Optimal design of future electricity supply systems
An analysis of potential bottlenecks in NW-Europe

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This paper analyses the potential bottlenecks that might emerge in the North-western European electricity supply system as a result of a number of (autonomous) long-term developments. The main long-term developments we identify are (i) a continuing increase in the demand for electricity, (ii) a gradual shift from conventional electricity generation towards unconventional (green) generation, (iii) a gradual shift from centralised generation towards decentralised generation and (iv) a shift from national self-sufficient electricity supply systems towards a pan-European electricity system. Although it has been recognised that these developments might cause certain problems in some or more elements of the electricity supply chain, a coherent and comprehensive framework for the identification of these problems is lacking. More specific, governments and regulators seem to focus on certain parts of the electricity supply system separately, whereas certain interdependencies in the system have received relatively little attention. This paper presents such a framework and identifies some potential bottlenecks that receive relatively little attention from policy makers. These are (i) the increasing penetration of distributed generation, (ii) an increasingly important role for demand response and (iii) the lack of locational signals in the electricity supply system. The potential role of governments and markets in these issues is briefly explored.

1. Introduction

The exact shape of the energy supply system in the long-run is uncertain. The major source fuelling system development is on-going technological progress. New innovations and new applications change the fundamental structure of the electricity supply system. In the old, pre-liberalisation and pre-privatisation days, these transitions could be incorporated in the system quite smoothly due to the organisational structure (e.g. vertically integrated) and the system's high ability to carry risk (through government ownership).

In the liberalised electricity system that is currently being shaped, continuing development works differently. On the one hand it is shaped by market forces in a liberalised context, including the before-mentioned technological progress, and on the other hand, it is highly influenced by (inter)governmental policy and regulation. Energy market actors integrate these forces into a gradual development of the energy supply system as a whole.

The implementation of the European Union's electricity market Directives (EC (1996) and EC (2003)) has led to the emergence of an electricity supply system in which every sub-element in the electricity supply chains stands alone as a competitive sub-market.[1] Figure 1.1 shows a schematic overview of the electricity supply system.

[1] Notable exceptions for what goes the competitive element are obviously the markets for transmission and distribution of electricity, which are designed as regulated monopolies.

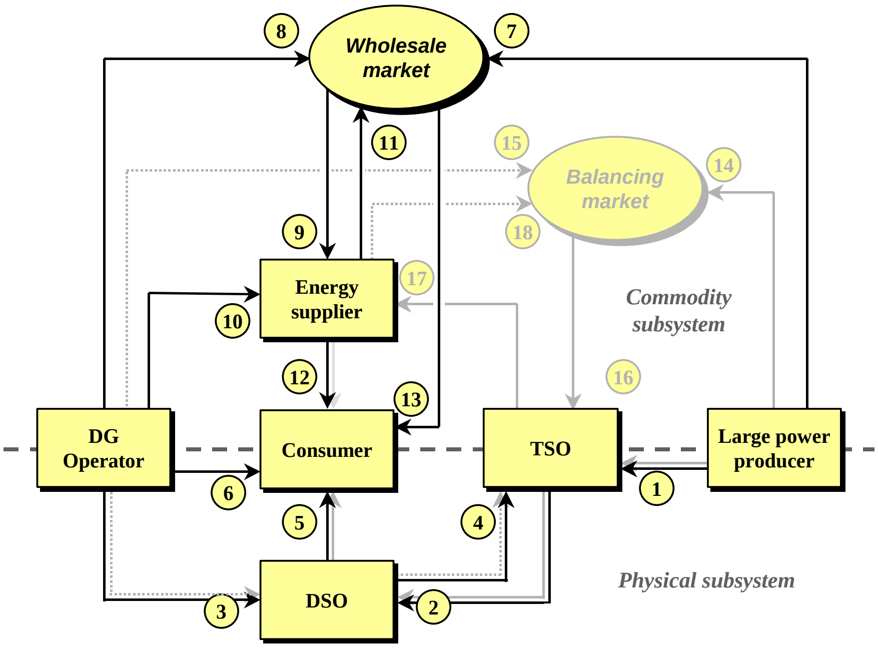

Figure 1.1 *Schematic overview of the electricity supply system* (Source: Van Werven and Scheepers, 2005)

In the figure, the electricity system is divided into a physical subsystem, centred around the production, transmission, and distribution of electricity, and a commodity subsystem. The physical subsystem comprises the generators (large power producers and DG operators), the transmission network (TSO), the distribution networks (DSOs) and the loads (consumers). In contrast with the physical power streams, the economic transactions related to the commodity flow are merely administrative and depicted in the upper part of Figure 1.1. Its goal is an efficient allocation of costs and benefits, within the constraints imposed by the physical system.

