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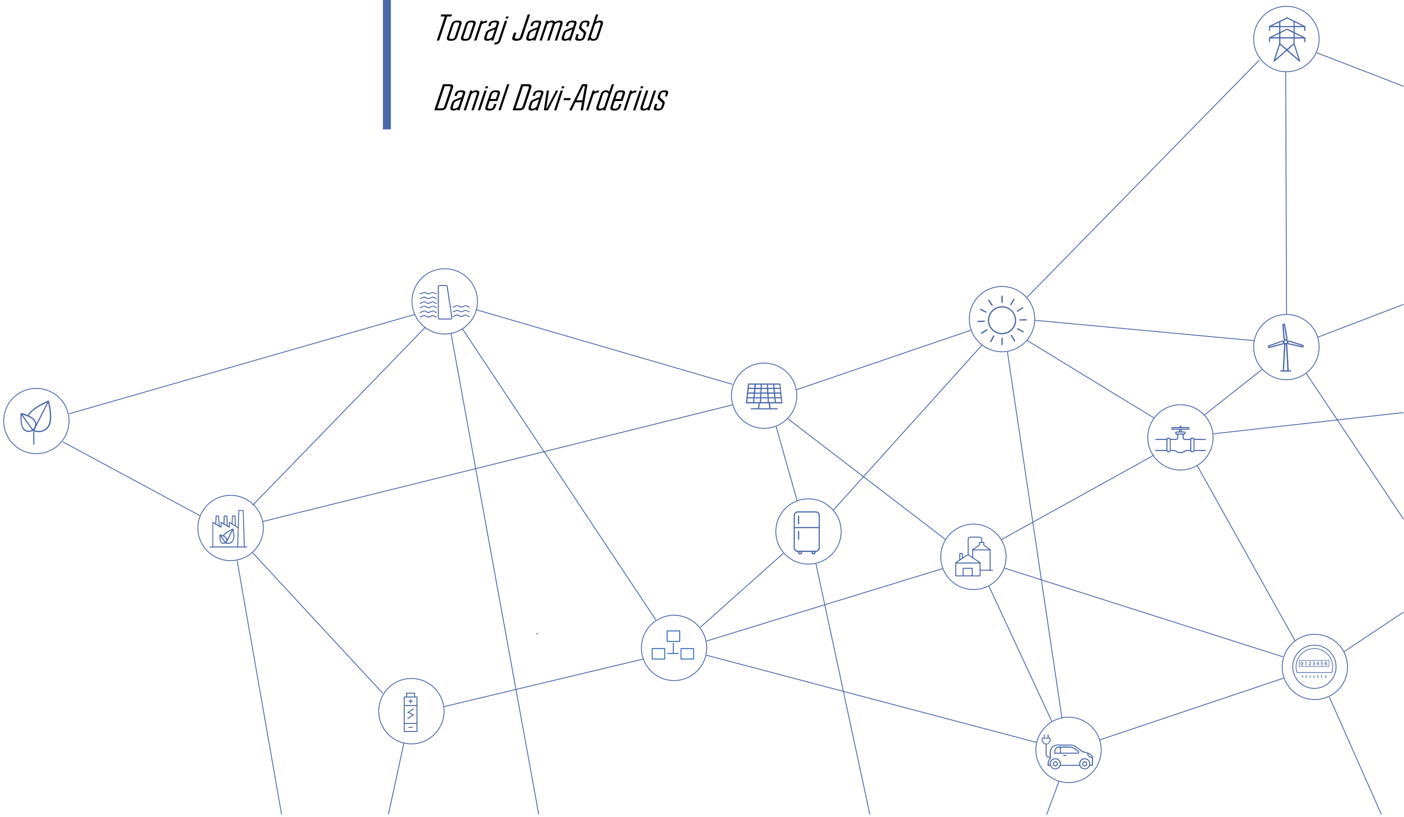

Department of Economics

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Energy Sector Digitalisation, Green Transition and Regulatory Trade-Offs

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Abstract

The green transition relies on electricity generation from intermittent renewable energy sources and the electrification of end-consumption such as heating, cooling, or mobility. At the same time, an increasing number of previously passive consumers are becoming active actors in the energy system, while the quantity of electric devices connected to the grid increases. These trends pose new operational, economic, and regulatory questions as the traditional roles of certain agents are mutating and multiplying. Digitalisation offers the possibility of implementing innovative solutions to the new challenges faced by grid operators, especially at the distribution grid level. In the EU Grid Action Plan, investments in grid digitalisation and real-time monitoring are deemed as crucial to achieve an efficient and fast energy transition. In this paper we present potential digital solutions to overcome the operational challenges posed by the 'future-proof' energy systems currently being devised and we address their economic implications. We also address some key aspects related to the digitalisation of the energy sector (efficiency and innovation, interoperability and standardisation, centralised vs decentralised solutions) from an economic perspective. Finally, a successful digitalisation of the sector requires adjustments in the regulatory frameworks. In the conclusion, we detail some recommendations needed for regulatory improvements.

Keywords: energy transition; digitalisation; standardisation and interoperability; economic principles; innovation; regulation.

JEL Classification: L1, L5, L9, Q4.

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1. Introduction

The current trend towards the all-encompassing digitalisation of key parts of the economy has also reached the energy sector (Sioshansi, 2020; Glachant and Rossetto, 2018). Digitalisation is mostly related to the fourth industrial revolution (Schwab, 2016), which relies on computational innovations brought out by the combined developments in the fields of Artificial Intelligence (AI) and quantum computing. As the Digital Economy and Society Index (DESI)[1] shows, the share of businesses that provided fully digitalised products and services increased from 34% before the COVID-19 lockdown to 50% during the pandemic (European Commission, 2022a). This was also connected to the use of cloud computing services that increased from 24% in 2019 to 41% in 2021. Digitalisation plays a crucial role, not only in increasing the efficiency of the energy system, but also in re-conceptualising the green transition, while posing new interesting economic and policy questions and trade-offs. The electricity sector is placed at the core of clean energy transition with technologies and options such as energy storage systems, heating, cooling, and demand flexibility and response that leverage digital technologies to significantly increase resilience and flexibility of the system (IEA, 2021). At the same time, electricity consumption is expected to increase up to 60% by 2030 (European Commission, 2023g). This paper aims to identify the key economic concepts and trade-offs associated with the current process of digitalisation of the electricity sector.

