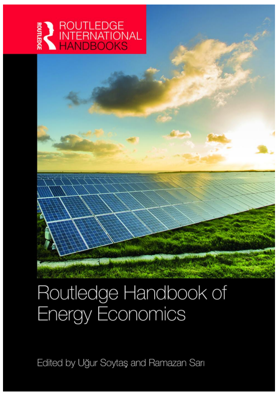

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Uur Soyta, Ramazan Sar

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Economic and social challenges of smart grids

Daniela Velte and Guillermo Gil Aguirrebeitia

1 Introduction

1.1 What makes an electricity grid smart?

The main difference between the conventional and the smart electricity grid consists in the flexible orchestration capacity of the latter. Smart grids create the conditions for intelligent operation, communication and data flows between grid components and between the different actors involved in grid operation, including the end user. They enable bidirectional flows of electricity and therefore the participation of the demand side both in the form of decentralized production and in the form of demand-side management (i.e. load and peak control, storage and more).

Transmission grids in Europe have already been equipped with intelligence and control devices and utilities are now in the process of modernizing the medium- and low-voltage networks.[1] The reasons for these investments by the grid operators are multi-fold, being the main benefits of smartening the grid on all network levels the following:

1. A better monitoring of electricity flows, including theft detection.
2. Reduced operational costs, due to remote control and monitoring of the grid components, early fault detection and quick repair, which leads to greater resilience, reduced outage times and better service.
3. An increased capacity and flexibility for operating the production from renewable and distributed energy sources in the grid, maximizing the output of these installations.
4. Support for "sector coupling", meaning the increasing use of electricity for transport and heating purposes (electric plug-in vehicles and heat pumps), and the optimized management of the different energy grids (electricity and gas networks, district heating and cooling etc.).

The benefits of investments in smartening the grid cannot easily be quantified, as a series of cost-benefit analyses (CBA) have shown over the years. Although the Joint Research Centre (JRC) keeps close track of developments in smart grids[2] and cooperates with relevant international bodies in the definition of a joint methodology for CBA[3] (US CHINA, 2016), the analysis needs to be done on a project-by-project basis and is very much influenced by the system boundaries chosen for the analysis (for further information see GIORDANO et al., 2012). The SG impact that is the hardest to measure in monetary terms is at the same time the most interesting for progress in the energy transition: the enabling effect in terms of market participation and generation of new business opportunities.

The developments both within the electricity grid, also called the "smart grid value chain" and the enabling effects of SG (smartness beyond the grid) are now described in more detail.

1.2 Smartness at grid level (SG value chain)

The electricity system we rely upon is undergoing a process of accelerated change towards a decentralized and decarbonized system. The final vision is an energy system that provides affordable, clean electricity worldwide. This implies a broad set of technical, regulatory, economic, and social challenges for the different agents operating along the value chain of the energy sector (Figure 29.1). Those interrelated forces drive and modulate the speed of smart grid deployment. At the same time, it is necessary to find a balance between the necessary investment in system modernization (that may lead to increased capital expenditure, CAPEX), the complexity of operation (that may lead to increased operational expenditure, OPEX), and the options for sharing benefits with the users in the form of lower electricity consumption and bills. The smart grid must create value for all actors involved. Otherwise, there is a high risk of leaving the households with the lowest investment capacity and no opportunities for self-production and consumption to pay the bill of the energy transition.

In this challenging context, digital technologies are driving the metamorphosis towards a smarter and more efficient electricity system, giving the user a more active role. The impact of digitization will affect all components of the electricity network, from generation to usage, and beyond.