Parallel to the gradual implementation of the electricity market directives, concerns were raised that next to the increased efficiency aimed at by European policy makers, several negative side effects might be emerging. For example, the still monopolistic or oligopolistic national electricity systems resulted in the fear for abuse of market power. Another potential problem concerned the long-term adequacy of supply: would electricity market actors sufficiently invest in new generation capacity?

Both of these potential problems were countered with adaptations in policy and regulation. In respectively Belgium, France and the Netherlands, the assumed market power of Electrabel, Electricité de France (EdF) and NUON was decreased by compulsory auctioning of generation capacity. To counter any market abuse, far-going information requirements were introduced, in this way reducing information asymmetry compared to new market entrants. Concerning the threat of insufficient investments, several studies acknowledged the fact that reserve margins in generation capacity (which can be seen as a legacy from the old era) were rapidly decreasing since liberalisation. Several measures have been proposed to remedy this problem.

Assessing the potential future bottlenecks is impossible when not having a reference standard. For this purpose, this paper uses the term 'optimal electricity market system'. This paper refrains from giving an exact definition of the 'optimal electricity system'. However, the optimality of the system is assessed on three criteria: (i) *reliability*, (ii) *sustainability* and (iii) *affordability*. A potential bottleneck implies a negative deviation compared to an 'optimal system' on one or more of these criteria.

This paper aims to bring under the headlight problems that could potentially emerge in the future and which, up until now, have to some extent received insufficient attention. First, section 2 identifies the main electricity market developments that are currently observed or are expected in the coming decades. Section 3 presents a coherent framework in which potential bottlenecks can be identified. Besides the already mentioned (and also countered) bottlenecks, various other potential bottlenecks are identified with this framework. Section 4 discusses a number of bottlenecks in more detail, and indicates how they potentially let the observed electricity supply system deviate from the optimal electricity supply system. Finally, section 5 summarises.

2. Major developments in the NW-European electricity system

This section identifies the major electricity system developments in NW-Europe. The research on which this section is based involved a literature study of a large number of documents dealing with the Belgian, German, French and Dutch electricity market, ranging from policy documents to national scenario studies. From all studied material, the major on-going and expected developments in the NW-European electricity market are distilled. Here, only the main findings are briefly discussed.[2]

The four main developments identified are:

1. a continuing increase in the demand for electricity;
2. a gradual shift from conventional towards unconventional (green) generation;
3. a gradual shift from centralised generation towards decentralised generation;
4. a shift from national self-sufficient electricity supply systems towards a pan-European electricity system.

Continuing increase in electricity demand
In contrast with expected stagnation or even decline in the use of oil and coal in the primary energy supply, electricity will continue to increase its share. The NW-European demand for electricity will continue to show significant growth in the next ten years, albeit at a lower rate than the previous decade. Over the time horizon of 2005 to 2030, highest growth is projected in the first ten to fifteen years. This picture seems to be applicable to the situation in Belgium, France and Germany as well.

Shift towards more unconventional generation
While the majority of electricity generated in NW-Europe still originates from power plants using conventional technology, whether it is based on nuclear (Belgium and France), coal (Germany) or gas (the Netherlands), an increasing amount is produced by more unconventional technologies as used with Combined Heat and Power (CHP) generation and generation from Renewable Energy Sources (RES) such as wind and hydro.

Shift towards more decentralised generation
A shift towards the use of more unconventional technologies comes, to a certain degree, together with more decentralised electricity generation. Generation from both CHP and RES-units are often connected to lower voltage networks instead of the high voltage network. Amongst the notable exceptions are the large-scale hydro and wind units (especially wind at sea) and the CHP-units located at industrial sites.

Shift from national electricity systems to (regional) European electricity systems
The large number of proposals for new interconnections and reinforcements of existing interconnections in itself indicates a fourth major electricity system development, namely: the transition of national self-sufficient electricity systems towards a pan-European electricity system.

[2] For a more in depth description of our literature study we refer to Van Werven et al. (forthcoming).

