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Smart grids: Another step towards competition, energy security and climate change objectives

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ABSTRACT

The deployment of smart grids in electricity systems has given rise to much interdisciplinary research. The new technology is seen as an additional instrument available to States to achieve targets for promoting competition, increasing the safety of electricity systems and combating climate change. But the boom in smart grids also raises many economic questions. Public policies will need to be adapted, firstly to make allowance for the potential gains from smart grids and the associated information flow, and secondly to regulate the new networks and act as an incentive for investors. The new competitive offerings and end-user pricing systems will contribute to improving allocative and productive efficiency, while minimizing the risks of market power. With real-time data on output and consumption, generators and consumers will be able to adapt to market conditions. Lastly smart grids will boost the development of renewable energy sources and new technologies, by assisting their integration and optimal use.

1. Introduction

The European Union is currently making several changes to the organization of the energy market and setting new targets for deregulation and combating climate change. Deregulation of the electricity and gas industries raises questions regarding genuine competition in the market place, the safety of system management, and the production and supply of energy commodities. In its ongoing drive to build a single energy market the European Commission has recently focussed fresh attention on these issues. A single market would be one of the possible solutions for securing energy systems and enjoying the benefits of competition for investment and industrial competitiveness (European Commission, 2010). But in addition to asserting its free-market values Brussels is determined to combat climate change. Such environmental concerns are reflected in the Climate and Energy package, and targets for energy efficiency, in particular to reduce greenhouse gas emissions and make more widespread use of renewable energy sources (European Commission, 2010). The Commission recently asked individual Member States to publish their targets in line with the measures covered by the climate and energy package.

The complexity of the systems and the links between the various targets makes it necessary to harmonize several measures. Taken as a whole such measures should bring the European Union closer to, or perhaps enable it to achieve, the ambitious goals set by the European authorities. Several scientific fields must contribute to attaining these targets, reaching from various established economic mechanisms (incentive policies, support for innovation and R&D instruments, swapping of emission permits, new taxes, etc.) to development of new technologies and materials, through changes in the behaviour of consumers and producers. In the electricity sector rising consumption (IEA, 2010a) will raise questions regarding dependence on fossil fuels, and their impact on environmental constraints, and ageing assets, which affect the safety and reliability of electricity systems. In recent years safety margins have been reduced and concerns regarding investments and the quality of supply, particularly on distribution networks, have surfaced again. According to the International Energy Agency (2010a) almost 70% of investment in Europe's energy sector between now and 2035 will concern electricity.

To build an open market and achieve targets regarding safety and lower emissions, smart grid (SG) technology has attracted considerable interest in fields as diverse as economics, sociology and electrical engineering (Coll-Mayor et al., 2007). Using the tools of economic theory such as regulation, incentives or competition analysis, we may provide a preliminary overview of possible solutions for encouraging the emergence of new technologies. The present article is divided into four sections. Section 2 sets out to define smart grids and the gains each of the players in the electricity value chain may expect. Section 3 explains the economic theory associated with the potential benefits of improving information in the electricity market. Section 4 reviews the

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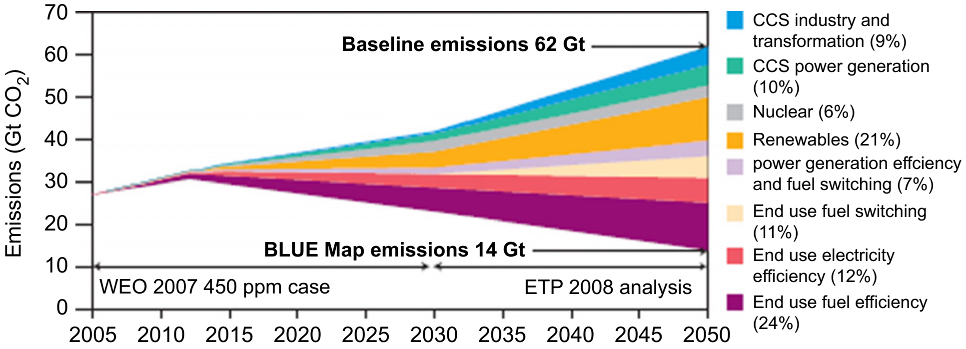

Fig. 1. Contribution of various sectors to achieving environmental goals by 2050 (IEA, 2008a).

various issues regarding regulation, which will be required to fulfil two purposes: regulating the new approaches to smart grid management and providing an incentive for investment in this technology, with the gains evenly shared between players. Lastly Section 5 discusses the usefulness of smart grids in the context of the increasing role played by renewable energy sources and new technologies in electricity systems.

2. Defining smart grids, impact on the electricity value chain

2.1. *Defining smart grids*

Smart grids may be defined in two ways. The first approach, generally used in Europe, defines them as "electricity networks that can intelligently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies".[1] An alternative definition, which we owe to the United States Department of Energy, does more to specify the aims assigned to a smart grid, seizing on the safety of a system as a guiding thread.[2] According to this definition, a smart grid must integrate the characteristics or deliver the performance described below: "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".[3]

The term may apply to several types of technology. In upstream (generator) or downstream (consumer) markets, smart grids are synonymous with smart meters measuring actual output or consumption in real time. Such meters may broadcast data in one or two directions, some leaving a supplier, transmission or distribution network manager the option of controlling loads remotely. On the other hand, in the context of an electricity network, smart grids are communicating instruments (sensors and communication networks) transmitting data on the network's status in real time. Massive investment will very probably be necessary in the near future to optimize the management of demand, decentralized production resources, storage and fleets of plug-in electric vehicles (PEVs), which many countries are planning to develop.

Many European countries (France, Ireland, the Netherlands, Spain, and UK) have set firm targets for smart grid development. For example smart meters now account for 85% of all such devices in Italy. The equivalent figure for France is 25%. Many governments are forecasting nationwide deployment by 2020 (Faruqui et al., 2010b). However smart grids are not exclusively designed to facilitate balancing of supply and demand. They would also encourage the elaboration and application of energy or climate-remediation policies, or even solve problems specific to individual countries (CRE, 2010). For Denmark and Sweden, for instance, smart grids would contribute to widespread use of plug-in electric vehicles. Spain wants to improve the quality of supply with fewer incidents. Portugal intends to improve integration of renewables in its electricity system. Italy hopes smart, communicating meters will reduce fraud. The Netherlands is expecting to save energy while cutting greenhouse gas emissions. The United Kingdom thinks it will be possible to boost the availability of dual-energy solutions, leading to economies of scale on the production and installation of meters. Lastly France is developing this technology to inform consumers, control demand for energy, increase the quality of supply and the operation of the energy market, and to limit costs for distribution network operators. Each country has its own view as to which market segment would gain most from smart grids. However there is an overall consensus regarding their usefulness (Pérez-Arriaga, 2010):

- Integrating consumers as active players in the electricity system; savings, achieved by reducing peaks in demand and improving energy efficiency, are one of the ways of reaching the appointed goals, particularly for cutting greenhouse gas emissions (see Fig. 1).
- Integrating renewables and energy storage in electricity networks, while optimizing their use and contribution to system services and wholesale markets.
- Promoting innovation, new energy products and services related to load handling.
- Enhancing the quality of energy supplied to end users (fewer outages).
- Optimizing the use of new or less recent electrical assets.
- Anticipating outages, with the necessary upgrading or maintenance of self-adapting networks.
- Developing information networks, data storage and management, and regulations governing access by the various players (ethics, data confidentiality).

