy services
- Faster grid connection

Producers

- Easier grid integration



The digital grid needs: System user flexibility utilization

Integrating flexible resources to enhance resilience and optimize asset usage

Definition

System user flexibility utilization refers to the ability to access and leverage **flexibility** provided by any grid connected entity (i.e., the system user); e.g., by addressing individual grid connection points (EVs, heat pumps, industrials, distributed RES-infeed, ...) via market and non-market mechanisms to manage peak demands

Technical requirements

Required functionalities:

Observability

Controllability

Balancing

Required technologies:

Software to detect, recommend, activate needed measures and

Software for confirmation of service delivery and billing process.

Power electronics (HDVC, FACTS, etc.)

Status Quo

- Flexibility measures are not yet fully embedded into grid operation processes; focus remains on traditional reinforcement ("more copper").
- Significant diversity of market mechanisms and flexibility technologies across countries creates integration challenges.
- High onboarding costs and complex, often proprietary solutions hinder the connection of flexible assets.
- Grid operators have limited experience and tools for managing flexibility; use cases are only slowly emerging.

What needs to happen

- Integrate flexibility systematically into network operations, supported by clear internal processes and responsibility frameworks.
- Harmonize technical, contractual, and market interface standards for flexibility across Europe.
- Incentivize investment into flexible resource management (software, processes, training) and customer participation.

Examples of stakeholder benefits

Network Operator

- Reduced operational costs
- Optimized grid planning and investments
- Better integration of renewable energy sources & additional electrified loads

Consumers (residential, commercial, industrials)

- Ability to participate in demand response programs
- Revenue opportunities
- Secure supply



The digital grid needs: Balancing

Adapting grid balancing strategies to accommodate increasing shares of RES and complexity

Definition

The ability to **continuously balance in-feed (supply) and extraction (demand)** across and between all voltage levels involving **all decentralized energy resources** ensuring system wide power quality

Technical requirements

Required functionalities:

Observability

Controllability

Integral data management

System user flexibility utilization

Data exchange (Ecosystems)

Automation

Required technologies:

Balancing software to detect, recommend, activate needed measures

Power electronics (HDVC, FACTS, etc.)

Status Quo

- Current balancing practices are reaching their limits due to the rising share of fluctuating renewable energy sources (distributed energy resources).
- Lack of transparency, fragmented knowledge of system interactions, and shortage of appropriately skilled workforce hinder progress.
- Absence of a comprehensive, forward-looking balancing strategy adapted to future system needs.

What needs to happen

- Identify new balancing requirements systematically and translate them into concrete, actionable measures (e.g., flexibility, dynamic grid control).
- Foster a cultural and mindset shift: what worked in the past will not suffice for the future energy system.
- Implement comprehensive strategies that link system observability, controllability, flexibility, and automation to future-proof balancing.

Examples for stakeholder benefits

Network Operator

- Enhanced grid visibility and control
- Reduced operational costs
- Improved power quality management

Producers

- Improved market participation
- More accurate settlement processes

Society/Environment

- Reduced economic costs
- Reduced carbon emissions

Cybersecurity is a full solution lifecycle requirement

A critical technology enabling a secure and interconnected EU digital grid

Digitalisation and cybersecurity are decisive to provide essential services and therefore of strategic relevance for critical energy infrastructure. (NCCS -DELEGATED REGULATION (EU) 2024/1366)

- Since the exploitation of vulnerabilities in network and information systems may cause significant energy disruptions and harm for economy and consumers, these vulnerabilities must be constantly assessed, identified and remedied to reduce cybersecurity risks. With digitalisation and the increase of OT technologies, **more attention to field equipment and its cybersecure posture** is necessary.
- **Cybersecurity is not one technology or one functionality.** Cybersecurity is a **mix of technologies and processes**, of human skills and design objectives as well as their respective deployment, implementation, operation and maintenance. **Cybersecurity is a full solution lifecycle requirement, which requires a fundamental change in processes and mindset.**
- **Cooperation of all involved stakeholders is necessary** to correctly address existing and upcoming cybersecurity challenges and cannot be treated in silos. **Grid operators along with their grid technology providers must maintain regular dialogue** and discuss the effectiveness of cyber measures and OT equipment cybersecurity capacity evolution and needs.
- Grid service providers such as system integrators, maintenance teams, commissioning engineers and related professional services play a very important role in the process of securing and operating with security grid solutions .
- Professional cybersecurity capacity and qualification are engineering **skills under stress and scarce**. Dedicated programs must be developed along with OT technology providers to qualify grid operator's staff and contractor's workforce.
- **Regulatory measures are ongoing, requiring several years of implementation.** Cybersecurity is everywhere, as it enables fundamental trust between the different applications, stakeholders and their systems. Information must be exchanged intelligently and cybersecure.

Application Spotlight: Flexibility

Flexibility can be accessed by any grid connected entity, behind the meter or in front of the meter. System User can be a consumer, a prosumer, a flexumer, on generation or on consumption side

Many definitions of flexibility:

The **Electricity Market Design** Regulation defines flexibility from a market perspective as *“the ability of an electricity system to adjust to the variability of generation and consumption patterns and grid availability,*

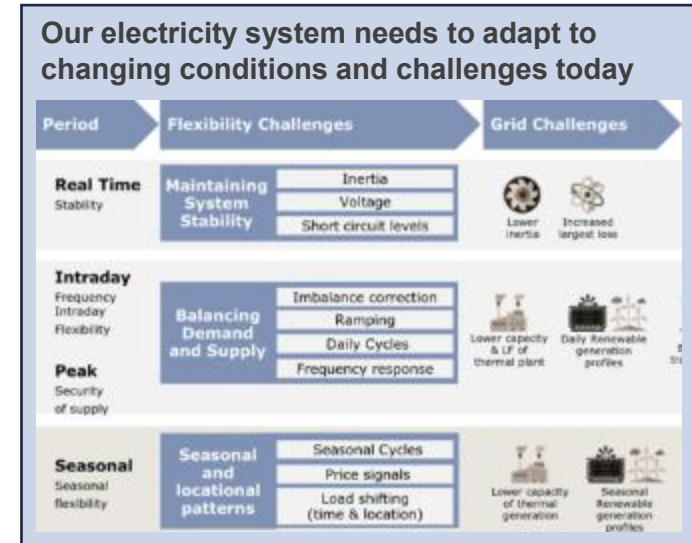
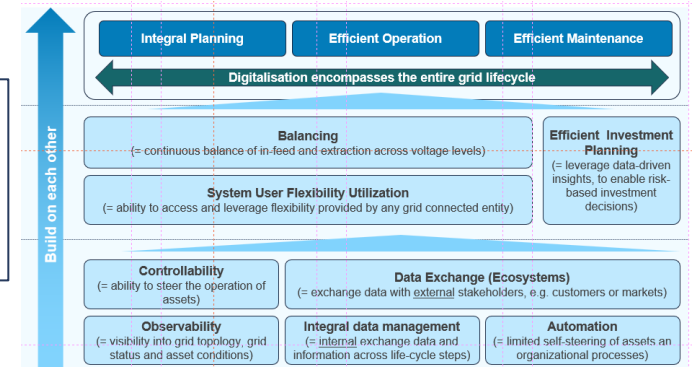
The **International Energy Agency** defines flexibility with a more technical approach as *“the ability of a power system to reliably and cost effectively manage the variability and uncertainty of demand and supply across all relevant timescales, from ensuring instantaneous stability of the power system to supporting long-term security of supply”.*²

Overall, the **definition of flexibility** needs to include additional aspects such as:

- All **types of flexibility-providing technologies** (traditional generation assets, but also technologies such as controllable units, energy management and supporting software solutions)
- Coverage across **different durations** (short time, seasonal, day-ahead, intraday...).
- Incorporation of **shifting, feed-in, storage, and demand behaviour**.
- **Activation** through both **grid and market mechanisms**.
- A **flexible framework** encompassing various purposes, such as self-optimization, grid-friendly, and market-driven approaches, without focusing solely on any single aspect.

It is crucial to explore **strategic recommendations that will address current challenges** and will pave the way for a robust and flexible grid infrastructure:

- Implement existing European legislation across Member States with a harmonised approach
- Unlocking flexible functionalities needs to be attractive for all stakeholders
- Consider the existing infrastructure and management solutions when implementing flexibility
- Flexibility needs **comprehensive grid digitalisation**
- Apply technical concepts across industries
- Participating in flexibility provision needs to be an inclusive process



Application Spotlight : Edge Connectivity

An overlooked communication enabler for the sustainable and digital transition of the electrical grid

Edge connectivity, standardisation and interoperability, provide the foundation for seamless communication, data exchange and collaboration in appropriate real-time

- Diverse vendor products, such as DER, build the electrical grid and create a rich mosaic of devices located at the edge of the electrical grid, such as smart meters, sensors, and other edge devices. These **Intelligent Electronic Devices (IEDs)** and their operational data can be used to monitor, control, and protect the power system through advanced automation.
- **Edge connectivity** establishes direct communication between the grid stakeholders and the resources at the grid's edge, providing gain real-time access to a wide range of data.
- Using the **existing edge connectivity offered by these devices behind the meter and in front-of-meter** can help speed up the roll-out of flexibility management. This approach requires interoperability at the back-end level with (standardized) ontologies and adequate control mechanisms to avoid vendor lock-in.
- In some countries, like Germany, national regulation will need to be adjusted.

The figure shows **three main options** to establish **end-to-end communication**.

- **Yellow path:** rolls out existing **grid automation technology** into lower voltage distribution grids. The advantage of this path is the use of proven technology. But current procurement and deployment costs need to be scaled down.
- **Green path:** **smart meter infrastructure** rolled out in many countries. The ability to use this communication path depends strongly on national smart metering regulations. The heterogeneity of the smart meter business can be complex to manage. Also, smart meter infrastructure is often only intended to collect data from the smart meters, limiting the capabilities to send data to the grid edge.
- **Blue path:** utilizes, where available, **existing communication between manufacturer of DER devices and its installed base**. Existing communication link to monitor the DER devices and to offer services (e.g., predictive maintenance or firmware updates). With this existing infrastructure the manufacturer can provide the pooled flexibility of its connected DER to a commercial aggregator.

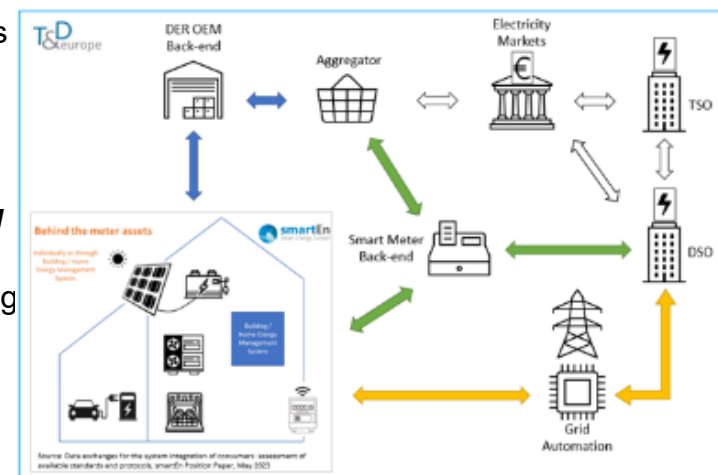


Figure: Three major communication paths towards the grid edge

- Bottom left: smartEN
- Top left and right: T&D Europe contribution

Application Spotlight: Digital Twins

Digital Twins can play a crucial part in many parts of the infrastructure needed for the energy transition

“Digital Twins are virtual replicas of physical assets, systems, processes, or software. They enable monitoring, analysis, simulation, forecasting and control. In the context of electrical grids, Digital Twins represent the entire grid infrastructure, including substations, power plants, distribution networks, and software systems.” (Digital Twin Consortium)

Digital Twins are a key element in facilitating the energy transition

- Digital Twins connect the physical and digital worlds
- Digital Twins **enable** grid observability, grid efficiency, grid reliability, improve asset system availability
- Digital Twins use data to enable the **most efficient and cost-effective** use of assets and the network
- Benefits increase if implemented in a digital ecosystem. The Digital Twin ecosystem needs to respect specific framework conditions of the EU energy sector to be effective

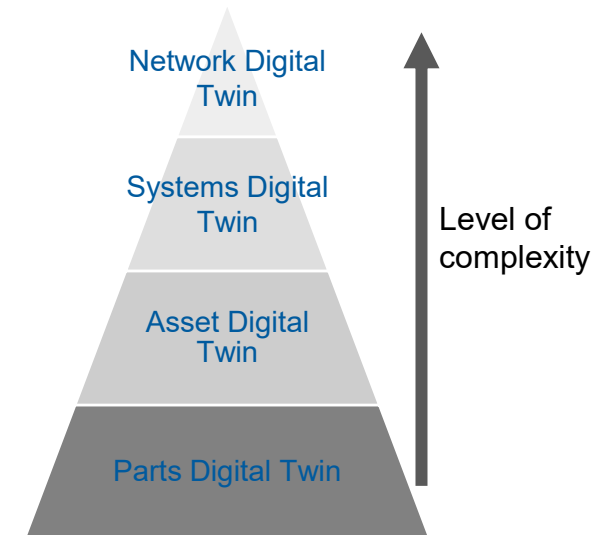
Digital twins enable smart grid functionalities across the life cycle:

- Continuous monitoring and forecasting of asset and grid status at all grid levels
- Dynamic balancing of generation and load
- Aligned system operation across all grid levels
- Predictive system management that leverages the operational limits of assets



These smart functionalities enable various use cases, for example:

- **Grid Optimisation** → enhance grid utilisation
- **Scenario Simulation** → ensure grid resilience
- **Asset Performance Management** → improve reliability and efficiency
- **Real-time Monitoring** → ease proactive decision-making



Digital Twins can vary in **complexity**: from **static** Digital Twins (static properties, e.g. catalogue data) to **near real-time** Digital Twins (dynamic, state and environment data enable grid state visibility and near real-time contingency analysis) covering the full life cycle

Application Spotlight: Asset Administration Shell (AAS)

A scalable technical concept to structure various data value sets from different use cases. Examples for first use cases include: Digital Product Passport, Flexibility Device Passport



A proven tool in Industry 4.0. The Asset Administration Shell serves as the standardized digital representation of an asset. It acts as a digital twin, provides a comprehensive and structured way to manage and exchange information about physical assets throughout their entire lifecycle. This allows various users to get access to product information across the entire value chain based on their needs.

Prepare extendable and digitally for new regulatory requirements with the AAS

- EU Ecodesign for Sustainable Product Regulation (ESPR) sets information provision requirements
- ESPR introduced the **Digital Product Passport (DPP)** for EU market products with one single access point
- EU mandates product specific information sets
- Mandatory from 2027 for the first defined product groups
- **The AAS enables the DPP and can be extended to additional technical and business use-cases**

Digitize onboarding processes through the AAS concept – save time and resources

Today

- Complex manual asset onboarding process
- Inputs from proprietary sources
- Prone to faults due to redundant processes
- Potentially lower data quality
- No single source of truth
- No digital file exchange



Tomorrow

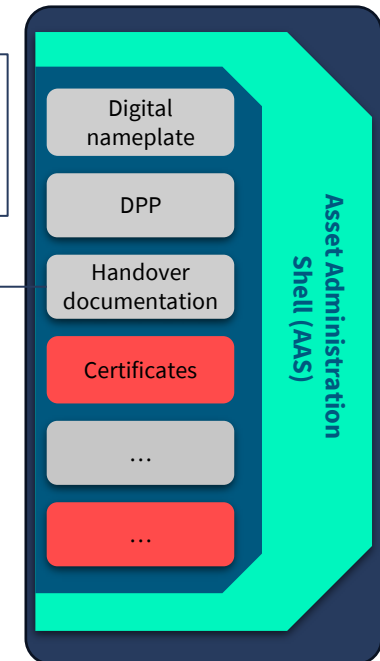
- Automated asset onboarding and digital file exchange
- Easy data access via identifier link
- Harmonized open-source set up
- High data quality for digital twins
- One lifetime single source of truth

AAS as one single source for all asset related information

- Combining sector specific and general value sets within a digital twin
- Machine readable identifier
- Scalable data models for supply chain, lifecycle and digital twin solutions
- Maintaining a proven data quality
- No lock in effects based on technology and vendor neutrality – open-source IEC 63278-1
- Submodel restriction enables user specific access control for data security

Scan and access stored information

AAS submodels: structured clusters of harmonized values



Public Submodel (grey box) Restricted Submodel (red box)

Application spotlight: Artificial Intelligence (AI) @ Energy

An emerging technology, AI could have transformative impact on the energy sector

Describes software that can learn and adapt, solve tasks requiring it to interpret the meaning of input data and adapt to the requirements (as opposed to natural intelligence, which relates to humans and other animals) – represents one of the transformative technologies of our time.