Digitalisation is a key enabler for an integrated energy system that addresses the energy trilemma, namely, energy security, energy equity, and environmental sustainability (Cambini et al., 2020; Jamasb and Llorca, 2019). These are three key elements for the achievement of the wider United Nations (UN) Sustainable Development Goals (SDGs) (Jamasb et al., 2024). In 2023, the United Nations Development Programme (UNDP) and the International Telecommunications Union (ITU), launched the SDG Digital Acceleration Agenda (SDGDAA), a global analysis of the connections between digital technologies and sustainable development, providing a roadmap to governments on their digital transformation. The SDGDAA includes diverse examples of how digital technologies help this process (ITU and UNDP, 2023). In detail, in relation to SDG 7, to "Provide affordable, reliable, sustainable energy for all by 2030" the SDGDAA showcases digital solutions,[2] including a data-driven finance vehicle for the off-grid solar sector ("Nithio" adopted in Nigeria, Uganda, Kenya, and Rwanda), and a simulation-based software for mini-grids electricity demand and community engagement platform to explore their own long-term demand growth and usage behaviour ("Comet", implemented in Malaysia, Indonesia, Myanmar, Somaliland, India, Nepal, and Fiji).

The SDGDAA identifies both the Digitalisation Opportunities ("Optimizing renewable energy production and using smart grids for more efficient consumption", "Transforming Information and Communications Technologies (ICTs) t to be less carbon intensive", "Improving the energy density of batteries for better storage") and the Potential Risks and digital harms ("Over-digitalization of smart systems can have adverse environmental impact"). However, it does not capture a fundamental economic dimension of digitalisation: its potential for being a radical transformer of existing market structures. This is due to two conflicting effects: digitalisation's ability to reduce market entry costs for potential entrants, while also reinforcing incumbents' market power. This last effect is related to the potential of

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[1] DESI monitors Europe's overall digital performance and the performance of the individual countries.

[2] https://www.sdg-digital.org/sdg/affordable-and-clean-energy.

digitalisation to provide economic value or to create markets for new commodities, based on the smart use of digitalised personal data, leading to the development of new business models.

This paper aims to address this policy and knowledge gap. It achieves that goal by discussing policies across the fields of digitalisation and energy infrastructures, whose joint study too often lacks a clear, strategic interaction-based analysis of the key public economic problems posed by the digitalisation of energy infrastructures. We will focus on different dimensions of these economic and strategic trade-offs: their impact on efficiency and innovation; on interoperability and standardisation; and on the design of centralised vs decentralised solutions in energy systems.

In October 2022, the European Commission (EC) launched the Digitalisation of Energy Action Plan in the scope of the European Green Deal and the REPower EU Plan (European Commission, 2022c, 2023a). This action plan considers that digitalisation plays a key role on the transformation of the power system and helps consumers to save on their bills. This plan includes smart buildings, smart meters and Electric Vehicles (EVs), Internet of Things (IoT) and other devices to provide key information to monitor energy consumption, boost data sharing, increase renewable integration and reduce costs for consumers. Moreover, the EC considers that innovative data services, apps, and energy management systems have a large untapped potential for energy users, but they need a further boost and adequate policy support measures to become ubiquitous. Indeed, the need to decarbonise the power system and connect large amounts of renewables to the grid in a short period of time, requires looking for innovative digital solutions to anticipate and, possibly, solve future technical and operational needs. At the same time, consumers should be empowered to take their decisions based on the new information available to them.

All these possibilities and changes due to the digitalisation of the energy system (with the electricity system at its core) require addressing new technical and regulatory challenges. First, grid operators should have efficient economic incentives in their regulatory frameworks to adopt, implement and optimise digital solutions. The EC considers that EUR 584 billion of investment in electricity grids will be required between 2020 and 2023, where digitalisation and grid real-time monitoring investments are relevant (European Commission, 2023g). Second, consumer rights should be guaranteed, especially those related to the data privacy and access to the information, while consumers should also derive individual economic benefits from the adoption of end-point digitalisation tools such as smart meters, so that their incentives are aligned with those of the providers and with the collective goal of decarbonisation. Third, interoperability and connectivity should promote seamless exchange of data between different actors to promote new activities and increase market competition. These interoperability rules should go beyond the technical aspects and standardise roles and responsibilities of all the involved agents across the European Member States (Reif et al., 2022). Moreover, European Commission considers the interoperability and standards as a lever to facilitate grid investments and cost savings (European Commission, 2022c, 2023g).

This brings us to the debate surrounding decentralised versus centralised digitalisation solutions in the energy sector that encompasses the physical configuration of assets, organisation and regulation, technological advancements and scale, standardisation, interoperability, scalability, and policy and regulatory considerations. The appeal to scholars and practitioners for decentralised approaches to structure electricity generation, transport and distribution networks, and consumption, has grown in the past 20-30 years. A European, decentralised, and open-source energy data space solution fits into this trend.[3]This is evidenced, for example, by the Electricity Directive (EU) 2019/944, which sets the rights to non-discriminatory and transparent access to metering, as well as production and consumption data for customers and third parties of their choice (European Commission, 2019a).

However, there is no one-size-fits-all solution. The choice between decentralisation and centralisation depends on several factors. It is also worthwhile to explore alternative combinations of centralised/decentralised solutions that transfer transparency and openness of energy data to the network edges while relying on a common 'centralised' framework to maintain trust as an essential element in enabling common dataspaces.[4]

It is helpful to recognise that consumer participation, especially that of residential users in the retail energy market, is not a given or exogenous factor. Rather, the participation of users should be viewed as endogenous and contingent upon the framework within which they participate. The main factors influencing active demand and the level of participation are technology, incentives, and information, which rely greatly on the ability to access and processing large quantities of microdata, evolving in real time.

These new technical and regulatory challenges should be tackled for an efficient digitalisation of the energy sector that can indeed contribute to the clean energy transition. In the following, we discuss these challenges in depth. In Section 2, we first picture how digitalisation can transform the energy industry, especially the electricity sector. Section 3 highlights the importance of setting common standards and interoperability rules across the entire energy supply chain to facilitate the digitalisation. In Section 4, we discuss centralised and decentralised digitalisation and governance solutions in the energy sector landscape. In Section 5, by providing a real-world example of digitalisation in the electricity sector, we outline several challenges linked to the digital economy. Finally, Section 6 discusses the policy implications of the energy sector digitalisation and provide a set of recommendations to improve and adjust several components of the regulatory frameworks required to facilitate the digitalisation process.

2. Digitalisation and Energy Transition

The decarbonisation of the power system implies the connection of many new Renewable Energy Sources (RES) capacity. In many cases, they are small plants connected behind a

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[3] Data spaces correspond to "a genuine single market for data, open to data from across the world – where personal as well as non-personal data, including sensitive business data, are secure and businesses also have easy access to an almost infinite amount of high-quality industrial data, boosting growth and creating value, while minimising the human carbon and environmental footprint." Moreover, "a common European data space brings together relevant data infrastructures and governance frameworks in order to facilitate data pooling and sharing" (European Commission, 2022b). The European Distributed Data Infrastructure for Energy (EDDIE) project financed by the European Commission through its Horizon Europe programme represents a perfect example of this type of energy data space solution. https://eddie.energy/.