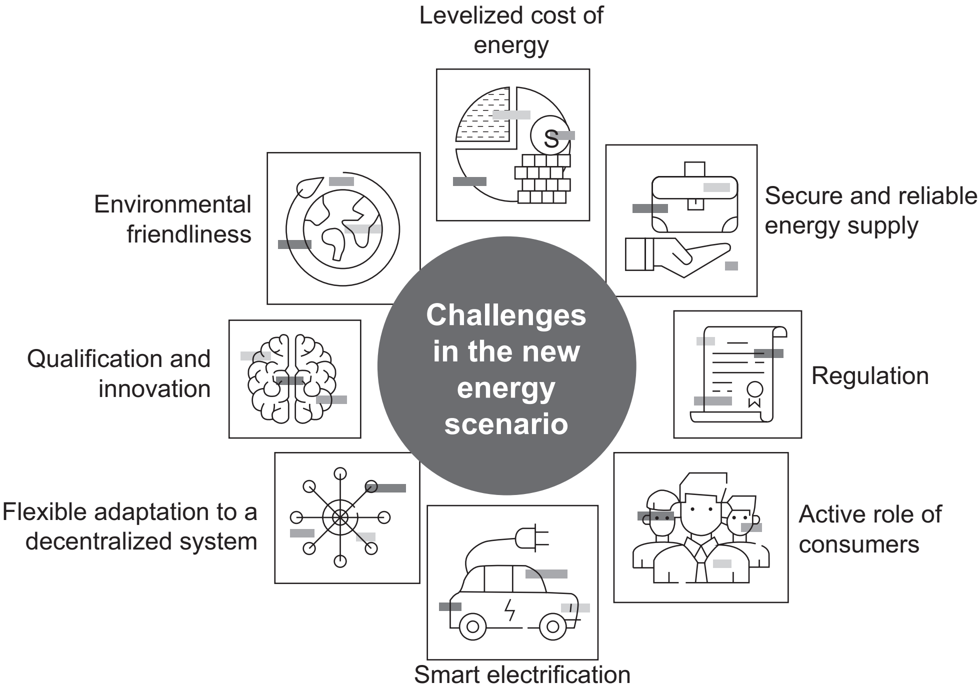

Figure 29.1 Challenges in the new energy scenario

Source: TECNALIA.

The most obvious impact is that digitization adds *smartness* to the system, creating a system that is more information-centric, intelligent and flexible. Sensors, actuators, smart meters, and many other IoT-like[4] devices are providing almost in real time precise information about system behavior and external factors, such as wind, weather, economic, or social restraints that may affect the whole system performance. Big data, analytics and the novel artificial intelligence (AI) techniques applied to the smart grid can manage the vast amount of the information produced from all these sources. They can give accurate predictions on power generation, network capacity, market conditions, and demand requirements, thus supporting the complex management and decision-making process, even in real time. At the same time, the intelligent orchestration and the smart operation of specific network elements in generation, transmission, storage, distribution, and eventually, customer management, allow for a fast reconfiguration of energy flows. It is a system that responds to sudden variations in generation conditions or demand patterns. As a result, electricity companies with smart agents can adopt new measures, such as price signals, when their own supply and demand requirements are not balanced to adjust the demand. As the smart grid turns into a dense, interconnected system of systems, in which millions or billions of actors interact, the complexity increases exponentially. Meeting all management needs without the smart-enabler technology is simply unthinkable.

Secondly, digital technologies also allow for a more *responsible* electricity system: one that is more efficient, that meets environmental and social objectives and that secures electricity provision. Efficiency is the primary goal of smart grids. This objective must be met to compensate for the additional electricity demand created by digitization itself in the form of data centers and new appliances.

Examples of more efficient grid management due to digitization already exist. For instance, in the production and transmission side, the introduction of the digital twin paradigm is leading to better operation and maintenance (O&M) strategies that improve energy production and lower overall maintenance costs. A digital twin is the software version of a physical asset to which it is interconnected via sensor and IoT-like devices. By accumulating data over time from the real asset and by applying physical dynamics modeling to the software version, it is possible to have a replica of the physical asset in the virtual world. Then, in this virtual world, it is possible to test different operation strategies much cheaper and faster than in the real world and to simulate the asset behavior under different operation conditions. The best strategies can then be deployed in the real environment with a clear O&M impact, for instance by lowering asset downtimes and by extending the asset life duration. By linking digital twins, larger parts of the entire smart grid system can be modeled and their complex interactions simulated in the virtual environment, giving precise insights and predictions about their future performance.

Yet, to reach the EU's emission reduction targets, energy efficiency must be increased at all stages of the energy chain, from generation to final consumption. The consumption part, such as in buildings and industry, have the greatest potential for energy savings, and because of that, European measures in energy efficiency focus on those sectors.[5] Building heating, cooling, and lighting is a focus of digital innovation with smart sensor, smart control, and smart operation systems to guarantee the desired comfort with lower energy bills.