Role of AI in Energy

- Smart sensors connecting all major electrical grid assets provide asset and network data
- Industrial-grade AI runs on robust algorithms which extract meaningful information from data
- Creating a digital twin, and the data from these twins enables simulations and planning, helps optimize asset operations and enhance reliability
- Operations and maintenance teams get to anticipate potential issues, avoid disruptions, reduce downtime, and improve grid reliability.
- Processes become faster, more sustainable, and more efficient while safeguarding critical IT/OT infrastructure
- AI models enhance information and thus optimize grid utilization, enhance prediction and increase energy efficiency

Example applications:

- Automated grid management, with reduced manual workflows and optimized planning, operations, and maintenance
- Enhanced prediction, simulation and forecasts

Role of Energy in AI

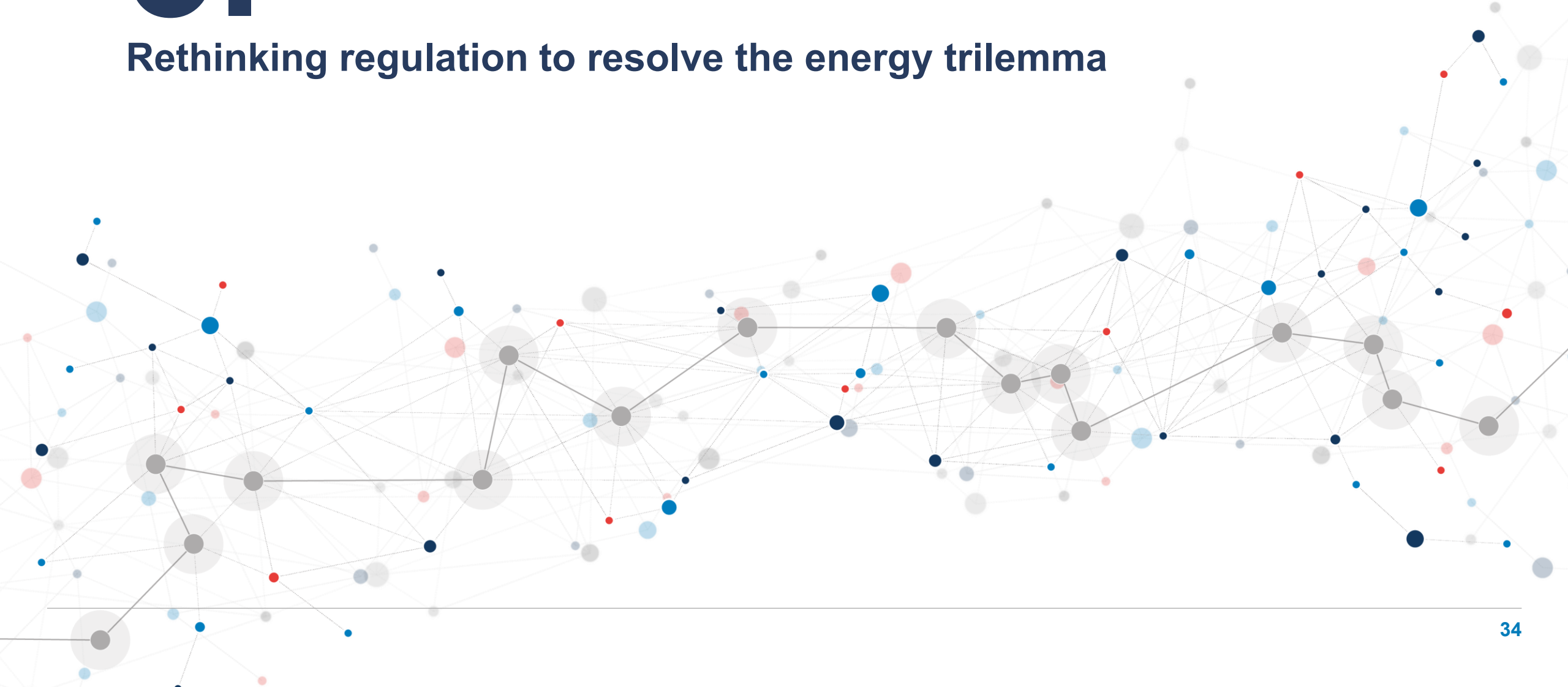
- There is no AI without electricity. Sheer size of increased (local) energy consumption from data centers will put significant stress on the grids
- Grids are becoming naturally more instable with the increase of intermittent power sources. Data Center energy consumption will add to volatility.
- On the other hand, Data Center can support grid stability by increasing their flexibility contribution
- Availability of electricity will be one determinant for Data Center localization. Aligning requirements of Data Center providers (availability of electricity, grid stability, and permitting) with the requirements of network operators (which demand, when and where) is critical.

- Predictive maintenance optimizes/ extends asset lifetime
- Flexibility management, including asset onboarding
- Energy consumption management energy consumption
- Reduced environmental impact, less emissions, enhanced resource efficiency

- **Digital, AI-ready grid infrastructure:**
AI is just one part of digitalisation and cannot be separated from grid digitalisation. A systems approach must be always considered.
- **Access to high-quality and reliable data:**
AI needs reliable high-quality data, especially also for training purposes. AI is only as reliable as the data it trains on
- **Harmonized implementation of EU regulation across all Member States:**
Greater policy coherence across different areas and between Member States to avoid overlap and double regulation
- **Digital skills and an AI mindset:**
Europe needs to develop skills and adopt an AI mindset, to build up the knowledge and expertise on how to utilise AI for a stronger and more efficient energy system. Collaboration, and building Ecosystems is key.

3.

Rethinking regulation to resolve the energy trilemma



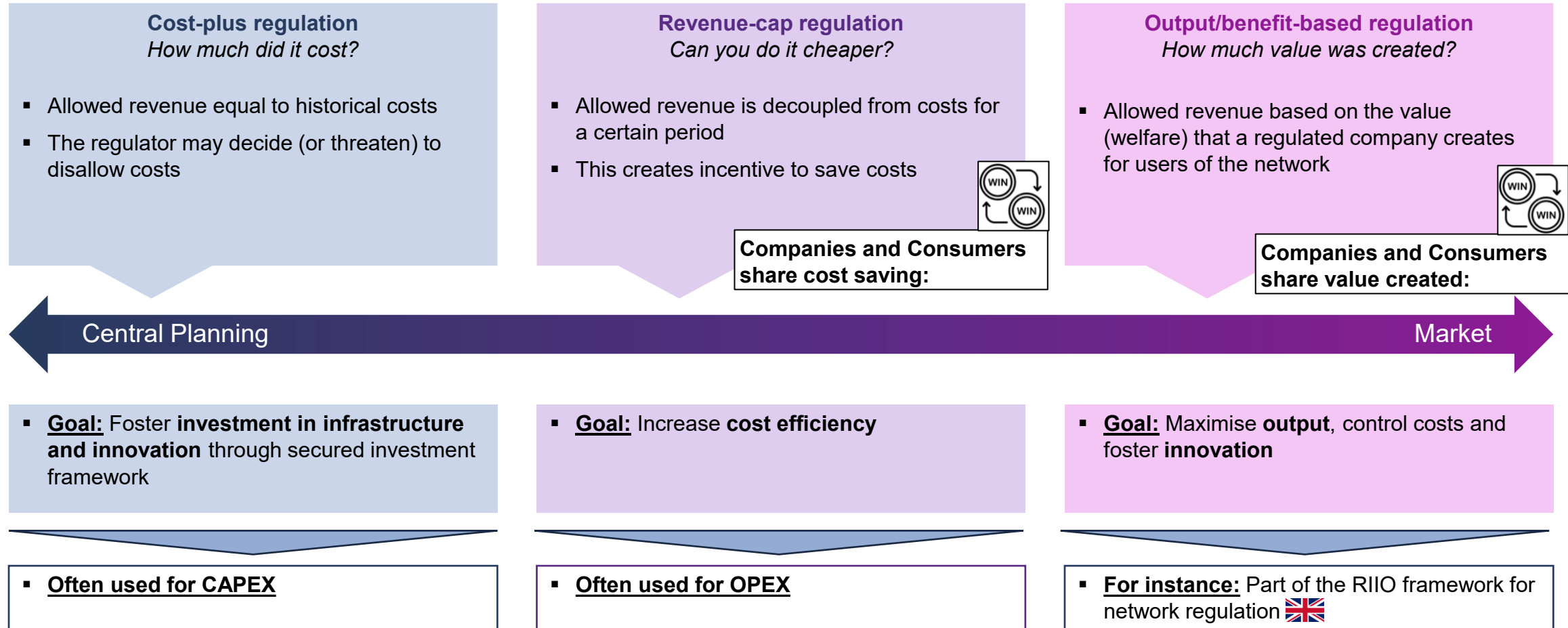
Regulatory frameworks of grids have evolved over the years, reflecting respective context and policy objectives

Current regulatory frameworks are not always fit-for-purpose and require appropriate adjustments

Time period (roughly)	Pre-2005	2005-2012	2012-today	Context and objectives of regulation
<u>Challenge and policy priority</u>	Investment certainty related to privatisation	Focus on reducing costs	Re-focus on investments and long-term grid expansion	Innovative and efficient investment and operation
<u>Description</u>	With privatisation, investment certainty was introduced through Cost+ regulation and Regulated Asset Base (RAB) to ensure financing of large investments	Focus on cost cutting by using fixed cost benchmarks Introduction of quality regulation to counterbalance incentive to cut quality (which was a first form of output-based regulation)	Energy turnaround introduced need for network expansion, which triggered a re-focus on investments and long-term grid expansion (this often created more CAPEX-bias)	Network expansion is becoming more expensive, putting a focus on grid utilisation. Digitalisation creates opportunities but also unclarity for the regulator and risk for the network operators.
<u>Regulatory solutions and regulatory innovations</u>	Cost + regulation and Regulated Asset Base (RAB)	Revenue cap regulation Quality regulation	Network development plans and investment programs were introduced. These are focused on primary grid components (lines, substations) rather than the development of advanced functionalities.	Regulatory framework needs to evolve to allow network operators to innovate and incentivise efficient investment and operation with DGTs. It will shape and enforce system transformation.

Regulatory evolutions reflect the evolution of the context and policy objectives. The next challenge is to address current regulatory hurdles for DGTs

Overview: The regulatory contract defining risk sharing and incentives between regulator and network can follow 3 general archetypes or (more often) a mixture of those.



Building blocks and cost-plus regulation

Traditional cost-plus regulation stimulates investment through assured cost recovery, but provides no incentives to improve efficiency

The traditional “cost-plus” approach

- **All costs of the operator are reimbursed** through the network tariffs paid by consumers, while the “plus” ensures that the operator receives a **compensation for the cost of capital**, based on a fixed rate of return.

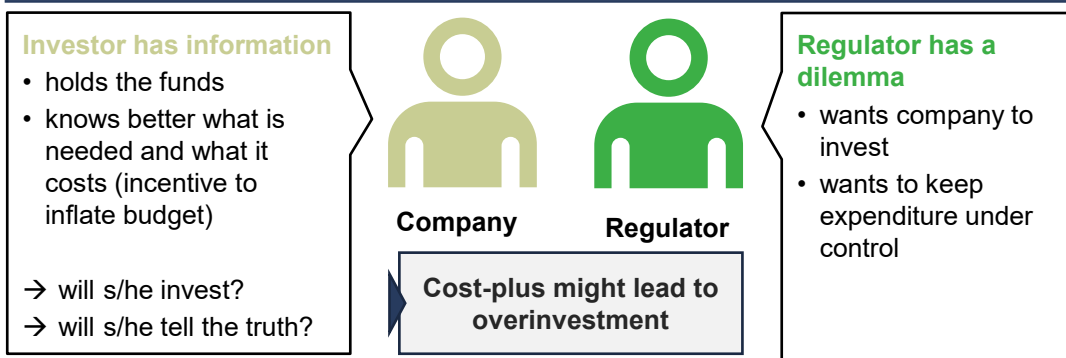


Gives certainty to the network operator that costs for (approved) investments can be recovered



Does not provide any incentive for the network operator to improve efficiency (i.e. decrease costs) over time

The information asymmetry problem



Introducing the building blocks

- Total expenditures of the firm (**TOTEX**) equal its capital charge (CC) and its operational expenditures (OPEX):

$$\text{TOTEX} = \text{Capital Charge} + \text{OPEX}$$

Incentives and revenue cap regulation

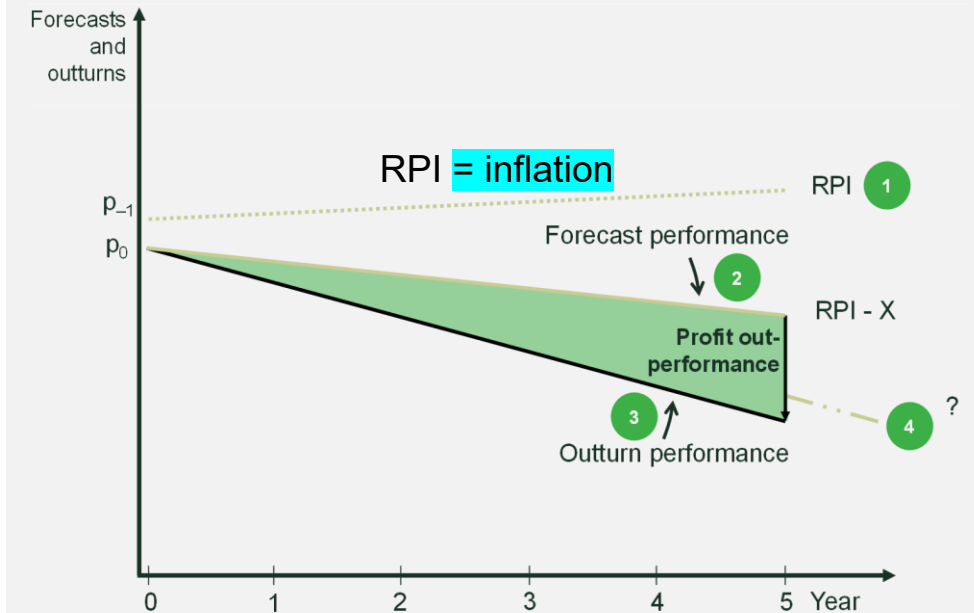
Revenue cap regulation aims to enhance efficiency by allowing the network operator to profit from cost savings, but might reduce quality of service and investments

The incentive regulation approach

- **Target:** to solve the issue of asymmetric information, whereby the firm might overstate its costs to receive higher returns.
- **Strategy:** revenue cap regulation incentivizes the network company to operate efficiently by **decoupling revenues from actual costs**. With its revenue predefined through a benchmark the firm directly profits from any outperformance achieved through cost savings.
- **Explanation:** This benchmark is defined for a limited time (the so-called 'regulatory period') after which the regulator reevaluates and adjusts the revenue cap, such that also consumers can benefit from additional cost savings.

- + Creates an incentive for network company to work **cost-efficiently**
- If the allowed revenues are set too high/low, this can lead to the network operator having excessive profits/financeability problems
- On a stand-alone basis, revenue cap regulation incentivizes companies to decrease the **quality of the provided service**.

Illustration of revenue cap regulation (in the form of RPI-X)



- 1 Prices are allowed to rise with the retail price index (RPI) ...
- 2 ... minus the expected efficiency improvement over the period (X).
- 3 The company can outperform the benchmark and generate profits.
- 4 At the start of the new regulatory period the regulator will adjust the benchmark.

Output-based regulation

Output-based regulation aims to expose the network company to the value it creates to induce an optimal level of effort and investment

The output-based regulation approach

- **Target:** to deal with issues regarding service quality in pure incentive regulation.
- **Strategy:** expose the regulated company to the value it creates, incentivising an efficient level of investment. As the remuneration is decoupled from the network company's actual cost, this provides incentives to operate cost-efficiently.
- **Explanation:** output-based regulation generalizes the principle of RPI – X regulation to outputs instead of inputs. A target is set and outperformance leads to reward payments, while shortcoming entails financial penalties.
- **Experience:** often keeps many of the features of RPI-X but adds various adjustments of revenue, based on pre-defined outputs.

