Digitalisation and beyond: Economic perspectives on granular energy data

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Energy transition relies on integrating renewable energy sources and end-use electrification. These pose operational, economic and regulatory challenges on the energy sector's stakeholders. Through smart metering, digitalisation enables suppliers to implement innovative dynamic tariffs and bundling services, while consumers are incentivised to adopt these bundled services and increase their demand flexibilities. Investments in grid digitalisation and real-time monitoring are crucial to achieve efficient, fast and fair integration of renewables. In this paper we discuss the challenges posed by the implementation of digital solutions in the power sector and discuss the mapping from technological solutions to economic incentives, needed to examine their economic implications and trade-offs. This is needed to overcome unintended consequences and incentives posing obstacles to the green transition and 'future-proofing' of the energy systems. We build this mapping by exploring some key economic issues emerging from the diffusion of smart meter granular data, focusing on the impact of data interoperability, standardisation and centralised vs decentralised solutions on efficiency, inequality and market competition. Finally, we derive regulatory recommendations for a successful energy systems' digitalisation.

Keywords – Digital market competition, economic value of data, energy system digitalisation, interoperability and standardisation, smart meter regulation

1. INTRODUCTION

The all-encompassing digitalisation of key sectors of the economy[1] has reached the energy sector [1][2]. While digitalisation is widely expected to increase the efficiency of the energy system, it brings the need to re-conceptualise the economics of the green energy transition. This requires the development of a *logical mapping* that starts from the new technological possibilities opened by the digitalisation of the energy sector and matches them to information economic concepts. This mapping is then used to frame the emerging policy trade-offs posed by this process and to provide a new perspective needed to identify the new energy system actors, understand the changing roles of the existing players and analyse the shifts in their incentive structures, in the digitalisation era. The aim is to discover processes that might reinforce competitive advantages for actors such as energy retailers and aggregators and enhance their ability to design targeted, profiled and bundled supply contracts, whose accuracy becomes unmatchable by entrants or competitors not having the same access to such data. This perspective becomes an imperative when assessing the market and distributional effects of these processes.

The possibilities emerging due to the digitalisation of the electricity system also pose new challenges. First, grid operators need efficient economic signals, regulatory incentives and

[1] In Europe, the share of businesses that provided fully digitalised products and services increased from 34% to 50% during the COVID-19 lockdown. This was also related to the use of cloud computing services, which increased from 24% in 2019 to 41% in 2021 [2].

[2] Digitalisation shaped the fourth industrial revolution [3] relying on computational innovations brought out by the combined developments in the fields of Artificial Intelligence (AI) and quantum computing.

frameworks to adopt digital solutions[3]. Second, consumers should benefit from the adoption of end-point digital tools such as smart meters so that their incentives are aligned with the societal goals of electrification and decarbonisation. Third, interoperability, as the ability of different data systems to exchange information, becomes a necessary condition to remove entry barriers and increase market competition[4] [5].

This brings us to the debate on themes such as decentralised versus centralised architecture of Data Management Models (DMMs)[5]. This requires exploring the options that bring transparency and openness of energy data to the network edges while still relying on a common 'centralised' framework to maintain trust, an essential element in enabling common data spaces, where data infrastructures and governance frameworks are brought together to form a federated data ecosystem based on shared policies and rules [8].

Finally, digitalisation endogenises consumer demand, as it provides the information necessary to choose and move across alternative tariffs and retailers, reducing energy prices, increasing demand flexibility and providing new bundling possibilities. The main factors influencing demand behaviours are the time-profiled economic incentives, made possible by the new granular data, which, however, often require refined cognitive abilities and digital and numerical literacies, for users to access and process massive quantities of real-time microdata.

These processes present new technical and regulatory challenges for achieving an efficient, equitable and timely digitalisation of the sector, which is too often neglected in the current energy policy literature. We address these knowledge gaps by creating a logical framework that connects the new technological possibilities introduced by the digitalisation of the energy sector with relevant concepts in information economics. Based on this mapping, we conclude this paper, exploring policies addressing digitalisation and energy infrastructures, encompassing a strategic incentive-based analysis of the economic problems posed. While exploring the different dimensions of digitalisation in energy spaces, we discuss solutions to similar issues that have been developed for the Internet sector, where digital interconnection choices and incentives have been addressed since its inception. Our analysis addresses how these issues affect economies of scale, cross-platform benefits and market entry incentives, while considering the new impacts and the economic value of personal data generated through the digitalisation of energy systems.

The remainder of the paper is organised as follows: Section 2 discusses energy sector digitalisation in the context of the green transition. Section 3 introduces the importance of digitalisation for grid operation. Section 4 discusses centralised and decentralised DMMs. Section 5 explores standards and interoperability rules across the energy supply chain to facilitate digitalisation. Section 6 provides a use-case analysis mapping the features of a digitalised user's energy tariff to the economic challenges and trade-offs linked to the strategic use of digital energy data. Section 7 presents a set of regulatory recommendations that help economically efficient digitalisation of the sector and address associated market risks.