IEA (2010b, p. 154) states that "Compared to the baseline scenario in 2050, smart grids offer the potential to achieve savings of between 0.9 Gt CO_2 and 2.2 Gt CO_2 a year". Reductions directly attributable to smart grids would range from 0.2 to 0.85 Gt CO_2 a year under the Blue Map scenario compared with the baseline scenario (Fig. 1). These direct reductions are related, among others, to changes in the way electricity is used, lower grid losses, faster

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[1] http://www.smartgrids.eu

[2] According to Frei (2008) the issue of energy security in general, and electrical security in particular, will be increasingly important in the future.

[3] http://www.doe.energy.gov/smartgrid.htm

deployment of energy-efficiency schemes and peak-hour energy savings. As well as reductions directly related to smart grids, other indirect cuts may be achieved thanks to the integration of plug-in electric vehicles, storage and renewable-energy sources; these indirect reductions would result in reductions in the above scenarios ranging from 0.65 to 1.31 Gt CO_2 a year (IEA, 2010b, p. 153). However, lack of incentives could impact energy-efficiency schemes, differing their application (Fox-Penner, 2010).

In France an initial academic result notes that, given the investment cost of €250 for each smart meter, it would be advisable to set an upper limit of 58% on the number of consumers being equipped. Above this share of the user base, the marginal cost of meter-deployment would be greater than the surplus generated by the extra meter (Léautier, 2010). According to the IEA (2010b, p. 156), investment in transmission and distribution networks would amount to USD 8.4 trillion and USD 12.3 trillion, respectively, in the baseline and the Blue Map scenarios. The difference is due, in particular, to the development of intermittent production sources and the cost of deploying smart grids. The latter cost has yet to be firmly established.

2.2. *Forecast impacts and benefits for the electricity value chain*

Modelling and experimental work on smart grids suggest that they may not only contribute to achieving environmental goals, but also reduce the strain on electricity systems currently subject to considerable stress.[4] Deployment of 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).

- For consumers, smart grids would reduce the length of outages; offer greater control over expenditure and a clearer picture of renewable-energy output and faults; optimize use of storage. The main issue which remains to be clarified concerns the incentives required to encourage consumers to use the available data, or authorize operators to use personal data.
- Generators would obtain a clearer picture of demand; accurate data on distribution-network in and out-flow; and the means of optimizing production resources in line with more clearly defined demand.
- Suppliers or utilities would be able to adjust competitive offerings to suit specific consumer profiles thanks to supply and demand-side management (Frei, 2008).
- Lastly, smart grids would offer network operators: optimized network traffic; shorter downtimes and failures thanks to rapid access to data; reduced grid losses; easier balancing of supply and demand, particularly thanks to scope for selective load-shedding at peak hours.[5]

Smart-grid technology, in particular the fitting of sensors to the grid, will mean that data on failures will be more readily available and that the grid can be reorganized after an outage. Losses will be measured more accurately and dealt with more promptly thanks to deployment of smart meters at end-users' premises (IEA, 2010b, pp. 149–151). "Smartly" used storage will enhance service during peak hours (IEA, 2010b, pp. 154–155). This point is discussed in greater detail in Section 5.2 of the present article.

3. Information gains and demand-side management

Using the approaches to competition and information offered by economics theory we may analyse the possible gains from improving the information system in an electricity market. Information asymmetry may prevent markets from achieving the expected productive and allocative efficiency. Such asymmetry generally leads to competitive prices in excess of marginal costs and waiting games with regard to new investments. If on the other hand the asymmetry is corrected by a system which makes data readily available, gains can be achieved in allocative (as costs move closer to marginal costs) and productive efficiency (additional information allows a quicker response and thus the means to satisfy demand for energy at a lower cost). Such gains will depend on the information rent arising out of information asymmetry (Lofaro, 2002). Reducing asymmetry will, in theory, lead to an increase in consumer surplus. Generators and suppliers will be in a better position to manage periods of tension and peak demand thanks to dynamic tariffing and various methods associated with the concept of demand response. They will offer prices closer to what consumers demand. This advantage could lead to the transfer of consumer surplus to suppliers, and thus an appropriation of part of the rent generated by improved information.

3.1. *Information and competition*

Information is necessary for energy players, and for decision-makers and regulators who must establish rules and mechanisms to provide a framework for a competitive market and allow smart grids to achieve optimal efficiency. The main forms of information which energy players should obtain are instantaneous consumption, an unbiased price signal—reflecting the status of the system or market, and competitive and regulatory guidelines, in particular for access to metering data. Regulators and policy-makers will above all need information on the business model, in order to redistribute revenue and design competitive and regulatory policies, and on costs related to the activity and the distribution of such costs along the value chain.

The allocative and productive efficiency emblematic of a competitive market may lead to lower prices, as expected and observed in Europe at the end of the 1990s, but this outcome is not absolutely certain. Lower competitive prices require lower costs, which is not compatible with a period of tension and the need for price signals to encourage investment. Furthermore allocative efficiency suffers from constraints or asymmetry in the marketplace or industrial organizations. Prices diverge from marginal costs when one of the players is under constraint, or when information asymmetry obscures the costs, behaviour or capacity of competitors. Under these circumstances, players apply prices higher than their marginal costs with the prospect of profits (Spulber, 1995; Lofaro, 2002; Kreps and Scheinkman, 1983; Tirole, 1993, p. 20). Energy markets fit into this theoretical line of study. Tension on systems, investments and regulations needed to improve the operation of the electricity market, information constraints and existing capacity may all lead to higher prices (Percebois, 2008) and rigging (Smeers, 2009; Crampes and Creti, 2005). Prices may also rise due to intrinsic constraints in the electricity system, not because of supplier's

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[4] Such tension is largely due to the fact that network operators must at all times balance supply and demand in real time (Meeus et al., 2010). This obligation also explains the design complexity of the electricity market (Glachant and Perez, 2010).