+ Ensures service quality while incentivising cost-efficient operation

- Outputs and generated welfare can be difficult to define or measure

Examples of incentivized outputs:

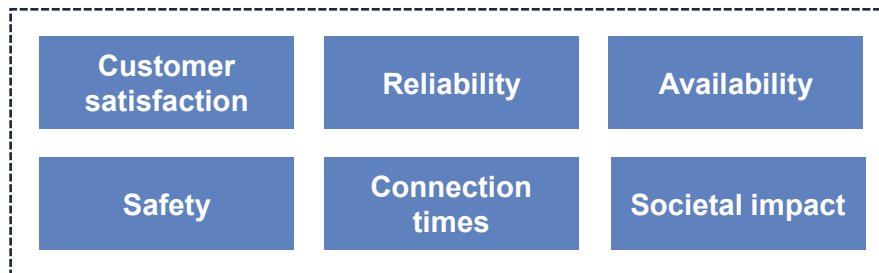


Illustration of output-based regulation



$$Quality\ incentive_t = \alpha \times (Welfare_t - Baseline_t)$$

Sharing factor

Regulation under uncertainty

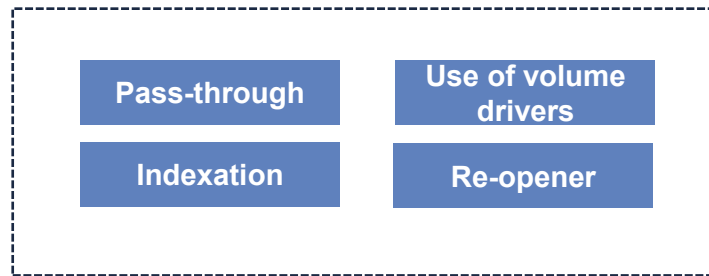
Digitalisation – as well as the energy turnaround in general – requires a more agile and forward-looking approach to regulation.

Forward planning

- **Target:** integrate a degree of uncertainty in regulation.
- **Strategy:** let a risk be borne by the party that can best control it or otherwise socialise it to reduce individual risk and financing costs.
- **Explanation:** allow for adjustments (**Uncertainty Mechanisms**) during regulatory periods depending on how uncertain some network demand estimates, costs estimates, or other estimates are.



Examples of
Uncertainty
Mechanisms:



Costs are...	How to regulate?
Controllable	<ul style="list-style-type: none"> ▪ use incentive regulation (here called budget principle; in other contexts, similar (not strictly the same) systems are called price cap, revenue cap or yardstick regulation)
Controllable but volatile	<ul style="list-style-type: none"> ▪ High degree of cost pass-through ▪ reopener if costs go beyond a certain threshold ▪ adjust benchmark with external variables if possible
Not controllable	<ul style="list-style-type: none"> ▪ direct cost pass-through—excluded from efficiency target

Efficient regulation to enable the deployment of digital grid technologies

The Grid of the Future must operate under different circumstances and adequate Smart Grid Indicators can be used to reflect these new conditions

	Holistic planning and investment decision	Efficient operation and maintenance	Risk profile
Future grid = traditional + digital solutions	<p>Optimized total cost & CAPEX-OPEX balanced</p> <p>+ Improved, integrated planning – reduced investment need relative to grid expansion w.o. innovative technologies</p>	<p>Enhanced and more granular / timely monitoring</p> <p>+ Efficient grid operation – improved utilisation, hosting capacity, faster connection</p> <p>+ Efficient maintenance – lower maintenance cost and higher reliability</p>	<p>Better controllability but higher residual risk profile, operating grid closer to its limit</p> <p>Some early-stage technologies may need a supportive framework</p>
Traditional grid	<p>CAPEX-dominated</p>	<p>Often based on limited set of normative indicators (e.g. standard lifetime, asset performance), lack of locational data</p>	<p>Designed to limit risk exposure of network operator but in a system with limited variability</p>

Digital grid technologies typically have a **different cost structure and risk profile** compared to traditional grid technologies. The **regulatory system**, tailored for traditional grid requirements, must be adopted to not disadvantage digital technologies and to **create a level playing field**.

Level playing field means a network operator will:

- Have KPI incentives to efficiently address the trade-off between inputs, outputs and risks associated with different technologies
- Consider all technologies on a level playing field and choose to add digital solutions to an existing grid or substitute some conventional network expansion for digital solutions if that is efficient
- Engage in holistic network planning and investment decisions that minimise overall costs, accounting for the interplay between all technological options

Section summary: regulatory framework must evolve

Each time comes with its own set of challenges. The regulatory framework must always keep evolving such that it is fit to accommodate the needs of the time.

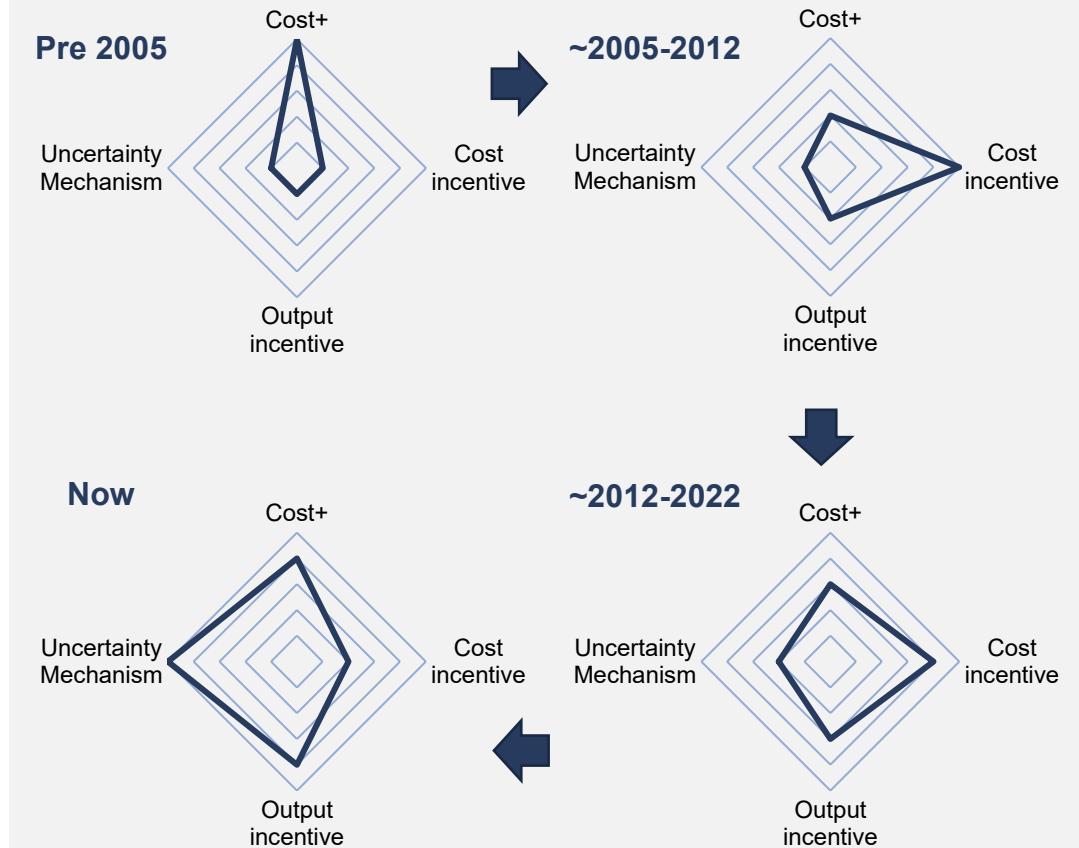
Practical regulatory frameworks are a combination of the 3 main archetypes + uncertainty management, which has evolved over time:

- **Pre 2005:** With privatisation, investment certainty was introduced through Cost+ regulation and Regulated Asset Base (RAB) concept to ensure the financing of large assets.
- **~2005-2012:** focus on cost cutting and first wave of output-based regulation through quality regulation
- **~2012-2022:** re-focus on investments and long-term grid expansion – often created more CAPEX-bias
- **Near future:** expansion is becoming more and more expensive and so improving the utilisation of the grid becomes a main target. Digitalisation creates massive opportunities but also unclarity for the regulator and risk for the network operators. A combination of agile regulation (Cost + and more OPEX-friendly) and output incentives to control costs can solve the issue.

The regulatory frameworks should adapt in the new paradigm

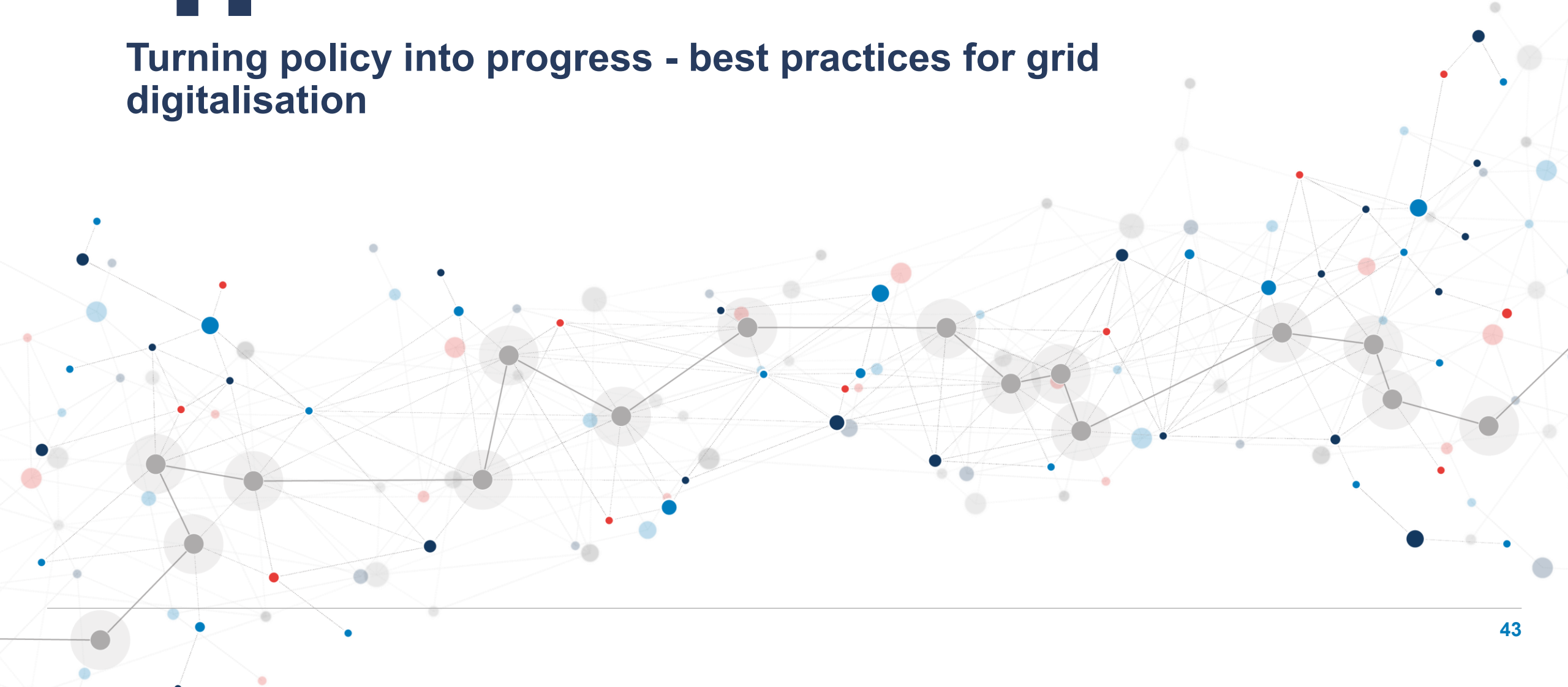
- The decarbonisation of the energy system involves significant investment needs, while the existing network faces high maintenance needs. **Cost+ approaches could tackle this issue.**
- Digitalisation creates cost saving opportunities and enables to increase the reliability of the grid. **Output-based incentives** offers the possibility of **develop BOTH digitalisation and traditional network** in an efficient way.
- A mix of cost+ approach and output-based incentives would be adapted to the new paradigm.

Illustration of evolution of network regulation in western Europe



4.

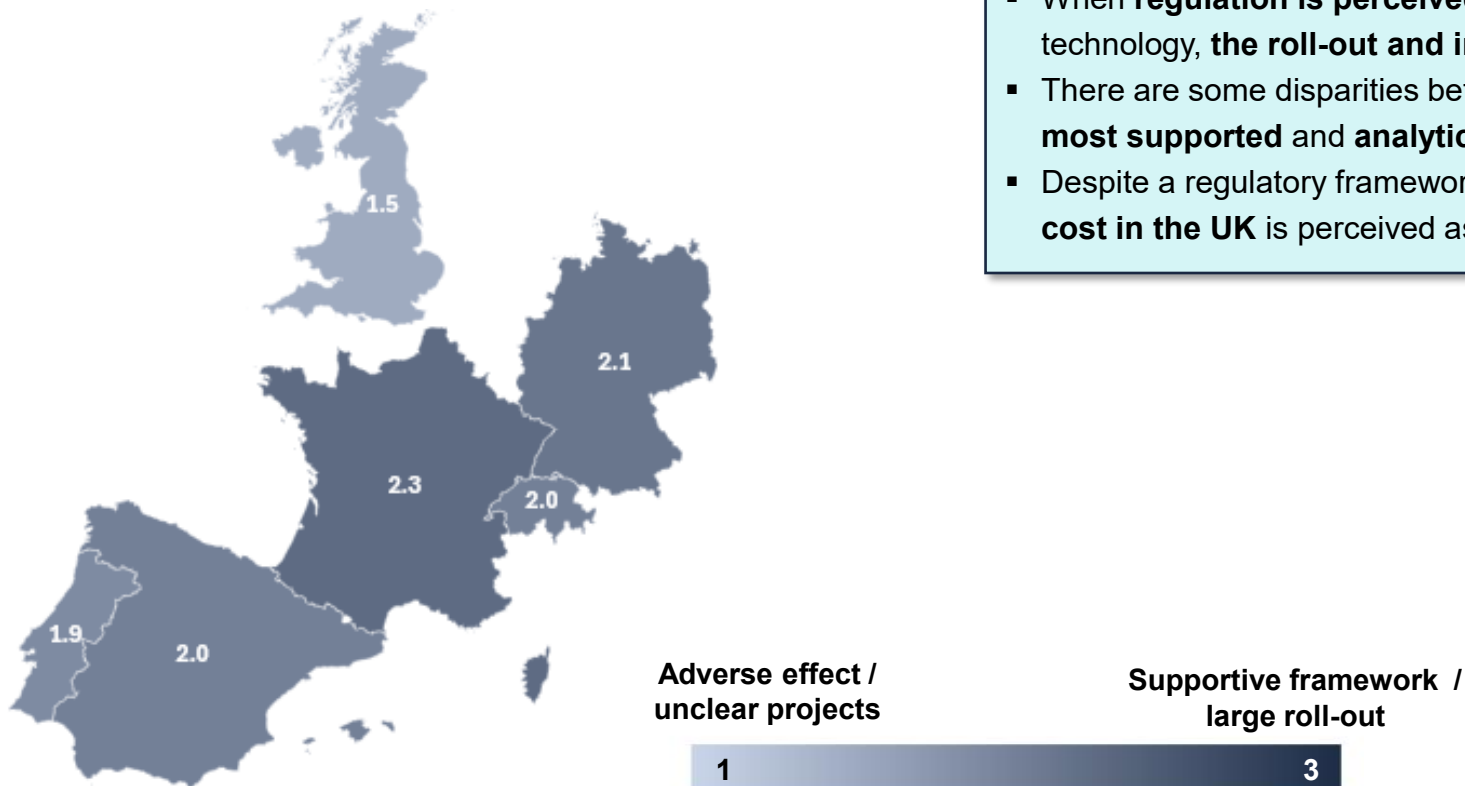
Turning policy into progress - best practices for grid digitalisation



Survey amongst selected T&D members - Uneven deployment of digital solutions

Grid digitalisation is rolled-out when the regulatory framework is supportive

Development of digital solutions in Western Europe



Country findings:





- When **regulation is perceived as supportive** in the development of a given technology, **the roll-out and inclusion in planning is more straight-forward**
- There are some disparities between technologies, with **smart meters being the most supported** and **analytics the less supported**.
- Despite a regulatory framework with few tipping points, the **incentive to reduce cost in the UK** is perceived as a significant limitation for digital deployment.

Methodology:

- CL addressed surveys to T&D members in the different countries. These regroup grid technology providers for the given country.
- Surveys included 4 categories (sensors, analytics, digital substations, smart meters). CL present the average of the 4 categories.
- Surveys included questions about the perception of (i) technology development and (ii) the supportiveness of regulation.