2. ENERGY TRANSITION AND DIGITALISATION

The EC predicts a 60% increase in electricity consumption by 2030 [4]. Digitalisation is a key enabler for an integrated energy system that addresses the energy trilemma, namely, energy security, energy equity and environmental sustainability [9][10]. These constitute three key elements for the achievement of the wider United Nations (UN) Sustainable Development Goals (SDGs) [11]. In 2023, the UN Development Programme (UNDP) and the International Telecommunication Union (ITU) launched the SDG Digital Acceleration Agenda (SDGDAA), a global analysis of the links between digital technologies and sustainable development, providing a roadmap for governments' digital transformation. The SDGDAA includes diverse examples of how digital technologies can help this process [12].

In line with SDG 7, to "Provide affordable, reliable, sustainable energy for all by 2030", the SDGDAA showcases digital solutions, including simulation-based software for mini-grids electricity demand and a 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).

In 2022, the EC launched the EU Action Plan for the Digitalisation of the Energy System [6][13]. This plan includes smart buildings, smart metering systems, Electric Vehicles (EVs), the Internet of Things (IoT) and other devices to provide key information to monitor energy consumption, boost data sharing, increase Renewable Energy Sources (RES) integration, and reduce costs for consumers. Moreover, the EC considers that innovative data services, apps, and Energy Management Systems (EMS) have a large, untapped potential for energy users, but they need further boost and policy support measures to become ubiquitous. Indeed, connecting large amounts of RES in a short time requires innovative digital solutions to anticipate

[3] The European Commission (EC) considers that EUR 584 billion of investment in electricity grids will be required by 2030, where digitalisation and grid real-time monitoring investments are relevant [4].

[4] The EC considers data interoperability and standards as a lever to facilitate grid investments and cost savings [6].

[5] This debate is similar to that of integrated (i.e., coordination) vs separated (i.e., competition) information and data management and electricity grid operation. For a discussion of the trade-offs between these options and the proposal of a novel governance approach, see [7].

and possibly solve future technical and operational needs. Simultaneously, consumers should be empowered to make informed decisions using the new information at their disposal.

The International Energy Agency (IEA) also emphasises the importance of digitalisation in enhancing energy efficiency and driving innovation in the sector [14]. To achieve these aims, a new perspective on Energy Data Spaces (EDS) is needed, one that should consider the effects of digitalisation on the energy system's incentives and efficiency. An EDS is the domain-specific instantiation of a data space for the energy sector: an interoperable, trustworthy environment for sharing electricity, grid, usage, forecast and market data across actors (Transmission System Operators (TSOs) and Distribution System Operators (DSOs), aggregators, regulators, consumers), designed to uphold data sovereignty, harmonised standards and governance rules to enable more efficient coordination, flexibility services and innovation in energy markets [15]. Interoperability and standardisation of the EDS are crucial for seamless integration and communication among diverse components within the energy infrastructure, as well as for cost-effective integration of RES into the system [16].

A European, decentralised, and open-source EDS solution to structure electricity generation, transport and distribution networks, as well as consumption, has been advocated [17], 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. However, while energy policies identify both the digitalisation opportunities and potential risks, they often do not capture a fundamental economic dimension of digitalisation: its potential to be a radical transformer of existing market structures, due to the competitive relevance of granular user data.

This competitive impact, results from two conflicting effects: the ability of digitalisation to reduce the cost of market entry for potential entrants and the role of digitalisation in entrenching incumbents' market power. This last effect is related to the potential of digitalisation to generate economic value and to create and link new markets for novel commodities and services, for instance, through bundling practices, such as leasing EVs, providing electricity to charge them, and, possibly, repurchasing the stored electricity from EV or household batteries at different times of the day, when this might be more valuable.

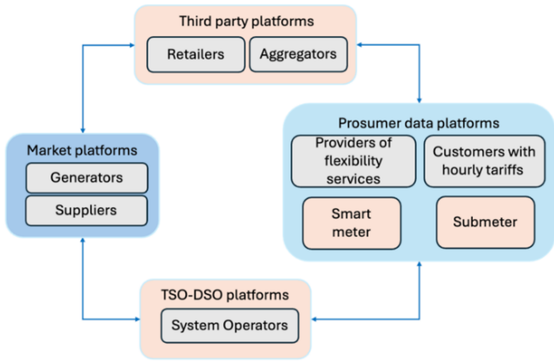

Figure 1 – Information exchanges between the main agents in the power system. Source: own elaboration

Fig. 1, shows a simplified version of the energy system, used as a reference when discussing pros and cons of 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. Transmission System Operator (TSO) and Distribution System Operator (DSO) platforms serve as dedicated data exchange hubs for grid operators, facilitating the coordination and management of energy flows. Market platforms enable the matching of energy supply and demand bids by connecting generators with retailers or by aligning grid operators' flexibility requirements with offers from aggregators. Prosumer platforms encompass the infrastructure necessary for measuring energy consumption and flexibility at the user level, such as smart meters and submetering devices. Finally, third-party platforms include energy retailers and flexibility aggregators that interact with both consumers and the broader energy market.

