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Security of supply and regulation of energy networks☆

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ABSTRACT

In recent years, the security of energy supplies has re-emerged as a central issue in the energy policy arena in the UK and elsewhere. This re-emergence takes place against a backdrop of increased liberalisation of the energy markets, so that security of supply needs to be revisited within this context. Security of supply is multifaceted, but is often discussed in terms of physical availability of energy sources and their commodity price risk. This paper discusses the relationship between security of supply and network regulation—that is, how the energy networks, and appropriate regulation of them, can contribute to security of supply in liberalised energy sectors. Energy networks are predominantly natural monopolies and as a result are generally subject to regulatory oversight. We discuss a range of issues and trends that pose challenges and opportunities to network regulation and which call for new and innovative measures. The paper identifies a number of areas where network regulation can play a significant role in increasing the security of supply of future energy systems.

1. Introduction

Following a period of relative calm, concerns regarding the security of energy supplies have recently re-emerged as a central energy policy matter in the UK and the rest of Western Europe. However, most current concepts of, and debate on, security of supply are centred on the physical delivery of energy sources. Their principal concerns are the production and upstream facilities of the supply chain and networks for transportation and delivery. Here, wider geopolitical factors, pipeline transit issues, and investments in production capacity in producing countries tend to take centre stage.

However, the electricity blackouts in Europe in recent years have been due to technical failure in the networks rather than resulting from shortages in generation capacity or fuel (see Bialek, 2004). Indeed, the UK Government's Joint Security of Supply Working Group (JESS) defines security of supply in electricity and gas as: (a) the availability of supplies of gas, (b) the availability of supplies of electricity and fuels used for electricity generation, (c) the adequacy of generating capacity, and (d) the adequacy of the UK's gas and electricity infrastructure.[1]

Security of supply in the context of liberalised energy markets is a multifaceted notion and needs to be redefined. There is a sizable literature on security of energy supply and related issues (see, for example, Finon and Pignon, 2008; Roques, 2008; Stern, 2006; von Hirschhausen, 2008; Wright, 2005). Egenhofer et al. (2004) revisit some of the more conventional definitions of security of supply. They suggest that, in liberalised energy markets, the roles of government, companies, and consumers change and supply security should be redefined in terms of risk and associated costs. In consequence, security of supply becomes a risk-management strategy with a strong inclination towards cost effectiveness, involving both the supply and the demand side (p.i). While security of supply in terms of physical availability and commodity price risk remains important, a crucial aspect that is often overlooked is the strategic role of energy networks and their regulation in improving security of supply.

Energy networks (by which we mean electricity and gas networks) are predominantly natural monopolies and as a result are generally subject to regulatory oversight. Since the 1990s, regulation has been regarded as playing a key role in the implementation of sector reforms, by improving the efficiency of investments in the networks, enhancing their operation, and facilitating competition in the production and supply of energy over the networks. This has resulted in important contributions from the theoretical and empirical literature, recent examples of which include Armstrong and Sappington (2007), Joskow (2008) and Lévêque (2006). The UK experience with post-liberalisation regulation of networks has, to date, generally been positive (see, for example, Jamasb and Pollitt, 2007; Joskow, 2008).

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[1] See http://www.berr.gov.uk/energy/reliability/security-supply/jess/.

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As with the economic efficiency objectives, appropriate regulation can also help the energy networks play an important role in increasing security of supply. Regulation can ensure that there are incentives for sufficient capacity and responsiveness of gas storage facilities, internal resilience of transmission and distribution systems, and capacity to receive supplies to national energy systems from a number of sources, via international gas pipelines, liquefied natural gas (LNG) import facilities, or electricity grid interconnections.

Security of supply is a rather broad subject and covers a diverse range of areas from physical availability, resource mix and technology to the price stability of energy supplies in upstream, downstream and end-use aspects. At a higher level, security of supply is also related to climate change and global security issues such as the proliferation of nuclear material. This paper attempts to link and explore the rather specific subject of the interrelationship between security of supply and network regulation—how the energy networks and appropriate regulation of them can contribute to security of supply in liberalised energy sectors.

