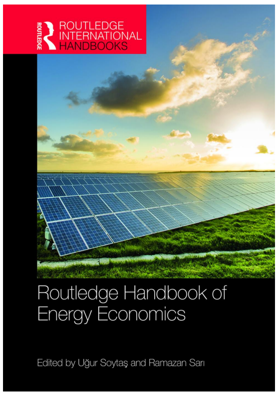

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Uur Soyta, Ramazan Sar

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Low carbon economy and smart grids

Cédric Clastres and Patrice Geoffron

1 Introduction

The transition towards a low carbon economy gives rise to scenarios based on dense deployment of renewable energy (RE) and greater energy efficiency (EE). By 2060 RE and EE are expected to respectively account for 35% and 40% of reductions in greenhouse gas (GHG) emissions, according to the 2°C scenario of the International Energy Agency (IEA, 2017a). The energy sector is contributing to this reduction by deploying intermittent and distributed RE technologies (primarily photovoltaic and wind). Changes of this nature necessarily impact the organization of the electricity sector, in particular balancing of supply and demand, and the security and reliability of electricity supply in the face of rising demand. It will consequently be necessary to "digitalize" the energy sector with a diverse portfolio of smart grid (SG) technologies, such as smart meters, sensors on electricity networks, data centers, software and appliances for demand-side management (DSM), and electric-vehicle chargers.

SG technologies have attracted considerable interest in fields as diverse as economics, sociology and electrical engineering for more than a decade (Coll-Mayor et al., 2007; Clastres, 2011). The European approach defines SG as "an electricity network that can cost efficiently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety".[1] In contrast the US Department of Energy focuses on safety. A smart grid should

> be self-healing from power disturbance events; enabling active participation by consumers in demand response; operating resiliently against physical and cyber-attack; providing power quality for 21st century needs; accommodating all generation and storage options; enabling new products, services, and markets; optimizing assets and operating efficiently.[2]

In Section 2 we briefly present the main issues regarding SG deployment, starting with the factors which prompted modernization of power grids. Section 3outlines the mechanisms for financing smart grids, given that the majority of their assets are still in the regulated public sector. Some private investment, particularly to enable demand to be managed (software optimizing energy consumption, energy boxes), may also qualify for subsidies due to uncertainty as to the return on such investments (Clastres, 2011). After all, any reduction in demand depends on the consumer, not just on power-system instrumentation. The gains actually achieved may therefore not match investments. In Section 4 we analyze consumer acceptance of SG technologies. These new devices can lead to misunderstanding and hostility. Alternatively, they may optimize consumption and prompt virtuous shifts in behavior. Acceptance is crucial to promoting integration of renewable energies and the march towards a "low carbon" economy. Consumers are often seen as the main source of SG-related gains. Without their involvement it will be impossible to reap the full economic, social, and collective benefits of this innovation. Section 5 presents demand-side management, a means of integrating renewable energies (demand flexibility making allowance for the intermittent nature of renewable energy) and power-system flexibility (shifting or shedding consumption can compensate for the loss of an electricity power plant or reduce congestion on a transmission or distribution network).

2 Deploying smart grids on energy systems: key factors and strategies

A smart network comprises several technologies deployed along the supply chain, enabling the various players to exchange data: sensors on transmission and distribution lines, source stations, dispatch centers managing data flows, and smart meters in the premises of final consumers. Smart grids are being deployed in many areas. In 2016 alone EUR 47 billion was spent on "digital energy" (IEA, 2017c). There is broad consensus as to their usefulness: among others they integrate consumers as active players in the electricity system, reduce peaks in demand, manage the intermittency of renewable energies, and improve energy efficiency.

Whereas the overall aim is to encourage the energy transition, national strategies vary (Clastres, 2011), setting different priorities: integrating plug-in electric vehicles on a large scale (Denmark, Sweden); enhancing quality of supply (Spain); integrating renewables (Portugal); combating fraud (Italy); reducing GHG emissions (Netherlands); promoting dual-energy solutions (UK); and better informing the consumer (France).