Regulatory systems in place – Variants of revenue cap approaches

The study reviewed 4 different regulatory frameworks across Europe

	Germany 	Spain 	UK 	France 
General information	<ul style="list-style-type: none"> Regulatory period: 2024-2028 (5 years) 	<ul style="list-style-type: none"> Regulatory period: 2020-2025 (6 years) 	<ul style="list-style-type: none"> TSO: 2021-2026 (6 years) DSO: 2023-2028 (6 years) 	<ul style="list-style-type: none"> Regulatory period: 2025-2028 (4 years)
Regulation approach for OPEX	<ul style="list-style-type: none"> Revenue cap based on non-controllable, controllable and volatile costs. Efficiency benchmark between TSOs and DSOs. 	<ul style="list-style-type: none"> Revenue cap based on non-controllable and controllable costs. 	<ul style="list-style-type: none"> Revenue cap based on TOTEX approach (fair margin). 	<ul style="list-style-type: none"> Revenue cap based on non-controllable and controllable costs.
Regulation approach for CAPEX	<ul style="list-style-type: none"> Cost +, with RAB model (fair margin). 	<ul style="list-style-type: none"> Cost +, with RAB model (fair margin). 	<ul style="list-style-type: none"> Revenue cap based on TOTEX approach (fair margin). 	<ul style="list-style-type: none"> Cost +, with RAB model (fair margin).
OPEX incentives	<ul style="list-style-type: none"> Controllable costs are incentivized at 100%. Congestion costs (costs incurred by limited transmission capacity) are incentivized. The cost of losses is considered volatile: uncertainty mechanism depending on efficiency according to the NRA. 	<ul style="list-style-type: none"> Controllable costs are incentivized at 100%. Incentives for network availability. Incentives to reduce losses and improve quality. 	<ul style="list-style-type: none"> Uncertainty mechanisms allow for a revisiting of the during the control period. Innovation incentives: Network operators compete against each other for substantial funding of demonstration projects (up to 2.5% of revenue). Output incentives: Rewards and penalties for customer satisfaction, reliability and availability, safety, connection terms, environmental impact, and social performance. 	<ul style="list-style-type: none"> Controllable costs are incentivized at 100%. Tariffs account for increased expenses related to cybersecurity, data management, smart monitoring of the network and R&D spendings. Incentives on service quality Incentives on innovation and on quality of data. Targets for digitalisation.
CAPEX incentives	<ul style="list-style-type: none"> The CAPEX trajectory may be revised during the period in the event of a significant investment approved by the regulator. 	<ul style="list-style-type: none"> Investment cap based to GDP growth. Incentive to keep fully depreciated assets operational. Norm cost approach. 	<ul style="list-style-type: none"> Uncertainty mechanisms allow for a revisiting of the during the control period. 	<ul style="list-style-type: none"> Specific budget for large projects Specific mechanism for IT and telecom expenses (TOTEX like)

Grid of the Future calls for a fundamental rethinking of not only how we regulate but also how we manage the grid

Country deep dives reveal 4 best practice areas for “fit-for-purpose” regulation

Lifecycle phases:



Key findings for digital technologies:

Informed by interviews and research made across multiple European jurisdictions*



Network regulation and network planning best practices:

Wider best practices: (integr. in operations, change management, market design, etc.)

- **Insufficient** transfer of project results to regulators/ insufficient incorporation into market solutions
- **Death by pilot:** adoption can be hindered by long processes or by not accepting pilots from other EU-countries
- **Planning doctrine** insufficiently considers cross-sectorial and/ or flexibility aspects
- Especially on distribution side, **limited anticipation and planning of evolving tasks** due to the energy transition
- **CAPEX-bias:** reasonable remuneration provided through CAPEX, while OPEX often loss-making (either delay or non acceptance by regulator)
- **“Reliability of supply” bias:** focus on avoiding risks resulting in missed opportunities to improve performance and/ or increase efficiency by innovation (e.g. new forms of congestion management; connection request processes)
- **Limited output incentive:** Grid operator revenues are mostly based on costs and not on the utility of network users

1 Improved network planning

Network planning should **make full use of and consider the possibilities** enabled by digital tools, such as digital twins.

Pilots, such as regulatory sandboxes, should reflect legal and regulatory frameworks and include respective expert stakeholders. Jointly develop criteria to define “proven technology” (TLR).

2 Cost recognition and risk sharing

Regulation must consider the new realities of **OPEX-driven technology** and **different risk profiles**. This can be resolved by easier capitalisation of OPEX and more elements of OPEX-friendly regulation.

3 KPI incentives

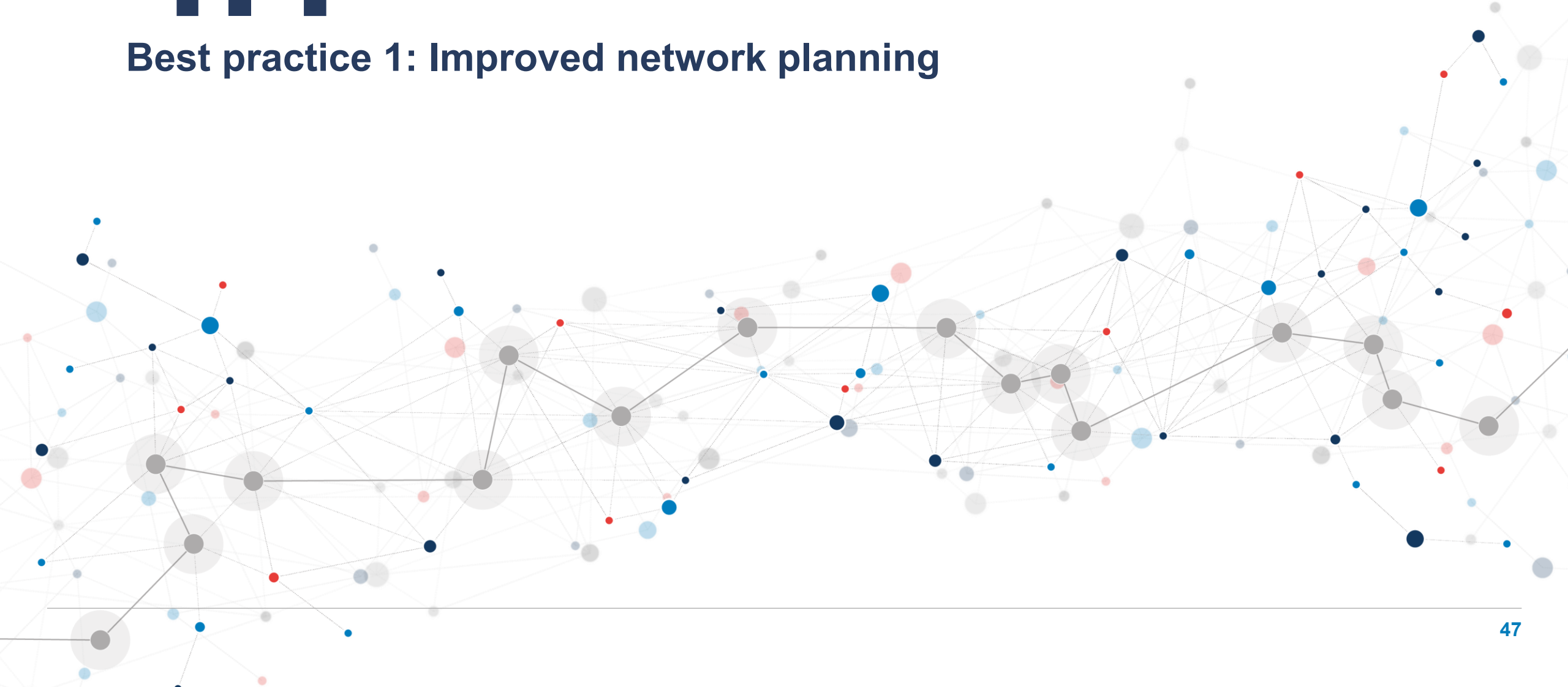
Across the lifecycle, targets need to be implemented, and risks should be assessed and adopted. Reasonable regulation risks should be allowed. Implementation / goals should be **incentivised**.

4 Integrated approach for digitalisation

The full value of digitalisation is unlocked only when technologies, processes and actors are **coordinated across the system**. This requires interoperability, coordination and efficient regulation.

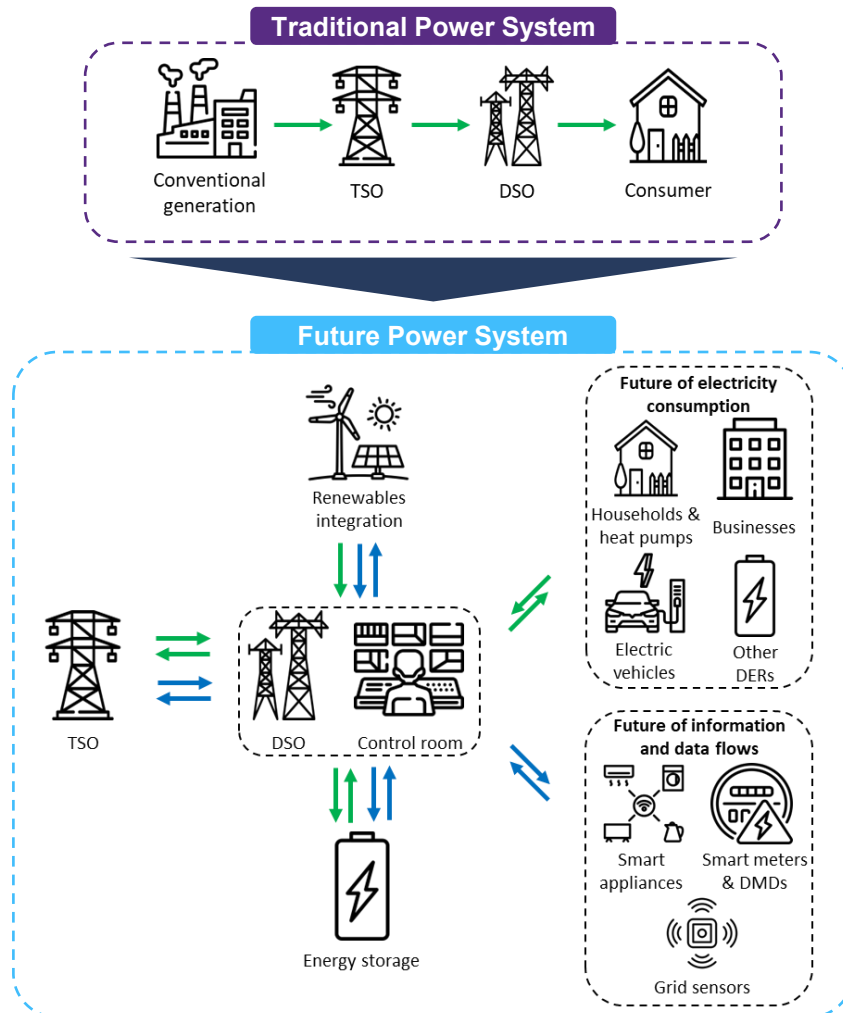
4.1

Best practice 1: Improved network planning



Best practices 1 – Improved network planning

Leverage data to improve planning, support innovation, and enable system transformation



Tipping points found

Investment doctrine focused on conventional technologies

- Digital and innovative solutions are usually not part of DSO grid development plans.
- They require market and technological readiness to get considered in planning.
- There is a lack of transparency and independence in decision-making.





R&D and pilots focused on the traditional system operation

- Traditional R&D and deployment may not be optimal in a system with multiple interfaces
- Long processes for pilots and not accepting pilots from other EU-countries also hinder the potential of new technologies.

Best practices

- **Digital planning:** Digitalise network planning itself and take on board data from all possible sources (digital twins).
- **NOVA principle:** Consider the potential of grids with a higher utilisation in network planning.
- **Rethink R&D and deployment approach:** Consider a system-wide approach, with decentralised benefits (not only for system operation but for other stakeholders) and multiple interfaces (storage, decentralised generation, demand-side flexibility, demand-side data flows).
- **End-To-End approach for digital:** planning should include R&D, studies, permits, and construction work for asset integration.

Network planning – National situations

National situations			
 Germany	 Spain	 Great Britain	 France
<p><u>Mechanism:</u></p> <ul style="list-style-type: none"> ▪ The NOVA-principle implies to first aim at investments for grid optimization before grid reinforcement before grid expansion ▪ TSOs only consider innovations with market availability/ readiness today or near future in planning ▪ Latest grid development plan considers only DLR and high temperature conductors <p><u>Perception of stakeholders:</u></p> <ul style="list-style-type: none"> ▪ It is not clear if the NOVA-principle is applied in a strictly technologically-neutral way ▪ DSO planning likely less developed and highly dependent on network (there are app. 800) ▪ Largely separate infrastructure planning for electricity, gas and hydrogen, but first steps to develop joint planning guidelines 	<p><u>Mechanism:</u></p> <ul style="list-style-type: none"> ▪ Uncertainty is considered within the scope of the transmission network development plan, in line with the guiding principle of “maximising the use of the existing network, renewing, expanding capacity, using new technologies” ▪ The following additional options to the traditional elements are assessed: Dynamic Line Rating, topology modifications (phase shifters, FACTS, LMS, Dynamic Power Flow), synchronous condensers, SATA. <p><u>Perception of stakeholders:</u></p> <ul style="list-style-type: none"> ▪ No plans to implement anticipatory investments. 	<p><u>Mechanism:</u></p> <ul style="list-style-type: none"> ▪ Large set of options are considered in grid planning including all commercial solutions proposed to ESO. ▪ Different scenarios are considered to enable best possible decision making. Short-term solutions may be considered to confirm the need for longer-term solutions (Single Year Regret Decision Making methodology). ▪ There are different Uncertainty Mechanisms in the RIIO framework enabling investment decisions when costs or timing of investment are more mature. Opportunities could be uncovered both at the planning stage, and throughout the length of the price control. 	<p><u>Mechanism:</u></p> <ul style="list-style-type: none"> ▪ The DSO published its first NDP in 2023, while the TSO NDP is much more advanced with analyses across multiple scenarios, with focuses on telecommunications, storage. ▪ Anticipatory investments are allowed for studies and administrative procedures in order to reduce the investment time. <p><u>Perception of stakeholders:</u></p> <ul style="list-style-type: none"> ▪ The use of flexibilities in system planning should still be clarified. The NRA considered that the 2020 NDP didn't incorporate sufficient flexibilities in the planning.
<p><u>Risks for digital:</u> Requires market and technological readiness to get considered in planning.</p>	<p><u>Risks for digital:</u> Lack of transparency and independence in decision making</p>	<p><u>Risks for digital:</u> reduced with Uncertainty Mechanisms</p>	<p><u>Risks for digital:</u> Lack of transparency and independence in decision making</p>

Sources: [RTE \(2025\) telecom focus](#), [Enedis \(2023\) NDP](#), [CRE \(2020\) NDP opinion](#), [RED \(2021\) NDP](#).

Abbreviations: DLR – Dynamic Line Rating, FACTS – Flexible AC Transmission System, LMS – Loss Measurement System, SATA – Storage As Transmission Asset, NDP – Network Development Plan, RIIO – Revenue = Incentives + Innovation + Outputs, ESO - Energy System Operator, NRA – National Regulatory Authority, TSO/DSO – Transmission/Distribution System Operator.

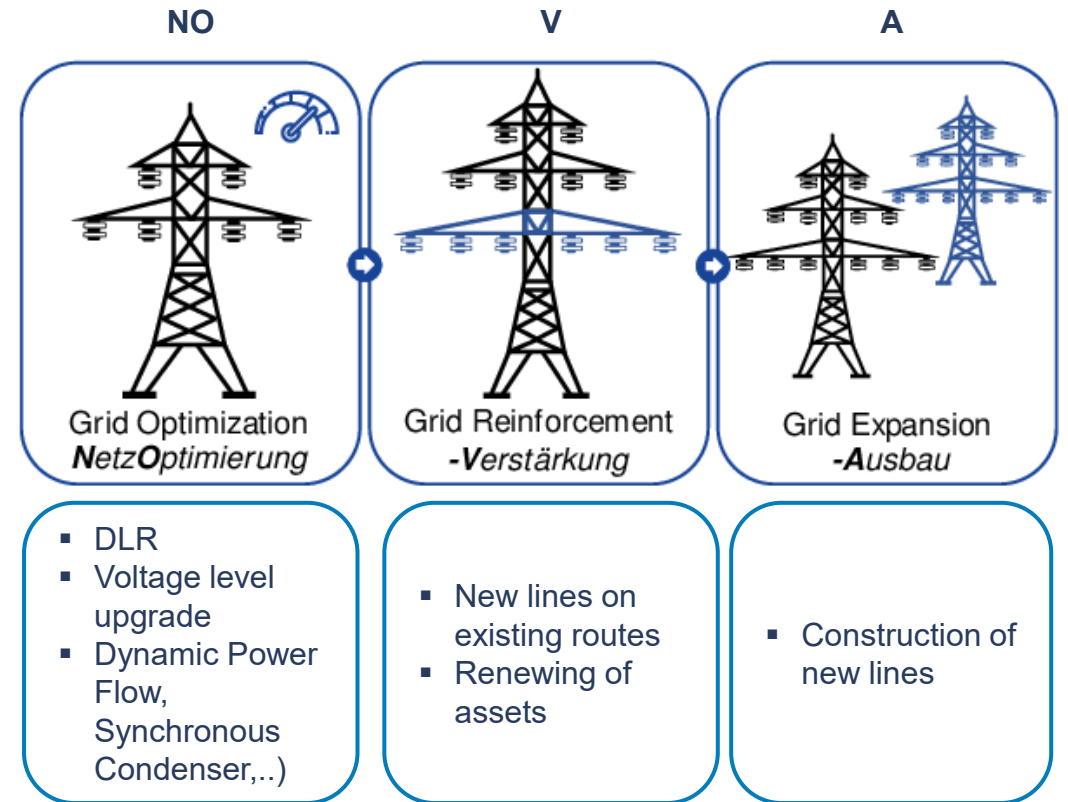


Best practice: According to German TSOs' NOVA principle, grid optimisation must be considered over grid reinforcement, over grid expansion

In Germany there is a huge social acceptance problem with network expansion. The NOVA-principle is built recognizing this, to make sure that expansion comes last.