We argue that the energy networks and their regulation can play a significant role in a range of areas in increasing the security of supply of future energy systems. The aim is not to propose specific and detailed regulatory measures here. Rather, we focus on identifying the trends and areas that pose major challenges to network regulation and are in need of new and innovative measures.

2. Network regulation and security of supply

How can the networks and their regulation reduce the short-term effects of supply shocks to the energy system and, at the same time, be a part of a long-term energy security strategy? Broadly, the primary aims of regulation of networks in improving security of supply in liberalised energy systems is to attract sufficient investment, promote adequate maintenance of existing facilities, promote the efficient operation of network infrastructure, and ensure adequate rewards for innovation and technological progress, if necessary through regulatory incentives.

Our discussions of energy networks apply to both gas and electricity. However, there are important structural and product differences between these two networks, and where the differences become important we distinguish between them. For example, electricity is a non-storable product and electricity networks accommodate a range of technologies and fuel. Natural gas is also a major input for electricity generation, and gas storage has operational and strategic importance.

2.1. Networks and upstream businesses

2.1.1. Sufficient investment in networks

The move from centralised electricity systems to liberalised markets has given rise to the issue of investment adequacy, in production as well as in networks. Investments in production have implications for investments in networks and vice versa (Lévêque, 2006). In centralised systems, the optimisation of investments could be achieved by coordination and command and control. In liberalised sectors this task should be addressed through market design and the regulatory framework.

The physical availability of energy supplies at the border is not the only, or indeed the most frequent, source of risk to security of supply. The biggest hazards are internal energy transportation networks, and it is these that offer the most scope to improve national energy security. Electricity and gas networks have been viewed as natural monopolies (Newbery, 1999). As such they have been regulated by independent regulators who periodically decide how much revenue they should recover. These 'price reviews' involve decisions about how much network investment is required. In the early years following privatisation, investment needs were modest and improvements in operating efficiency were significant. Now, as the age of the UK and continental European energy networks gradually increases, their investment needs are also rising. Recent regulatory price control reviews of electricity distribution and of gas and electricity transmission have involved substantial increases in investment, leading to the expectation of rising real prices for network services (Pollitt, 2008).

In some instances it may be possible to supplement the regulation of network investments with market and incentive mechanisms such as merchant electricity transmission networks (Joskow and Tirole, 2005), or user involvement in electricity transmission and distribution system expansion, as in Argentina (Littlechild and Ponzano, 2007). Another example is the use, where possible, of competition in US gas transmission pipelines (Makholm, 2007). Clearly the regulator has a crucial role in ensuring sufficient network investment while keeping price rises down via appropriate incentives (Pollitt and Bialek, 2008). The main challenge is to ensure adequate, timely investments at reasonable cost, and avoid tendencies to over-invest.

2.1.2. Sector structure and unbundling

Unbundling of networks can increase competition among the producers over networks and facilitate more effective incentive regulation of them. Effective unbundling of networks can also reduce the geopolitical concerns associated with the desire of producing companies to own distribution networks in consuming countries. The pros and cons of different types of unbundling of networks are of current interest to a number of European regulators. Pollitt (2007) reviews alternative structural arrangements for energy transmission networks. The study concludes that full ownership unbundling of transmission networks is more efficient than alternative arrangements and is in line with the objectives of liberalisation. This is because it reduces the ability of incumbent generators and suppliers to use control of the energy transmission networks to discriminate against competitors. It also facilitates the better regulation and management of focused network companies. However, there remains further scope for empirical investigation of the relative merits of different forms of network unbundling, and whether ownership unbundling should apply to electricity distribution.

2.1.3. Diversification of supply sources via competition

The most commonly suggested remedy for increasing security of supply is diversification, to reduce overdependence on individual countries or regions, and on particular types of supply. For both natural gas and electricity systems, this can be achieved via the diversification of sources of pipeline gas through increased interconnection to the main supply countries, and through the building of LNG import capacity.