[4] For more detail see https://www.opendei.eu/wp-content/uploads/2022/10/OPEN-DEI-Energy-Data-Spaces-EHM-v1.07.pdf.

household meter – self consumption – or through local energy communities. Moreover, this coincides with the connection of new electricity consumers such as EVs, heating, or cooling devices, among others. In many cases, they are connected to the distribution grid, which covers more than 10 million kilometres of grids (Eurelectric, 2020; European Commission, 2023g).

However, these changes in the supply and demand, challenge the network operation and grid operators therefore face grid bottlenecks and new network operational constraints (Davi-Arderius et al., 2023a; 2023c). In some cases, they would need to implement new advanced solutions, most of them requiring the fine-grained information only available through the wide adoption and diffusion of digitalisation tools and solutions (Di Silvestre et al., 2018; Davi-Arderius et al., 2023b). These tools include innovative grid planning and operation solutions to monitor and operate the grid, implement flexibility services, and transform traditional passive consumers into active consumers through the control of their end-use devices by aggregators. Participants in these flexibility services receive economic compensation for modifying their consumption or generation at the request of the grid operator (Nouicer et al., 2023). This flexibility was simulated by De Villena et al. (2021), based on a case study in Wallonia, focusing on the transition between being a potential to an actual prosumer, showing that this percentage reaches 100% with schemes providing incentives for solar PV. However, Passey et al. (2017) found a low correlation coefficient between capacity-based tariffs and network peak, leading to a very low optimal demand-side flexibility level.[5]

In order to explore users' demand flexibility, the Electricity System Operator (ESO) of the National Grid in Great Britain, launched a study into how domestic households can provide flexibility for energy demand in view of reducing stress on the electricity system.[6] The main aims were to quantify the electricity flexibility potential from UK households; identify the key parameters that influence households' flexibility, such as technology and tariff structure; understand the cost of incentivising flexibility and which flexible services will be most relevant to the mass market; guide market development of domestic flexibility-related services. One of the key research questions is the analysis, based on large granular datasets, of how domestic consumption respond to price incentives and the technologies providing flexibility. This was based on two types of interventions. First, assessing the change in demand resulting from a change from a flat to a dynamic energy price or Time-of-Use (ToU) tariff. Second, assessing the change in demand from single events of limited duration, such as the 2-hour duration "Big Turn Up" and "Big Turn Down" events, with customers notified of the request and opting in ahead of time. Clearly, digitalisation, plays a key role, both for the behavioural analysis of customers demand flexibility, and for its actual implementation.

In the power system, digitalisation is also needed for a more efficient allocation of resources, both from a current and a dynamic perspective. In the transmission and distribution networks, digitalisation includes detailed monitoring of the energy flows through each asset, thus improving efficiencies of the network design and operation processes, while also easing the

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[5] Focusing instead on the supply side role of flexibility, Hadush and Meeus (2018) found that while Transmission System Operators (TSOs) are accessing flexibility resources connected to the distribution grid also the Distribution System Operators (DSOs) are beginning to actively manage distribution grid constraints.

[6] See CrowdFlex Phase 1 available at: https://www.nationalgrideso.com/document/230236/download.

implementation of advanced operating techniques such as Dynamic Line Rating (DLR).[7] Grid planning processes are used to forecast the future grid investments and to provide an optimal allocation of resources, benefiting from a more detailed and accurate historical data of energy flow accessible through digitalisation. Concerning the grid operation processes, increased grid monitorisation allows for a better forecast of local overloads, an improved preventive identification of events in the grid, and for a more efficient resolution of unforeseen events in real-time. Lastly, digitalisation and artificial intelligence help in reducing the interruption times and improve the quality of supply (Barja-Martinez et al., 2021; InnoGrid, 2023).

Digitalisation is also related to the provision of new information to customers and renewable promoters such as maps of hosting capacity or digitalising the communication with third parties. This includes the grid connection processes for new generation or consumption devices, as well as the billing processes for retailing activities (European Commission, 2023g).

Another relevant example of digitalisation is related to the replacement of the traditional electricity meters by smart meters able to measure hourly, or even 15-minute, energy use (Regulation EU/2017/2195) (European Commission, 2017). Smart meters provide comprehensive information to both users and providers about households' consumption profiles that are essential to implement energy efficiency solutions. Smart meters also allow setting individually tailored hourly (or quarterly) tariffs to customers, which incentivises electricity consumption planning based on time-of-use over a 24-hour interval. Accordingly, customised hourly tariffs reshape the profiles of electricity consumption in certain hours over others and enable the implementation of specific flexibility services.

The deployment of smart meters requires the adoption of implementing acts on interoperability data for consumption and metering data to enable a smooth exchange of data, avoiding excessive administrative costs for eligible parties, and ultimately promoting competition in the retail market (European Commission, 2023b). A related EU regulation on interoperability requirements about validated historical metering and consumption data and non-validated near-real time metering and consumption data provided through smart meters, was approved in 2023.[8] In this regulation, data should be provided through a standardised interface or through remote access in order to be used and processed by an energy management system, an in-home display, or another system.[9]

As shown in Table 1, digitalisation covers a wide spectrum of activities and functionalities in the power system.

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[7] DLR, also known as Real-Time Thermal Rating (RTTR), allows the operation of the grid at a maximum load without damage, depending on the environmental conditions (Degefa et al., 2014).

[8] 'Near real-time metering and consumption data' means metering and consumption data provided continuously by a smart meter or a smart metering system in a short time period, usually down to seconds or up to the imbalance settlement period in the national market, which is non-validated and made available through a standardised interface or through remote access in line with Article 20(a) of the Electricity Directive (EU) 2019/944. (European Commission, 2023b).

[9] An energy management system is a framework for energy consumers, including industrial, commercial, and public sector organisations, to manage their energy use. It can be useful to adopt and improve energy-saving technologies. For a more detailed description, see, e.g., https://www.unido.org/stories/what-energy-management-system.

Table 1. *Link between different solutions based on digitalisation and its technical benefits.*

Benefits / **Digital Solutions**	**Anticipate congestion and voltage issues in the grid**	**Implement hourly tariffs to incentivise time profiles of consumption**	**Improve the quality of supply**	**Improve the efficiency of the grid infrastructure**	**Additional benefits**
Monitoring devices in the distribution grid assets	Yes		Yes	Yes	Reduce electricity losses
Monitoring DER in real-time	Yes		Yes	Yes	
Replace traditional meters by smart meters	Yes	Yes	Yes	Yes	Increase users' awareness of their consumption patterns, helping to reduce inefficiencies
Dynamic line rating				Yes	Adapt loads to the optimal conditions of each asset, i.e., aging
Implement advanced network operating systems (DER Management Systems* or DERMS)	Yes		Yes	Yes	DERMS can use all the other digital solutions to operate the grid
Digital Twins			Yes	Yes	Digital twins enable simulating outcomes from potential solutions

Source: Own elaboration.