3. DIGITALISATION AND GRID OPERATION

An efficient integration of large volumes of variable RES requires addressing new operational challenges, as they include Inverter-Based Resources (IBR) with limited operational capability compared to the rotating synchronous generators in replaced thermal plants, i.e. combined cycles or fuel plants. Overloads (congestions), voltage control or inertia problems pose operational challenges. In many cases, grid operators should curtail some of the scheduled RES in the markets to ensure power system reliability, which represents a source of inefficiency [18][19]. In the case of urban microgrids, essential for integrating distributed RES and enabling local energy exchanges, there is a need for interoperable IT frameworks to overcome the data challenges [20].

Digitalisation enables the implementation of advanced operational solutions to anticipate and solve these new operational challenges [21]. Most of these solutions use data from monitoring energy flows through the grid or smart meter systems. Among others, they include Distributed Energy Resource Management Systems (DERMS) to operate large volumes of small RES or Dynamic Line Rating (DLR) that consider weather conditions when defining the maximum load of each line [22].

Digitalisation and AI can also help reduce interruption times and improve the quality of supply [23] [24]. However, this is not straightforward and grid operators need advanced tools using big data analytics. Some studies have estimated 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, with investments in digitalisation of the low-voltage networks at which most of the small customers are connected [25].

These efficiency-enhancing processes are implemented in parallel with important developments in technologies and data processing. They 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 data processing (primary or secondary substations), and possibly quantum computing to expand computational power and address the needs of big data requirements [26] [27].

In many cases, addressing the new operational challenges of RES integration requires specific consumers (or generators) to modify their consumption (generation) pattern to change energy flows in the network. This, however, involves implementing flexibility services and transforming traditional passive consumers into active consumers by allowing aggregators to control their end-use devices or batteries [28]. Participants in these flexibility services receive economic compensation for modifying their consumption or generation at the request of the grid operator [29].

To explore the potentials of flexible consumption from households, the UK's National Energy System Operator (NESO)[6], launched a study into the potential mechanisms to influence the households' flexibility (e.g., technology and tariff structure) and to guide the development of markets for flexibility services[7].

However, implementing digitalisation solutions by grid operators is not straightforward and requires properly designed regulatory frameworks for their investments. Digitalisation investments differ from conventional investments in lines, cables or transformers (see Table 1). These differences increase the complexity of how regulators approve, incentivise and supervise investments in digitalisation made by grid operators. This concern is especially relevant when capital requirements for grid digitalisation are high and the investment benefits might differ across the grid. For instance, a more congested grid might need a higher level of monitoring than the rest. This issue is also related to the anticipatory grid investments defined in the EU Grid Action Plan [4], which are essential in facilitating the connection of new RES. Moreover, the ambitious grid investments declared in the EU Grid Action Plan require setting a reasonable Weighted Average Cost of Capital (WACC) for the digitalisation investments[8].

Table 1 provides a summary of the key differences between traditional investments in electrical assets and investments in digitalisation made by grid operators.

Table 1 – Comparison between traditional investments in electrical assets and investments in digitalisation by grid operators. Source: own elaboration

	Electrical asset investments	**Digitalisation investments**
Useful life of investments	Long-term capital investments (40 or more years)	Short-term capital investments (10 or less 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 National Regulatory Authority (NRA).	Few international standards and regulations because of recent and constantly innovative solutions. Mid/low standardisation of digitalisation investments related to innovative solutions. Difficult to set benchmark costs by NRA.
Criteria to audit investment by regulators	NRA sets short list of network design criteria for grid operators.	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 variety of standardisation, cybersecurity, interoperability and existing solutions in each company.

[6] https://www.nationalgrideso.com/

[7] See the press release "Energy consortium launches the UK's largest domestic flexibility study" at https://www.nationalgrideso.com/document/212851/download.

[8] WACC reflects the rate of return that regulators allow grid operators to recover on their investments.

	Electrical asset investments	**Digitalisation investments**
NRA replicability and assessment of the optimal investment volumes	Easily 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. Relevance of using digital twins for replicability. NRA should use Key Performance Indicators (KPIs) to compare efficiencies from different grid operators.
Implementation of economic incentives to grid operators	Easy to implement incentives to make investments below benchmark costs.	Benchmark costs are more difficult to be set, and digitalisation grid investments might not be easily comparable. Difficult to calculate profitability of investment, as this depends upon faster obsolesce, and results depending on different types of network externalities, the dynamic of which might be highly path dependent [30] [31]

4. CENTRALISED VS DECENTRALISED DATA MANAGEMENT MODELS

Historically, the usefulness of many energy solutions has been dependent on the ability to upscale or downscale technologies. In the 1990s, Combined Cycle Gas Turbines experienced technological progress that enabled the building of new, less costly plants. These developments facilitated the entry of independent power producers into newly liberalized electricity markets, removing some pre-existing barriers to competition [32]. Progress in RES technologies was accelerated by allowing the emergence of initially small wind turbines, then gradually leading to the entry of ever larger installations, i.e. exploiting economies of scale. Recently, some innovative solutions, such as local energy communities or community-based projects, which share generators or storage devices between some customers, have been proposed [33][9]. These mechanisms empower customers and local economies. Nevertheless, data exchange processes are essential for the success and development of those energy communities[10].