The UK illustrates the ability of market competition to ensure a diversity of supply sources for both electricity and gas. In electricity, privatisation and liberalisation led to a sharp reduction in the UK's dependency on expensive and politically unreliable domestic coal (Newbery and Pollitt, 1997). In gas, the price spike of 2004–2006 led to an increase in LNG import capacity and was accompanied by significant investment in pipelines (for example from Norway), raising the UK's daily import and storage capacity to about 35% of the highest historical daily peak demand. However, as UK gas production declines, the import and storage capacity needs to increase (see JESS, 2006a, p. 30). In both of these cases, the role of the regulator was to resist calls for intervention to prevent the diversification from happening, on subjective rather than objective security of supply grounds. Thus the UK had security of supply problems with home-produced coal during the 1984/85 miners' strike, but not with imported natural gas.

The long-term benefits of such deregulation seem to be the stimulation of the market for imports of LNG, and appropriate investment in storage facilities to diversify the supply mix. Technological progress, learning by doing and research in LNG systems are likely to reduce the cost advantage of pipeline gas over LNG. As a result, LNG trade is expected to increase the globalisation of the gas market and the flexibility of national markets. As the number of LNG facilities grows, the network effects of larger systems and greater numbers of exporting and receiving points will further develop the market and the allocation of LNG supplies. Regulation can make storage capacity an important part of the gas networks while contributing to competition in the market. This can be achieved by allowing equal access to market actors, for example through auction mechanisms.

2.1.4. Pipe-to-pipe competition

Apart from natural gas supplies from the Norwegian Sea, the UK is at the end of the European gas pipeline and electricity networks. A continuation of EU energy sector liberalisation and regulatory reform will be beneficial for the security of supplies in the UK by reducing the costs of market-driven responses in the UK. A Europe-wide energy market will improve the efficiency of allocation of gas and electricity supplies among the users and reduce the need for political intervention.

Both incentive regulation of networks and the regulation of competition over the networks are important for liberalised energy markets. The deregulation of the interstate gas pipelines in the USA has useful lessons for Europe. While much of the regulatory effort in Europe has been on efficient operation of the gas pipeline networks, the emphasis of US gas network regulation has been on promoting competition over the networks. This has improved the resilience of the system in coping with supply shortages and sudden price rises (see Doane et al., 2004; Makholm, 2007).

However, concentration in the European energy markets has increased significantly in recent years. Indeed, the mobility of capital and firms has proved to be significantly more than that of the regulatory and policy coordination among the member states (see Jamasb and Pollitt, 2005). This consolidation has resulted in large national and European electricity and gas utilities. This increased concentration is likely to slow down the pace and limit the scope of the European energy market reform. However, recent moves by the European Commission following the energy sector inquiry are encouraging (European Commission, 2007).

2.1.5. Rewards and penalties for security of supply

There is an extensive debate about the extent to which regulators can leave energy markets to set the level for security of supply. These debates have led to the introduction of capacity payments for generation capacity in some electricity markets (e.g. North East Independent System Operator and the PJM regional transmission organisation in the US; see Bowring, 2008) and for minimum gas storage capacity in some European countries (e.g. Belgium). In the UK, auctions have been introduced for peaking capacity at times of maximum electricity demand (see JESS, 2006b). The extent to which these extra payments provide real additional security is unclear. They can be very expensive and it is not clear whether the level of security they achieve is optimal. One good reason for this is that security of supply is multidimensional, so regulators have to make choices about incentives, which may have precise impacts on some of the components of security of supply but not others.