The potential of these types of smart systems to monitor comfort and to provide personalized, accurate energy services is not yet fully harvested. Innovation and market reforms are still needed to ensure that the savings in energy consumption make up for the required investment. One of the most promising cases for savings through demand response (DR) participation and controllable load are advanced electric heat pumps, for which Bang et al. (2014) found that

> in a typical Danish house, the annual savings associated with intelligent control in accordance with hourly spot prices was roughly 300 DKK (EUR 40). By participating in the

> regulation of the power market, the annual savings are considerably higher, but also more uncertain. Even if the heat pump only contributes with down regulation, the increase in annual savings can easily be 500 DKK (EUR 67).

In this context the European Economic and Social Committee (EESC, 2017) remarked that it is necessary to "clarify the value of user interaction with the electricity system for operators and consumers". Studies on user motivation[6] have found additional barriers, beyond economics, for example the unwillingness of consumers to hand control of certain appliances over to third parties or the lack of user-friendly interfaces and feedback to the consumer. At the same time, industry reports indicate that the market for home energy management (HEM) systems is on the rise and expected to continue to grow in the coming years.[7]

Beyond the lowering of energy bills, energy efficiency policies and innovation offer a massive potential to reduce the reliance on fossil fuels and to meet environmental objectives.

Another important topic for a responsible electricity system is to secure service provision. The assurance of electricity supply is an obligation established by the EU.[8] Due to the digitization level of the smart grid value chain, cybersecurity innovation has started to play a vital role to protect the system against vulnerabilities and attacks, and to ensure reliability and security of supply. Such attacks already occur: in December 2015, in what is considered the first successful attack to a smart grid, hackers could manipulate information systems of three energy distribution companies in Ukraine and temporarily disrupt electricity supply to more than 225,000 end consumers.[9] Apart from stealing or modifying customer data from smart meters, a devastating scenario can be imagined in which hackers, could manipulate the joint information and control systems to provoke a complete collapse of the service once the smart meters are widely deployed.

Finally, the digitization of the electricity network, along with market and regulatory factors, has a decisive impact in the *dynamism* of the system. By getting more precise information, by accessing a larger variety of contractual mechanisms, or by allowing network operators to manage some appliances remotely, users are, slowly but steadily, adopting a more active role in the smart grid value chain. In some cases, for instance when users produce energy (this is, they are prosumers) or have storage capacities (such as batteries or electric vehicles), this energy can eventually be marketed to electricity companies to meet supply and balancing requirements.

On the user side, the progressive digitization and *smartization* of systems and appliances merge with other trends, such as the prosumer role of users and electrification of the consumption. This is a breeding ground of opportunities for new entrants willing to develop new business models in a field that used to be the exclusive domain of traditional utilities. Smart grids offer opportunities for emerging actors along the entire value chain (for example, related to cybersecurity, energy marketplace platforms, or virtual power plants (VPP)), but the user interaction beyond the grid is an especially fertile field for new entrants.

1.3 Smartness beyond the grid

An obvious consequence of the development of the smart grid is that the stakeholders taking part of this development start to engage in a process of digital transformation. The grid evolves with energy-based technologies and with computing, communication and information technologies. The energy grid is overlapped with a "digital grid". The different actors need to transform themselves to manage the new situation, in which the digital transformation affects different levels in each organization. One of the most relevant implications for an organization engaged in this digital transformation process is its progressive shift towards a more customer-or user-centric paradigm. This turn from system-centric to user-centric opens the door to new opportunities beyond the grid, in the user area. By managing the consumption of appliances in the user environment, the electricity suppliers can increase flexibility and instantaneous adaptation to energy needs. If traditional energy suppliers are reluctant or fail to activate consumers, there is an opportunity for new entrants and intermediaries for accessing this potential market. However, competition in the front-end field, in this customer interface, is enormous, coming particularly from native digital players who are already occupying this interface in other domains (such as communication, entertainment or social domains) and are quickly tapping into other industries. Also, due to its dynamism, this space is very attractive for new and emerging businesses with lower overheads (e.g. no capital investments) and agile adaptation to market needs. For a company operating on the smart grid value chain, the gradual shift to a more customer-centric paradigm means to develop a better understanding of consumers, to offer a more personalized portfolio of services and to deploy a wider set of engaging mechanisms. The established utilities can take advantage of the physical and digital channels already available between providers and consumers, and this constitutes an entry barrier for new service providers, such as aggregators, who need to build their customer base from scratch. Existing IoT service providers, however, do not face this hurdle since they can easily broaden their service offer to their massive customer base.