** Note: DER stands for Distributed Energy Resources.*

From a grid operator perspective, better information about what is happening in real-time in its network, improves the reliability of energy flows forecasts and anticipates congestions or voltage issues or grid stability problems that might affect the quality of supply or ultimately limit the operating volumes of RES (Davi-Arderius et al, 2024). However, this is not straightforward and grid operators need advanced tools using big data analytics. Some studies quantify that DSOs in EU-27+UK would need to invest between EUR 25 and 30 billion between 2020 and 2030 to achieve the decarbonisation targets (Monitor Deloitte, 2021), with investments in the digitalisation of the low voltage networks where most of the small customers are connected. These are connecting many behind the meter DERs and charging points for domestic EVs.

These processes are implemented in parallel with important developments in technologies and data processing. These include the establishment of (energy intensive) data centres hosting cloud solutions to store increasingly large and distributed amounts of data, the development of appropriate algorithms for big data analytics to obtain added value from multiple sources (e.g., historical metering data, real-time monitoring data, or weather forecasts), continuous development of AI solutions, often based on natural language processing tools, to improve customer service (day-to-day processes, customer call centres or claims management), edge computing to decentralise the data processing (primary or secondary substations), and possibly quantum computing to expand the limits on calculation powers and address the needs of the big data requirements (Masanet et al., 2020; Charbonnier et al., 2022). Finally, the recently launched EU Grid Action plan sets the anticipatory grid investments to accelerate and not delay the connection of renewables and new electricity consumption. In this process, data sharing between different TSO and DSO, and digitalisation investments should also follow the same anticipatory approach, which requires detailed analysis from grid operators to efficiently exploit potentials from digitalisation and data processes implemented in the power system (European Commission, 2023g).

3. Interoperability and Standardisation

A key success element for digitalising the different sectors of the economy is to set interoperability measures among different systems and technical solutions, which seamlessly enable data exchange and communication across a sector and even at a cross-sectoral level. In this section, we discuss interoperability and standardisation in the context of digitalisation.[10]

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[10] On one side, 'interoperability' means the ability of different energy or communication networks, systems, devices, applications, or components to interwork to exchange and use information in order to perform required functions, in the scope of the smart, efficient and sustainable energy systems (European Commission, 2019a). For instance, Electricity Directive 2019/944 mandates Member States to ensure interoperability of the deployed smart meters. On the other side, 'standard' means technical specifications defining requirements for products, production processes, services, or test-methods. They are developed by industry and market actors following some basic principles such as consensus, openness, transparency, and non-discrimination. Standards aim to ensure interoperability and safety, reduce costs, and facilitate companies' integration in the value chain and trade. European Standards are under the responsibility of the European Standardisation Organisations such as CEN, CENELEC or ETSI (European Commission, 2023e).

The integration and coordination of various energy resources and end-use devices, requires their design to use common standards and be interoperable. Standardisation is the process of providing a shared foundation for various stakeholders to communicate and share data. In other words, standardisation sets the groundwork for interoperability. From a technical point of view, data interoperability is one of the components of the technology building blocks in data spaces.[11] In this context, achieving full interoperability requires adoption of common standards in form of compatible data models and data formats for data sharing purposes, via Application Programming Interfaces (APIs). Interoperability also requires data to be traceable and trackable from its origin to its end-use point.

Given the critical role of interoperability, a survey conducted by EC in 2018 lists it as the main technical barrier for data sharing (Botta, 2023). In fact, lack of interoperability acts as an entry barrier as it hinders seamless exchange of data between different stakeholders and formation of innovative data-driven solutions. Information asymmetry is another consequence of lack of interoperability. Critical data is exclusively possessed and used by certain stakeholders, and competition, as a result of asymmetric information, is hindered. Therefore, also from an economic perspective, interoperability is important for promoting free entry and the ensuing dynamic efficiency, and policies focussing on the interface of energy and digital markets should promote and facilitate interoperability whenever possible. To this end, it is essential to establish common standards, protocols, information models and data formats (see Table 2).

In the EU, policymakers have addressed the issue of interoperability in several cases. Article 24 of the Electricity Directive (2019/944) mandates the interoperability for access to energy data to promote competition in the retail market and avoid excessive administrative costs for eligible parties. According to the EU Digital Market Act, if deemed necessary, the EC has the authority to request European standardisation bodies to develop the necessary standards with the goal of promoting interoperability (European Commission, 2023c). These standards aim to ensure technical compatibility and safety across diverse energy systems, devices, and processes as well. The creation and enforcement of common technical and operational standards remove the entry barriers associated with interoperability issues in a data sharing context.

In June 2023, the Commission adopted the Implementing Act on metering and consumption data (European Commission, 2023b). This legislation aims to ensure that metering and consumption data across countries follow a common reference model that can be customised at national level. This legislation is part of the Digitalisation of Energy Action Plan launched by the European Commission in October 2022. It is stated that the focus of the Implementing Act is on “interoperability requirements and non-discriminatory and transparent procedures for access to data.” However, it should be noted that the legislation does not address the ‘technical interoperability issues.’ Rather, the act focuses on legislative and administrative procedures. Interoperability, nevertheless, is also a technical tool and should be achieved by setting industry-wide standards first. The EU legislator addressed the technical aspects of interoperability by establishing the Data Spaces Support Centre (DSSC) in October 2022,

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[11] The other components are data sovereignty and trust and data value creation. For more detail see: https://www.opendei.eu/wp-content/uploads/2022/10/OPEN-DEI-Energy-Data-Spaces-EHM-v1.07.pdf.

funded by the European Commission under the Digital Europe Program, to identify common standards, technologies, and tools to support the establishment of sectoral data spaces in Europe.[12]

However, both the Implementing Act and the Digital Europe program do not address the potential for market failures that can materialise if upcoming technical standards end up favouring certain stakeholders or companies. Focusing on the energy sector, on the one hand, historically and due to infrastructure ownership, grid operators have the highest degree of access to consumer data, the corresponding demand and supply as well as network data. Accordingly, their ICT infrastructures are designed to support their specific operations, and, in many cases, they have their own technical standards. On the other hand, digitalisation is a "relatively new" concept in the energy sector,[13] while the digital market itself is filled with "Big Tech" companies, which have vast resources and the required knowledge to quickly take up the market shares in other sectors when these sectors integrate digital solutions. The "Big Tech" companies, often achieve this by leveraging their own technical standards. Setting standards that reflect the infrastructure or the know-how of the incumbents of both sectors can quickly become an entry barrier for smaller third-party service providers that would require access to consumer data for providing their innovative data-driven solutions. Therefore, it is crucial to involve smaller/new stakeholders in the initial stages of establishing standards and interoperability rules to avoid favouring incumbent providers and manufacturers over others.

Table 2. *Pros and cons related with the implementation of interoperability requirements and standardisation.*

	Pros	Cons
Interoperability	• Seamless communication and data exchange among different systems and devices	• Setting interoperability requirements might favour some providers or manufacturers over others
Standardisation	• Standards are known in advance • Standards are a relevant part of the interoperability processes. • Lower economic and technical barriers to implement new information exchange processes	• Listing standards in the EU or national regulation might limit the adoption of future innovative standards and might let outside some manufacturers. • Complex process to approve new standards. Moreover, some standards might favour some manufacturers over others. • Standards in the EU might differ from those in US and other Regions. • Their specifications are voluntary (European Commission, 2023e). • The implementation of new standards might be compatible with other existing ones.