An interesting example is gas storage capacity. The average storage capacity in Europe is 19 days of peak demand, while in the UK the unregulated figure is 10 days (Energy Business Review, 2007). The UK has less total storage capacity but can maintain normal flow for longer because significant quantities of gas generating capacity (17%) can now switch to using distillate (see JESS, 2006b). This illustrates the need to define carefully what sort of supply interruptions regulatory interventions are aimed at mitigating, and to analyse precisely why these are not best left to market forces to determine. However, at a more micro level, UK regulation has successfully improved 'quality of service' in electricity and the environmental impact of gas distribution networks (Jamasb and Pollitt, 2007; Ofgem, 2007). This has been done by a fairly tough reward and penalty system for incumbent network owners, which has provided incentives for investments in improving the operation of networks.

2.1.6. International and regional regulatory coordination

Security of supply can be enhanced by strengthening regional energy markets, which link national energy markets. Integration of regional markets needs new or enhanced interconnections between national markets (see European Commission, 2007). Regulatory cooperation can enhance the long- and short-term efficiency of markets through coordinated investments in these interconnections and in their operation. Regional markets and regulatory coordination are especially beneficial for countries at the fringes of the European supply networks, such as the UK. Although regulatory coordination is promoted by the European Commission and there are a number of efforts, there is still a need for further improvement. Even in the well-integrated Nordic electricity market, there remains scope for further coordination to improve efficiency.

2.2. Networks, demand and customers

2.2.1. Activating the demand side

A price-responsive demand side can be an important factor in reducing the effect of supply shortages, and there is considerable scope to reduce energy consumption in times of supply shocks. This potential can be utilised effectively by increasing the price responsiveness of demand. Recent illustrations of this include the electricity supply shocks in Chile (1998–1999), New Zealand (2001) and Norway (2002–2003), all induced by a shortage of rain in hydroelectric reservoirs. In the winter of 2002–2003 in Norway, water shortages led to a rapid increase in the price of electricity. Demand responded by adjusting to the new market prices (von der Fehr et al., 2005). In this case, average prices were higher by 30% during the April–November period, resulting in a 7% fall in demand and avoiding the need for intervention and rolling blackouts.

This indicates that in well-developed competitive wholesale and retail markets, the price mechanism facilitates the allocation of available energy and allows customers to adjust their consumption levels. At the same time, there is a need for more evidence to ensure whether consumer reaction is limited to rare events or can also be observed in the long run with repeated incidents of price increases, when the consumers may internalise possible regulatory intervention.

2.2.2. Smart metering, flexible networks and microgeneration

Price responsiveness can be significantly increased in the UK system. This has to be achieved by exposing customers to real-time pricing. This would also facilitate the installation of equipment to remotely switch on and off domestic microgeneration and non-essential loads such as refrigerators, freezers, dishwashers and washing machines, which do not require continuous supply. One of the most effective ways to achieve an active demand side, currently being debated in a number of countries, is through the use of 'smart' metering. Smart meters can be an effective tool in increasing the price responsiveness of demand and in allocating and saving energy more efficiently (Brophy Haney et al., 2008). Smart metering requires smart information infrastructures, but also needs to be supported by smart pricing through competitive wholesale and retail markets. Effective use of smart meters requires effective unbundling of the competitive segments from natural monopoly networks. The roll-out of smart meters requires specific regulatory guidelines and incentives to ensure that network operators and suppliers adopt suitable smart metering technologies. The benefits of smart meters will be most profound in the event of supply shocks and sudden price rises, while integrated electricity and gas smart meters are likely to have extra benefits by integrating the two energy sources (Sustainability First, 2007).[2] However, the system-wide cost implications of the universal adoption of smart meters must be studied further as the current estimates cover a fairly wide range.

The expected increase in the use of microgeneration technologies by domestic and commercial users will need to be coordinated with the possible roll-out of smart meters. Such technologies, as well as energy-efficiency measures, will particularly need to target new buildings, where adoption costs are lower. It is difficult to imagine how the Government's stated target of building one million zero-emission homes by 2020 can be achieved without developing and adopting innovative regulatory measures and without some of these involving the networks directly or indirectly.