The current, historically shaped, national electricity systems are already or soon will be exposed[3] to the above developments. The question is whether these developments give rise to problems or bottlenecks in the current system. Is the current design of the electricity system able to adapt to these changing circumstances or is additional policy and regulation necessary? In the next section a framework is presented with which the potential problems and bottlenecks can be identified.

3. Presenting the framework

This section presents the most important bottlenecks in the (autonomous) development to an optimal electricity system in northwest Europe in the longer term. An analytical framework has been constructed to identify possible problems and bottlenecks in a structured way.

Three criteria are used to assess the relevance of the identified bottlenecks and to indicate the direction of change that the problem implies, relative to an 'optimal electricity supply system'. The first criterion is the reliability of the electricity system, focused on the production segment and the network. The second criterion is aimed at sustainability, focused on realising environmental objectives by means of (market conformable) policy measures. The third criterion, affordability, deals with the economic efficiency of the electricity system, which comprises market competition and the effectiveness of network cost regulation. An important element of affordability is the electricity price. A distinction is made between the production, network, and demand segments of the electricity system. An important aspect that is taken into account considers the interaction between the three segments. Furthermore, the balancing mechanism is incorporated in the analytical framework, as well as policy and regulation.

To be able to identify possible bottlenecks in the development to an optimal electricity system, an analytical framework has been set up. The aim is to identify possible (future) problems in a structured way, trying to make an overview that is as comprehensive as possible. For this purpose the segments production, network, demand, and balancing are plotted in a matrix. In this way, problems within the segments as well as interactions between the segments can be made clearly visible. In addition, the framework also includes policy and regulation in order to identify problems between the segments on the one hand and policy and regulation on the other. It offers a structured approach for the identification of problems and resulting bottlenecks, covering all relevant aspects of the electricity system. Table 3.1**Error! Reference source not found.** gives the matrix that is used as the analytical framework.

[3] The current degree of exposure and the speed at which these developments take place vary per country.

	Generation	Network	Demand	Balance	Policy	Regulation
Generation	• Lack of transparency • Market power • Intermittent capacity • Lack of innovation • Risk averse behaviour					
Network	• Distributed generation • Lack of locational signals					
Demand	• Long term adequacy of supply		• Inelastic demand curve			
Balance	• Intermittent capacity • Offering balancing power is not optimal	• Congestion	• Insufficient price information • Insufficient demand response			
Policy	• Regulatory uncertainty • Stimulation of DG and RES	• Unbundling			• Internally conflicting policy	
Regulation	• Permits	• Incentive regulation • Lack of innovation incentives			• Complexity of regulation and subsidy system	

Table 3.1 *The analytical framework including possible problems*

The list of potential problems presented in table 3.1 is surely not exhaustive, but we feel that the major problems are indeed included. Note that certain issues, such as more *intermittent capacity* appear in several cells due to interrelatedness of the various electricity market segments. Remember though, that the framework provides a concise way to identify and position problems in the electricity system, and cannot provide an extensive view on the causes and consequences of a certain issue.

In the next section, a selection of problems from the analytical framework will be discussed. These are (i) the increasing penetration of distributed generation, (ii) an increasingly important role for demand response and (iii) the lack of locational signals in the electricity supply system. The potential role and responsibility of governments and markets in these issues is briefly explored.

4. Analysis of potential bottlenecks

4.1 Increasing penetration of DG[4]

The increasing penetration of distributed generation (DG; including RES and CHP, whether or not intermittent) will lead to numerous technical challenges as DG, connected to the distribution network or at the customer side of the meter, is gradually changing the electricity supply system in NW-Europe.[5]

DG influences the arrangement of the power system as it interacts in a different way with the network system than centralised generation. In the past, electricity was mainly withdrawn from the distribution grids, but nowadays more and more decentralised produced electricity is also fed into the distribution grid. DG units are mostly connected to the distribution network at low voltage levels, but these sites were originally not meant to connect power generation facilities. This might pose new problems for DSOs in terms of stability and power

[4] This section is partly based on Van Werven and Scheepers (2005).
[5] Several technical experts have addressed the issue of growing DG levels in existing distribution networks (e.g. Nielsen, 2002; Strbac and Jenkins, 2001).

quality. If DG supply exceeds the local electricity demand, grid reinforcements might be required in order to transport electricity reliably and with the right quality to other demand areas via higher voltage grids.