Source: Own elaboration.

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[12] See https://internationaldataspaces.org/the-data-spaces-support-centre-is-now-launched/.

[13] It can be argued that digitalisation in the energy sector is not a novelty in itself. As Rossetto and Reif (2021) point out, the process can be seen as series of consecutive digitalisation waves that have covered diverse parts of the system. The latest wave addresses issues related to distribution networks, consumers' premises, and retail markets.

4. Centralised vs. Decentralised Solutions

There are two distinct, but interrelated aspects when considering the pros and cons of decentralised solutions compared to centralised ones. One relates to the physical configuration of the assets. The other is concerned with its governance, i.e., organisation and the rules and regulation governing the system. These aspects reflect somehow the differences between active and passive infrastructure sharing modalities in telecommunication regulations (ITU, 2021). Both aspects are, in turn, related to technology and scale. Historically, the usefulness of many energy solutions has been dependent on our ability to up-scale or down-scale technologies. For instance, in the 1990s, Combined Cycle Gas Turbines (CCGTs) experienced renewed technological progress that enabled building of new plants that were smaller, cheaper, and faster. This facilitated entry of Independent Power Producers (IPPs) into the newly liberalised electricity markets, removing some of the pre-existing barriers to competition. Progress in wind and solar power technologies was also accelerated by allowing the emergence of initially small wind turbines, then gradually leading to entry of ever larger installations. In this context, innovative solutions such as local energy communities or community-based projects, which are shared generators or storage devices between some customers (e.g. the *Swaffham Prior Heat Network*), have been developed.[14] These mechanisms empower customers and local economies.[15]

The development of early electricity and town gas systems in the 1800s provided our first encounter with key policy questions around centralised vs. decentralised infrastructure models. The early systems were mainly the result of local private or public initiatives. National and central systems emerged only later, as the need for technical standardisation and operational coordination grew. For instance, in the UK, at the time of establishment of the national electricity grid in 1926, there were more than 600 electricity distribution networks that operated at different voltage levels. A national system was clearly needed for technical standardisation of assets and harmonisation of system operations (Jamasb and Pollitt, 2007).

Also, the network benefits of systems supporting Automated Teller Machines (ATMs) and mobile phones were vastly enhanced with the harmonisation of standards and protocols for access to these networks , by all users. Different from these technologies, the Internet, evolved around the development of a unified protocol (TCP-IP), allowing universal interoperability, across many different international networks, whereby cross network digital exchanges were managed by Border Gateway Protocols (BGP) (D'Ignazio and Giovannetti, 2006). Still, national governments and corporations, managed to create spaces outside universal connectivity (intranets and other type of national walls), while the governance of digital interconnection, and its contractual agreements (peering, transit), limited the scope of economic interconnection incentives, notwithstanding the technical interoperability.

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[14] The Swaffham Prior Heat Network project led the way in the UK, to be the first village to develop a rural heat network. The mix of air source and ground source heat pumps have capacity to supply 1.7MW of heat to 300 homes, this allowed to address energy poverty and local environmental issues caused by the village's reliance on oil heating. In this case, Cambridgeshire County Council owns the energy company and heat network assets. (https://www.cambridgeshire.gov.uk/residents/climate-change-energy-and-environment/climate-change-action/low-carbon-energy/community-heating/swaffham-prior-heat-network/about-swaffham-priors-heat-network).

[15] https://www.iea.org/commentaries/empowering-people-the-role-of-local-energy-communities-in-clean-energy-transitions.

‘Centralisation’ may promote competition or achieve better regulation, since it is often a means for achieving technical and non-technical ‘standardisation.’ Standardisation is, in turn, important for promotion of ‘innovation.’ Markets alone cannot be relied on to provide these elements in an efficient way due to the specific ‘public’ nature of the good provided (network infrastructure). In fact, economic theory suggests that markets do not supply enough amounts of public goods and the above elements of the energy systems, bear characteristics of public goods, with consequences for private underinvestment due to incentives for free riding (Atkinson and Stern, 1974). These might emerge when there are nonexcludable and/or non-rivalrous elements of the energy infrastructure, for instance, due to asymmetric information about data referring to individual usage of the shared grid. Similarly, the presence of diverse types of (direct, indirect, cross side) network externalities pose challenges to markets for delivering efficient outcomes. These potential sources of ‘market failures’ call for regulatory and policy scrutiny, and, possibly, intervention.

However, centralised solutions might not always be the most efficient, especially when some pieces of the puzzle are already developed separately in different platforms. The idea that the existing energy data systems can be coordinated and used to form a data exchange platform falls in line with this attribute. In these cases, decentralised and interconnected solutions might be more efficient, less costly, and easier to interconnect the individual parts. Indeed, the Internet is working nowadays as a network of networks, of different scales and sizes, interconnected, granting universal end to end connectivity. However, also the Internet, is exposed to threats to the universal connectivity, due to many proprietary sub-ecosystems, as for example those of mobile social networks, and apps, that require additional elements/memberships/apps to be accessible by users. In the debate on the relative merits of decentralised vs. centralised solutions, it is important to look at the requirements for effective delivery of policy objectives. In this debate, it is important to consider the new approach stated by the European Regulators in ACER (2022), when they declare as priority implementing “single and common-front door” for the independent aggregators in the flexibility registers. This solution enables several decentralised platforms to act as a unique (centralised) platform by the third parties, i.e., independent aggregators, suppliers or customers. Similar solutions are already implemented with some DSO-shared platforms: Datadis for the metering data in in Spain, and SIORD for monitoring RES (Datadis, 2023; Canales Laso et al., 2023).

As discussed in Section 3, a successful and quickly available energy data space requires both technical standardisation and harmonisation of the rules governing the access to and use of data across systems and borders. Both requirements can, in principle, be met in decentralised models. Indeed, a centralised system is not a prerequisite of a technically and operationally functional data space. However, some degree of coordination and standardisation is necessary for a decentralised network of networks. In other words, centralisation is neither necessary nor sufficient for standardisation and harmonisation of an interoperable network of networks, and implementing a single and common front-door can be a feasible solution.[16]

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[16] ACER (2022) considers the “common front-door” as a solution to make compatible both centralised and decentralised platforms at the same time. This approach prioritises the single access to third parties over which is the ITC architecture used behind. This enables using existing centralised and decentralised solutions, without implementing new expensive centralised solutions.

The aim is to maximise the efficiency of the system using its positive network externalities. From technological and business perspectives, in the last decade, many companies dedicated large resources to centralise their data processes with the cloud migration (Hasan et al, 2022), with data coming from many (decentralised) physical servers. This reduced costs and increased security and accessibility, among others.