2.2.3. Demand in public and commercial sectors

The public and commercial sectors are major users of electricity (Grubb and Wilde, 2008). There is therefore an important role for regulation in addressing the growing demand in these faster growing sectors by developing end-use-specific schemes and by addressing the low price elasticity of demand in these sectors (often a result of the landlord–tenant split, whereby the price of energy is included at a fixed amount in the rent and is invisible to the tenant and not related to actual usage). The emergence of a more active market for energy management services and more extensive use of district heating and cooling schemes would seem to be important. In particular, it is important to develop specific and innovative schemes aimed at utilising the potential of smart meters and economic incentives for energy use in the public sector.

2.2.4. Network charging methodologies

Locational pricing within transmission and distribution networks would seem to be very important for providing clear cost signals to users and generators on where connection to the energy networks would be most valuable. The UK zonal transmission charging systems for electricity are unsophisticated relative to the charging schemes in the PJM nodal pricing system in the USA, which provides strong incentives to reduce marginal energy losses (see Bowring, 2006).

There is also considerable scope for the extension of locational charging within electricity distribution schemes. One such scheme has been partially implemented in the electricity distribution utility South West (see Li, 2007). The access charging methodologies adopted by the utilities to collect their allowed revenues can also have significant efficiency dimensions (Jamasb et al., 2005). The charging methodology is important for the allocation of network access and usage costs between existing and new connections. European regulators are now required to approve the utilities' charging methodologies. Access charges and arrangements will be closely related to the adoption of microgeneration technologies and the use of smart meters. The charging methodology must provide efficient and cost-reflective price signals to customers.

2.3. Heat energy networks

Heat networks can significantly improve the efficiency of energy utilisation. Heat accounts for about one-third of primary energy consumption in the UK and has considerable scope for energy-efficiency gains (Defra/BERR, 2007). Heat networks can also increase the flexibility of the energy system and improve security of supply by expanding the basis for increased use of renewable energy. However, the potential for the efficient use of heat energy in the UK is under-utilised. This is mainly due to the lack of networks for the use of combined heat and power (CHP), as well as to the fact that waste-to-energy district heating is considerably less developed in the UK than in the best-practice countries (see London Energy Partnership, 2007). For example, in Denmark, six out of ten heat consumers receive their heat from public supply systems and in the year 2000 about 55% of households were supplied by co-generated heat and electricity plants (see Danish Energy Authority, 2005).

In response to EU directives, the UK has adopted ambitious targets to reduce the amount of waste that is sent to landfills. Waste-to-energy is increasingly regarded as an effective means of reducing municipal solid waste as well as producing heat and some electricity. The economics of waste-to-energy plants improve significantly where both the heat and electricity can be utilised. In Denmark and Sweden, where district heating networks are well developed, the share of waste directed to waste-to-energy facilities is among the highest in Europe. Development of an appropriate regulatory framework for the heat networks is, therefore, crucial for their development in the UK. However, Ofgem does not currently provide this framework (see Sustainable Development Commission, 2007).

2.4. New forms of network management and ownership

In the future, new types of network owners may emerge in the energy sector. One such possibility lies in the rise of local councils as owners of electricity or district heating systems in existing or new developments. They may also own generation plants that supply networks with heat and power for local neighbourhoods, or commission the supply via a public–private partnership. While only a few examples of such council-owned networks exist, they may grow in number. Their emergence would pose new regulatory challenges, as these networks would be operating within the service areas of regional monopoly electricity and gas distribution utilities.

One such example is the Energy Service Company (ESCO) set up by Woking Borough Council. This company supplies electricity and heat—based around a CHP plant—to council buildings, council housing and neighbouring buildings, and has a private wire network. The company outsources much of its activity to a private Danish company (Xergi). The Woking ESCO, Thameswey, is profitable and is considering expansion. Other such local

[2] See also Sustainable Development Commission (2007) on Northern Ireland experience with smart metering.

companies exist, but their expansion seems to be limited by the licensing rules for electricity generators, suppliers and distributors (London Energy Partnership, 2007).