DG, however, can also bring several advantages to the electricity network. Firstly, DG can reduce transmission and distribution losses by reducing the electricity flow from the transmission system through the transformers and conductors to the distribution system. Secondly, DG could lead to the deferral of distribution and transmission capacity investments. Thirdly, certain DG-units have the ability to offer certain network ancillary services to the network operator, such as reactive power support and voltage control, which might improve power quality. However, these advantages largely depend on the specific location of the DG unit.

DSOs need to change their network management philosophy from '*passive*' to '*active*'. In conventional electricity systems, distribution networks typically show only very limited metering or control devices that allow influencing the use of the networks or the flow of energy. Because of this lack of active control mechanisms, these systems are sometimes attributed as '*passive networks*' (Künneke, 2003; Beddoes and Collinson, 2001). An '*active network*' operator provides market access to DG by acting as a market facilitator and it provides several network and ancillary services through intelligent management of the network. This includes the incorporation of advanced information exchange between generation and consumption, the provision of ancillary services at the distributed level, management of the network to provide network reliability and controllability, and improvement of customer benefits and cost-effectiveness. Currently such services are partly provided at the centralised level by TSOs.[6]

Table 4.1 briefly presents the score of this problem on the three criteria identified in section 1.

Table 4.1 *Evaluation of problem on the basis of optimal electricity system criteria.*[7]

Increasing penetration of DG		Score	Explanation
Reliability	- Supply	+	Installed (controllable) capacity increases
	- Network	–	Changing power flows are hard to handle
Sustainability		+	DG is often more environment-friendly than conventional generation
Affordability		–	Network costs increase drastically if DG penetration is met by conventional reinforcements

Roles for market and government

Should policy-makers more pro-actively stimulate the adaptation of this new business model by DSOs? Because DSOs are operating in a regulated environment instead of in a competitive market, the statement that competition leads to innovation does not hold for DSOs. There is little incentive coming from the regulated market itself; regulation may even have a contradictory effect (Van Werven and Scheepers, 2005). Paradoxically, it is regulation that should provide incentives to DSOs to change their passive behaviour into an active and entrepreneurial attitude. Regulation should at the least not be a hindering factor in this process. Another barrier to the development of active DSOs can be an insufficient unbundling of the DSO with its parent company. Legal unbundling may not be drastic enough to let the DSOs act completely independent, thereby inhibiting them to become active network managers. Ownership unbundling may then be considered as a logical and necessary step in reaching the desired situation.

[6] According to Akkermans and Gordijn (2004), with active management of distribution networks, the amount of DG that can be connected to existing distribution networks can be increased by a factor of three to five without requiring network reinforcement.

[7] For each criterion, a qualitative value is given to indicate the direction of change that the problem implies, relative to an optimal electricity supply system, ranging from '+' to '–'.

Amongst the four countries studied here[8], only the Netherlands seems to act on the issue of increasing DG penetration very pro-actively.[9] Last year, the national energy regulator (Dte, 2004) undertook a large-scale study into the position of DG. This resulted in some slight modifications of regulation and in the introduction of 'compensation payment' for DG units that is based on avoided grid losses.[10] On behalf of the Dutch Transmission System Operator (TSO) Tennet, DSOs will pay a charge to the DG operator per kWh fed into the grid. The costs of these payments are socialised though the transportation tariffs (Dte, 2005). In addition, the total allowed increase of DSO tariffs is not only related to the economic efficiency improvement of the DSO, but also related to a quality indicator reflecting the improvement in quality of delivered service of the DSO (the so-called '*CPI-x-y'*-rule). This could be seen as a step in the right direction. What is still failing though is the incorporation of an indicator for future quality and efficiency of network management in distribution system regulation (through investment planning or investments in network innovations). All in all, NW-European distribution system regulation will need to show a considerable amount of effort in the further incentivisation of active network management of the DSOs.

4.2 Increased importance of the deployment of demand response

The importance of the role of demand response (DR) is acknowledged for quite some time but its potential role increases even further with the further penetration of intermittent generation. The development of DSR as an instrument for the TSO to balance the electricity market on the very short term could potentially increase efficiency of the market.

The increase in the penetration of intermittent generation (such as electricity generation from CHP or wind technology) will cause a considerable increase in the demand for balancing capacity. Due to limited controllability of intermittent sources and the variable and unpredictable output, additional back-up capacity is needed to successfully integrate increasing shares of intermittent capacity without affecting the reliability of the electricity system.