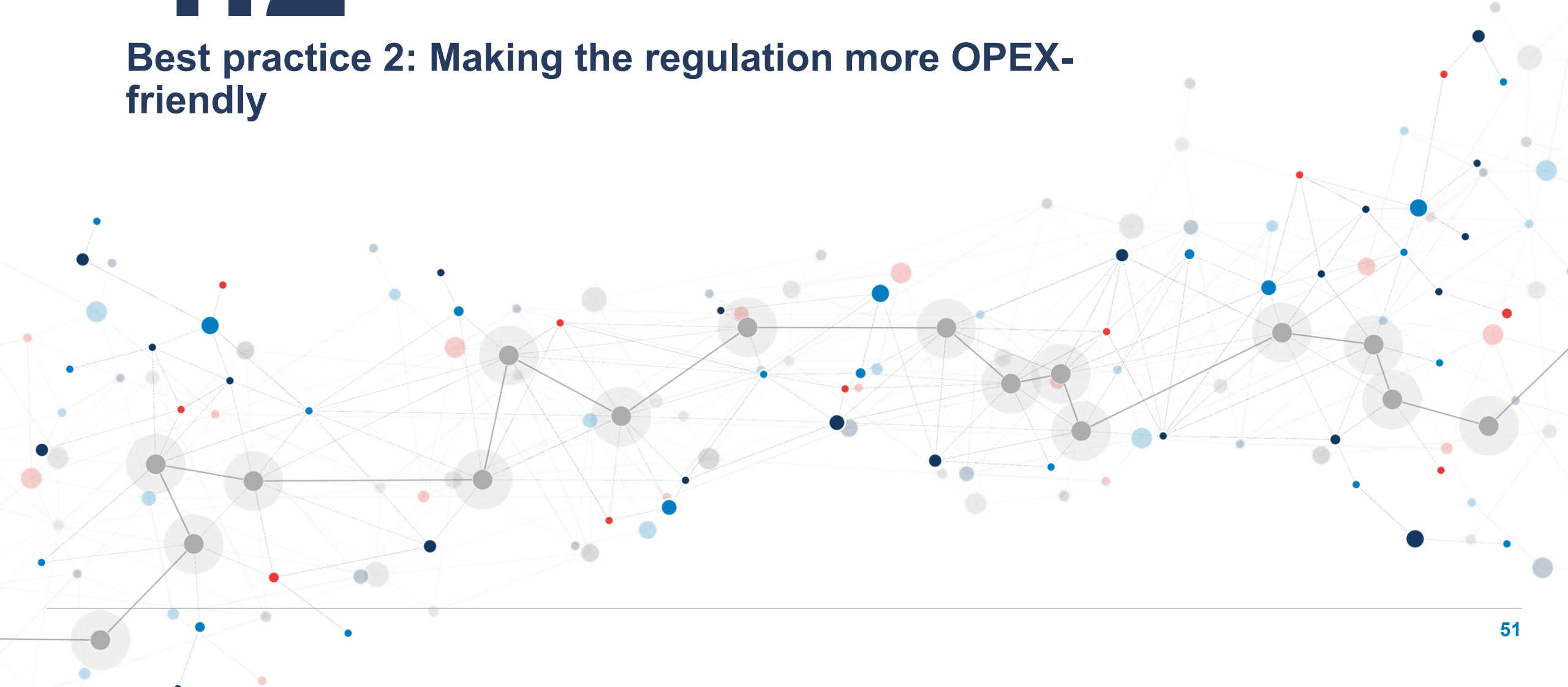
- German TSOs follow a network planning principle which favours firstly optimising and strengthening the existing network and secondly extending the network.
- Each category contains different options which are examined before moving on to the next.
- The NOVA procedure ensures that the most efficient solution is implemented and that no new lines are built where the network could be strengthened at lower cost.

Grid Planning Principle "NOVA"¹



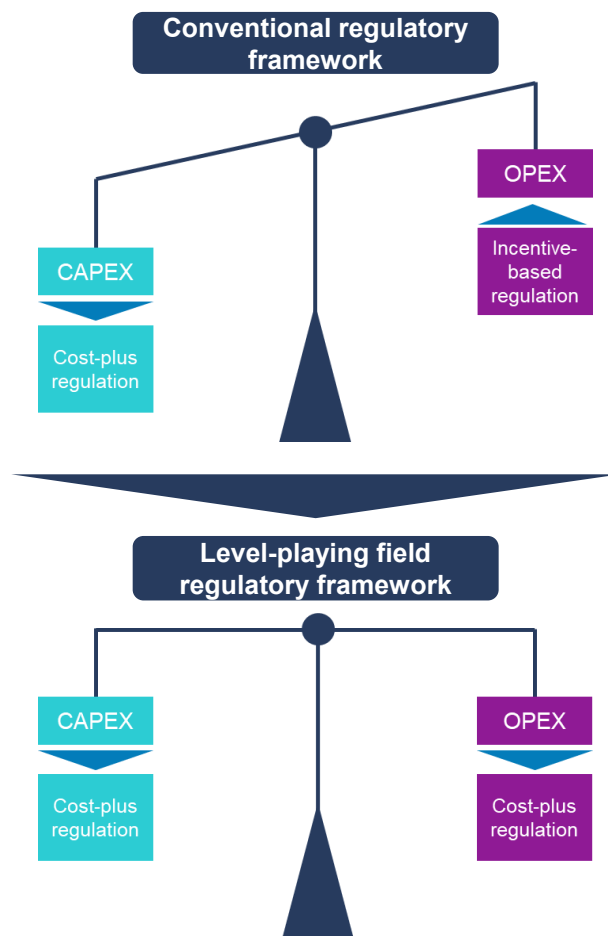
4.2

Best practice 2: Making the regulation more OPEX-friendly



Best practices 2 - Making the regulation more OPEX-friendly

Foster a level playing field for cost recognition and an efficient management of risks and uncertainties



Tipping points found

CAPEX bias / OPEX disadvantage





- Most European regulatory systems treat capital expenses (CAPEX) more favourably than operating expenses (OPEX).
- This so-called **CAPEX-bias** means that using digital solutions can be less financially attractive than investing in physical assets.
- More specifically, the rules of cost recognition may distort the way in which network operators invest in digital solutions.
- Digitalisation is evolving rapidly. But most regulatory frameworks **lack the possibility to deal with uncertainty** and inaccuracy (for example of cost forecasts).

Best practices

Making the regulation more OPEX-friendly

- Cost+ regulation for digitalisation expenses would ensure greater certainty and speed for recognition of costs by implementing a scheme guaranteeing a remuneration of costs plus an adequate return.
- Increased possibility for capitalisation of OPEX.
- This would create a level playing field with other technologies that are more CAPEX-intensive.
- In order to maintain an efficiency incentive, uncertainty mechanisms may be defined based on an adequate sharing of the risks for TSOs.

Making the regulation more OPEX-friendly – National situations

National situations			
 Germany ^[1]	 Spain	 Great Britain ^{[2] [3]}	 France ^[4]
<p><u>Mechanism:</u></p> <ul style="list-style-type: none"> OPEX are typically under a strict budget, which is only updated every five years (“every base-year”), and typically only on the basis of invoiced and audited costs in this year. On the other hand, CAPEX remuneration can be rolled-over into network user tariffs very quickly, often in the same year. <p><u>Perception of stakeholders:</u> Interviews highlighted that CAPEX would be less likely to be cut or disallowed in the regulatory cost audit. The result is an incentive for network operators to prefer capital-heavy (traditional) solutions.</p>	<p><u>Mechanism:</u></p> <ul style="list-style-type: none"> Investments are generally limited by investment caps relative to GDP, which often limit overall investments. Rigid system of norm categories and ex-post evaluations. Norm categories are standard technical solutions, which also specify allowed CAPEX and OPEX and seem to not contain digital solutions. Categories are approved for the TSO, but not yet for DSOs. To be implemented. <p><u>Perception of stakeholders:</u> To not face issues in ex-post reviews, Spanish network operators often limit investments to solutions clearly specified as norm categories. This limits digitalised/innovative solutions.</p>	<p><u>Mechanism:</u></p> <ul style="list-style-type: none"> The UK has successfully introduced TOTEX regulation (see below for description).^[1] Part of the spending on OPEX for flexibility measures or other smart solutions would also be remunerated as CAPEX. Moreover, Uncertainty Mechanisms allow for an increase in OPEX expenses both for pilot and roll-out stage. <p><u>Perception of stakeholders:</u> Although National Grid highlights a number innovations in their strategy (roll-out of DLR and smart wires, visual inspection), stakeholders raised some doubts, that the framework in the UK has become too complex.</p>	<p><u>Mechanism:</u></p> <ul style="list-style-type: none"> There is a TOTEX mechanism for IT and telecom expenses. This mechanism could be improved to align with a standard TOTEX mechanism. This mechanism incentivises CAPEX and OPEX separately. In turn, the TSO pilots the 2 envelopes separately, which limits the possibilities of optimisation. <p><u>Perception of stakeholders:</u> Interview with the French regulator CRE highlights that digitalisation expenses can be passed-on relatively well in France.</p>
<p><u>Risks for digital:</u> CAPEX bias may favour traditional technologies over GETs.</p>	<p><u>Risks for digital:</u> Investment cap limits innovative projects. Rigid system of norm categories.</p>	<p><u>Risks for digital:</u> Effectiveness of complex regulation for GETs.</p>	<p><u>Risks for digital:</u> Effectiveness of complex regulation for GETs.</p>

Best practice: Remove CAPEX/OPEX-bias that serves as barrier to OPEX-based innovation

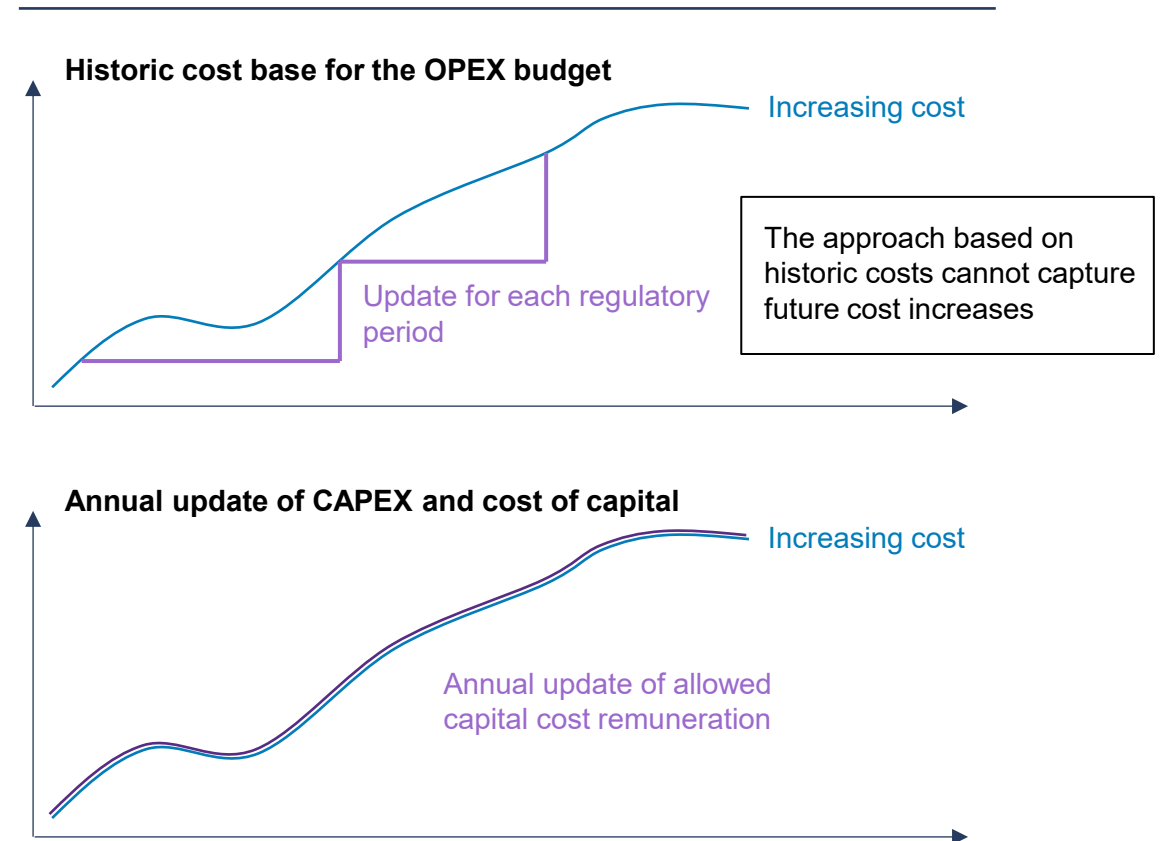
CAPEX and OPEX are often not treated through different regulatory approaches. CAPEX are capitalised and receive a remuneration based on depreciation and capital/financing costs. In contrast, OPEX are differentiated wrt controllability. Controllable costs are indexed on the basis of a photo year (base year) to incentivise cost minimisation. In turn, investments in OPEX instead of CAPEX solutions are disincentivised.

- **CAPEX-Bias:** CAPEX-heavy solutions tend to be favoured. It could therefore often be difficult for network operators to invest in OPEX-intensive solutions. This poses a problem, as necessary investments in efficiency improvements (e.g. innovations and IT solutions) become more difficult.
- **Base year problem:** If OPEX-intensive investments are made in non-reference years, these investments will not be reflected in the permitted revenue until the next cost update in the base year. Uncertainty exists with regard to cost approval for innovative OPEX solutions in the base year, as it may be questioned if these costs are recurring throughout the regulatory period.
- **Revenue cap:** In contrast, expansion or restructuring investments (typically CAPEX-intensive) also extend the revenue cap during a regulatory period.



This can incentivise investment in CAPEX-intensive solutions, even if an OPEX-intensive solution has lower total costs*.

Illustration - CAPEX-Bias



Best practice: Introduce possibility of OPEX increase for digital solutions or allow for capitalised digital spendings

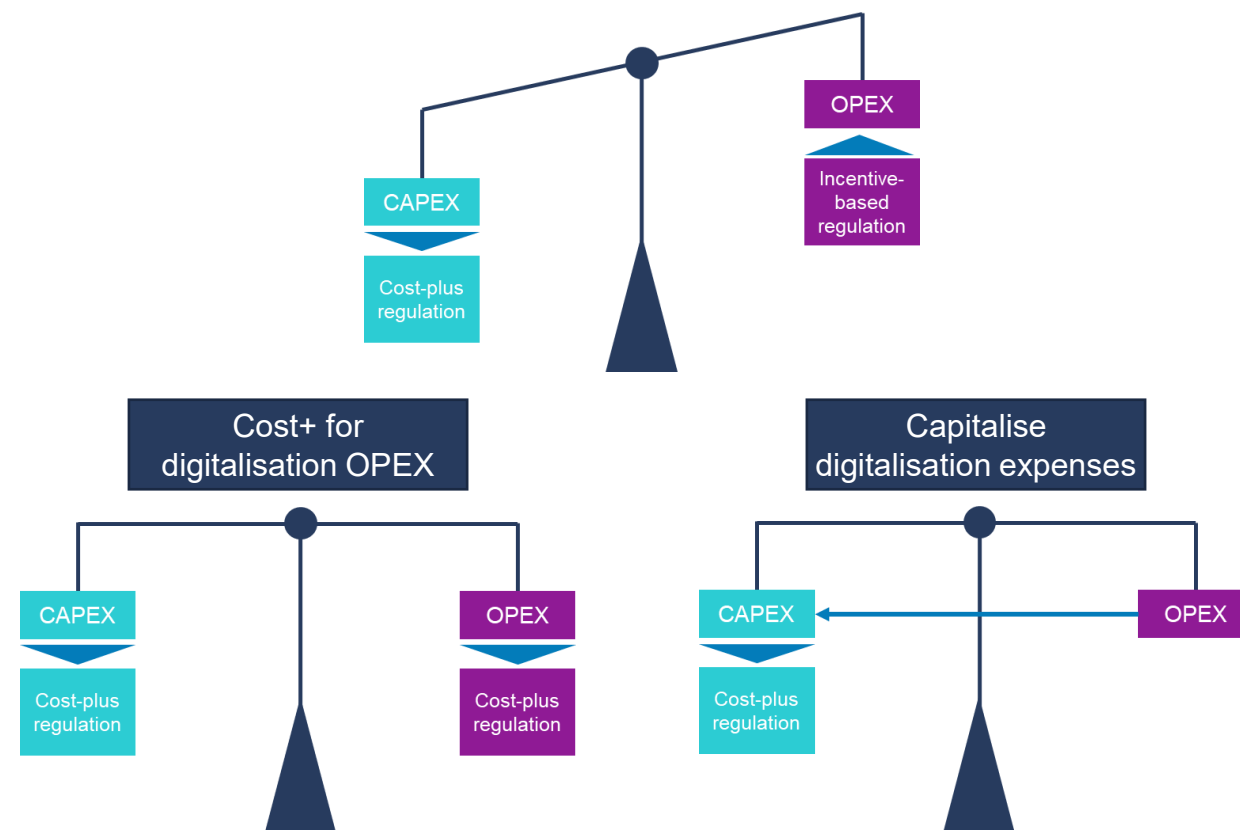
The CAPEX bias can be addressed in different ways depending on the countries

- A cost+ framework for digitalisation would enable a more systematic approach to enable digitalisation expenses.
- The possibility to capitalise digitalisation expenses could provide a similar effect, although it raises questions on the accountability of the different technologies.