The development of early electricity and town gas systems in the 1800s already posed 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 only emerged later, as the need for technical standardisation and operational coordination grew. For instance, in the UK, at the time of the establishment of the national electricity grid in 1926, there were over 600 electricity distribution networks that operated at different voltage levels. A national system was needed for the technical standardisation of assets and harmonisation of system operations [34].

Often, centralisation may promote efficiencies or achieve better regulation since it is a means for achieving technical and non-technical 'standardisation'. Standardisation is, in turn, important for the 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 service provided (network infrastructure). Economic theory suggests that markets do not supply sufficient public goods, and the elements of energy systems mentioned above exhibit characteristics of public goods, leading to private underinvestment due to incentives for freeriding [35]. Public goods emerge due to non-excludable and non-rivalrous elements of the energy infrastructure, for instance, due to information asymmetry linked to data on individual usage of the shared grid.

However, centralised solutions may not always be the most efficient, particularly when certain components were previously developed separately on different platforms. This attribute aligns with the idea of coordinating and using existing energy data systems to form an energy data space. In these cases, the existing decentralised and interconnected solutions might be more efficient, less costly and easier to apply than new centralised solutions.

A useful example of an integrated decentralised network is provided by the Internet, a network of networks of different scales and sizes, interconnected and able to deliver universal end-to-end connectivity. In this sector, the establishment of Internet Exchange Points [3] provided an alternative form of "Localised centralisation" of traffic exchanges, often based on not-for-profit governance, reducing overall costs of access [36]. These changes also resulted in a more decentralised hierarchy of the global Internet, enabling it to reap broader benefits from its original technical interoperability. However, the Internet is also exposed to

[9] For instance, 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. Resultant economies of scale allowed to address energy poverty and local environmental issues caused by the village's reliance on heating oil. 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.

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

threats to universal connectivity due to many proprietary sub-ecosystems, for instance, mobile social networks that require additional elements/memberships/apps to be accessible by users.

The current approach by the EU Agency for the Cooperation of Energy Regulators (ACER) prioritises implementing a "single and common-front door" for the independent aggregators in the flexibility registers [37]. This solution enables several decentralised data platforms to act as a unique (centralised) platform by the third parties, i.e., independent aggregators, suppliers or customers[11]. Similar solutions are already implemented with some DSO-shared platforms such as Datadis for the metering of consumption data in Spain or SIORD for monitoring RES and future flexibility resources [39][40].

As previously discussed, 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 and efficient solution. From technological and business perspectives, in the last decade, many companies have dedicated large resources to centralising their data processes through cloud migration [41], with data coming from many decentralised physical servers. This approach reduces costs and increases security and accessibility, among other benefits, while aiming to maximise the system's efficiency by leveraging its positive network externalities.

The diffusion of edge computing is currently driving a new trend towards decentralisation. 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 decentralisation trend provides relevant benefits, as it reduces data flows, simplifies computational needs, reduces vulnerabilities in the power system, reduces computation latency and increases reliability. Currently, their implementation in the power system is in an incipient stage, but future developments are expected in the coming years, mostly related to the operational challenges due to renewables [27].

Similarly, decentralisation on the Internet is exemplified by the emerging trend of dense interconnections among small and medium-sized regional networks, a practice known as "doughnut peering", [42] [43] which is used to bypass the largest central players and create a "doughnut hole" architecture.

However, decentralisation also has the potential unintended consequence of increasing the market power of initially external operators, becoming able to leverage their existing market position in contiguous markets, such as edge computing in the retail energy market.

5. DATA INTEROPERABILITY AND STANDARDISATION

A key success element for exploiting potential economic benefits from digitalisation is to set interoperability measures that seamlessly enable data exchange and communication across a sector – and even at a cross-sectoral level – and lower barriers to participating in the flexibility services defined in Section 3 [5][44][12].

The physical configuration of the DMM, and the rules and regulations governing these systems provide a key example of the relevance of interoperability between different data resources. This governance is particularly relevant for an ecosystem that supports the full lifecycle of energy communities, by addressing socio-technical challenges in planning, deployment and operation to enable active participation, data-driven decision-making and the broader goals of energy democracy [45].