[5] In 2009 the FERC noted that smart grids and active consumer participation would reduce peak consumption by 20% in the US between now and 2019. Such energy efficiency gains could reach 12% of US consumption by 2030, assuming widespread deployment of smart grids. To this gain could be added a 5% reduction in indirect consumption by controlling investment and avoiding excess capacity.

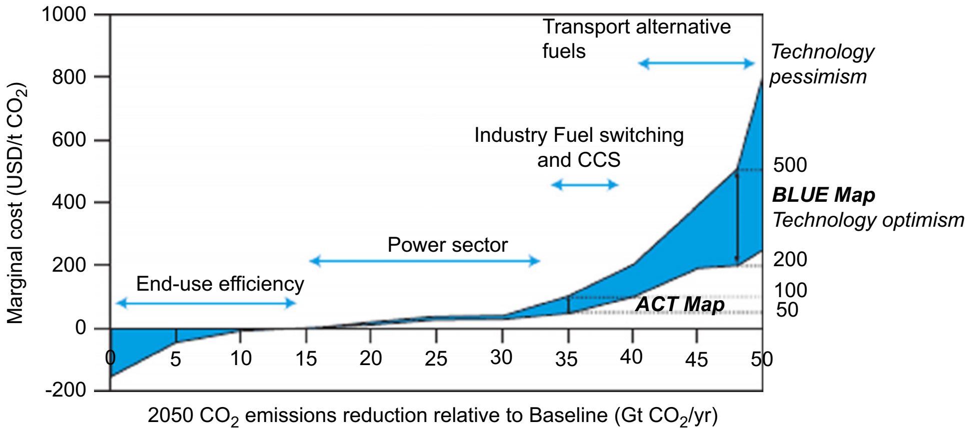

Fig. 2. Marginal cost of reducing CO_2 emissions by 2050 (IEA, 2008a).

market power (Finon and Glachant, 2008). The need for investments (European Commission, 2010), climate-related constraints and just-in-time balancing of supply and demand on electricity markets all exert upward pressure on electricity prices. Development of smart grids raises the cost of regulation and of investments. In turn these costs will necessarily have an impact on transmission prices and indirectly on the price of energy. The positive effect expected of smart grids is not necessarily a drop in prices but rather a reduction in the bills paid by consumers. It is estimated that gains from optimizing or reducing consumption will counterbalance higher prices due to regulation of and higher security on the electricity system (IEA, 2010b).

Gains in allocative efficiency are linked to the possibilities offered by smart grid technologies for more dynamic end-user tariffing strategies. This would encourage consumers to adjust consumption depending on signals issued by the tariffing system; consumers would play an active role, either directly or through recommendations passed on to their supplier, or network operator, regarding the level of comfort they require (Woo, 1990; Chao, 2010). Of the possible tariffing systems, real-time pricing, which fully reflects the operational costs of a marginal plant, would carry the highest incentives. However deploying real-time pricing for all customer categories would be expensive and would involve a large range of prices. It would be easier to deploy time-of-use or critical-time pricing, as is already the case for example with France's peak and off-peak rates. However to convince risk-adverse agents to switch from tariff-of-use to real-time pricing would require adequate information, incentives, insurance or other forms of coverage against higher bills[6] (Faruqui et al., 2010b). Operators, policy-makers and regulators still have little idea of how risk-adverse agents will react to new technologies.

The purpose of greater allocative efficiency, due to dynamic tariffing, would be to transfer surplus between various players. But the authorities responsible for regulation and competition would need to supervise such transfers to prevent abuse of market power. Several types of transfers of surplus may occur between players. Suppliers may increase the surplus derived from consumers through better targeted pricing systems and a wider range of contracts. In a tense system market, prices can be manipulated, with an impact on pricing systems. Regulators and competition authorities make a point of monitoring these anti-competitive transfers. The need for suitable regulation coupled with investment incentives transfers surplus from consumers and suppliers to system operators. Part of this surplus is redistributed in the form of services or improved quality of supply (less congestion). However, here again, regulators check that costs linked to regulation are fair to prevent manipulation by system operators.

Distribution network operators will improve the efficiency and safety of the assets they manage, of maintenance, supervision and work on the network, thanks to the flow of information collected from smart grids. It will also be easier for regulators to monitor such efficiency gains and pass on to network operators incentives corresponding to their performance.

3.2. *Consumer response and demand management*

3.2.1. *The role of smart grids and energy-efficiency policies*

After the second oil crisis, US utilities drew up plans to promote energy efficiency through services controlling energy demand. Certain results, with respect to reducing demand and avoiding costs for the electricity industry, showed that such measures could achieve more widespread goals such as cutting greenhouse gas emissions or reducing the strain on electrical systems (Hirst et al., 1996).

According to the Blue Map scenario (IEA, 2008a), controlling energy consumption and electricity production are two relatively inexpensive ways of cutting greenhouse gas emissions by 2050 (see Fig. 2).

Today, measures to control demand involve information campaigns and financial incentives to change consumer behaviour primarily in technological terms (Fox-Penner, 2010). With smart grids, it will be possible to obtain accurate, real-time data on consumption profiles and the status of electricity systems, with scope for isolating certain items on which it is appropriate to act (heating, household devices, etc.). Measures to promote energy efficiency and control consumption will benefit from the new behavioural data (Jackson, 2010). However there are no clearly defined rules for applying these measures, in particular with regard to rewards. In some cases, the main reward for the consumer is the cost saving achieved by reducing demand or shifting to an off-peak period. The reward for the supplier takes the form of savings on production costs and substantial balancing during periods of high demand (Fox-Penner, 2010). Financial incentives for transfers between suppliers and consumers could become common practise.

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[6] Large price variations and outages are the main risks facing consumers (Percebois, 2007). Smart grids are one of the solutions, which could reduce exposure to these risks.

3.2.2. Effectiveness of demand-side management

Demand-side management (DSM) may take two forms, with emergency DSM to absorb a sudden variation in demand which supply cannot meet; and economical DSM which adjusts consumption to prevailing market conditions to avoid price hikes and increased generating costs. These forms of demand-side management either shift or reduce peak periods, or save electricity consumption.