A wider reflexion on all expenses should also be engaged to avoid CAPEX bias

- Efficiency benchmarks tend to rely on the number of conventional assets to determine the efficiency of network operators.
- This provides an indirect incentive for CAPEX spending in conventional technologies, which is very detrimental to digitalised technologies and often goes in the opposite direction to national targets for digitalisation.
- A simplified solution could be given more weight to enhanced network assets in benchmarking as they provide more benefit compared to traditional lines only.

CAPEX bias and recommended solutions





Best practice: UK regulation (RIIO) played a key role in fostering the development of Innovative Grid Technologies in GB

Context

- In 2010, OFGEM found that a change in the regulation of energy networks was **necessary to deliver value for network users and support the transition to decarbonised energy.**
- The objective was to **strengthen the role of network companies in the transition** while improving **value-for-money** for consumers.
- There was a perception that innovation in the network industry had been reduced during the years of incentive regulation relative to when the industry was run as a public service.

Regulation

The RIIO concept: Revenues = Incentives + Innovation + Outputs. A TOTEX based approach to solve the CAPEX/OPEX trade-off:

- RIIO addresses the CAPEX bias by implementing a **TOTEX-based approach** to the calculation of allowed costs. Independently from the actual expenditures of the regulated company, a **fixed share of the total cost, set ex-ante by the regulator, is treated as CAPEX and contributes to the formation of the RAB**, while the rest is treated as OPEX and remunerated within the book year. In practice, this means that part of the spending on OPEX for flexibility measures or other smart solutions would also be added to the RAB.

IGT = Innovative Grid Technologies

Challenges identified by Ofgem at the time of RIIO implementation

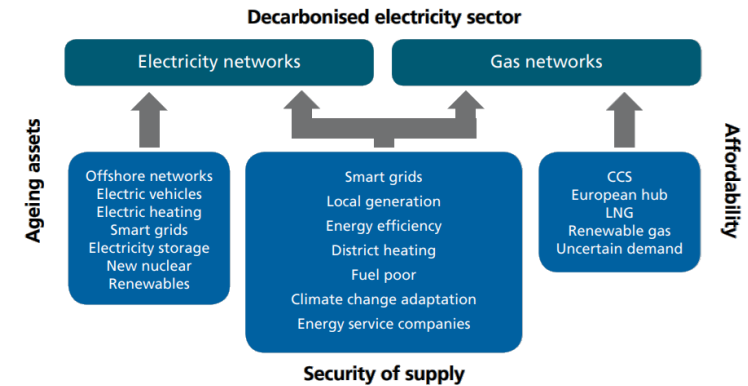
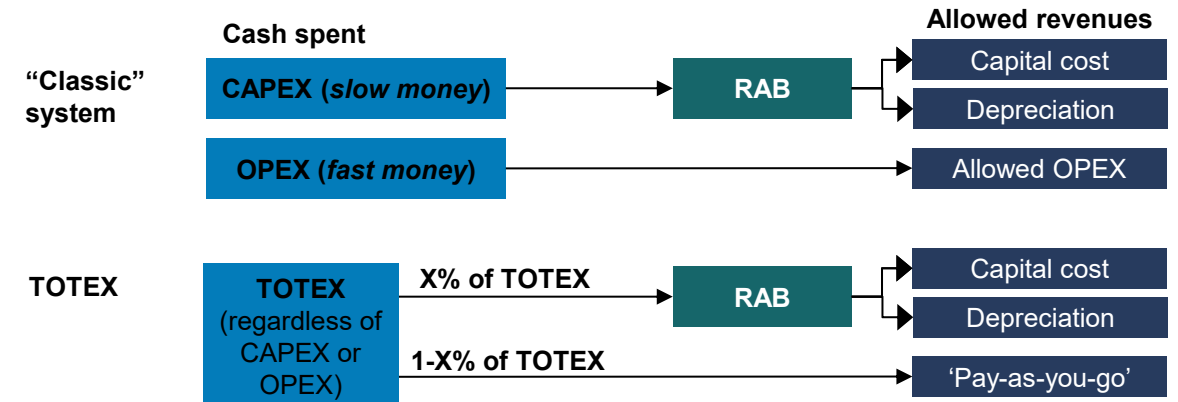


Illustration of a TOTEX regulation*



Note : 'Pay as you go' refers to costs that are recovered every year or during the control period, and therefore are treated similarly to OPEX in the "classic" system.

Abbreviations: OPEX/CAPEX/TOTEX – Operational/ Capital/ Total Expenditures, RAB – Regulatory Asset Base



Best practice: The “Net Zero Industry Act” (NZIA) gives the option for Member States to introduce regulatory sandboxes to test using digital grid technologies (DGT) and IGT

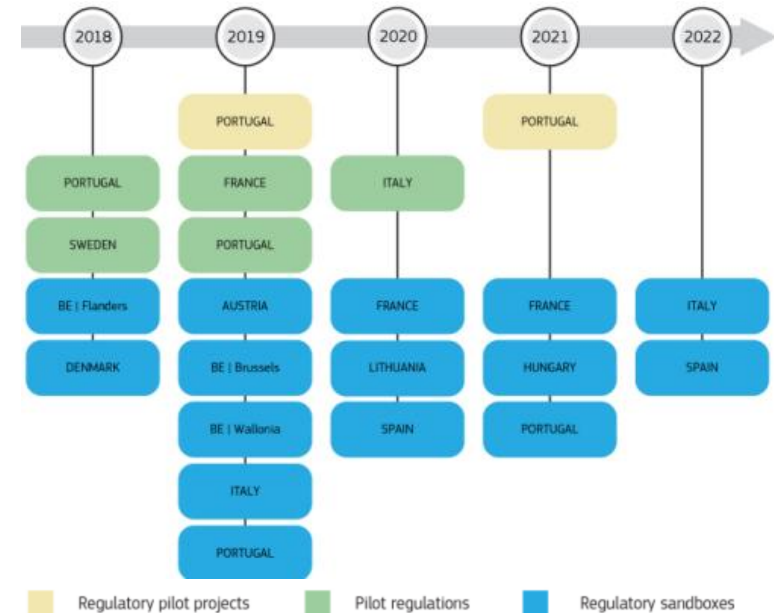
The NZIA issued in 2023 establishes a framework to strengthen net-zero technologies (including grid technologies)

- In the regulation, the European Commission defines the goal that by 2030, the energy system’s manufacturing capacity of **strategic net-zero technologies** (which include **grid technologies**) should reach at least “40% of the Union’s annual deployment needs”¹.
- A particular focus is set to “**innovative net-zero technologies**”, defined as net-zero technologies that: (i) Have a TRL lower than 8, (ii) are not currently available on the market, (iii) are advanced enough to be tested in a controlled environment

The NZIA gives member states the possibility to establish regulatory sandboxes, to test innovative net-zero technologies in a controlled environment for a limited amount of time, with the objective of removing regulatory barriers²

- Regulatory sandboxes should allow “for the development, testing and validation of innovative net-zero technologies, in a controlled real-world environment for a limited time before their placement on the market”¹.
- The identification of regulatory barriers can be done by innovators, but the regulator can also identify legislative provisions for testing.
- In this process, Member states should:
 - Introduce implementing acts giving guidance to developers of innovative net-zero technology that apply for regulatory sandboxes
 - Design sandboxes such that regulatory lessons learnt can be shared between the national competent authorities

Adoption timeline of regulatory experimentation initiatives in the EU³



Regulatory sandboxes implementation phases³





Best practice: Uncertainty Mechanisms enable timely investment decisions and review of uncertain OPEX expenses

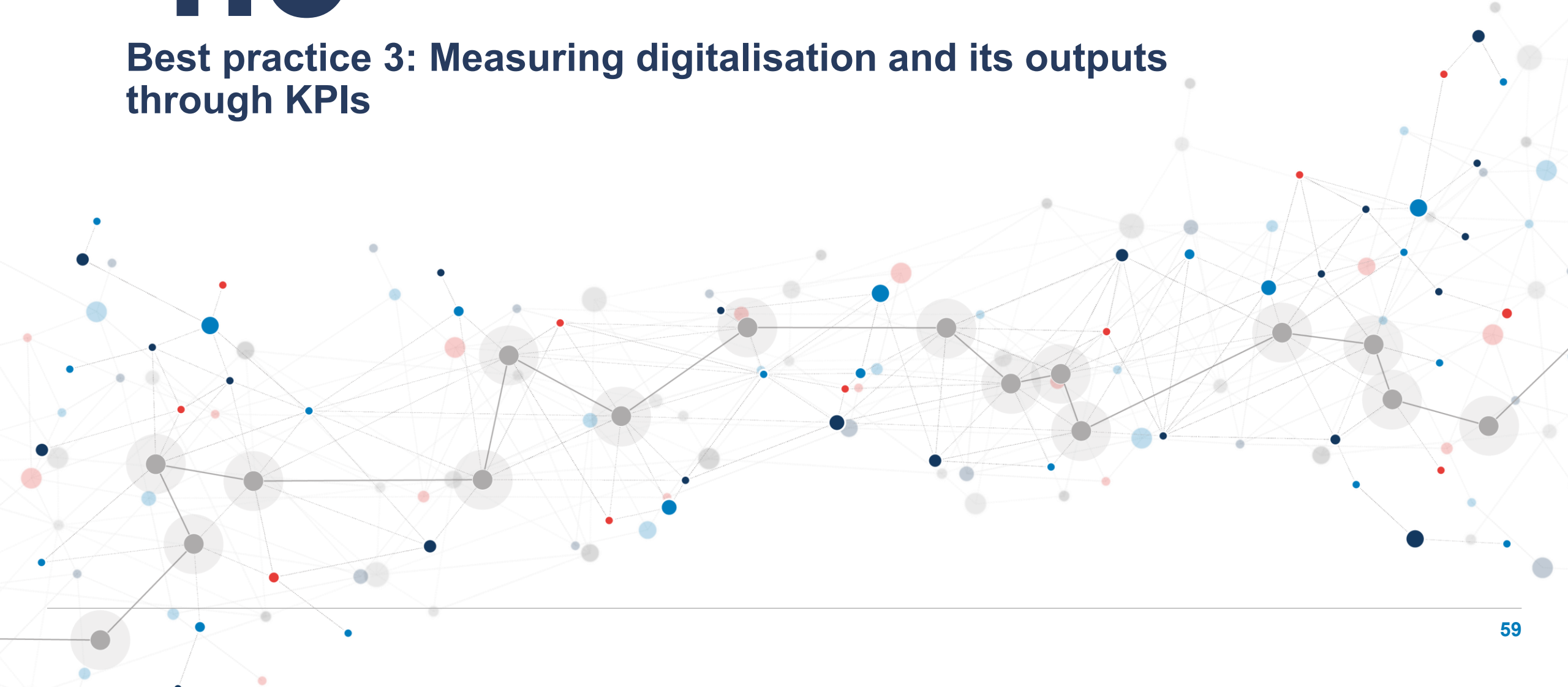
Uncertainty mechanisms allow changes to a network company's allowed revenues to be made in light of what happens during the price control period.

- There are always uncertainties about the appropriate outputs companies should deliver and around their expenditure requirements over a price control period.
- These are greater under an eight-year price control than under a five-year one. The RIIO framework includes a number of elements to help deal with these uncertainties.

Uncertainty Mechanisms	
<p>Pass-through</p> <ul style="list-style-type: none"> ▪ Adjust allowances for costs over which NOs have limited control. ▪ E.g. severe weather event. 	<p>Volume driver</p> <ul style="list-style-type: none"> ▪ Adjust allowances in line with the actual volume of work delivered. ▪ E.g. connections.
<p>Indexation</p> <ul style="list-style-type: none"> ▪ Protection against the risk that outturn prices are different than forecast. ▪ E.g. inflation, cost pressure. 	<p>UIOLI</p> <ul style="list-style-type: none"> ▪ Adjust allowances where the need for work has been identified, but uncertain nature of work or costs ▪ E.g. small Net Zero projects
<p>Re-opener</p> <ul style="list-style-type: none"> ▪ Decide, within a price control period, on additional allowances to deliver a project or activity once there is more certainty on the needs case, project scope or quantities. ▪ E.g. non-operational IT and telecoms Capex. 	

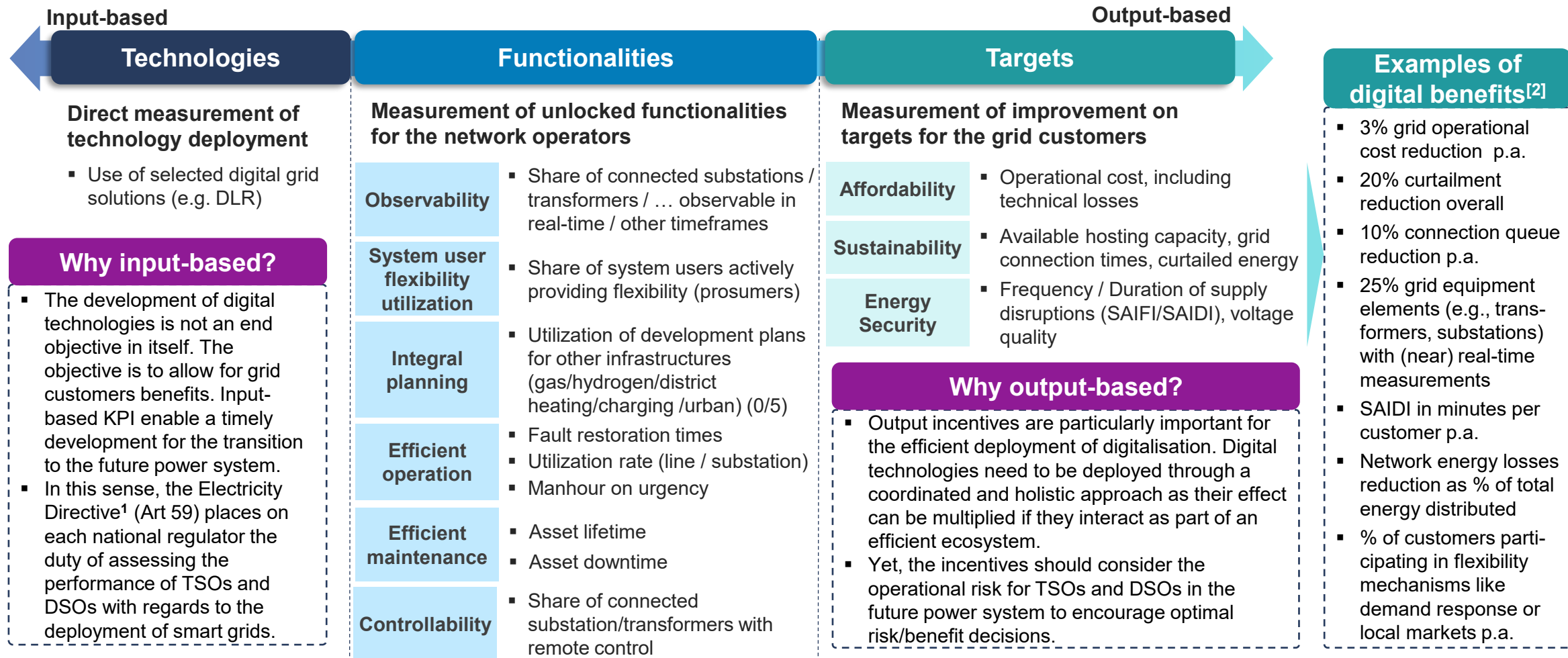
4.3

Best practice 3: Measuring digitalisation and its outputs through KPIs







Best practices 3 - Measuring digitalisation and its outputs through KPIs

Incentivize and reward grid operators based on metrics reflecting the benefits of the digital grids