By focusing, again, on the Internet experience, this network evolved around the development of a unified communication protocol (TCP-IP), allowing universal interoperability across many different international networks, whereby cross-network digital exchanges were managed by Border Gateway Protocols (BGPs)[13][46]. However, notwithstanding technical interoperability, the governance of digital interconnection and its contractual agreements limited the scope of economic interconnection incentives, creating hierarchical upstream Internet markets that affected affordability, especially in less developed and landlocked countries. To address this, The World Bank, in collaboration with the International Telecommunication Union (ITU), developed the Open Fibre Data Standard (OFDS) initiative[14]. This standard provides a framework for collecting, sharing and utilising data related to fibre optic infrastructure in a consistent, interoperable manner. The OFDS improves transparency and reduces information asymmetry by standardising the collection and sharing of data about fibre networks. Hence, in this case, interoperability among many relevant dimensions of these networks is necessary in ensuring that data can be shared and integrated across different platforms and systems.

[11] Easy access to metering and consumption data is essential for liberalized electricity markets, and with the EU requiring Member States to report their data access practices [17], a role-model framework is emerging that enables a taxonomy of data management models showing trends in centralisation, governance, data volume challenges and the importance of near real-time data [38].

[12] 'Interoperability' means the ability of different energy or communication networks, systems, devices, applications or components to interwork to exchange and use information. 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 [17][4].

[13] Still, national governments and corporations managed to create spaces outside universal connectivity (intranets and other types of national walls).

[14] The initiative is a multistakeholder effort involving the World Bank, ITU, Mozilla, Liquid Intelligent Technologies, CSquared and the Internet Society. https://documents1.worldbank.org/curated/en/099063023160023332/pdf/P1761460fac12e0b09cb90f26880158a4f.pdf.

Refocusing on energy systems, digitalisation provides added value by combining data from different sources, i.e., energy resources or end-use devices. This requires their design to use common standards and be interoperable. Standardisation lays the groundwork for interoperability. From a technical perspective, data interoperability is one of the components of the technology building blocks in data spaces[15]. In this context, achieving full interoperability requires the adoption of common standards in the 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.

A survey conducted by the EC in 2018 listed interoperability as the main technical barrier for data sharing [47]. A lack of interoperability acts as an entry barrier, as it hinders the seamless exchange of data between different stakeholders and the formation of innovative data-driven solutions. Information asymmetry is another consequence of lack of interoperability. Certain stakeholders exclusively possess and use critical data, and this type of asymmetric information hinders competition [48]. Therefore, also from an economic perspective, interoperability is important for promoting free entry and the ensuing dynamic efficiency [49].

In the EU, policymakers have addressed the issue of interoperability in several cases. The EC [17] mandates interoperability for accessing 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 that European standardisation bodies develop the necessary standards aiming to promote interoperability [50].

In June 2023, the EC adopted legislation to ensure that metering and consumption data across countries follow a common reference model that can be customised at the national level [51][16]. However, this legislation only addresses administrative procedures. The EU legislator addressed the technical aspects of interoperability by establishing the Data Spaces Support Centre (DSSC) in October 2022, funded by the EC under the Digital Europe Programme, to identify common standards, technologies and tools to support the establishment of sectoral data spaces in Europe[17].

In the energy sector, grid operators handle a high variety of data: consumer metering data, network operation data or detailed technical data about their lines or transformers. In this context, standards set by grid operators may form barriers for new entry and third parties that would require access to consumer data for providing their innovative data-driven solutions [52]. Moreover, standards also enable exchanging data between different grid operators for operating processes. Therefore, it is important to involve smaller or newer stakeholders in the initial stages of establishing standards and interoperability rules to avoid favouring incumbent providers and manufacturers over the others.

Finally, digitalisation is a “relatively new” concept in the energy sector [53]. This scenario is in evident contrast with the “Big Tech” sector, whose key companies have vast resources and the required knowledge to quickly take up market shares in new sectors when they integrate digital solutions. “Big Tech” companies might achieve these objectives by leveraging their own technical standards across sectors. This situation presents new regulatory challenges related to leveraging market power across recently connected sectors through digitalisation [54].

In summary,

- Interoperability benefits are that:
  - it allows for seamless communication and data exchange among different systems and devices, while,
  - on the other hand, setting interoperability requirements might favour some providers or manufacturers over others.
- At the same time, standardisation benefits are that:
  - a relevant part of the interoperability processes, are known in advance and help lowering economic and technical barriers to implement new information exchange processes.
  - However, listing standards might limit the adoption of future innovative standards and leave some manufacturers out. The processes for approving new standards may be complex and the standards in the EU may differ from those in the US and other regions. Also, implementing new standards might be incompatible with other existing ones and, finally, the adoption of existing data standards into EDS might entrench market power from a few gatekeepers, leveraging their market power from the ICTs to EDS.

6. ECONOMIC CONSIDERATIONS ON PERSONAL ENERGY DATA SHARING

The replacement of traditional meters with smart meters is a key element of digitalisation and the customer-centric strategy. They track household consumption in real time, which is essential to implementing timely tariffs and economic incentives to value customers’ flexibility.