Studies have shown that consumers do alter their behaviour if additional information is available.[7] This change leads to drops in consumption which may be substantial (up to 20%), with a corresponding drop in energy bills (FERC, 2009). Smart grids and the data transmitted to consumers gain in effectiveness if they are combined with dynamic tariffing. Energy savings may be as much as 14% of consumption (Faruqui et al., 2010a), compared with only 7% when only the data from the meters is used. To make such systems even more effective, segmentation of the various loads needs to be refined. Experiments in Europe and the US show that the effect of automated DSM[8] is 30–100% greater than its non-automated counterpart when applied to managing energy and reducing consumption at certain points in time. According to Faruqui et al. (2007), automated management can reduce peak demand by 20—50%, and overall demand by 10–15%. However, the danger with automated management is that peak consumption may simply shift, reappearing when all the loads reconnect at the same time. A large number of pilot schemes (Faruqui and Sergici, 2010) are consequently underway worldwide (Canada, US, and Japan) and experiments show that on the whole consumers welcome scope for controlling electricity consumption. However an authority is needed to complete these experiments and help consumers take the plunge. Regulatory bodies will play an essential role encouraging a long-term change in behaviour. Remote control of smart devices by transmission and distribution network operators, and energy suppliers seems to be the preferred solution, in order to prevent system from being too complicated for end-users. On the other hand, this solution may be hampered by fears of privacy infringements.

Demand-side management thus seems just as important as investment in energy sources with a lower carbon footprint (Pollitt, 2008). Smart grids will enable better management, in particular by combining signals carrying information on the status of the system and dynamic price incentives. DSM will optimize investments in peak generator, transmission and distribution resources, and such gains will be further augmented by savings on unconsumed energy.

3.3. Economic incentives and dynamic pricing

The need for regulatory incentives was first highlighted by the difficulty calculating precisely the costs avoided by demand-side management and by utilities' quest for short-term gains, which often reduced the impact of these measures on collective welfare (Hirst et al., 1996). The measures currently underpinning DSM in this field consist of financial incentives and time-variable pricing (FERC, 2011). DSM schemes based on financial incentives reward customers for reducing consumption during periods of high demand. The reductions to their load made by customers are aggregated then passed on to an operator (independent system operators, regional transmission organizations, traders) in exchange for a reward (Fox-Penner, 2010). Schemes based on dynamic pricing are an incentive for consumers to adjust demand in response to price signals (Storelli and Pillet, 1997). Prices vary depending on the period of use and system stress. Such pricing strategies make electricity demand, which is supposedly inelastic, more responsive to price variations, or in other words more elastic. Pricing of this sort would result in a 6% cut in peak demand on the French production system (Faruqui et al., 2010b). The various rewards would enable consumers and suppliers respectively to reduce the negative impacts of price rises and supply costs on surpluses.

Such pricing systems, by coming closer to the marginal cost price, should lead to an increase in surplus and attain the goals of allocative and productive efficiency. However, if prices are off-target or players can exert market power, unjustified transfers will appear between consumers and suppliers. They have a high social cost, residential consumers being particularly vulnerable (Percebois, 2007; Percebois and Wright, 2001). By identifying the beneficiaries and supervising them, one-way transfers can be prevented.

Suppliers will be able to test a new contract offering load-shedding, which may also be based on dynamic pricing or self-rationing (Woo, 1990; Orans et al., 2010). Agents responsible for balancing these offers, or energy suppliers, will lose part of the planned consumption and will also incur imbalance penalties. Debate on distributed load-shedding operators[9] raises questions about optimal financial transfers, demand subscription service price or curtailable rates, and the most suitable market 'design' for this type of exchange (Chao, 2010). One source of income for such operators is load-shedding offers put up for sale on the balancing market. The problem is to determine whether consumers should share in any such gains and whether transfers to jeopardized suppliers are needed (Crampes and Léautier, 2010; Glachant and Perez, 2010).

Current pricing systems, in particular price-capping or the lack of data to charge at the short-term marginal cost, do not provide clear enough signals to motivate demand restrictions at peak hours. Furthermore, as gains are not immediately apparent, regulation is currently seen as the prime means of funding smart grid investment. One way of kick-starting the development of smart grids would be to change pricing systems (critical-peak or real-time pricing), a move which would increase the usefulness of the new meters and boost the expected gains. However such a change may entail risks for risk-adverse agents. According to Faruqui et al. (2010b), another possible option would be to make the pricing of electricity networks more dynamic. This would have an impact on suppliers who would seek to optimize power injected into the network, giving them an incentive to develop such technology and reducing the time frame for potential gains. The European Commission (2011) notes that smart grids would reduce CO_2 emissions by 9% a year and residential consumption by 10% a year, representing an annual saving of about €60 per household. Possible gains could take two forms, achieved by reducing procurement through optimized energy purchasing, and optimizing transmission costs associated with their business. Faruqui et al. (2010b) demonstrate that it is clearly necessary to make every effort to facilitate the roll-out of smart meters, in order to optimize the associated gains and achieve an attractive

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[7] Consumers reduce or displace part of their demand to periods when there is less strain on electricity systems. A 1.6% drop in annual sales of electricity and a 6.8% drop in summer peak demand were observed in the US following initial deployment of demand-side management by US utilities in the 1980s (Hirst et al., 1996).

[8] Automated demand-side management allows direct load-shedding by suppliers or TSO/DSOs. Such intervention depends on an agreement reached with the end-user on which loads may be managed remo

[9] A distributed load-shedding operator offers consumers a system by which their load is shed over a given period of time. The saving on consumption linked to such load-shedding is then valorized by the operator on the balancing market. The case of the French operator Voltalis illustrates the difficulties distributed load-shedding operators may encounter making this solution pay.

cost–benefit differential for deployment. Without massive penetration gains are likely to remain marginal in relation to the investment and installation costs of these meters.

4. Regulating new networks and investment incentives

The gains from smart grids will be felt all the way down the electricity value chain, but the technology is still in the R&D phase. Regulation will be needed to launch investments. Regulation and pricing must offer a sufficient incentive to trigger viable investment, stipulating the gains involved for each player in order to distribute regulation-induced revenue (Fox-Penner, 2010). The question of whether these new investments should be regulated using a price-cap or cost-plus model has already been raised, with scope for varying or using both forms of incentive, one targeting effectiveness, the other targeting the launch of the technology. It is also important that regulation should improve the information system. Ownership and sale of information will be two key questions requiring a framework. This begs the question of ownership of smart meters[10] (suppliers or infrastructure operators), leading on to the problem of how to set a sale price (to be determined by negotiation, regulation or the market?).

4.1. *Investing in smart grids*

Several players may invest in smart grids. In theory several economic agents may invest in developing the transmission network. It is preferable for transmission owners to decide on investments to improve reliability (Joskow and Tirole, 2005). It is difficult to fit investment in smart grids into either of these categories. If we approach the matter from the point of view of developing communications infrastructure, such investments may be seen as improving the reliability of the system and should ideally be carried out by the network owner. The exception to this rule is the possibility of making greater allowance for efficiency gains in network management. This could prompt system operators to make the investments directly.[11] Indeed system operators, in our case the distribution system operator, seem ideally placed to invest in meters whereas private investors are more likely to take a stake in control boxes located downstream from the meter. Private investment in a form of metering could reduce competitive pressure on the market, as the meters would make some end-users captive consumers.