Measuring digitalisation and its outputs through KPIs – National situations

National situations			
 Germany ^[1]	 Spain	 Great Britain ^[2]	 France ^[3]
<p>Mechanism:</p> <ul style="list-style-type: none"> While German regulation has quality incentives, there are no output-based incentives that would incentivise digitalisation or outputs digitalisation would produce (although there is some incentive for efficiency through the efficiency benchmarking). <p>Perception of stakeholders:</p> <ul style="list-style-type: none"> It was said in the interviews that it is too easy for DSOs to defer necessary actions like preparing to comply with regulations mandating the used of flexibilities (§14a) – no real incentives to act. The regulatory cost benchmarking could create an incentive to maximise outputs over inputs, but it is unclear if that works 	<p>Perception of stakeholders:</p> <ul style="list-style-type: none"> Lack of measure for digitalisation as output. 	<p>Mechanism:</p> <ul style="list-style-type: none"> Output-based incentives and innovation budgets (RIIO framework) The DSO Incentive aims at a more efficient develop and use the network, taking into account flexible alternatives to network reinforcement and the TSO new infrastructure Stakeholder Engagement Survey. The cost for pilots and innovations are also well covered by the tariff and through Strategic Innovation Fund (SIF) and Network Innovation Allowance (NIA). <p>Perception of stakeholders:</p> <ul style="list-style-type: none"> The regulatory system in the UK is now sometimes criticised for being too complicated. 	<p>Mechanism:</p> <ul style="list-style-type: none"> Targets for digitalisation are set by the NRA. As such, the efficiency of digitalisation depends on how well those targets are set. 8 actions have been detailed for the upcoming regulatory period, including: <ul style="list-style-type: none"> Contracts for local flexibility Map of preferred battery location and time signal. Map of network congestion Study of congestion between France and Spain <p>Perception of stakeholders:</p> <ul style="list-style-type: none"> Digitalisation expenses can be passed on to customers relatively well.
<p>Risks for digital: Lack of incentives to unlock the benefits from digitalisation</p>	<p>Risks for digital: Lack of incentives to unlock the benefits from digitalisation</p>	<p>Risks for digital: Effectiveness of complex regulation for digitalisation.</p>	<p>Risks for digital: KPIs are interesting to set foundations for digital, but may be extended to more direct digital outputs</p>

Best practice: Existing incentives in France and the UK

Specific incentives relevant for digital solutions have been introduced in France and the UK and could be an inspiration for choosing KPIs for regulation in other jurisdictions.



DSO Incentive

- **Aim:** More efficient develop and use the network, taking into account flexible alternatives to network reinforcement.
- **Indicators:** Stakeholder Satisfaction Survey, Performance Panel (and Outturn Performance Metrics)



Major Connection Incentive

- **Aim:** Improve the service for connecting projects to the grid.
- **Indicators:** Customer Satisfaction Survey and the Annual Report



External Innovation Incentive

- **Aim:** Compliance by RTE of deadlines for implementing actions identified as “priorities” to facilitate innovative use of the network.
- **Indicators:** Implementation dates for aFRR auctions, congestion map, improving local flexibility integration (IT and contracts), providing data to the MARI platform.



Connection Incentive

- **Aim:** Improve commissioning of connections and decision process.
- **Indicators:** Deadline and budget compliance for proposal and connection agreement, average duration for different categories of connections.

Only few countries explicitly incentivize the use of flexible technologies.

Similar connection incentives exist in numerous countries



Best practice: Output-based regulation in Italy

The Italian regulator has introduced an output-based regulation framework to incentivise Terna to maximise cross-zonal transfer capacity

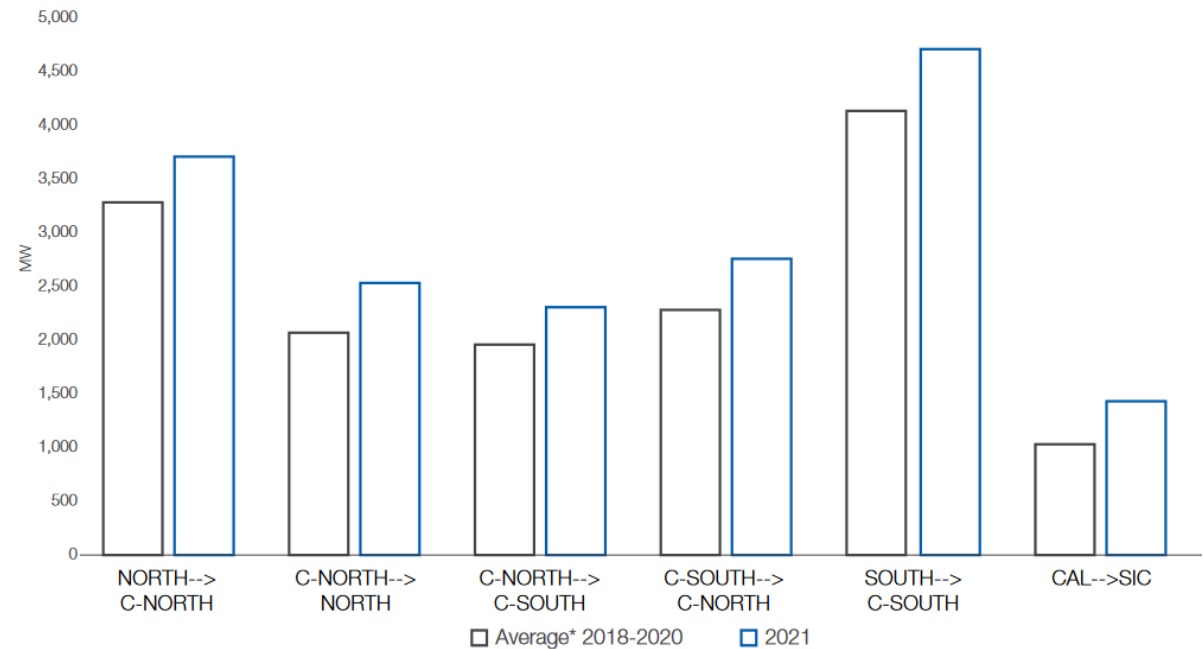
Regulation

- Italy introduced output-based regulation for electricity transmission in 2015. Among the outputs identified by this new regulatory framework, there is the increase of the cross-zonal transfer capacity that the TSO makes available to market parties. To promote the integration of the various market zones cost-efficiently, both within Italy and cross-border, two dedicated incentives were offered to the TSO until the end of 2023:
 - A reward if the TSO can expand the transfer capacity up to a certain level, which is approved by the regulator based on an assessment of the system needs.
 - On the other hand, the TSO receives a further reward if the solution adopted entails smaller CAPEX than a reference value set by the regulator for each border.

Impact

- By implementing a series of low-CAPEX solutions (e.g., new protection schemes and dynamic line rating), the Italian TSO was able to increase cross-zonal transfer capacity by 1450 MW in 2020 at comparatively low cost (roughly 5.5 m€), generating an expected benefit for the system of more than 1 bn€.
- Based on these results, the Italian regulator has awarded a premium of roughly 143 m€: 103 m€ linked to the increase of the transfer capacity and 40 m€ linked to the use of capital-light solutions.

Average cross-zonal transport capacity made available for the day-ahead market (DAM) between 2018 and 2020 and in 2021¹



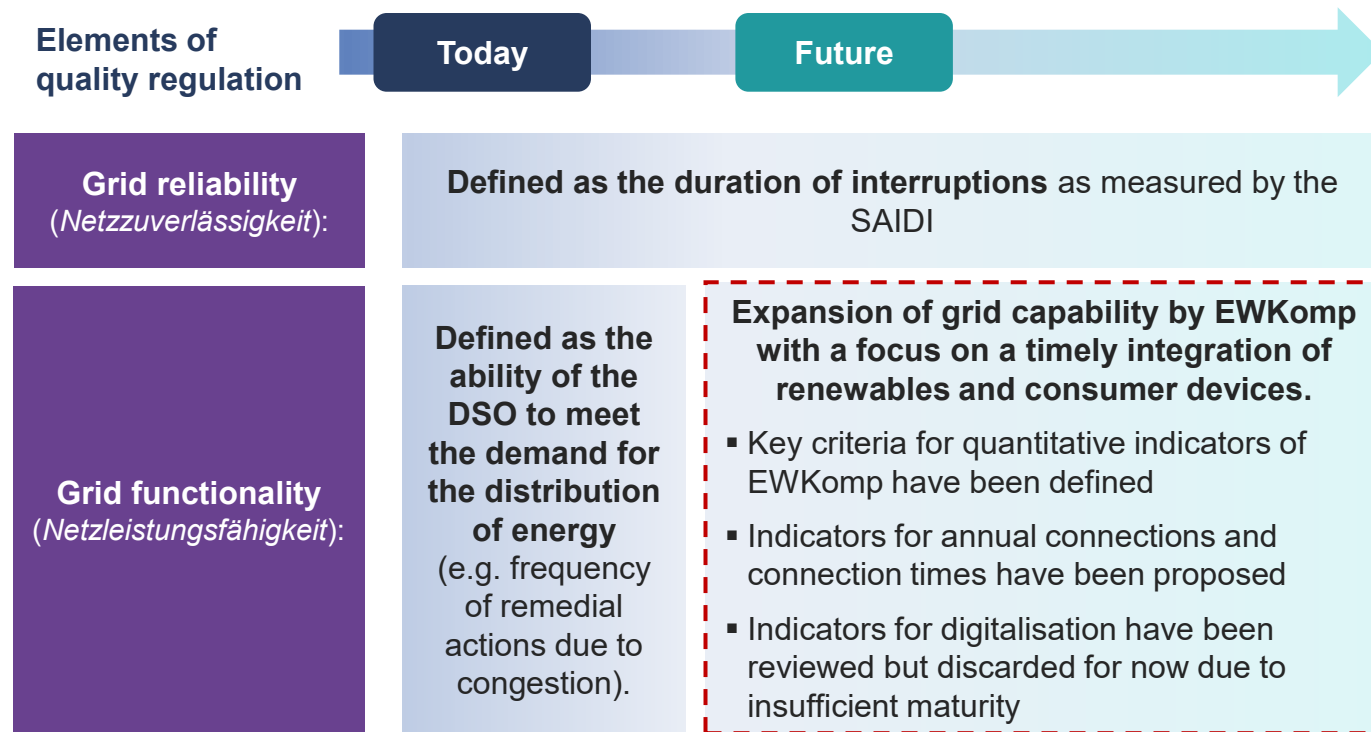


Best practice: *Energiewendekompetenz* (EWKomp) in Germany

The German regulator, BNetzA, has launched a process to review and extend its quality regulation, aiming at making “energy transition functionality” a key pillar of the regulatory framework

Energy transition functionality is set to reshape quality regulation in Germany:

BNetzA incentivises two elements through bonuses / penalties in the context of quality regulation for DSOs:



» *Energy transition functionality in the distribution grid describes the – potentially forward-looking – implementation of requirements that promote the transformation of the grid infrastructure across all grid levels with regard to the energy transition, sustainability, reliability and affordability.* «

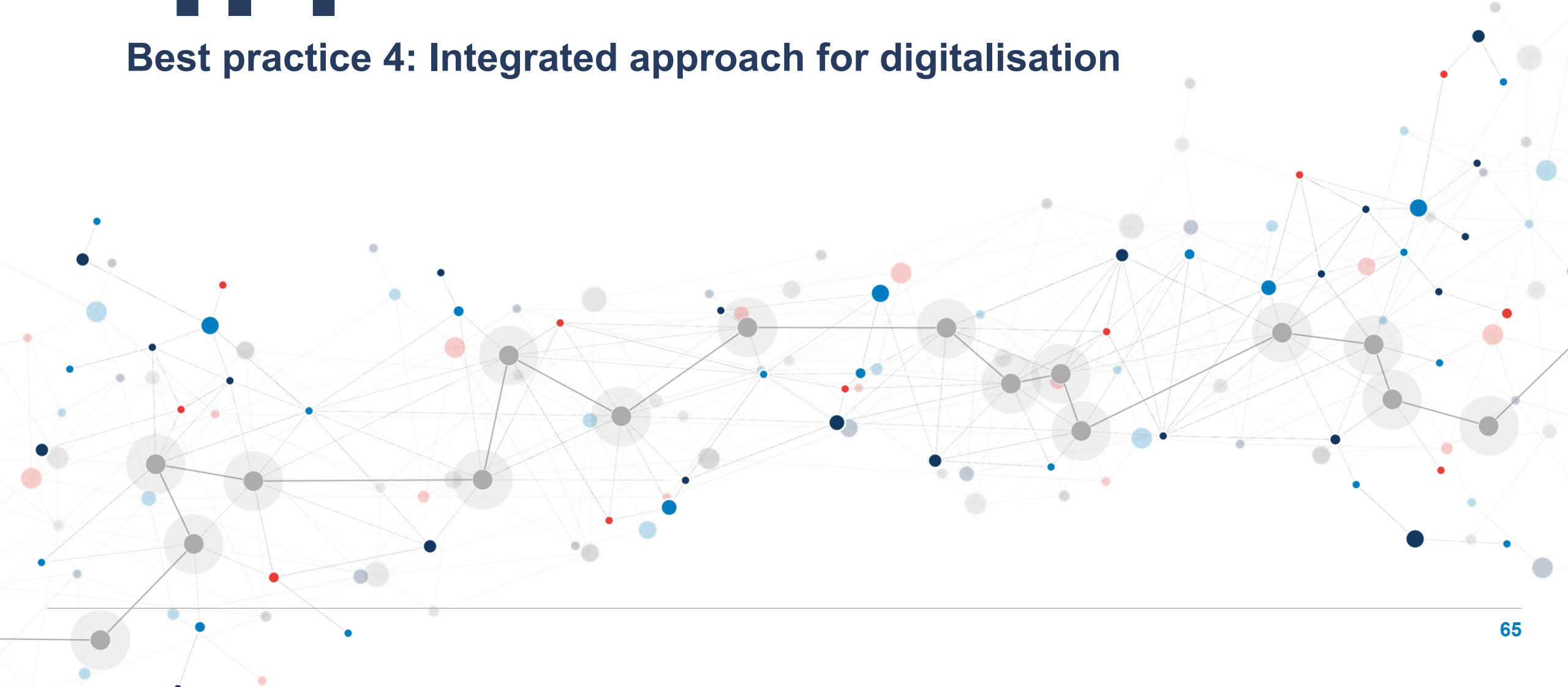
» *Accordingly, grid functionality in the future should be described as the **ability of the grid to meet the demand for the distribution of energy, primarily from renewable energy sources.*** «

A stakeholder consultation on the proposal has taken place in Q4 2024 and results are currently being reviewed by the BNetzA.

BNetzA is in the process of implementing output KPIs.

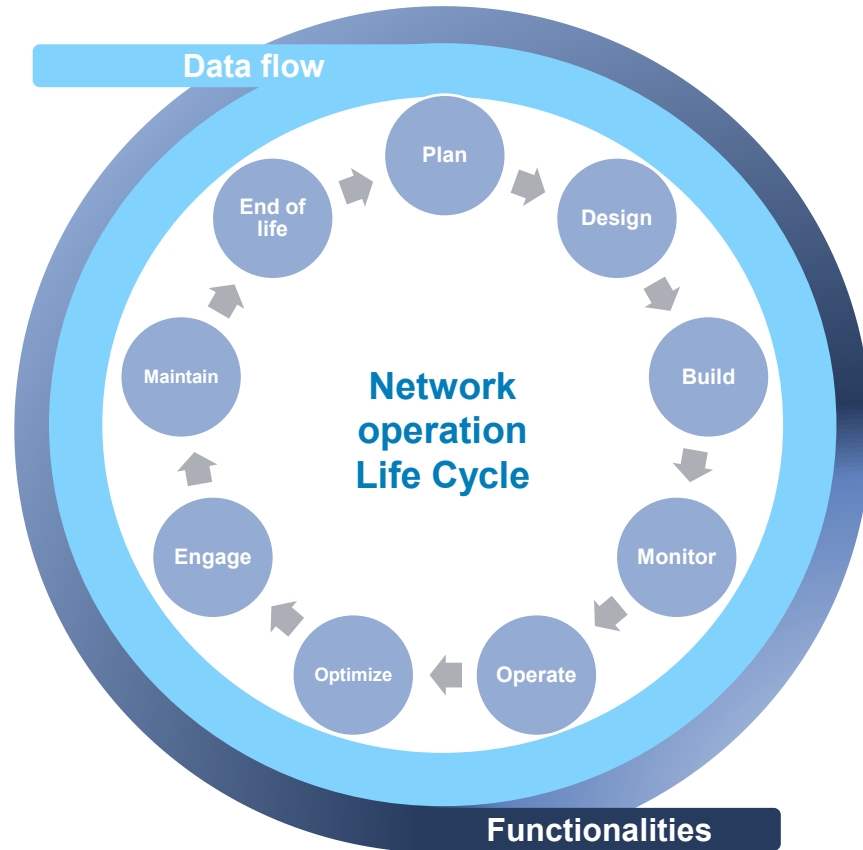
4.4

Best practice 4: Integrated approach for digitalisation



Best practices 4 - Integrated approach for digitalisation

A system wide approach to digital grid technologies is need to maximize value across the network operation life cycle



Tipping points found

Digitalisation is considered as technology roll-out, not as system-wide transformation

- **Lack of interoperability:** isolated solutions increase costs, delay deployment, and require bespoke integration
- **Lack of coordination:** Data exchange between actors – such as between TSOs and DSOs or between grid and adjacent sectors/infrastructures – is progressively standardised, structured and embedded in day-to-day operations
- **No lifecycle integration:** Each stage – planning, investment, operations, and maintenance – generates and depends on data. The different stages are not yet connected.