Nowadays, edge computing drives a new trend towards decentralisation of the data. This implies moving from a central cloud platform that operates and makes decisions for all the network assets towards multiple small edge devices that take their own decisions and operate decentralised assets. This new trend provides relevant benefits, as it reduces the data flows, simplifies the calculation needs, reduces vulnerabilities of the power system, reduces computation latency, and increases their reliability. Currently, their implementation in the power system is in an incipient stage, but future developments are expected in the next years, mostly related with the operational challenges due to renewables (Charbonnier et al., 2022). However, the economic impact of decentralisation due to edge computing should be followed and analysed as well to understand whether such decentralisation pathway has the potential to become a tool for market power.

5. Economics of energy data sharing

In previous sections, we discussed some of the key links between digitalisation and the energy transition (Section 2), the key requirements for rolling out digitalisation and making data accessible to all energy sector stakeholders (Section 3) and, whether energy sector digitalisation should follow a centralised or a decentralised path (Section 4). In this section, we focus on the key economic issues and trade-offs, that shape the incentives underlying these processes.

In detail, as shown in Table 1, different digitalisation activities can be mapped into different technical potentials. One of the key elements of this process resides in the replacement of traditional meters by smart meters. These are essential to implement hourly tariffs and incentivise to change the rigid consumption profiles, which is necessary to efficiently integrate large amounts of variable RES. At the same time, by modifying demand, smart meters also implicitly affect the energy supply of prosumers, that feed into the grid their surplus of generated energy, mirroring their changed load profiles. Moreover, smart meters also enable implementing the flexibility services discussed in the previous section when they validate the modification of the household consumption in real-time, as shown in the UK's largest domestic flexibility study, Crowdflex, conducted in 2021 by National Grid ESO, Scottish and Southern Electricity Networks Distribution, Octopus Energy and Ohme. This study, based on 25,000 households, found a 15-17%, demand reduction during the evening peak, in response to incentives incorporated into flexible time-of-use tariffs. Moreover, households with an EV achieved even greater flexibility, with reductions of up to 23% in the proportion of their daily demand consumed during the evening peak.

Smart meters were shown as possibly affecting all the technical potentials identified in Table 1. Crucially, these potentials entail significant economic consequences. For instance, they impact the market definition, both from a geographic and from a product perspective. Moreover, they influence the incentives to enter the relevant markets, users' switching and the lock-in costs, the incentives for incumbent providers to price more or less aggressively, and to offer profiled pricing and bundling strategies, aimed both at generating new surplus through quality innovations, but also at maximising this surplus' extraction by exploiting potential rent due to the access to, and algorithmic operability on, users' data. These economic consequences are also relevant to the grid operators' business since implementing smart meters requires hiring high-skilled workers or adopting new digital solutions across all their low voltage networks to communicate with smart meters.

In the following, we focus on one specific case, exemplifying how smart meters might play a key role in shaping economic incentives linked to the supplier activities. Moreover, we use this case to explore some key related economic issues, including economies of scale due to network effects (Katz and Shapiro, 1994), cross platforms benefits (Rochet and Tirole, 2003), the incentives to enter into the market (Giovannetti and Siciliani, 2020 and 2023), and the economic value of personal data and data portability (Krämer, 2021; OECD, 2021).

Consider, as an example, the choices offered to a new customer, by a transnational supplier such as Octopus Energy.[17] The possibilities are multiple, as indicated in the section on "Smart Meter Data Preferences."[18] Here, the supplier asks the customer: "How would you like your readings stored?“ (this is essential to set customer's tariffs) and provides three alternatives for price discrimination: 1) Half-hourly, 2) Daily, and 3) Monthly. After the choice is made, the user is made aware that by: "Choosing to store your readings half-hourly, will help us better match the electricity you are using with renewable generation and reduce carbon emissions." This statement implicitly induces, or nudges, the consumer to use the smart meters through the "feel good" factor of knowing that this choice affects the collective benefit of reducing carbon emissions.[19] This is followed by a seemingly 'deterring statement': "Important: If you choose daily or monthly reporting, you will not be able to access your half-hourly data through us." However, implementing efficient half-hourly tariffs requires that the customer can adapt their consumption to the different prices, either through demand that can be remotely activated (EV charging point, storage device) or through changes in their behaviours.

By continuing reading on the potential usage of the personal data collected, one finds more interesting elements that help in describing economic incentives towards the sharing of personal data. Indeed, the conditions a user needs to agree with are that: "We may use your smart meter readings to":

1. "Help reduce costs." This statement focuses on emphasising the benefits of half-hourly information transmission from the user to the provider, who will supply, in turn, information to the consumer, on how to adapt their timing of energy consumption in view of reducing costs. Such reduction is based on the improved efficiency, congestion modelling, market outcomes, and on the "promise" to share these insights with the user for their own private benefits. These information flows, based on half-hourly smart meter reading will also provide systemic benefits for the forecasting and

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[17] Octopus Energy Group is a British renewable energy group specialised in sustainable energy. It was founded in 2015. It now supplies green energy in the UK, Germany, the USA, Japan, Spain, Italy, France, and New Zealand.

[18] See https://octopus.energy/blog/track-my-energy-use/.

[19] In behavioural economics, a nudge is a way to set a choice framework that affects people's behaviour in a desired direction without restricting options (for full details and policy examples, see Thaler and Sunstein, 2021).

optimisation modelling of the provider. While the efficiency gain of a detailed information flow is obvious, the reverse flow of promised advice from provider to consumer might introduce an element of "brand loyalty" (Chen and Xie, 2007) that will decrease the consumer's willingness to look for alternative providers, hence reducing potential competition by implicitly increasing the consumer's search costs.

2. "Reduce carbon emissions," the second statement linked to the choice of half-hourly readings is also interesting from an economic incentive viewpoint. It links the most frequent metering reading option to the provision of a higher quality product, i.e., one associated to reduced carbon emissions. This increases the satisfaction of the user, if carbon emissions negatively affect its preferences (if they are an economic *bad* rather than a *good*). Higher preferences also lead to a higher willingness to pay, expressed in the consumers' demand, that might lead to higher prices, absent other competitive effects. Otherwise, under more competitive scenarios, such higher perceived quality allows the incumbent provider to maintain a price differential vs. its immediate competitors or entrants when these are unable to match such quality. While these effects are standard elements of traditional economic competition analysis, the difference in this setting (the frequency of smart meter readings), is that this increased perceived product/service quality, has a cost that is not borne by the seller, but it only results from improved quality of timing and allocation of energy infrastructure flow, that is only due to the feeding of the most frequent user data into the grid optimisation algorithms. Hence, we might paradoxically find that, due to the economic value of private users' data, with no extra costs, the provider might charge a user a higher price, based on the higher perceived quality of energy unit with a reduced carbon footprint. In sum, the provider might either extract extra 'rent' from the user's data, by selling a higher priced service or a better quality one, whereby the quality investment is based on the interaction between the user's data and the (already existing and paid for) algorithms. Or, in a more competitive market the provider might use these customers' personal data to outcompete possible entrants or existing competitors that have no direct access to these data or to their derived versions when matched with the existing provider's algorithms. In this second case, while regulation on data portability (European Commission, 2023b) seems to be a clear indication on how to redress these potential rent extraction activities,[20] clearly, these effects depend on the range/scope/definition of personal data. For example, on whether these include derived products/services that are the outcome of (proprietary) algorithms to whom the portable data were fed. Indeed, this is linked to data traceability or data provenance which is a dimension of data quality. Denoting that data sources and any transformation of data should be easily traceable during its entire lifecycle. In this sense, including data traceability as a standard might play a role in changing the dynamics of rent extraction.