But the principles for the ownership and sale of data are complex. Regulation has an important part to play, not only to limit market power but also to prevent waiting games. The uncertainties regarding potential gains and regulation, as well as free-riding strategies, delay investments by market players who are waiting for lower-risk revenue before deploying the technology. Many parties will benefit from these investments, which complicates the task of classifying each party's gains and thus the mechanisms for redistributing the resulting rent and for motivating the investments in the first place. Investments will concern the distribution network, impacting on the system's management, reliability and future expansion. They consequently require more detailed study to prevent waiting games and free-rider type behaviour.[12] According to some authors (Hogan et al., 2010), all this new instrumentation will do nothing to improve coordination between the various transmission-system operators, often the cause of outages.

By monitoring intermittent production in real time and acting on loads, smart grids will impact on the management of grid congestion. But, at the same time, congestion is a source of revenue for some players in the energy value chain (Glachant and Pignon, 2005). The loss or reduction of congestion revenue will act as an incentive or dis-incentive for investment, with gains for some – consumers, owners of merchant lines – and losses for others – generators, owners of existing networks – due to cuts in congestion revenue. Intuitively, these reductions in system tension will contribute to greater efficiency in the industry. Price differentials between the various nodes will be reduced and the quality of supply improved. This relates to the issue of new dynamic pricing systems made possible by smart grids. The pricing systems will restore a price signal representative of market conditions, which simple pricing systems cannot convey.

The exercise of market power is already an incentive to over or under-invest (Joskow and Tirole, 2005). There is generally little incentive for players (generators, suppliers, and network owners) enjoying market power to invest in new network infrastructure. Any positive effects rarely make up for the loss of revenue associated with a reduction in market power (Léautier, 2001).

4.2. *The predominant role of regulation as an incentive*

4.2.1. *Regulation tailored to suit smart grids*

In view of the problems posed by incentives, various forms of regulation (Kristiansen and Rosellón, 2006) will play a key role in the development of the new grids. Distribution system operators will certainly make the investments, but the beneficiaries and users will be more widespread. Firstly, suppliers with access to the relevant data will be able to adjust their commercial offering and upstream procurement strategies, thus reducing price-risks and pocketing part of the revenue or surplus resulting from supplying electricity. Secondly, consumers will be able to control consumption thanks to prompt, accurate information on their profile. By managing their demand they may counterbalance the transfer of surplus to suppliers. All consumers could directly manage their consumption with smart grids. However, some of them, given the complexity of the demand management, will certainly content themselves with clear warnings of electricity-system stress or remote control of certain loads by their distribution system operator or supplier. Lastly local authorities may use smart grids to achieve targets set at national or European level. Gains will be felt throughout the electricity industry. Incentive regulation will be needed to enable investments, free-rider strategies potentially leading to waiting games if distribution system operators alone are required to invest, shouldering the full cost of investment but having to pass on information to other players. Regulation cutting both ways is needed, on the one hand to carry out investments and manage data, and on the other hand to provide the various players with information from smart grids. Regulators may choose to integrate new investments in existing regulatory measures—the mechanism which sets the network-access tariff, or to take account of the fact that such investments are subject to an additional risk, known as stranded costs. They will have to decide whether to impose a higher rate of return on these investments than for other types of infrastructure, or to set

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[10] In this present section 'smart meters' refers not only to the meters themselves but also the downstream boxes, which may be connected to the electrical system. These boxes deliver real-time information on loads, pass on signals to consumers on system status, and can control consumer loads remo DSOs are no longer the only players investing in such devices.

[11] In general system operators are not investors. They operate the network and negotiate with the owners the extensions they consider necessary to improve operations. In this respect, although the operators are not investing in smart grids, the question of information ownership needs to be addressed. A financial transfer for the sale of information will be needed to pay the investor.

[12] Jackson (2010) notes that a new 'free-rider' problem may arise, reducing the profits expected from the deployment of smart grids.

up a specific regulatory framework. Although cost-plus regulation is not entirely effective (Kopsakangas-Savolainen and Svento, 2010), it can be used to launch a new technology in an industrial sector.

4.2.2. Dual regulation of electricity networks

In the United States much of the investment in transmission capacity is planned and regulated on a cost-plus basis decided by the relevant regulator(s) (Hogan et al., 2010). Dual regulation has been experimented in the north-east of the US (investments governed by both planning and an auction system) and in Australia (merchant mechanisms and incentives) (Kristiansen and Rosellón, 2006). In Argentina dual regulation is being used for old and new transmission infrastructure (cost-plus for new investments, merchant financial-transmission rights for existing infrastructure) to optimize system usage and efficiency (Littlechild and Skerk, 2008).

Financial-transmission rights solve all or part of the problems posed by sliding-scale yields on transmission and distribution infrastructure. Deployed on their own, they would not encourage transmission-system operators to maximize welfare but rather the revenue derived from selling such rights. This restricts this instrument's incentive value for investment in new technology. However by imposing a certain regulatory constraint on the earnings of transmission-system operators, FTRs do nevertheless improve welfare, with their price converging towards marginal costs (Hogan et al., 2010). This idea confirms the fact that in order to optimize welfare when introducing merchant trading processes, a regulation mechanism is often necessary to contain monopolistic behaviour and secure the investment's viability. Joskow and Tirole (2005) note that investments in transmission infrastructure underpinned by a merchant rationale require sufficiently liquid wholesale markets to be effective and prevent over or under-investment.

Ex ante (incentive) regulation may prove difficult for the new networks, because the costs of the new embedded services are uncertain and there is information asymmetry on such costs between regulators and network operators (Lévêque et al., 2008; Meeus et al., 2010). As new technologies tend to be hampered by timid investors, this regulation is sometimes adjusted to include part of the costs on an ex-post (or cost-plus) regulatory basis. The latter approach requires strict supervision by the authorities, output being difficult to define and even more difficult to measure. The production function between input and output has not yet been clearly established, periods of regulation are sometimes too short and do not provide sufficient visibility given the long time frame for investments (Stoft, 2006).

Dual regulation could also emerge from negotiations between sellers and buyers to clarify demand for the new services offered by smart grids. The aim would be to create a market for services rendered by the smart-grid infrastructure. A negotiated solution would have several advantages, in particular avoiding excess costs for investment and reducing the associated risks thanks to better definition of demand (Pollitt, 2008). Negotiations were used in Canada to work out the regulations setting the price of 'network services' in the oil and gas industry, leading to a reduction in conflicts between users and infrastructure owners and/or operators (Doucet and Littlechild, 2009). However the costs that can be recovered using such methods may not be sufficient to prompt investment (Littlechild and Skerk, 2008). It may be necessary to set a fixed premium to maintain the incentive and recoup fixed costs (Rubio-Oderiz and Pérez-Arriaga, 2000). In this incentive configuration the regulator will play a supervisory role regarding the effectiveness and usefulness of investments. According to Littlechild and Skerk (2008), for this new form of organization it is necessary to clearly establish the quality of the service and the beneficiaries of investments, calculate the costs to be shared out between all the beneficiaries, and take account of all the players' preferences.