Deploying smart grids would consequently bring new opportunities all the way down the electricity value chain, with improvements to the overall management of electrical systems (Nair and Zhang, 2009), and potential gains for all the players (Meeus et al., 2010). However, such gains may not be sufficient to cover investment costs. For instance, in France, with investment costs of EUR 250 per meter, it would make sense to equip no more than 60% of the consumer base. Above this level the marginal cost of meter deployment would exceed the surplus it generated (Léautier, 2014).

New offers are available to consumers in the deregulated sector, such as "energy boxes", various sensors, smart plugs and "in-home displays" (IHD) delivering various forms of data (consumption, temperature, tariff period). Widespread demand-management schemes could reduce investment in electricity infrastructure by $270 billion by 2040 (IEA, 2017b).

3 Finance and regulation

In most countries smart grids have been launched with demonstrators or experiments. These projects have been financed by a combination of private and public funds (Spain, France, the United States, the United Kingdom, Portugal) depending on how keen the authorities are to make allowance for the risk incurred by companies financing investments (in Australia for instance, private companies shoulder the full burden of risks related to SG projects). Other tools have also been used such as a monthly rent paid for the installation of a smart meter (Spain), and taxes on consumers to pay for infrastructure (New York State), preferential loans (Japan) or accounting facilities (France) for investors. Some energy companies have also issued green bonds to finance RE and EE investments.

Regulators have not yet defined specific schemes for the deployment of smart grids. Regulators have not yet defined specific regulatory schemes to supervise, regulate, and fund the roll-out of smart grids. Such investments are covered by regulatory mechanisms for the funding of technological innovation on power grids (Perez-Arriaga, 2010). Regulators appear to be waiting to see the outcome of demonstrator projects, which will give decision-makers a clear picture of the benefits of smart grids. However, price-cap or revenue-cap mechanisms (Kristiansen and Rosellon, 2006) do not seem suitable due to the uncertainty of both deployment costs and associated gains. Nor do regulatory contracts (Baron and Myerson, 1982; Crouch, 2006), which allow regulators to make allowance for the existing information asymmetry between regulators and regulated firms, seem appropriate either. Cost drift following the implementation of an innovation would cause a significant drop in revenue, or even losses, for the regulated company (Cossent and Gómez, 2013). So dual regulation seems the likely model for the future, with a cost-plus including "subsidized rates" for new investments, and incentive regulation for other transmission and distribution assets, to optimize system usage and efficiency (Littlechild and Skerk, 2008).

One initial step taken by regulatory authorities has been to make allowance for part of the risks incurred by the distribution system operators (DSO) by defining subsidized rates of return for "smart" investments (Italy, France, Portugal). Given the risks weighing on profits, these regulatory decisions are an attempt to "secure" some of the investments. Additional performance-related regulations (PBR) have been added to these relatively "classical" regulatory decisions. The latter measures generate additional revenue for DSOs, which maintain a quality of service in line with regulatory performance targets (Sappington, 2005). The regulator thus enjoys additional leverage for giving DSOs an incentive to invest, allowing them to keep part of the benefits generated by smart grids (reduced frequency and duration of failures, improved management of supply and demand). The threshold values for these efficiency targets is also an issue, in order to avoid "double financing" of smart infrastructure (involving the use of cost-benefit analysis). Despite regulation some costs may not be recovered, including stranded costs (Clastres, 2016). This question arose, for example, in New York State, where the cost of old, unamortized meters replaced by smart devices was not covered.