On the user side of the smart grid, another element to consider is the prosumer role of users, those that both consume and produce energy. By using solar panels, smart control systems, batteries, and eventually electric vehicles, prosumers could integrate their systems and energy production into the smart grid system and become a more active actor in the electricity market. Apart from the direct prosumer-to-grid commercialization, new models are possible, such as peer-to-peer commercialization and prosumer community management. For instance, ENECO, a Dutch utility company, announced in 2016 CrowdNett, a plan directed to homeowners, who already have rooftop solar systems, to offer a battery system, in cooperation with TESLA, and to create with all of them a virtual power plant by tapping into a percentage of each user's storage capacity. They offer a discount on the price of the system for customers willing to participate, as well as a yearly fee if they permit CrowdNett to "borrow" up to 30% of the battery's capacity when needed. Audi, in conjunction with other partners, is carrying out a pilot project in 2018, Audi Smart Energy Network, to test the combined automobile, home, and power supply in an intelligent energy network that also interacts with the power grid. Also in this case, the systems are interconnected to form a virtual power plant. The goal is to optimize the power consumption, with renewable sources providing a greater proportion of energy and the power grid providing less.

Even though it is unlikely that a strong demand of new services from the consumer side will drive the development of new opportunities by its own, it is expected that the market developments will be the result of a collective, competitive action on the supply part, both with existing players and with new entrants, and much enhanced intervention capacity of the user on the demand-side. The big question that remains open presently is how quickly these changes can be implemented to support the successful governance of the energy transition.

2 Challenges and opportunities of smart grids in the energy transition

2.1 Technical

Progress in the implementation of SG depends in part on the technology diffusion rate of IoT for energy management in companies, administration and households, but also on the speed of deployment of high-speed communication networks. Technology diffusion has gained momentum in recent decades and digitization has become an important driver in this field, whereas new

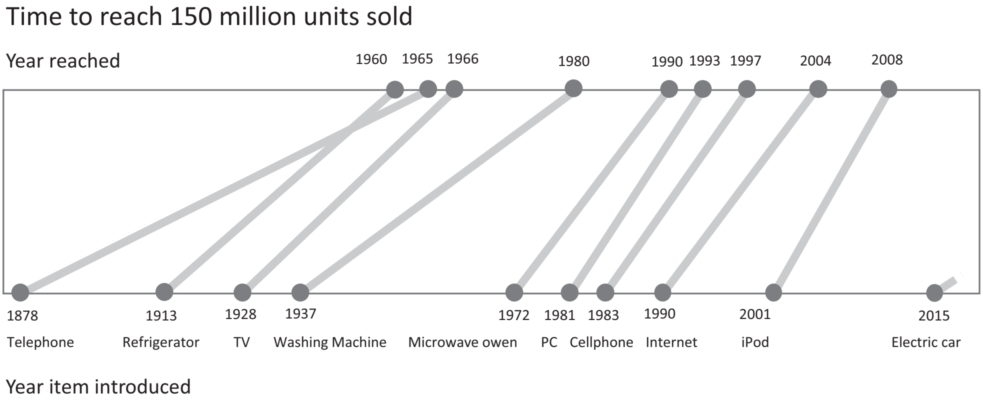

Figure 29.2 Adoption rates of new technologies (data for US households)

technology developments in the energy sector have traditionally been much slower (Figure 29.2), with longer lead times.

Technology diffusion can be slowed down by different types of barriers; among them cost, managerial complexity of data interoperability, lack of business models, and the "collective action dilemma", meaning the need for standards to facilitate cooperation between different types of actors and devices (Schwister and Fiedler, 2015). Velte et al. (2017) furthermore inform about SG experts pointing to possibly insufficient data transfer capacity to allow millions of devices to communicate with each other.