The problematique and the regulation of smart grids must be seen in the light of this effort to establish dual regulation: one form of regulation for existing assets which only benefits energy suppliers or generators, another for the new metering technology and the handling of the resulting data, which may interest – in addition to the existing operators – trading activities and distributed load-shedding operators.

For example the British regulator Ofgem has introduced two incentive systems to enable the electricity network to be modernized and pilot schemes to be launched, while facilitating the transition towards innovative, smart networks (Lorenz, 2009). In the first case, the Innovation Funding Incentive recognizes that the risks inherent in new innovative investments are different from those usually associated with investments in electrical infrastructure. It consequently allows investors to recoup a larger share of investment costs and to integrate them in network-access prices. This high-incentive scheme prompted a significant surge in research into new projects. In the second case, Registered Power Zones encourage distribution-network operators to develop the connection of renewable energy sources to distribution networks. Generators connected to the distribution network finance this fund. This solution has proved a less powerful incentive than the previous one, in particular due to the tougher demands placed on potential solutions.

4.2.3. Some conclusions

Choosing a suitable form of regulation is one of the key steps towards successful development of smart grids, in particular due to:

- uncertainty regarding the gains achieved by this technology and even greater uncertainty as to consumer behaviour; and
- doubts as to how such gains should be shared out between players.

This climate of uncertainty leads to investments being postponed. Furthermore, in view of the initial conclusions of experiments, regulatory measures involving incentives (price-cap) or merchant mechanisms (financial-transmission rights) allow greater efficiency in this business but also entail the risk that costs related to this investment may not be recovered. Two-pronged regulation, consisting of an incentive mechanism for investments which have already been made and a guaranteed rate of return (cost-plus or rate of return regulation) would have the advantage of triggering investment while minimizing the risk of non-profitability. However regulators should be wary of the possible side-effects of this type of regulation, in particular the risk of over-investment (Averch–Johnson effect). To avoid this pitfall, regulators may draw on benchmarks based on worldwide return-on-experience (Faruqui and Sergici, 2010). Many pilot schemes are also underway in Europe with IEA backing.

Much research is still being carried out, particularly in Europe, on policies or regulatory measures to enable smart grids to develop. Such policies will be complex, obliged to take into account both the costs and benefits for each player, as distribution system operators will not be the sole beneficiaries (Fox-Penner, 2010). The specific features of each country – goals for climate-change or the integration of new technology – the energy mix and the structure of demand will inevitably impinge on incentives to develop technology and on the corresponding regulation. Such measures must apply to two sectors: the electricity grid and the communications network with data management.

5. Easier integration of intermittent renewable energy sources in electricity systems

The drive to feed increasing amounts of renewable energy into the grid, assisted by new technologies, has already substantially altered the electricity market. Renewable energy sources are intermittent and the power they generate may be fed into the system via a large number of nodes. The development of storage infrastructures and plug-in electric vehicles will boost the flow of electricity in networks, with a corresponding increase in system complexity. Data gathered by smart-grid technology will be valuable in arbitrating between such flows.

5.1. *Easing the integration of intermittent renewable energy in electricity systems*

Recent policies supporting the development of renewable energy sources have resulted in a substantial increase in the number of decentralized generators. Their expansion is justified by the expected benefits for managing electricity systems, safety thanks to less demand being placed on the network, and progress in combating climate change (Nair and Zhang, 2009). The incentives included in these policies, coupled with changes to market design, have affected the strategies of the various generators. Feed-in tariffs, or the absence of imbalance penalties for renewable-energy generators, encourage the dominant strategy of reselling production at a guaranteed purchase price without worrying about the impact on system balance. Thus, some authorities have consequently changed incentive mechanisms, firstly to make generators responsible for the imbalance they create, and secondly to encourage local consumption of renewable energy generated in the area.[13] In this way the rationale by which players resell all the energy they generate may give way to other strategies based on consuming one's own output and managing the surplus (Clastres et al., 2010). Some countries, such as Germany or the UK, have already set up incentive systems favouring the consumption of locally produced renewables. Advanced management of output comes into its own with the new configurations slated to develop with smart grids.

As renewable energy output does not necessarily coincide with periods of demand the development of smart grids, of storage technologies and the corresponding demand-control services, as well as measures to improve overall energy efficiency will help absorb part of the variations in output (Moura and De Almeida, 2010; Newborough and Probert, 1990). Smart sensors integrated distribution networks will localize failures quickly and accurately, and efficiently reconnect renewables in the event of faults (Nair and Zhang, 2009).

The emergence of smart grids will make it easier to manage renewable output pooled to form virtual power plants. Such regrouping has already proved a source of added value (Erdil et al., 2008; Reichling and Kulacki, 2008) and lower risk, either through risk-sharing (IEA, 2008b) or thanks to the complementary nature of energy sources (Jaramillo et al., 2004; Angarita and Usaola, 2007). Redistribution schemes strictly deployed inside the virtual power plant reward individual services or alternatively penalize shortcomings. Smart grids, with their powerful monitoring and communications infrastructure, will facilitate redistribution (Aunedi et al., 2009).

5.2. *Developing plug-in electric vehicles and storage*

We have recently seen growing interest in development of plug-in electric vehicles. Among potential benefits, they would reduce dependence for short trips on petrol and reduce transport's footprint, it being one of the main sources of CO_2 emissions, after electricity generation (IEA, 2010a). They could ease the strain on the electricity system by serving as decentralized storage/supply units, depending on pricing signals.

The development of such vehicles would have an impact on the electricity system, which would need to develop infrastructure for charging their batteries and power plants to recharge the fleets of vehicles. Recharging will certainly be spread out in time, to avoid displacing the problems encountered during peak consumption. The study carried out by the Rocky Mountain Institute (2006) is a perfect illustration of the handling of peak demand followed by massive reconnection which simply shifts the periods of system tension. It notes that intelligent energy management, either entirely automatic or dependent on pricing signals sent to consumers, really does reduce demand at peak hours. Reconnection then leads to another spike, which can be managed by staggered reconnection of loads depending on their type.