SG-related investment is not limited to power grids, the communications sector also being impacted by the large volume of data exchanged. Current debate focuses on the additional investments in bandwidth which Internet operators will have to make to enable this new batch of information to pass through their networks. Investment costs will have to be shared, as will data transmission rates, Internet operators being impacted in their investment strategies by these new data flows from the energy sector. Some authors (Heidell and Ware, 2010) consider that DSOs should make and manage part of these new investments. The increasingly close relations between the energy and telecommunications sectors will be reinforced with the development of the "energy Internet" (Huang and Baliga, 2009) and the "Internet of things". This degree of complementarity is also fueling research on links between the two regulatory authorities responsible for the data or energy markets: regulations decided by one authority, providing incentives and funding for certain investments, will impact the regulatory decisions and competitive structure managed by the other. For example, the share-out of broadband-network investment costs between the two sectors determines the access tariffs paid by users. Since tariffs for accessing the network can either be regulated or contractually fixed between Internet operators and energy players (aggregators, demand-response modes, load managers, or suppliers), the competitive structure in the Internet can impact the energy market. Expensive access to the Internet would certainly hamper the development of the load-management market by reducing access to data transmissions. The deployment of smart grids may consequently be delayed for lack of alternative data-transmission technologies. For this reason, online carrier current could be developed to compete with Internet service provider (ISP) transmissions. The advantage would be to keep data transmission in the energy sector – or even in the hands of a regulated body – enabling economies of scale and reducing the impact of the oligopolistic competitive structure of ISPs (few operators, few backbones). On the down side, data would certainly be lost during long-distance transmission over the power grid. To which must be added the cost of line reinforcement. Here we see a complex ecosystem combining regulatory authority, stakeholder strategies, and complementary or substitutable networks. With this in mind Fiocco and Scarpa (2014) studied the impacts on collective well-being of a business requiring intervention and coordination by two regulatory bodies. They concluded that it would be preferable for the two agencies to meet and come to terms. Exceptions to this rule arise when activities are substitutable or lobbying is intense: a single body can be "captured" more easily, thus reducing the benefits for competition of substitutable goods.

4 Acceptability and consumer willingness to pay

The behavior of consumers and their ability to control their demand for electricity is one of the key factors in successful deployment of smart grids. Kaufmann et al. (2013) indicate that consumers are more inclined to accept technology if it is of value to them. Pepermans (2014) calculated this willingness to pay (WTP) for smart meters and related devices. His results show that the WTP to switch from a conventional to a smart meter is about EUR 200. WTP for devices is ranked according to various criteria. The most important one seems to be protection of privacy with a high WTP for devices with no impact on privacy. Then comes comfort, with a preference for devices that are not visible. Consumers prefer to act on their own rather than letting an operator control their consumption. Direct load control (DLC) is thus perceived by consumers as being more "intrusive". Trust in the supplier or pilot operator is essential for users to accept DLC. Trust may take the form of actions carried out by the operator in the consumer's interest, such as only providing equipment that is strictly necessary and at the lowest cost, customer service, and follow-up (Kaufmann et al., 2013). The operator must also manage and use confidential personal data properly (Gerpott and Paukert, 2013), communicating regularly with consumers (explaining bills, for instance) in order to create trust (Krishnamurti et al., 2012). In the main consumers want to keep control over their own behavior with low preference for DLC (Leijten et al., 2014). However, given the heterogeneity of consumers, operators must diversify their offering, proposing different levels of technologies to suit individual preferences and reduce the risk of rejection (Darby, 2010).

These results also prompted the development of consumer profiles reflecting individual preferences for technology and the associated offering. The literature generally identifies four profiles reflecting consumer preferences (Kaufmann et al., 2013): technology; smart home services and not only energy supply; risk aversion (preference for homogeneous pricing); and price sensitivity (preference for well-differentiated pricing). These profiles are also borne out by the main motives cited by consumers to explain a change in behavior (Gangale et al., 2013). Consumers aim to reduce their energy bills, control consumption and use, improve comfort or reduce demand depending on their "environmental" preferences. For example, users in Great Britain equipped with smart devices and attaching great importance to information and the environment were satisfied with the services offered. In contrast, those wishing to reduce their energy bills were less happy because the gains achieved fell short of expectations.

Willingness to pay also depends on consumer beliefs regarding the benefits for other players in the electricity supply chain following adoption of smart meters (Verbong et al., 2013). So there is uncertainty as to the interests served by technological adoption and behavioral changes. Consumer WTP for smart technologies is low under these circumstances. They prefer a clear reward for their adaptation. Information provided to consumers is important because patterns of consumption and user expectations will determine the positive effects of demand-side management. It is generally advisable to combine several signals, leading to better results (Bergaentzlé et al., 2014). Raw and Ross (2011) concluded that smart meters could yield savings of about 10% at some times. To achieve this, information must be easily accessible and directly linked to the period of consumption (at least once a month) in order to optimize consumer attention (Carroll et al., 2014). In the long run there is less incentive to respond to information (through overload or lack of interest), so contact must be sustained frequently (Schleich et al., 2013; Faruqui and George, 2005). Kaufmann et al. (2013) note that WTP for real-time information is greater, so in-home displays are preferable to smart phone applications.