The attractiveness of local initiatives is partly in demonstrating that alternative energy service business models (which are not reliant on selling more energy) can be profitable, and partly in offering the potential to jointly address issues of demand-side management, energy poverty, local siting, electricity and heat production in ways that existing electricity and gas companies have been reluctant to do. If these local networks were to develop significantly, they might duplicate some of the existing network infrastructure while offering more choice, more network resilience and lower costs.

2.5. Innovation and technological progress

Future electricity systems can be described as 'active networks' that interact with both demand and supply sides. Industrial CHP, distributed renewable generation, and microgeneration units installed by households equipped with smart meters, will challenge networks to innovate and adopt new technologies. Also, climate change and security of supply considerations require new technologies for integration of conventional back-up facilities and intermittent sources into the system. Most areas of the electricity industry are anticipated to achieve technological progress in the coming decades and this progress will have direct and indirect implications for future networks (see Jamasb et al., 2006). Innovation and technological progress are also crucial for long-term efficiency and flexibility of the consumer and the entire energy supply system. Also, many of the possibilities and futures discussed here are dependent on the development and implementation of new technologies.

Technical change in energy networks is sensitive to the regulatory framework and incentives for investment and participation in research and development (R&D) and implementation of new technologies. Recent attempts to promote innovation in the UK through the Innovation Funding Incentive (IFI) promoted by the energy regulator Ofgem or the establishment of the Energy Technologies Institute (ETI) are positive steps towards this aim. However, following the decline in energy R&D in the UK after liberalisation, these recent initiatives come from a low base and they will need to be strengthened and sustained (see Mott McDonald, 2004). At the same time much can also be achieved by designing access charging methodologies that would provide the incentives for the network companies to develop and adopt new technologies (Jamasb et al., 2005).

Innovation must also allow the possibility of the emergence of radically different ways of delivering energy services. Walt Patterson asked 'What is the network for?' in his recent book, *Keeping the Lights On* (Patterson, 2007, p. 93). He holds out the possibility of a highly decentralised electricity system with multiple small-scale local sources of generation. The emergence of generally zero-emission houses, which produce their own energy, together with small-scale local networks based around district heating for larger buildings, would suggest the emergence of large numbers of isolated loads (albeit with some legacy connections) or networks very much 'smaller' than today. It is important that regulation does not preclude this world from emerging as it would undoubtedly be good at addressing the sort of macro security of supply concerns (e.g. dependency on Russian gas) that politicians are concerned about. It would also be a world in which individuals might accept much more significant behavioural changes (with respect to siting of generating capacity, demand management, etc.) than is the case in a centralised electricity system.

3. Conclusions

Security of energy supply, broadly defined, has a strong network element, which is often overlooked. At the same time, energy networks are natural monopoly businesses. Also, climate change and security of supply concerns are likely to co-exist and exert influence on the energy policy agenda in the UK and elsewhere in Europe for the foreseeable future. As a result, regulation of networks can play a crucial role in allowing networks to mitigate security of supply risks.

With regard to the upstream energy sources, security of supply generally leads to recommendations such as an increase in: (i) energy efficiency, (ii) the share of renewable energy, (iii) the use of nuclear power, and (iv) the use of domestic coal. The last-mentioned gives rise to a conflict with climate change objectives and hence the focus on carbon capture and sequestration in recent years (see Jamasb et al., 2008).

However, energy efficiency and renewable energy sources have clear implications for energy networks and in particular the electricity transmission and distribution systems as well as the demand and customer segments. Therefore, there is a need for flexible electricity networks capable of accommodating and efficiently locating the large shares of renewable energy and distributed resources as well as being able to integrate smart meters and microgeneration technologies.

The smart and flexible networks of the future that will improve security of supply and address climate change concerns require innovative and forward-looking regulatory models and measures. As discussed, our ability to address the security of supply and climate change concerns is dependent on our success in developing and implementing suitable regulatory models. While there are signs that some of these are emerging, there remains significant scope for innovation in network regulation.

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