The speed of deployment of smart grids and of the devices capable of interacting with the grids will be essential to cope with additional demand derived from the "electrification" of the transport and the heating sector. In a scenario of high penetration of electric vehicles (80% of all vehicles in 2050), Europe would have to add 150 GW of new capacity (Kasten et al., 2016, p. 49) only for transport purposes, to which another 111 GW (or 223 TWh) would have to be added, by 2030, for electric heat pumps (Wind Europe, 2017, p. 12). Highly efficient and advanced applications will be able to make a substantial contribution to grid management, but not all the technologies that are presently being deployed fulfill the criterion of grid interaction capability.

In the race for decarbonizing the European transport system, electricity has the advantage of being the most flexible energy carrier offering universal access in basically all parts of Europe. These facts, together with the advancements in battery technologies and their decreasing costs, offer a reasonable perspective of progressive penetration of electric vehicles, rather than a wider uptake of alternative fuels, at least in road transport.

Transport and heating are, however, not the only sectors putting pressure on electricity demand. The deployment of more and more electrical appliances that serve users at residential, business, or public spaces also contributes to demand increase, even if the smartness of these appliances provides certain flexibility in use and charging patterns. This trend is reflected in the rising electricity consumption of data centers. Recent data on this part of electricity consumption is not available for Europe, but Avgerinou et al. (2017) point to the global developments: "information technology (IT) sector nowadays consumes approximately 7% of the global electricity, and it is forecasted that the share will rise up to 13% by 2030". For Europe, IT electricity consumption could reach 104 TWh in 2020.[10]

Self-production and self-consumption of electricity from renewable sources could help to solve these challenges if decentralization of production receives decisive support from policy and market. Wind and biomass can contribute to this, but solar technologies have the additional advantage of scalability and capability of product integration. Again, smart solutions, in this case smart inverters, play a decisive role in this context. Field trials have shown that intelligent control of PV inverters by DSOs can increase the capacity of the network for hosting distributed generation by 50% (MetaPV, 2014), and therefore maximize the contribution that solar can make to the electricity system. At the same time, the smart inverters provide feedback on energy use and production to the system owner, which can trigger investments in energy efficiency measures and change of behavior (Klöckner et al., 2018). What has been little explored so far is the potential impact of photovoltaic integration in buildings, vehicles and products on overall electricity demand, especially when combined with energy-harvesting techniques.

2.2 Market

The increasing importance of digital technologies and the associated management of large quantity of data constitutes the entrance points for new actors in the energy sector, among them aggregators, for example Actility,[11] and/or DR providers, for example Voltalis[12] in France. Blockchain-based green energy trading platforms, such as WePower,[13] are creating new access routes to financing of renewable energy projects. Virtual energy markets are starting to blossom but only in those countries in which regulation has been adapted to the new rules by opening the market up to DR and aggregation, among them France, the United Kingdom, and Belgium, as well as some regional markets in the United States.[14] It can be expected that other national energy markets follow up as soon as the newcomers have demonstrated that they have a viable business case and reliable technology. For the still lagging German market, Loßner et al. (2017) estimate that revenue for VPPs could increase between 11% and 30% by 2030, depending on the market setting and the characteristics of the distributed energy resources that are present in the system. If the distributed renewable energy resources continue to be intermittent and baseload provided by fossil-fuel power plants and nuclear continue to lose market share, the value of flexibility services to balance the market (i.e. smart grid solutions), is likely to increase, especially in a scenario of strong demand increase for electricity. There are, however, alternative solutions available for dealing with the intermittency of renewable energy generation, not least electricity storage, which are also likely to influence developments in the market. The complexity of developments makes it difficult to elaborate trustworthy forecasts of the value and price of flexibility services, and several scenarios are plausible. One can even imagine that the role of aggregators is provisional and will become less relevant when the digitization of grids, devices, building, and infrastructure reaches a higher stage of automatization.