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[20] The European Commission has addressed the issue of data portability in Art. 20 of the General Data Protection Regulation (GDPR), granting data subjects the right to request transferring their data to other service providers than the data holder.

3. “Make recommendations and offer free or discounted energy, based on your consumption.” This third element of the smart tariff offer is a composite one. The key statement here is that, in exchange of the users half-hourly information provided by the smart meter, the provider will make recommendations (this is fairly generic) and it is possibly related to advertising and bundling the supply of energy services with additional type of services or commodities (for example, a home EV charger, or an air source or ground source heat pump replacement for gas boilers). However, this third incentive also promises to offer free or discounted energy. Economics is the discipline that studies allocation of scarce resources to competing ends based on price systems, used as a self-regulating mechanism. The allocative efficiency of price systems depends on a set of critical assumptions (never actually met in the real world, but a useful benchmark). In traditional markets, therefore, zero prices are an indication of a lack of scarcity or economic trade-offs. Discarding *a priori* the hypotheses that zero prices are the result of charitable behaviours, the offer of zero prices must be linked to a related cross-subsiding product or service, so that the combined offer has a positive average price. These zero-price offers are typical of the digital economy (Kende, 2021) whereby many services, from WIFI access in coffee shops to social media accounts, email addresses, and basic cloud services are priced at “zero”. However, the network/platform structure of these services implies that a zero price is averaged with different values, often extracted from the personal information that users agree to provide when signing the agreements on terms of use of the free service, after confirming of having read lengthy complex contractual agreements. Such terms and conditions, often refer to the use of personal information, either directly provided, but more interestingly, even indirectly provided (for example, by agreeing on the use of cookies and tracking, whose detailed information is clearly richer than what the user is aware of). Zero prices can be of relevance in platform competition as they might be strategically used to attract critical masses of customers on one side of the platform. Thus, the other side of the platform, for example advertisers or sellers of complementary products, might be willing to be pay higher prices to the platform due to the cross platform benefits they receive due to the number of customers on the opposite side of the same network. Such cross-side platform externalities might be pivotal in inhibiting competition and entry into platform markets (Rochet and Tirole, 2003). Their interplay with the lock-in costs introduces further policy dilemmas often linked to distributional judgments since alternative regulatory scenarios might help one side of a platform while weakening the other. They can also have differential and opposite effects even within each single side of the platform (Giovannetti and Siciliani, 2023), if, for example, users suffer from different switching costs due to an asymmetric distribution of search costs or cognitive abilities.

The economic potential and risks of digitalisation of the energy systems, are better understood through the additional details of this case-example. Octopus asks its customers whether they are willing to join a “tracker-based” cutting edge beta smart tariffs. The tariff is advertised as being “Built with fairness in mind.” It features energy prices that change daily based on the wholesale cost of energy and requires monthly submission of meter readings, but crucially, requires the installation of a smart meter.

The provider may also analyse information collected from smart meters to develop new products and services and to tailor these to the customer's (data owner) needs. The stated rationale for doing this is "because of our legitimate interest to develop new products and services for the energy market" (innovation). Product and service development are offered based on customer's data process to:

- "Better understand our customer demographic and the content of customer communications and requests to create more relevant campaigns, products, and services" (Advertising; **economic benefit:** increased information; **economic risk:** reduced competition due to asymmetric providing of the information).

- "Make predictions about future behaviour based on current behaviour, to help develop and tailor our products and services" (Tailoring; **economic benefit**: increased preference due to product differentiation (Hotelling, 1929); **economic risk**: softening of competition, linked to stronger brand loyalty effects due to tailoring and induced increasing switching costs (Klemperer, 1987).

- "To build a profile personally for you, so we can do things like show you products and services that we think will be of particular interest and relevance to you." (Market segmentation; **economic benefit**: better identification of preferences due to better profiling of the services, **economic risk**: softening of competition, e.g., the increased market power resulting from increased market segmentation).

Clearly, a provider could supply more added value products if it can combine data from other sources. For instance, we can imagine Amazon or Google acting as retailers. Combining all the information they have from a customer; they could provide a product that could match better with its characteristics. While this could, in theory, be good, it also has possible negative consequences, since the market is less likely to be competitive when a supplier has access to more information than its competitors. In these cases, appropriate regulatory policies could set some unbundling rules between all these activities. Otherwise, Big Tech companies, might build an insurmountable competitive advantage over their market competitors.

At the core of these "smart strategies" there are data collection processes. These also work when consumers are simultaneously energy producers/exporters or prosumers (Gautier, et al., 2018). For them, the same company offers a "Smart Export Guarantee" as one of available export tariffs, reserved for customers who also want to benefit from any of the smart EV tariffs at the same time as being paid for their export electricity, without the need of being a customer for importing energy.

Finally, it is important to understand the nature and the source of information on which such tariffs are based and whether such information is easily accessible to a wide range of service providers.[21] Are these just personal data, or derived data, are they collected from a sole source of information or merged from different sources, so that implementing regulation on actual data portability might be feasible in theory but complex in practice? As an example, the above discussed tariffs are based on a mix of data sources. These include third parties such as price comparison websites, and affiliates or partners, which may send customers' personal information. These tariffs are also based on the provider's access to the national energy databases, including information about a customer's property, meter details, and previous suppliers from these databases,[22] EV charging points services, location data in line with the location settings on customers' phones when using the mobile app. Cookies are also used to distinguish users of the provider's website. Moreover, third parties (including, for example, advertising networks and providers of external services like web traffic analysis services) may also use cookies, which the provider does not have any control over. These cookies are likely to be analytical/performance cookies or targeting cookies.

6. Conclusions and policy implications

Current regulatory frameworks include laws and regulations for all the involved agents in the energy and interrelated sectors. However, the increasing digitalisation of the energy sector requirements should be considered when suggesting improvements and adjustments in the different components of the energy regulatory framework. These include the remuneration framework for grid operators, the standardisation and interoperability of all the involved devices and data formats, and the provisions to incentivise and promote innovative solutions. Below, we detail some of the most relevant regulatory improvements.