Best practices

- **Harmonization:** Accelerate the implementation of existing EU regulations and directives in a harmonized way across member states.
- **Data access:** Clearly delineate the rights of usage across network operators and third parties for the data measured in a digitalised grid.
- **Better use of flexibility to support grid stability:** Develop effective mechanisms to access and incentivise the use of reliable flexibilities (incl. flexibility platforms and local flexibility markets) and define the related responsibilities and coordination needs between T/DSOs.

Why Grid Digitalisation must be integrated

The full value of digitalisation is unlocked only when technologies, processes and actors are coordinated across the system

Digitalisation is a System Transformation

Digitalisation is not simply technology roll-out – it changes how the grid must be planned, managed and maintained.

- Domain-specific requirements and related domain- or application-specific systems create fragmentation and limit system benefits.
- Installing sensors and actuators is only viable, when the collected information can be analysed and used for improved decision-making
- Integration must be designed from the start – spanning technologies, data infrastructure, organisational practices, and governance.
- Such a system-wide transformation requires:

Harmonisation

Harmonised requirements and standardized processes are essential for acceleration

- Isolated solutions increase costs, delay deployment, and require bespoke integration.
- Regional regulation/ framework, customer requirements or mechanisms can result in fragmentation and a potential solution log-in
- Interoperability is foundational to vendor diversity, scalability and secure integration of advanced functionalities.
- Harmonised data formats and communication protocols enable data exchange.
- Standardised onboarding (e.g. via AAS) allows grid components to be integrated seamlessly and at scale.

Coordination Across Actors

System benefits emerge when stakeholders operate in a coordinated manner.

- Electrification, flexibilization and renewable generation need to be deployed in a system serving way.
- Data exchange between actors – such as TSOs and DSOs or grid and adjacent sectors/ infrastructures – must be harmonised, structured and embedded in day-to-day operations.
- Markets (e.g. for local flexibility) are essential to aggregate decentralized information and efficiently align decisions without relying on centralised planning.
- Cross-stakeholder collaboration, including data access and sharing rights, is crucial

Lifecycle Integration


Digital tools must connect decisions across the full asset and system lifecycle.

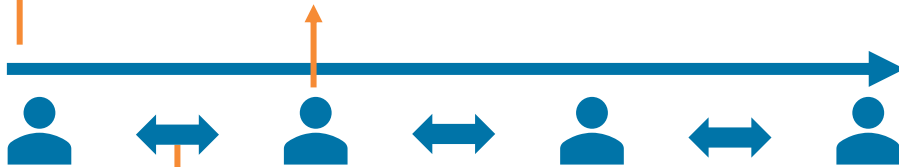
- Each stage – planning, investment, operations, and maintenance – generates and depends on data.
- If these stages are disconnected, opportunities for optimisation and learning are lost.
- For example: insights from real-time operation should feed back into planning, asset design, and procurement.
- Lifecycle integration unlocks compounding benefits over time: e.g., better reliability, lower costs, and improved adaptability.

System user flexibility: Steps for a harmonized implementation

Policymakers and regulators need to define key framework parameters per use case such that the industry can define and choose the standards that best fulfil the interface requirements

Each use case must be specified:

1. What is the (Business) use case?
 - What is the “value chain“? What is the procedure?
2. What does  need for each step of the use case?
 - Which information per interaction and what are the conditions of the exchange?



3. Which standards to exist/ could be adjusted?
 - IEC, CEN/CENELEC
- 4) Which existing (test) profile can be reused? / Is a new one required?

Each use case is different, e.g., activation of flexibility is a different use case from the use case payment of related flexibility services.

Example System User Flexibility

1. Utilization of decentralized flexibility to support the power system

EU Targets: EMD, Network code demand response, energy data space, several communications on prioritized flexibility utilization

2.

Who	What	When	Under which conditions
The involved stakeholders	The nature of the information exchanged	Time-based communication requirements (response speed, signal latency, ...)	Any additional requirements, such as e.g. (cyber) security
Network Code Demand Response expected end of 2025 will define roles and responsibilities The implementing acts and the data4energy group working on more details	The network code demand response names the general information processes, however more granularity may still be needed	Implementing Acts	Additional regulation

3. Industry defines / chooses adequate standards

Data Flow across the lifecycle of the electrical system is key

Digitalisation connects life cycle steps through continuous data exchange, and enables data flow, with the functionalities of Integral Data Management and Data Exchange (Ecosystem) at the core

- **Unified Data Across All Phases:**

A digital grid gathers real-time data from every stage, meaning that planning, daily operations, and maintenance all draw from the same reliable information. This shared view prevents data silos and helps everyone make better decisions.

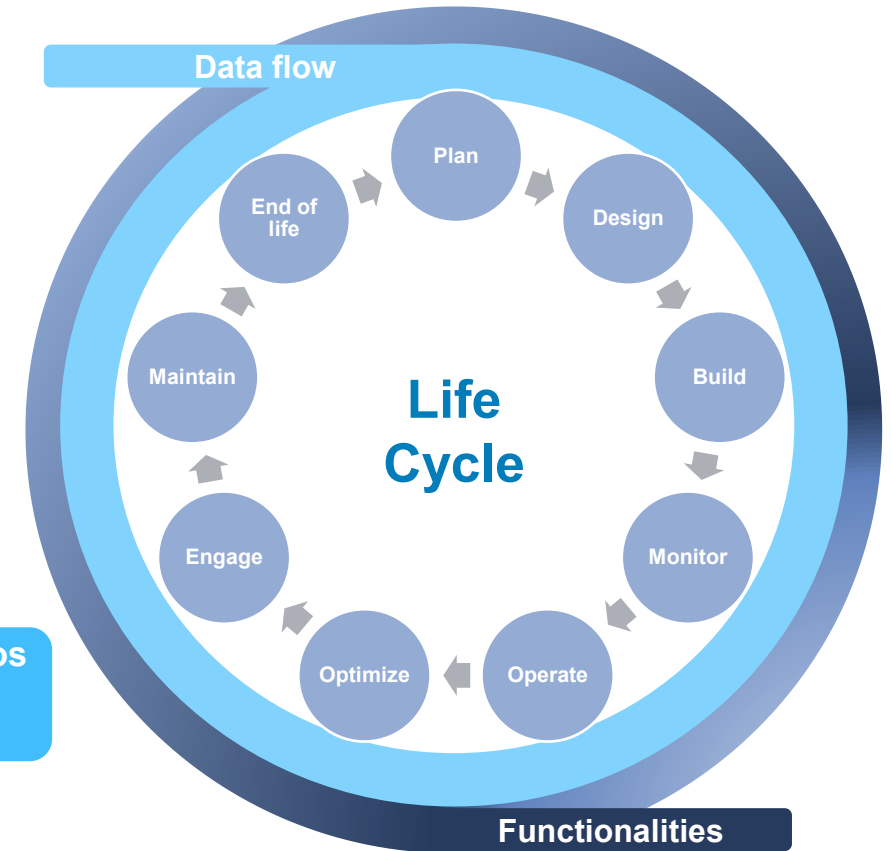
- **A Continuous Cycle of Improvement:**

With insights flowing freely between lifecycle stages, lessons learned during operation and maintenance directly inform future planning and investment. This ongoing feedback loop helps the system adapt and improve over time.

- **Holistic Management for a Resilient and Sustainable Grid:**

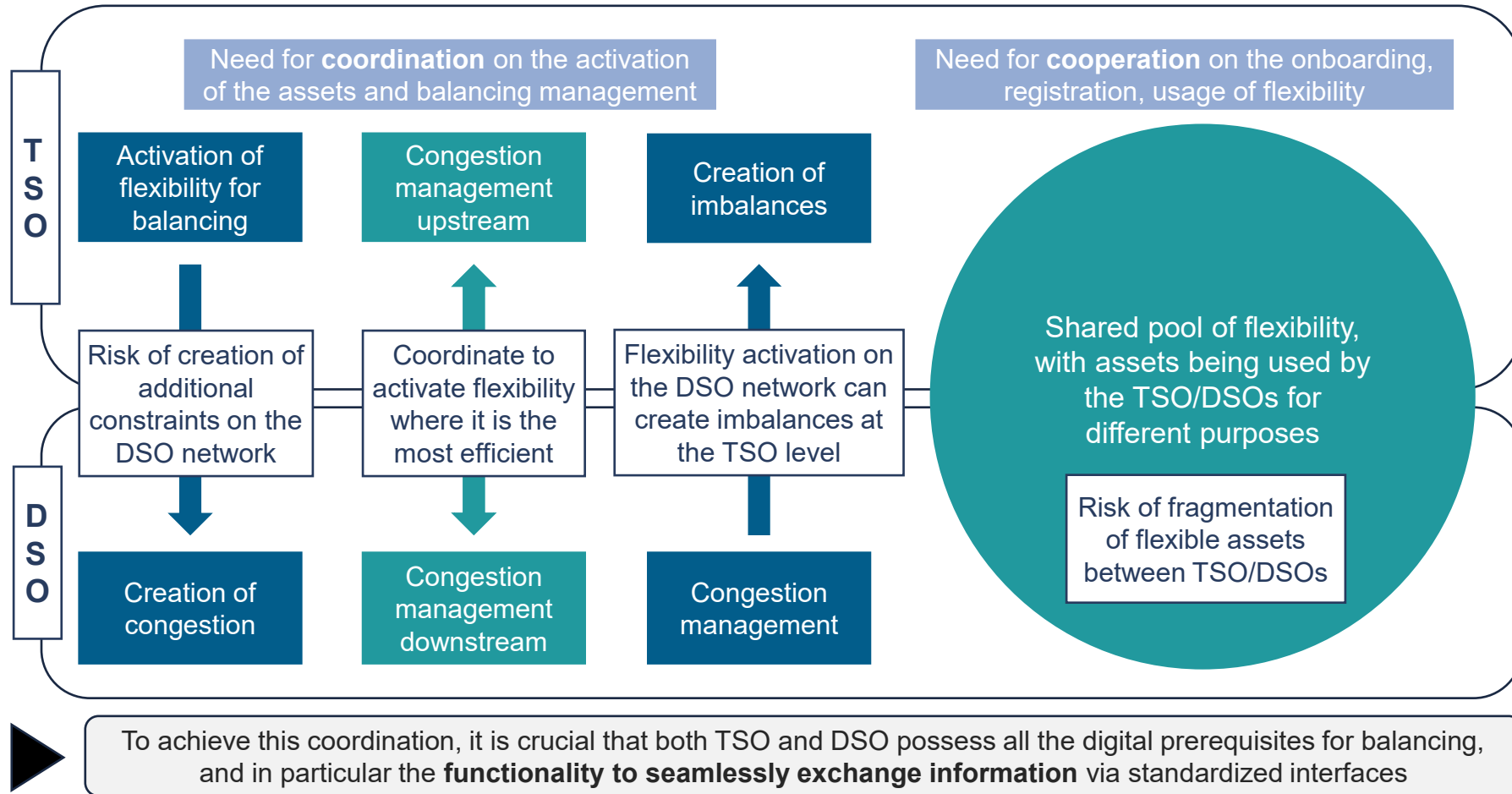
By treating the grid lifecycle as one interconnected process, digitalisation makes it easier to spot problems early, optimize asset use, and plan for long-term sustainability. This integrated approach ultimately reduces costs and extends asset lifespans.

▶ The functionalities of a digitalized grid connect lifecycle phases, overcome data silos and create an interconnected system where all decisions are continuously refined and enhanced across the entire asset and system lifespan.



TSO-DSO coordination

Increasing congestion management and balancing needs call for more cooperation and coordination between TSOs and DSOs – crucially relying on data exchange and controllability functionalities



With fewer thermal power plants, TSOs and DSOs increasingly rely on flexible resources to **manage congestion** and balance the grid, yet their actions can create unintended constraints for each other.

Effective coordination is crucial to ensure flexibility is activated where it is most efficient, preventing imbalances at the TSO level or congestion on DSO networks.

A **shared pool of flexibility** can optimize system-wide efficiency, but without clear cooperation frameworks and system interoperability, there is a risk of **fragmentation and competition for resources** between TSOs and DSOs, undermining overall grid stability.

5.

From legacy to leadership: Europe's path to digital grid transformation



Grid digitalisation creates benefits for various interconnected stakeholders, contributing to a more efficient, sustainable, and resilient energy system

Grid digitalisation is more than infrastructure. Regulation is a key enabler for the energy transition

Energy Trilemma	Sustainability	Resilience	Affordability
Stakeholders	Network Operators & Utilities, Renewable Producers, Regulators	Network Operators & Utilities, Market Operators, Consumers, Regulators	Network Operators & Utilities, Market Operators, Consumers, Regulators
Benefits from grid digitalisation	<ul style="list-style-type: none"> ▪ Reduced carbon emissions <ul style="list-style-type: none"> • Easier grid integration for RES, better forecasting capabilities • Better RES grid connection management • Less RES redispatch ▪ Reduced environmental impact <ul style="list-style-type: none"> • Optimized grid planning • Reduced congestions and technical losses 	<ul style="list-style-type: none"> ▪ Improved energy security <ul style="list-style-type: none"> • Enhanced grid visibility and control • Improved asset management and maintenance prediction • Better outage management and faster restoration ▪ Improved power quality management ▪ Increase internal digital maturity of network operators 	<ul style="list-style-type: none"> ▪ Reduced economic costs <ul style="list-style-type: none"> • Reduced operational costs • Reduced technical losses • Optimized grid planning and investments • Improved market efficiency and in the long run liquidity ▪ Enhanced industrial competitiveness ▪ Greater choice in energy services

To generate its full potential, grid digitalisation necessitates a fundamental rethinking of how to regulate and manage the grid:

- Failing to adapt and continuing to evaluate tomorrow's grid with yesterday's regulations and performance considerations will inevitably sideline crucial innovations vital for the energy transition.
- Failing to adopt new approaches will deny stakeholders the full benefits of grid digitalisation, including enhanced sustainability, improved resilience, and greater affordability.

Recommendations: we have identified 4 categories of best practices

To unlock the benefits of digital grids, the regulatory paradigm should evolve with a wholistic perspective

Recommendations for regulators and network operators

Best practices 1: Improved network planning

- **Digital planning** - Digitalise network planning itself, making use of the wealth of data now available.
- **NOVA principle** - Consider the potential of higher utilisation of the existing grid in network planning.
- **Rethink R&D and deployment approach** - Consider a system-wide approach, with decentralised benefits and multiple interfaces.
- **End-To-End approach for digital** - Planning should include R&D, studies, permits, and construction work for asset integration.

Best practices 2: Make the regulation more OPEX-friendly

- **Cost pass-through** - for specific expenses (digitalisation and operation), some elements of cost pass-through should be introduced to account for the uncertainties around digitalisation projects (with efficiency incentives coming from output incentives – see Best practices 3)

Best practices 3: Introduce output-based incentives for digitalisation

- **KPI incentives** - Using KPIs based on digital measurements for regulatory incentives, is a great opportunity for the development of effective regulation going forward. Those could be defined with:
 - network users, to understand their needs;
 - other stakeholders like technology providers, to fully consider possibilities

Best practices 4: Integrated approach for digitalisation

- **Harmonization:** Accelerate the implementation of existing EU regulations and directives in a harmonized way across member states.
- **Data access:** Clearly delineate the rights of usage across network operators and third parties for the data measured in a digitalised grid.
- **Better use of flexibility:** Develop effective mechanisms to access and incentivise the use of flexibilities (incl. flexibility platforms and local flexibility markets) and define the related responsibilities and coordination needs between T/DSOs.

Locations

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