The business case of aggregators is intrinsically linked to the fate of decentralized production, and, particularly, the possibility to implement shared solutions. However, the lack of appropriate regulatory settings for shared self-production and consumption schemes is hindering the adoption of innovative solutions in most member states presently. Even where such schemes are supported by the legal framework, technical and administrative hurdles remain that make the business case unviable for the time being.[15] This is not only due to interventions of the incumbents of the energy system to combat "load defection",[16] but also to genuine concerns on the policy side about the sharing of burdens and benefits in the energy transition. Rising electricity prices in a world that depends increasingly on a secure and affordable supply and distribution system will aggravate the problem of energy poverty in Europe, as it will affect primarily those households that are "hooked" to the grid and this could trigger political action in the population, as has already occurred in Bulgaria.[17]

3 Longer-term outlook

Longer-term scenarios on the role of smart grids in the energy transition are often strongly technology driven, since technological progress is a strong driving force within the energy transition. However, as pointed out before, the speed of deployment and market uptake of new technologies is moderated by a complex combination of legal, market and social factors that deserve due consideration. Velte et al. (2017) propose two possible scenarios for smart grid development that are not technology but policy driven. The main difference between the more conservative "networks in control" and the more ambitious "people have the power" scenarios, which were both developed with vast expert support, resides in the celerity of opening the distribution networks to service offers from new actors, including prosumers, industrial and residential DR programs, and mobility service providers. Active market participation and interaction with the distribution network is essential to create a successful and stable business case for aggregators during the transition period, to support the viability of combined heat and power (CHP) plants, to achieve a more efficient management of heat and electricity and to assure benefits from the self-production of energy. If SG implementation remains limited to the transmission and distribution system, as described in the "networks in control" scenario, efficiency gains will mainly benefit the system operators through improved prediction and self-healing capacity, but the efficiency potential of demand-side management will be exploited to a much lower degree.

The EU has just agreed to raise renewable contribution to the energy mix 32% by 2030 and has set a separate target for transport (14%).[18] The agreement also clarifies the rules for self-production, consumption, storage, and sale of self-produced energy for installations up to 25 kW. These recent decisions are especially relevant for the main driving force behind the energy transition: the citizens, who are making a major financial contribution by investing in small-scale renewable projects either individually or collectively. The member states have 18 months to transpose these decisions into national law, but many governance aspects of the transition are still under negotiation at EU level, and these aspects have a strong impact on the effectiveness of policy implementation on national level. What Europe is still lacking is an efficient tool to track progress and efficiency gains in the final use of energy, and the contribution that smart grids make to this.

4 Conclusions

The energy system, essentially unchanged for many decades, is recently evolving towards a decarbonized and decentralized system with a deep impact on the existing electricity infrastructures. The share of renewable low-carbon and fossil-fuel-free energy from distributed sources across the electricity network will increase, due to social, environmental, and economic factors. At the same time, electricity demand is expected to grow due to the digitization of the society and the general electrification trend in sectors with high energy demand, such as in transport or heating. These factors create major technical and economic challenges for the efficiency and governance of the electricity system. In response to these challenges, smart grids are a critical pillar to ensure the provision of the affordable and clean electricity that our society and environment need.

The transition towards the full vision of the SG creates multiple challenges that require an interdisciplinary approach of future research directions, combining technical, economic, and social requirements.

The digitization of the grid, together with new energy-based technologies – such as batteries – is changing the approaches for electricity system management and its flexible adaptation to oscillations in production or demand. This digitization process of the network with new digital enablers, such as sensors, actuators, or AI-based agents, is still in its initial stages. The grid's current capacity to cope effectively with all the new requirements related to intermittent generation, on-site production, and secure supply is limited, especially when considering the changes that are under way in the electricity system itself. Beyond the grid, smart appliances for users and energy-related applications, such as solar panels, batteries, or electric vehicles, are progressively becoming part of the system. This leads to millions of electrical and digitally connected installations, which will play an increased role for the real-time adaptation of the smart grid once they are fully integrated through intelligent decision and control systems. A holistic planning and management approach involving all actors is needed to ensure the secure delivery of energy services in the next decades.

At the same time, the willingness for the user to participate in the game depends on how clearly the benefits are transferred to them. In this sense, the smart grid is changing the energy business concept and providing a fertile ground for new, customer-centered business models for both existing and new actors of the electricity value chain.

Notes

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12 Voltalis; www.voltalis.com/.

13 WePower UAB; https://wepower.network/#.

14 For a recent overview of aggregators in these countries, see www.adlittle.com/en/node/22770.

15 For more information on the situation in the member states, see the PVP4Grid project at www.pvp4grid.eu/.

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