As a result the various plug-in electric-vehicle technologies and development projects will not all have the same impact on the electricity system (Belmans, 2010). It seems relatively straightforward to implement recharging of vehicles at users' homes, coupled with improvements to existing incentive pricing signals. Outdoor charging-points seem more difficult to implement and would involve large-scale deployment of communications technology to determine many parameters (presence of a vehicle at the charging-point, projected use of vehicle, battery-charge capacity, state of networks at a given node, etc.). Quick recharging would have an impact on distribution networks, with significant short-term peaks in consumption which would be repeated, yet unpredictable. Battery swapping would have the advantage of making it relatively easy to manage battery charge and discharge. However this option is hampered by vehicle design constraints.

Other storage technologies may supplement the electricity network. New forms of storage capacity will need to fulfil many functions, such as voltage support, smoothing output from renewable sources and optimizing distribution-network flow (Frei, 2008). With the spread of smart grids these technologies will find new openings (arbitration, contribution to system services). It will be possible to valorize such openings either directly on one of the existing electricity markets, or indirectly through services rendered to the community. But first, government will have to set up incentive systems to promote their development. Although their development may suffer from an economic imbalance between deployment costs and the resulting profits, measures to internalize certain negative externalities could compensate for this handicap. The effects for the community may prove positive, justifying state intervention with incentive policies. At present certain simplified models of the electricity system show that the opportunities offered by storage systems could generate sufficient profits to cover the costs related to their deployment (Wade et al., 2010).

6. Conclusion

The development of smart-grid technology has raised high hopes of reconciling targets for climate-change (cutting greenhouse gas emissions), energy (managing consumption, energy efficiency), competition, and safety of systems and technology (to integrate renewable energy sources, storage and plug-in electric vehicles in electricity systems). Pilot schemes have shown that smart

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[13] The Spanish authorities have changed the incentives promoting renewable energy sources by developing the 'premium' system which involves paying for such production on the basis of the price on the electricity market to which is added a fixed premium for every kWh produced (Del Rio Gonzalez, 2008). Renewable energy generators may incur imbalance penalties.

management of demand can limit periods of strain on network and electricity markets. Automated management amplifies this effect.

The smart-grid problematique prompts economic questions related to their deployment. The first question concerns the form of regulation most likely to act as an incentive for operators to deploy such technology. Dual regulation is required to launch infrastructure investment, as the return is uncertain and has to be shared. The second issue relates to ownership of data and its transfer between agents. Here again, a regulation system clearly defining the beneficiaries and tariffs for data access, with protection of consumer rights, would be necessary to prevent misuse of such data.

Smart grids encourage dynamic pricing solutions for end users. Such pricing systems should contribute to greater allocative efficiency, with prices coming close to short-term marginal costs. 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 negative side-effect would be an increase in transfers between consumers, and generators and/or suppliers. Surplus skimming could reduce, perhaps even reverse, the previous positive impact. Regulators and anti-trust authorities would have a key role to play in preventing monopolistic transfers and a few players from taking all the surplus.

Lastly smart grids will make it easier to integrate and manage new technologies thanks to real-time communication of the system's status. Additional information on intermittent, decentralized generation, congestion, and integration of plug-in electric vehicles or storage capacity, will be an additional decision-making factor offering new variables to reduce current strains on the system. The deployment of communications resources will also offer new players (aggregators, managers of storage or intermittent generation resources) a range of strategies and levers for arbitration to ply their trade on reconfigured markets.

References

Angarita, J.M., Usaola, J.G., 2007. Combining hydro-generation and wind energy. Biddings and operation on electricity spot markets. Electric Power Systems Research 77, 393–400.

Aunedi, M., Štrbac, G., Pudjianto, D., 2009. Characterisation of portfolios of distributed energy resources under uncertainty. In: 20th International Conference on Electricity Distribution, CIRED 2009, Prague, 8–11 June 2009.

Belmans, R., 2010. Communication at the electricity grids—a key enabler in the delivery of a sustainable energy policy. Joint ENARD/IEA Grid Policy Workshop, April 28, 2010.

Chao, H.-P., 2010. Price-responsive demand management for a smart grid world. The Electricity Journal 23 (1), 7–20.

Clastres, C., Ha Pham, T.T., Wurtz, F., Bacha, S., 2010. Ancillary services and optimal household energy management with photovoltaic production. Energy 35, 55–64.

Coll-Mayor, D., Paget, M., Lightner, E., 2007. Future intelligent power grids: analysis of the vision in the European Union and the United States. Energy Policy 35, 2453–2465.

Crampes, C., Creti, A., 2005. Capacity competition in electricity markets. Economia delle fonti di energia e dell'ambiente 2, 59–83.

Crampes, C., Léautier, T.O., 2010. Dispatching, redispatching et effacement de demande. Institut d'économie industrielle, Toulouse, septembre.

CRE, 2010. Smartgrids projects in Europe. Energy Regulatory Commission. ⟨www.smartgrids-cre.fr⟩.

Del Rio Gonzalez, P., 2008. Ten years of renewable electricity policies in Spain: an analysis of successive feed-in reforms. Energy Policy 36, 2917–2929.

Doucet, J., Littlechild, S.C., 2009. Negotiated settlements and the National Energy Board in Canada. Energy Policy 37, 4633–4644.

Erdil, E., Ilkan, M., Egelioglu, F., 2008. An experimental study on energy generation with a photovoltaic (PV)—solar thermal hybrid system. Energy 33, 124–1245.

European Commission, 2010. Europe 2020 initiative—energy infrastructure priorities for 2020 and beyond: a blueprint for an integrated European energy network. November, 17.

European Commission, 2011. Next Steps for Smart Grids: Europe's Future Electricity System will Save Money and Energy. Brussels, April 12.

Faruqui, A., Hledik, R., Newell, S., Pfeifenberger, J., 2007. The power of five percent. The Electricity Journal 20 (8), 68–77.

Faruqui, A., Sergici, S., Sharif, A., 2010a. The impact of informational feedback on energy consumption—a survey of the experimental evidence. Energy 35, 1598–1608.

Faruqui, A., Harris, D., Hledik, R., 2010b. Unlocking the €53 billion savings from smart meters in the EU: how increasing the adoption of dynamic tariffs could make or break the EU's smart grid investment. Energy Policy 38, 6222–6231.

Faruqui, A., Sergici, S., 2010. Household response to dynamic pricing of electricity: a survey of fifteen pricing experiments. Journal of Regulatory Economics 38, 193–225.

FERC, 2011. Assessment of Demand Response & Advances Metering. Federal Energy Regulatory Commission, February.

FERC, 2009. A National Assessment of Demand Response. Federal Energy Regulatory Commission, June.

Finon, D., Glachant, J.M., 2008. La hausse inéluctable des prix de l'électricité en France: faut-il corriger les effets de l'intégration du marché européen ? Larsen, Fontenay-aux-Roses. Working Paper 8.