[15] The other components are data sovereignty and trust and data value creation.

[16] Implementing Act on metering and consumption data is part of the Digitalisation of Energy Action Plan launched by the European Commission in October 2022.

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

Crowdflex[18], the UK's largest domestic flexibility study, based on 25 000 households, estimated a 15-17% demand reduction during the evening peak in response to incentives incorporated into flexible Time-of-Use (ToU) tariffs[19]. Furthermore, households with an EV demonstrated even greater flexibility, reducing their daily demand consumption by up to 23% during the evening peak.

Smart meters were shown as possibly affecting most of the technical dimensions of energy systems, as described in Section 2. Crucially, these dimensions entail significant economic consequences. For instance, smart meters influence the crucial regulatory activity of "market definition" from both geographic and product perspectives, as they provide granular data used in dynamic tariffs that subsequently affect demand elasticity[20], as well as market power and market boundaries [55].

The availability of smart meter data also enables market participants to actively participate in the energy markets, as this data eases metering the hourly consumption and the overall process of switching providers [56]. At the same time, the availability of hourly metering data also modifies the strategic incentives for incumbent providers. They might want to price more aggressively and offer profiled pricing and bundling strategies to keep entrants off the market. While these incumbent strategies are likely to generate economic surplus, as they are based on service quality improvements, they will simultaneously aim at maximising the extraction of consumer surplus by the incumbent. The incumbent's unregulated access to users' data and its algorithmic operability will likely reinforce these processes.

These economic consequences also cascade throughout the entire energy data ecosystem since implementing smart meters requires hiring highly skilled workers or adopting new digital solutions to communicate with them. Moreover, smart meters might be owned and operated by grid operators or third parties, which might have implications for the energy agents' market position.

A key factor in the success of smart meters rollout is their adoption strategy. In some countries such as Austria or Spain, their installation is mandatory by grid operators and recovered by network tariffs, while in others such as Germany, it is optional and directly funded by customers. In the latter case, installation costs and ease of use may represent a significant socioeconomic barrier to consider their deployment. Moreover, consumers do not necessarily have extensive knowledge of smart meter systems, which may increase their reluctance to install them. In the following, we focus on one specific use case, exemplifying how smart meters might play a key role in shaping economic incentives. Furthermore, we use this case to explore some key related economic issues, including economies of scale due to network effects [57], cross-platform benefits [58], the incentives to enter the market [59][60] and the economic value of personal data and data portability [61][62].

Consider the contractual choices offered to a new UK customer by Octopus Energy, a transnational supplier[21]. Under the heading on "Smart Meter Data Preferences" the supplier asks, "How would you like your readings stored?" and provides three alternative temporal profiles:1) Half-hourly, 2) Daily, and 3) Monthly. After the user's choice is made, a message appears stating that "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 encourages (nudges) the consumer to use the smart meters' more frequent readings and information storage, by emphasising the collective benefit of reducing carbon emissions[22]. Then, a "deterring" statement follows: "Important: If you choose daily or monthly reporting, you will not be able to access your half-hourly data through us". Clearly, the benefits from the efficient half-hourly tariffs will differ among users, as they require that the customer can adapt their consumption to the different prices through demand that can be remotely activated (EV charging point, storage device) and simpler changes in the time of domestic energy usage.

The usage by the retailer of the collected personal data highlights some interesting economic incentives and trade-offs of personal data sharing.

- First, personal data sharing is useful for **reducing asymmetric information**.
  - A clear benefit is that by supplying granular information to the consumer, the retailer helps them to adapt their timing of energy consumption in view of reducing costs.
  - However, the associate risk is that granular data-based advice from the retailer to the consumer clearly has the potential of reinforcing "brand loyalty" [64], decreasing consumers' willingness to look for alternative providers, hence reducing potential competition by implicitly increasing consumers' switching costs.

[18] An Ofgem Strategic Infrastructure Fund project conducted in 2021 by NESO, Scottish and Southern Electricity Networks Distribution, Octopus Energy and Ohme. See https://www.nationalgrideso.com/future-energy/projects/crowdflex

[19] This was shown by the differences in energy consumption between flexible (Agile) tariff customers vs flat tariff customers, in correspondence to a price plunge on 25 October 2020.

[20] The traditional economic metric for measuring market responsiveness to price increases.

[21] Octopus Energy Group is a British renewable energy group specialising 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. "Smart Meter Data Preferences" were obtained from Octopus' webpage, https://octopus.energy/blog/track-my-energy-use/ Accessed in spring 2024.

[22] In behavioural economics, a nudge is a way to set a choice architecture that affects people's behaviour in a desired direction without restricting options [63].