Hargreaves et al. (2010) note that information expressed in monetary terms is more effective than in terms of energy or CO_2 emissions. Incentives must be powerful (savings on bills, dynamic pricing, etc.) but of course depend on the distribution of consumer profiles. Efforts may also focus on incentives and hedging measures which allow consumers to choose more dynamic pricing, tailored to their consumption profile and convictions (Buryk et al., 2015). These incentives must be more powerful if electricity bills are low, consumers are poorly informed (particularly about pricing structures), or they choose a pricing system with higher incentives. This last point must make allowance for consumer risk aversion, with the threat of higher bills as a result of dynamic pricing (Clastres and Khalfallah, 2015; Park et al., 2014). Some consumers have suffered a loss of welfare after switching to dynamic pricing (Herter, 2007).

5 Demand response and value allocation

Demand response (DR) refers to reducing or shifting a load from peak to off-peak consumption, adding elasticity to electricity demand. DR is facilitated by smart grids because more information is available about demand and connected appliances managing consumption. Deploying smart grids and DSM programs should consequently reduce the last obstacle in the way of optimizing consumption: the inelasticity of demand by electricity consumers (Stoft, 2002; Haney et al., 2009). Many pilot schemes have been carried out to study DR in the United States and more recently in Europe (Coll-Mayor et al., 2007; Faruqui and Sergici, 2010; Faruqui et al., 2010a, 2010b). The initial conclusions suggest that peak load-shedding may be significant (Faruqui et al., 2007). According to the IEA (2017b), DR could concern as much as 40,000 TWh per year, or 15% of overall electricity consumption, mainly achieved by optimizing the building sector. In 2009 the FERC noted that smart grids and active consumer spending could be reduced by 20% in the United States by 2019, with a proportional decrease in users' electricity bills.

Information or tariff signals must reach consumers if they are to adapt their consumption. The literature has studied a variety of DR tools (Bergaentzlé et al., 2014; Buckley, 2018; Faruqui and Sergici, 2010; Horowitz and Lave, 2014). The simplest mechanism is time-of-use (TOU) or critical-peak pricing (CPP); the most complex systems involve real-time pricing (RTP). These dynamic tariffs are intended to send a signal to consumers about the state of the power grid. Thanks to SG infrastructure and smart applications, consumers can adapt their behavior, generally maintaining an equivalent level of comfort (Woo, 1990; Chao, 2010).

These signals may, however, lead to negative incentives because of the risk aversion of consumers. As dynamic pricing implies a price increase at times of high demand, some consumers may be worse off due to the increase (Horowitz and Lave, 2014; Clastres and Khalfallah, 2015).

Consumers, by reducing their consumption at certain times, are likely to reduce the size of their bills. However, such energy savings create value for the power system, which can be captured by other players in electricity value chain (suppliers, distributors). Some work has focused on how consumers are rewarded for this service, for they should receive a share of the gains a third party derives from DR (Crampes and Léautier, 2015). Several papers have studied the appropriate market design to compensate for load-shedding. Chao (2011) shows that, in a perfectly competitive market, the pricing of load-shedding equals to the difference between the retail rate and the real-time price should be optimal for welfare. Orans et al. (2010) show that a three-part rate, including time-of-use, a fixed fee, and compensation, provides an efficient means of giving consumers an incentive to adapt their behavior.