Fox-Penner, P., 2010. Smart Power: Climate Change, the Smart Grid, and the Future of Electric Utilities. Island Press, Washington, DC.

Frei, W., 2008. What if… ? Utility vision 2020. Energy Policy 36, 3640–3645.

Glachant, J.M., Pignon, V., 2005. Nordic congestion's arrangement as a model for Europe? Physical constraints vs. economic incentives. Utilities Policy 13, 153–162.

Glachant, J.M., Perez, Y., 2010. L'analyse économique appliquée à la problématique des effacements diffus. Revue de l'énergie 597, 312–321.

Hirst, E., Cavanagh, R., Miller, P., 1996. The future of DSM in a restructured US electricity industry. Energy Policy 24, 303–315.

Hogan, W., Rosellon, J., Vogelsang, I., 2010. Toward a combined merchant-regulatory mechanism for electricity transmission expansion. Journal of Regulatory Economics 38, 113–143.

IEA, 2008a. Energy Technology Perspectives: Scenarios and Strategies for 2050. OECD, Paris.

IEA, 2008b. Empowering Variable Renewables: Options for Flexible Electricity Systems. OECD, Paris.

IEA, 2010a. World Energy Outlook 2010. OECD, Paris.

IEA, 2010b. Energy Technology Perspectives: Scenarios and Strategies to 2050. OECD, Paris.

Jackson, J., 2010. Improving energy efficiency and smart grid program analysis with agent-based end-use forecasting models. Energy Policy 38, 3771–3780.

Jaramillo, O.A., Borja, M.A., Huacuz, J.M., 2004. Using hydropower to complement wind energy: a hybrid system to provide firm power. Renewable Energy 29, 1887–1909.

Joskow, P., Tirole, J., 2005. Merchant transmission investment. Journal of Industrial Economics 53, 233–264.

Kopsakangas-Savolainen, M., Svento, R., 2010. Comparing welfare effects of different regulations schemes: an application to the electricity distribution industry. Energy Policy 38, 7370–7377.

Kreps, D., Scheinkman, J., 1983. Quantity precommitment and Bertrand competition yield Cournot outcomes. Bell Journal of Economics 14, 326–337.

Kristiansen, T., Rosellón, J., 2006. A merchant mechanism for electricity transmission expansion. Journal of Regulatory Economics 29, 167–193.

Léautier, T.-O., 2001. Transmission constraints and imperfect markets for power. Journal of Regulatory Economics 19, 27–54.

Léautier, T.-O., 2010. Selected Smart Meters Economics. Presentation to the Smart Grid Workshop. Ecole Polytechnique and EDF. October, 21.

Lévêque, F., De Muizon, G., Glachant, J-M., Saguan, M., 2008. La régulation incitative appliquée au transport de l'électricité. Théorie et application au Royaume-Uni, en Espagne, en Belgique, en Norvège et en Italie; Pratique et positionnement de la régulation en France. Microeconomix, rapport pour le RTE, janvier.

Littlechild, S.C., Skerk, C.J., 2008. Transmission expansion in Argentina: the origins of policy. Energy Economics 30, 1367–1384.

Lofaro, A., 2002. On the efficiency of Bertrand and Cournot competition under incomplete information. European Journal of Political Economy 18, 561–578.

Lorenz, G., 2009. Regulatory Framework to Incentivise Smart Grids deployment—EURELECTRIC views. CEER Workshop on Smartgrids, Brussels, 29 June.

Meeus, L., Saguan, M., Glachant, J.-M., Belmans, R., 2010. Smart regulation for smart grids, EUI Working Paper no. 45.

Moura, P.S., De Almeida, A., 2010. The role of demand-side management in the grid integration of wind power. Applied Energy 87, 2581–2588.

Nair, N.K.C., Zhang, L., 2009. SmartGrid: future networks for New Zealand power systems incorporating distributed generation. Energy Policy 37, 3418–3427.

Newborough, M., Probert, S.D., 1990. Intelligent automatic electrical-load management for networks of major domestic appliances. Applied Energy 37, 15–68.

Orans, R., Woo, C.K., Horii, B., Chait, M., DeBenedictis, A., 2010. Electricity pricing for conservation and load shifting. The Electricity Journal 23 (3), 7–14.

Percebois, J., Wright, P., 2001. Electricity consumers under the state and the private sector: comparing the price performance of the French and UK electricity industries 1990–2000. Utilities Policy 10, 167–179.

Percebois, J., 2007. Energy vulnerability and its management. International Journal of Energy Sector Management 1, 51–62.

Percebois, J., 2008. Electricity liberalization in the European Union: balancing benefits and risks. The Energy Journal 29, 1–19.

Pérez-Arriaga, I.J., 2010. Regulatory Instruments for Deployment of Clean Energy Technologies. EUI RSCAS; 2010/25; Loyola de Palacio Programme on Energy Policy.

Pollitt, M.G., 2008. The future of electricity (and gas) regulation in a low-carbon policy world. The Energy Journal 29 (Special issue), 63–94.

Reichling, J.P., Kulacki, F.A., 2008. Utility scale hybrid wind—solar thermal electrical generation: a case study for Minnesota. Energy 33, 626–638.

Rocky Mountain Institute, 2006. Automated demand response pilot, 31 March.

Rubio-Oderiz, J., Pérez-Arriaga, I.J., 2000. Marginal pricing of transmission services: a comparative analysis of network cost allocation methods. IEEE Transactions on Power Systems 15, 448–454.

Smeers, Y., 2009. How well can one measure market power in restructured electricity systems?. In: Glachant, J.M., Lévêque, F. (Eds.), Electricity Reform in Europe: Towards a Single Energy Market.. E. Elgar, Cheltenham, pp. 207–268.

Spulber, D.F., 1995. Bertrand competition when rivals' costs are unknown. Journal of Industrial Economics 18, 1–11.

Stoft, S., 2006. Problem of transmission investment in a deregulated power market. In: Lévêque, F. (Ed.), Competitive Electricity Markets and Sustainability.. E. Edgar, Cheltenham, pp. 87–130.

Storelli, S., Pillet, G., 1997. La tarification dynamique de l'électricité. Bulletin SEV/VSE, no. 15/97.

Tirole, J., 1993. Théorie de l'organisation industrielle, tome II. Economica, Paris.

Wade, N.S., Taylor, P.C., Lang, P.D., Jones, P.R., 2010. Evaluating the benefits of an electrical energy storage system in a future smart grid. Energy policy 38, 7180–7188.

Woo, C.K., 1990. Efficient electricity pricing with self-rationing. Journal of Regulatory Economics 2, 69–81.