- Second, personal data sharing is useful in **reducing carbon emissions** as
    - frequent meter readings allow for a better integration of RES, through better demand forecasts, leading to reduced carbon emissions. Awareness of this benefit also increases customers' satisfaction, if carbon emissions negatively affect their preferences.
    - However, higher preferences lead to a higher willingness to pay, possibly leading to higher prices, absent from other competitive effects. Under more competitive scenarios, higher perceived quality allows the incumbent retailer to maintain a price differential vs its competitors or entrants when they are unable to match such quality.
- Third, personal data sharing is useful in constructing a set of **retailer's recommendations based on actual customers' consumption**.
    - Hence, in exchange for real-time metering information, the provider will make recommendations, possibly advertising and bundling energy services with additional types of services or commodities: a home EV charger, an air-source or ground-source heat pump. The retailer may also provide free or discounted, or even zero, energy prices when wholesale prices decrease.
    - However, one can strategically use zero prices or cross-subsidisation within platform markets to attract customers on one side of the market. Thus, the other side, e.g., advertisers or sellers of complementary products, are willing to pay higher prices to the platform due to the cross-platform benefits they receive. Such cross-side platform externalities might be pivotal in inhibiting competition and entry into platform markets.

These considerations show that the time-frequency of smart meter readings leads to an increased perceived product/service quality with no marginal cost borne by the seller. Increased quality is only due to the feeding of the most frequent user data into the grid optimisation algorithms, whose cost is mainly a fixed one. Hence, paradoxically, due to the economic value of private users' data, at no extra cost, the retailer might charge a higher price based on the user's higher perceived quality of energy, for example, as it might have a reduced carbon footprint, which is only achieved because of the availability of the user's data.

In summary, the provider might extract extra 'rent' from the user's data by selling a higher-priced service with better quality, whereby the cost required to increase quality is only based on the interaction between the user's data and the retailer's algorithms. Or, in a more competitive market, the provider might use this customer personal data to outcompete possible entrants or existing competitors that have no direct access to this data or to their derived versions when fed to train the incumbent provider's pricing algorithms. In this second case, while regulation on data portability seems to be a clear indication of how to redress these potential rent extraction activities [23], its success depends on the range/scope/definition of personal data and on whether these include derived products/services that are the outcome of (proprietary) algorithms to which the portable data were fed. Hence, including data traceability as a standard might play a role in changing the dynamics of rent extraction.

Moreover, zero prices in traditional markets would signify the absence of scarcity or economic trade-offs. Instead, when based on personal data sharing, zero-price offers, typical of the digital economy [65] from Wi-Fi access in coffee shops to social media accounts and basic cloud services, are averaged with the value the retailer extracts from the personal information that users agree to provide when signing the agreements on the terms of use of the free service, after confirming to have read lengthy, complex contractual agreements. Such terms and conditions often refer to the use of personal information, either directly provided or, even more interestingly, indirectly provided, for example, by agreeing on the use of cookies and tracking, whose detailed information might be richer than what the user is aware of.

In this context, zero prices become a crucial business strategy, generating cross-side platform externalities, reducing competition and entry into platform markets. The interplay of these externalities with the lock-in costs introduces further policy dilemmas often linked to distributional implications, since alternative regulatory scenarios might help one side of a platform while weakening the other. In these settings, regulatory intervention might also exert differential and opposite effects not only between but even within single sides of the platform [56]. This might be the case if users on the same side of a platform are exposed to different levels of switching costs due to an asymmetric distribution of search costs or cognitive abilities.

Moving to more advanced use of personal data obtained via smart meters, below we discuss the economic implications of the specific "tracker-based" cutting edge beta smart tariff offered to Octopus's customers[24].

The tariff was advertised as being "Built with fairness in mind". It features energy prices that change daily based on the wholesale cost of energy and, crucially, requires the installation of a smart meter.

Once again, these types of "tracker-based" smart tariffs enable specific business strategies, which in turn present potential economic risks and benefits.

- The first strategy is **advertising**, defined in the tracker cookies agreement as the ability to "Create more relevant campaigns, products, and services". This clearly has the benefit of
    - increasing users' information,

[23] The EC 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.

[24] Based also on details on this tariff. For a summary see: https://octopus.energy/blog/track-my-energy-use/

- while risking reducing inter-retailer competition due to the new asymmetry of information linked to the retailer's advertising.
- The second strategy is **tailoring**, defined in the tracker cookie agreement as the ability to "make predictions about future behaviour based on current behaviour", to help develop and tailor our products and services.
- This clearly has the benefit of leading to an
  - increased level of user satisfaction, due to products' tailoring and differentiation [66],
  - while, however, risking the softening of competition, linked to stronger brand loyalty effects due to tailoring, leading to increased switching costs [67].
- The third strategy concerns **market segmentation**, defined in the tracker cookies agreement as the ability 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". This clearly has the benefit of allowing:
  - better identification of users' preferences due to improved profiling of the services available in a segmented market.
  - However, this approach risks softening competition because of the increased market power resulting from reduced demand elasticity in a more segmented market.
- The fourth strategy involves **ecosystem alliances and mergers**, that might allow data firms to enter the market as energy retailers.
  - This strategy offers the advantage of combining various customer personal data sets to provide superior products.
  - However, markets become less competitive when a merged supplier has access to more complementarities and information than its competitors.
- Finally, smart tariffs create opportunities for "**supply-side demand strategies**". These are possible when consumers are simultaneously energy producers and exporters or prosumers [68].
  - This arrangement has the benefit of allowing prosumers to switch roles between demand and supply of energy, smoothing demand and reducing cost. As a result, intertemporal elasticity is increased.
  - However, a multiplication of the roles of users and the ensuing increased tariff complexity might result in a decrease in price elasticity of demand when choosing among different retailers within a given time.