So deriving value from DR induces transfers between players giving rise to redistribution of rent (Chao, 2010; Crampes and Léautier, 2015). However, the issue of value allocation, between each of the economic agents involved, is particularly complex, because conflicting legitimacies clash:

- Consumers – who own their data – want to benefit from flexibility, over and above a cut in their energy bills.
- DR operators are used to aggregating various sources of flexibility and, in some cases, bear the risk and cost of investing in specific devices.
- Suppliers and balance managers may have to cope with imbalances following DR. As they are not responsible for such imbalances, it may be economically desirable for them to receive compensation (Crampes and Léautier, 2010).
- Network managers developing data-transmission infrastructures may also capture some of these benefits through the regulation scheme fixing their earnings.
- Producers see demand management measures as an additional source of risk for the return on investment in generating resources. The profitability of conventional production capacity (mainly used in advanced generation) is already jeopardized by incentive policies for the development of intermittent renewable energies. It becomes even more difficult to determine in a context of increasingly flexible demand. New payment schemes are needed to make allowance for some of these additional risks, such as the creation of capacity markets (Cramton and Stoft, 2005; Khalfallah, 2011) or the redistribution of benefits related to the valuation of DR (Crampes and Léautier, 2015).

The added value derived from DR and the redistribution of the resulting rent are still subject to debate. Uncertainty as to the level of these benefits discourages investors considering the deployment of new DR technology. The benefits of DR may not cover the cost of deploying smart technology which allows consumers to receive information signals that modify their behavior. This question was addressed in particular in the context of widespread deployment of smart meters (Léautier, 2014; Allcott, 2011). Such results confirm the intuitive assumption that, for deployment of smart technologies to be sustainable, they must benefit the entire electricity supply chain (especially network operators and producers who can achieve significant savings in terms of avoided investment). Analysis of the economic problem posed by DR must carry over into discussion of which market designs will maximize the associated added value. Consumers (or DR operators who aggregate them) resell their ability not to consume electricity for a given period. This resale raises the question of the purchase of an ex ante consumption profile by consumers. Consumers, having bought this profile, then benefit from the choice to consume the electricity on offer or give it up, thus allocating value to the DR achieved on the market (Crampes and Léautier, 2015). This solution, which is disputed by the DR operators and some consumers, makes it possible to take into account part of the risk incurred by suppliers and producers and boost the efficiency of DR (Chao, 2011). If DR, with the benefit of excess payment, takes the place of inexpensive production, then adaptation exceeds the collectively desirable level. Which in turn reduces collective welfare. The savings on production costs are offset here by the cost associated with the excess value of DR.

6 Conclusion

Deploying smart grids is one of the available means of achieving climate targets: greenhouse gas emissions can be reduced by improving the management of power grids and energy demand. However, these gains are tainted by uncertainty because they are observed over the long term and depend on many factors. The main factor is undoubtedly the behavior of consumers who must adopt these new technologies, thus contributing to better system management. The main gains expected from demand response are prompted by information and price signals. Recent studies have demonstrated that the use of nudges could also lead to interesting results in energy conservation (Buckley and Llerena, 2018). Consumers will be able to adapt their behavior in line with pressure on the power grid, while making direct and indirect financial gains (respectively through lower bills, and by deriving added value from flexible use of electricity markets or contractually with utilities). Similarly, utilities will benefit from this flexibility to reduce their investment costs, and better balance supply and demand, especially with increasingly intermittent supply. Reductions in consumption are therefore likely to take the place of infrastructure investments, both for centralized transmission, distribution and generation. Nykamp et al. (2012) has demonstrated the substitutability between traditional investments in expanding and reinforcing grids and "smart solutions".

The acceptability of smart technologies (see Chapter 17 in this handbook on acceptance and public engagement) obviously implies extended researches in psychology and sociology (Silvast et al. 2018). Il the economic field, this also goes hand in hand with an understanding of the signals sent to the various players along the electricity chain. To this end a certain allocative efficiency can be restored and improved thanks to dynamic pricing. In this respect the new approach to pricing would have a positive impact on collective welfare. The real price signal should be restored. However, the risk for consumers of manipulated prices cannot be ignored. To avoid price manipulation, we need electricity markets which optimize productive efficiency. The alternative would be unjustified surplus transfers between consumers and suppliers or producers. Similarly, although regulations are designed to reward risk, surplus profits for distributors must be avoided (otherwise SG would be deployed at the expense of consumers). Surplus skimming could reduce, perhaps reverse, the initial positive impact on welfare. Competition and regulatory authorities will therefore play an important part in the roll-out of smart grids, allocating profits all the way along the value chain.

Notes

1 http://s3platform.jrc.ec.europa.eu/smart-grids
2 See Kezunovic, McCalley, and Overbye (2012).

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