Traditionally, this back-up capacity was (and still is) provided by flexible (commonly gas fired) units active on the balancing market. The large role of supply-side actors on the balancing market was undoubted since the demand-side is known to be very unresponsive: elasticity of demand for electricity is very low. Still the potential back-up capacity of the demand side is large. DR resources have the ability to change demand for electricity as a response to variations in real-time market prices. This concept could enhance the functioning of the electricity market during times of scarcity by making demand more price-elastic. Increasing demand response could theoretically make it easier and less costly to meet demand reliably and could at the same time reduce price volatility (Van Werven and Scheepers, 2004).

One of the biggest challenges in electricity systems in the next decade could very well be the mobilisation of DR. The largest bottleneck is the cost of developing and installing the appropriate technology needed for the various electricity consumers to respond to real-time market prices. This will largely be a matter of consumer education and, more importantly, investing in the necessary communications infrastructure to provide consumers with the necessary information. In addition, consumers may need to invest in equipment that can help them program their loads, for instance timers or devices that switch off loads if the electricity prices exceed a specified level. All in all, implementing these arrangements on a large scale would take considerable time and investment.

Table briefly presents the score of this problem on the three criteria identified in section 1.

[8] Belgium, Germany, France and the Netherlands.

[9] For an overview on the regulatory conditions for DG in the EU member states see Skytte and Ropenus (forthcoming).

[10] The measure is called RUN ('Regeling Uitgespaarde Netverliezen') and will be effective from the 1st of January 2006.

Table 4.2 *Evaluation of problem on the basis of optimal electricity system criteria.*

Insufficient demand response		Score	Explanation
Reliability	- Supply	–	Demand insufficiently reacts to demand
	- Network	n/a	
Sustainability		n/a	
Affordability		–	Scarcity is met inefficiently

Roles for market and government

To consider the (potential) role of markets and government in tackling this issue, two aspects need to be distinguished. On the one hand, there is the technological development that is needed to eventually introduce, amongst other technologies, real-time metering equipment on a large scale. On the other hand, there is the general energy market climate that can be influenced by government. Concerning the adoption of demand-side response, the government should take a passive stand that is limited by removing barriers and setting the general conditions.

Governments could have a supplementary role in the development of the needed technology, since it could accelerate the transition towards a sustainable electricity system. In economic terms, the benefits of innovation in this field to society are theoretically larger than the private benefits to the investor.

The adoption of demand response measures could potentially be indirectly beneficial for both electricity consumers and suppliers through a more efficiently working balancing market. The most basic demand response measures include the interruptible contracts that large industrial consumers have signed with electricity suppliers. Under these contracts, electricity suppliers are under certain conditions allowed to disconnect the electricity consumer. In return, the consumer receives a financial compensation for the risk of being disconnected and a financial compensation when actually being disconnected. Lately, the Dutch TSO TenneT signed several of these contracts as a means to increase emergency capacity.

4.3 Lack of locational signals

The costs and benefits of distributed generation to the electricity system are related to the geographical point of connection. Therefore, in an optimal system these costs and benefits must be reflected in the use of system charges, connection charges and electricity pricing to the distributed generator. The presence of significant physical interdependencies between the network and generators needs to be reflected in the economic and institutional design of the sector (De Vries, 2004).

More specifically, locational signals that take into account long-run system costs and benefits should be incorporated. This locational (price) signal may be positive in the case of cost to the system, or negative in the case that DG entails benefits to the system (Van Werven and Scheepers, 2004). In the vertically integrated utilities of the past, operational control of the network was integrated with the dispatch of generators, and system development was also planned from an integrated perspective. But in the current unbundled, liberalised electricity systems in northwest Europe, locational signals are not present, and that may become a bottleneck in the development to an optimal electricity supply system.

The current system is based on fixed transmission charges that are primarily aimed at recovering network costs and do not offer an opportunity for coordination of generation investment with network development (De Vries, 2004). Furthermore, for connections smaller than 10 MVA, network connection charges are based upon shallow connection costs, while the deep connection costs are socialised.[11] A difficult issue with deep connection costs is that they are hard to determine, not transparent and, therefore, easy to abuse by system operators. In this way, system operators may obstruct the building of new generating capacity.

Table 4.3 briefly presents the score of this problem on the three criteria identified in section 1.