First, the EC has defined the EU Data Strategy to improve the access to data and incentivise the data-driven innovation.[23] In this frame, the EC has adopted several legal instruments:

- The Directive on open data and the re-use of public sector information (Directive (EU) 2019/1024) mandates the release of public sector data in free and open formats (European Commission, 2019b).

- The Data Act (DA) aims to make more data available for use and set rules on who can use and access data. EC expects that DA provides cheaper prices for aftermarket services, new opportunities and services related to the data and better access to data collected by devices.

- The Data Governance Act (DGA) sets the frame to share data across sectors and Member States, also incentivising the development of common European data spaces

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[21] Designing and introducing data spaces where energy data is efficiently shared with all the energy sector stakeholders is at the core of the EDDIE project, funded by the European Commission.

[22] For example, notifications from property owners or letting agents may provide the name and email address, as well as the date that a customer occupied the property from, and any opening meter readings that were taken from old suppliers if they hold information that the provider needs to provide their services.

[23] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-data-strategy_en.

in several sectors such as energy, agriculture, mobility, finance, environmental or health (European Commission, 2023d).

Second, implementing the digitalisation in the energy sector requires that the incentive schemes for regulating the grid operator's investments are well addressed and properly designed. This is not straightforward because the nature of digitalisation investments made by grid operators is very different from those traditional investments in electrical assets such as lines, cables, and transformers (Table 3). These differences increase the complexity for regulators to approve and supervise investments in digitalisation made by grid operators.

Table 3. *Comparison between traditional investments in electrical assets and investments in digitalisation made by grid operators.*

	Electrical asset investments	**Digitalisation investments**
Useful life of investments	• Long-term capital investments whose useful life is 40 or more years.	• Short-term capital investments whose useful life is between 4 and 10 years.
Standardisation of investments	• Wide number of international standards and regulations. • High standardisation of grid investments: cables, transformers, substations. • Easy to set benchmark costs by NRA.	• Lower number of international standards and regulations because of recent and constantly innovative solutions. • Mid/low standardisation of digitalisation investments related with constant innovative solutions and lower standardisation. • Difficult to set benchmark costs by NRA
Criteria to assess the investment needs by NRA	• NRA sets network design criteria for grid operators. • NRA can assess using the grid structural information applied to an optimal power flow software and the network design criteria.	• NRA might set digitalisation design criteria for some activities (smart meters), but not for others (IT communications, characteristics of monitoring devices). • Digitalisation design criteria are more complex and highly dependent on a wide variety of open issues: standardisation, cybersecurity, interoperability and existing solutions in each company
NRA replicability and assessment of the investment needs	• Easy replicable by NRA with the grid structural information and the network design criteria	• More difficult to replicate by NRA. • Difficult to define and compare digitalisation structural information between grid operators.
Implementation of economic incentives	• Easy to implement incentives to make investments below	• More difficult to implement incentives to

	benchmark costs (easy to have benchmark costs for grid investments).	make digitalisation investments below benchmark costs. Benchmark costs are more difficult to be set, and digitalisation grid investments might not be easily comparable. - Many grid investments should be paid according to the incurred costs, making difficult to improve economic efficiencies. - Difficult to calculate profitability of investment, as this depends upon faster obsolesce, and results depending on different type on network externalities, the dynamic of which might be highly path dependent (David, 1997 and 2007).

Source: Own elaboration

Note: NRA means the National Regulatory Authority for the power system of each country

Third, remuneration schemes for grid investments should include specific incentives to encourage make TSOs/DSOs invest in the digitalisation solutions where and when is more efficient from a societal welfare point of view. This is especially relevant when grid digitalisation needs are very high, and the investment profit might differ between different points of the grid. For instance, a more congested grid might need higher monitoring level than others. This is also related with the anticipatory grid investments defined in the EU Grid Action Plan, which are essential to not delay the connection of new RES. Moreover, the ambitious grid investments declared in the EU Grid Action Plans requires setting an attractive Weighted Average Cost of Capital (WACC) for the digitalisation investments.[24]

Fourth, the implementation of innovative digital solutions needs a specific regulatory framework. For instance, the technical developments in smart meters have opened the possibility to install them beyond the point of connection with the grid and for specific purposes. They are known as submeters (or second meters) and are devices installed to record the flexibility provided by a specific unit within an industrial building or household, e.g., a cooling device, a water heating device or an EV charging points. Aggregators and providers of flexibility consider them as key in the deployment of flexibility service from small resources and consider them useful for billing or settlement. Submeters are introduced in the Reform of Electricity Market Design (EMD) though the dedicated measurement devices (DMD), which are devices linked to or embedded in an asset that provides demand response or flexibility services to grid operators. In EMD, Member States should establish national requirements to check and ensure the quality and consistency of its data, as well as their interoperability requirements (European Council, 2024).

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[24] WACC considers the interest rate paid by regulators to finance the investments made by TSO/DSO.

Fifth, setting interoperability requirements becomes increasingly relevant with the connection of more digital devices in the power system and is essential to ensure fair competition in the provision and adoption of digital solutions. Few interoperability frameworks might result in economic barriers to manufacturers, additional devices to enable the communication with devices or higher administrative costs, among others. In this context, the Article 24 of the Electricity Directive (EU) 2019/944 mandates setting implementing acts, interoperability requirements and procedures for access to data to promote competition in the retail market and avoid excessive administrative costs. The first Implementing Regulation on interoperability was approved in 2023 (European Commission, 2023b). Future implementing acts would include interoperability requirements, and non-discriminatory and transparent procedures for access to data required for demand response and customer switching (European Commission, 2022c).

In the coming years, digitalisation will be a key factor for efficient use of the physical energy assets within a given economic framework. The overarching aim of an energy data space should be to enable the emergence of new business models supported by appropriate regulatory frameworks. In doing so, such frameworks should aim to (i) maximise the network effects, (ii) minimise the transaction costs of using the data space, and (iii) prevent the emergence of dominant players, whose market power might be greatly enhanced by access to, and processing of, vast sets of integrated micro, meso, and macro data. Ideally, the transaction costs of a centralised data space can be lower. However, political economy considerations of cooperation among the constituent systems and countries that make the enterprise feasible are more likely to be present in a decentralised structure.

It is important to note that new areas for utilising decentralised energy data will evolve gradually over time. Again, just as the early town gas networks evolved over time and with the new uses of the fuel, a future energy data space will also evolve with the increased electrification of the economy and services as a path-dependent process. Therefore, it is important to allow for time and co-evolution of the data space and the energy sector to generate new business models. However, innovative solutions such as edge computing enable another transformation from the centralised solutions towards the decentralisation.

Finally, the aim of regulation when assessing centralisation, standardisation, coordination, and innovation perspectives is to maximise ‘network benefits’ or ‘positive externalities.’ As the data space facilitates the emergence of new services, it should also aim to reduce information asymmetry and prevent market power and formation of private information rent. Market competition, regulation, and data spaces should act as instruments of transferring whole sector efficiency gains to consumers.

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