Finally, in assessing the benefits and risks of the strategies enabled by the digitalisation of the energy systems, it is important to focus on the nature and source of information on which such tariffs are based and whether such information is easily accessible to a wide range of service providers.[25] Is this just personal data or derived data? Are they collected from a sole source of information or merged from different sources, so that implementing regulations on actual data portability might be feasible in theory but complex in practice? As an example, the above-discussed smart tariffs are based on a mix of data sources. These include, according to their terms and conditions, third parties such as price comparison websites and affiliates or partners, which may send customers' personal information. These tariffs also rely on the provider's access to national energy databases, which include information about a customer's property, meter details, previous suppliers, EV charging point services and location data that corresponds with the location settings on customers' phones when using the mobile app. Additional regulatory efforts are necessary to address this complexity, with a focus on ensuring the transparency of the algorithms that receive data from personal users' smart meters.

7. CONCLUSIONS AND REGULATORY IMPLICATIONS

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 adopting a new perspective on how to implement improvements in the energy regulatory framework. In this paper, we followed an approach akin to that of Montero and Finger [69] who adopt a multidisciplinary perspective to understand how digitalisation affects various infrastructure-based industries.

It can be argued that digitalisation in the energy sector is not a recent phenomenon. Rossetto and Reif [53] note that this process has occurred through a series of consecutive digitalisation waves, each covering different parts of the system. The most recent wave focuses on distribution networks, consumer premises and retail markets.

Likewise, we developed a logical mapping to reflect on the impact of digitalisation on the economic incentives shaping interactions within the energy sector, with particular attention to the relationships between retailers and their customers, and by drawing lessons from solutions adopted in the Internet sector. Based on this mapping, we discussed how this new perspective on how to implement improvements in the energy regulatory framework, should include the standardisation and interoperability of all the involved devices and data formats and the regulatory framework for grid operators and the rest of the involved agents.

[25] Designing and introducing EDS 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. https://eddie.energy/.

The first element of this perspective requires setting a pan-European framework to improve access to data and incentivise the data-driven innovation.[26] Current European regulation should be further developed to provide cheaper prices for aftermarket services, new opportunities and services related to the data, and better access to data collected by devices. It is critical to establish a framework for sharing data across sectors and Member States while also incentivising the development of common European data spaces in various sectors such as energy, agriculture, mobility, finance, environment and health.

The second element, for a new perspective, requires implementing digitalisation solutions in the energy sector and a regulatory framework for all the involved agents that is properly designed. On the one hand, grid operators need efficient regulatory incentives to implement digital solutions that improve their operational efficiencies, which improves social welfare. On the other hand, the regulatory framework for suppliers should enable implementing innovative tariffs to further develop flexibility from customers.

A third step for a new perspective is the awareness that 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 point. Aggregators and providers of flexibility consider them key in the deployment of flexibility services from small resources and consider them useful for billing or settlement [28]. Submeters are introduced by the EC [70] where Member States are mandated to establish national requirements to check and ensure the quality and consistency of their data, as well as their interoperability requirements.

A fourth requirement, for a new perspective, is the setting of interoperability requirements, as these become increasingly relevant with the connection of more digital devices in the power system. Such interoperability requirements are essential to ensuring fair competition in the provision and adoption of digital solutions. Few interoperability frameworks might result in economic barriers to manufacturers, additional devices to enable communication with devices or higher administrative costs, among others. The first Implementing Regulation on Interoperability was approved in 2023 [51]. Future implementing acts would include interoperability requirements and non-discriminatory and transparent procedures for access to data required for demand response and customer switching [6].

Digitalisation is a key factor for efficient use of the physical energy assets within a given economic framework. The overarching aim of an EDS should be to enable the emergence of new business models supported by a new perspective on the 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. In principle, 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.

Lastly, it is important to note that new areas for utilising decentralised energy data will evolve gradually over time. Just as early town gas networks evolved over time and with new fuel uses, a future EDS will also evolve with increased electrification of the economy and services, following 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 centralised solutions towards decentralisation. From an economic perspective, as future EDS facilitate the emergence of new services, a new perspective on this sector's regulation is instrumental in transferring whole sector efficiency gains to consumers. This is only possible if accompanied by a reduction of the information asymmetries necessary to prevent the use of smart meter granular data for private information rents based on proprietary and exclusive algorithms from gaining more market dominance.

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