[11] This holds for the Netherlands.

Table 4.3 *Evaluation of problem on the basis of optimal electricity system criteria.*

Lack of locational signals		Score	Explanation
Reliability	- Supply	n/a	
	- Network	–	DG at 'wrong' locations engenders network problems
Sustainability		n/a	
Affordability		–	DG at 'wrong' locations increases costs

Roles for market and government

In the improvement of locational signals for (distributed and centralised) generation and network investments, there is a clear role for the government and the regulator. The market will most probably not be able to initialise a shift towards an electricity system with locational signals since network tariffs based on regulation. Therefore, the general framework conditions for an electricity supply system with improved locational signals should be provided in national electricity law, whereas the specificities are determined in the codes of the energy regulator.

5. Conclusions

The exact shape of the energy supply system in the long-run is uncertain. The dynamics of the system are based on market forces in a liberalised context, including on-going technological progress, on the one hand, and the direction of government policy and regulation on the other. Energy market actors balance these two forces into a gradual development of the energy supply system as a whole.

One method to discover the direction that the current electricity supply system is heading for is a systematic analysis of policy documents and scenario studies. With the focus on NW-Europe in specific, this method was applied to identify a number of 'robust' developments in the electricity supply system. This concerns both developments that can already be observed in the present and developments that are to be expected in future (i.e. the next 10 to 15 years). The four main developments identified are:

1. a continuing increase in the demand for electricity;
2. a gradual shift from conventional towards unconventional (green) generation;
3. a gradual shift from centralised generation towards decentralised generation;
4. a shift from national self-sufficient electricity supply systems towards a pan-European electricity system.

Whereas each of these developments might behold some advantage for the electricity system as a whole or for one or more electricity market actors, the transition or adoption itself might pose considerable problems. In order to identify emerging potential problems, a framework is developed. While a number of problems are well acknowledged (such as the concentration of market power or the long term adequacy of supply) other problems might have received relatively few attention.

Three of such 'less established' problems are shortly discussed. These are (i) the increasing penetration of distributed generation, (ii) an increasingly important role for demand response and (iii) the lack of locational signals in the electricity supply system.

The increasing penetration of DG does in fact pose several technical challenges, mainly at the DSO level. Depending on the position of the considered DG-unit, advantages or disadvantages emerge concerning (i) grid investments, (ii) transmission losses and (iii) power quality and reliability controls. In general, a larger DG penetration should cause DSOs to re-consider their network management philosophy: the passive network management of the past needs to be replaced by active network management. In this transition, a clear role is to be played by the energy regulator, since this actor is providing the investment incentives in the regulated market of electricity distribution.

The importance of the role of demand response (DR) is acknowledged for quite some time but its potential role increases even further with the further penetration of intermittent generation. The development of DR as an instrument for the TSO to balance the electricity market on the very short term could potentially increase efficiency of this market. The largest bottleneck in deploying large-scale DR is the cost of developing and installing the appropriate technology needed for the various electricity consumers to respond to real-time market prices. This will largely be a matter of consumer education and, more importantly, investing in the necessary communications infrastructure to provide consumers with the necessary information. To consider the (potential) role of markets and government in tackling this issue, two aspects need to be distinguished. On the one hand, there is the technological development that is needed to eventually introduce, amongst other technologies, real-time metering equipment on a large scale. On the other hand, there is the general energy market climate that can be influenced by the government. Concerning the adoption of demand-side response, the government should take a passive stand that is limited by removing barriers and setting the general conditions.

In the present liberalised electricity, there is *a lack of locational signals.* The costs and benefits of distributed generation to the electricity system are related to the geographical point of connection. Therefore, in an optimal system these costs and benefits must be reflected in the use of system charges, connection charges and electricity pricing to the distributed generator. The current system is based on fixed transmission charges that are primarily aimed at recovering network costs and do not offer an opportunity for coordination of generation investment with network development. In the improvement of locational signals for (distributed and centralised) generation and network investments, there is a clear role for the government and the regulator. The market will most probably not be able to initialise a shift towards an electricity system with locational signals since network tariffs based on regulation.

While each potential problem caused by shifts in the electricity supply system is to be tackled in its own specific way, one general lesson should always be kept in mind. The tackling does not need to be a government or regulator's responsibility. That is, the electricity market might well be capable of untangling the issue at stake by itself, with the government or the regulator only on the background setting the general conditions.

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