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State-of-the-art research: Optimal investment in market-based electric power systems

by

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Preface

This paper documents the State-of-the-art research part of the research grant 06-MARK-I25 from the Nordic Energy Research to the Energy Forum EF for 2007-09, administered by the SNF. The state-of-the-art topic chosen for 2007 was "Optimal investment in market-based electric power systems: Market and regulatory issues". A presentation of the project, with some preliminary observations and discussion, was given by the first author, Einar Hope, at the Energy Foresight Symposium (EFS) in Bergen in March 2007; see www.snf.no/energyforumef.

A Reference Group was appointed for this part of the project, consisting of Professors Eirik S. Amundsen, University of Copenhagen, Fridrik Mar Baldursson, University of Iceland, Lars Bergman, Stockholm School of Economics, and Pertti Haaparanta, Helsinki School of Economics. We thank the members of the RG for constructive advice and comments.

The literature survey in section 5 of the paper builds partly on SNF-report R02/08: *Overview of investments in electricity assets*, written by the second author of the paper, Frode Skjeret. This Report is financed by the Norwegian Water Resources and Energy Directorate (NVE) and Statnett. There is no financial overlap between that project and the present NER-project.

CONTENT

1. Introduction

Optimal investment in market-based electricity systems is one of the most important, complex and challenging problem presently to be faced within the realm of energy economics research, and also with regard to the operational implementation in optimal investment market design and regulation. It is complex and challenging because of the special properties and characteristics of electricity as a commodity in investment market terms, and it is important because the pressing need for new capacity investment in the electricity industry asks for optimal investment solutions with regard to quantity, quality, timing and location of specific investments.

A wealth of knowledge and insights has accumulated in recent years about the experience of various countries and regions with electricity sector reform and the liberalization of electricity markets.[1] The evidence of the pros and cons of power sector reform emerging from those studies is not clear-cut and uniform, but at least it should give policy reformers some guidance and understanding of how to undertake successful market and regulatory reforms in this complex sector. However, the evidence, e.g. with regard to economic efficiency gains from market reform,[2] stems largely from the effects of liberalization and deregulation within power systems of a *given capacity*, while our experience with market-based investment for the *optimal dimensioning* of the capacity of a given system is much more limited. This is partly due to the fact that generally there was considerable excess capacity in the power systems exposed to liberalization prior to the market reform, and thus the reform could proceed without the investment market being put to a real test of optimal capacity dimensioning until the excess capacity more or less was absorbed by increased demand for electricity.

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[1] Notable examples of collections of such studies are the comprehensive volumes edited by Sioshansi and Pfaffenberger (2006) and Sioshansi (2008), the five developing countries' studies edited by Victor and Heller (2007), the Special Issues of The Energy Journal (2005) and (2008), and an issue of the periodical Economic and Political Weekly (2005), devoted to global experience with electricity market reforms. A recent up-date is Joskow (2008). For a study specifically of the experience with the Norwegian electricity market reform, see Bye and Hope (2006). There are also quite a few studies undertaken in connection with sector reform programmes, e.g. by the World Bank.

[2] A recent study of cost reduction in the US electric generating industry due to regulatory restructuring is Fabrizio, Rose and Wolfram (2007).

The purpose of this state-of-the-art research paper is to surveying the literature on investment in market based electricity systems as a background for identifying and discussing some important issues in the optimal design and operation of such systems. A fundamental distinction goes between the generation and trading part of the system on the one hand, or more generally the competitive system part, and the electric power network part on the other, or more generally the natural monopoly system part. Can the two parts really be analyzed separately in relation to each other or are they so intertwined that such a separation cannot be made? We survey and discuss the two parts separately, with due regard for their inherent interdependencies with regard to the optimal design and functioning of the integrated system and then discuss some of those interdependencies more specifically.[3]
The focus of the study is on optimal investment in market-based electric power systems and not on market-based energy systems more generally. Thus, issues related e.g. to investment opportunities and investment market design deriving from horizontal diversification across the energy industry are not covered, i.e. from electricity into other energy network sectors like natural gas, district heating, oil product distribution, etc. but also to other network sectors like telecommunications and water systems, due e.g. to economies of scope; cf. the term multi-utility firms.

In section 2 we list some special market characteristics and properties of electric power as a commodity and of electricity markets to be taken into consideration when discussing optimal investment in market-based electricity systems, while section 3 lists the performance criteria that we will use in the study, with economic efficiency as the overall objective. In section 4 we ask the question: why should not optimal investment occur in well-designed electric power markets and then discuss potential causes of market failure in such markets. section 5 is devoted to a survey of the literature on investment in electric power systems, where generation (production) and transmission of electric power are treated separately, while section 6 discusses interdependencies between generation and

[3] Already in 1983, when the discussion of a deregulation and liberalization of the electricity sector was at an early stage, Joskow and Schmalensee (1983) pointed to the crucial role of the transmission network for the efficient functioning of electric power markets and warned against liberalization of the markets without taking transmission access issues, transmission rights and network capacity constraints into account.

transmission. In section 7 we make some reflections on the basic question whether optimal investment will occur in decentralized, market-based electric power systems, ending the state-of-the-art paper with some concluding remarks in section 8.

2. Market characteristics and properties of electric power

Above we have referred to special characteristics and properties of electricity as a commodity and of electricity markets, without listing them explicitly. Some of the most important market characteristics and properties in this context are:

- Electricity cannot be stored (except for water storage in hydro power based systems), and is a homogeneous product in market terms. However, technically electric power is a multi-dimensional product (energy (kWh), capacity (kW), voltage, frequency, reactive power, reliability, etc.), with implications for investment decisions in relation to stated objectives for the power system.
- Supply and demand of electricity have to be balanced instantaneously by a system operator to avoid system breakdowns or delivery fallouts.
- Demand for electricity is very inelastic in the short run. Demand responsiveness of consumers is limited and occurs generally with a time lag, because there is limited scope for real time pricing, particularly for small consumers, at least at the present state-of-the-art of technology and the operational design of real time pricing arrangements.
- Supply of electricity is also rather inelastic in the short run, particularly when approaching capacity constraints in production. The long run price elasticity is also typically low.
- Production and transmission of electricity are capital intensive and investments in capacity extensions are typically lumpy, irreversible, and long-lived. Generally, there is a fairly long gestation period for new investment, with implications, e.g., with regard to contestable entry to the market.
- The technology of generation of electric power from different energy forms (hydro, nuclear, coal, oil, etc.) has different cost structures and characteristics. Thus, the optimal composition of the production system in relation to demand is an important investment consideration.
- The electricity transmission network is of fundamental importance as an instrument or facilitator for decentralised, market based transactions and the efficient functioning of electricity markets. Thus, the mechanisms determining

optimal investment in the transmission network have to be clarified and understood.

Prior to the early electricity market reforms of the late 1980s, many observers, particularly from the engineering side, warned strongly against any attempt at market liberalization of the electric power sector, just because of the special characteristics and properties of electricity in market terms. Even though there still are some fundamental critics and sceptics, the general attitude now, across disciplines, is that those properties should be thoroughly understood and taken due account of in the optimal design of electricity markets - short run as well as long run ones.[4]

3. Objectives and performance criteria

The Norwegian Energy Act of 1990 can be taken as an example of a modern formulation of the legal basis for a market-based electric power system. The purpose of the Act is stated as follows:

> "The Act shall ensure that the generation, conversion, transmission, trading, distribution and use of energy are conducted in a way that efficiently promotes the interests of society, which includes taking into consideration any public and private interests that will be affected."

The purpose is stated fairly broadly and generally, but the overriding objective is economic efficiency throughout the value chain from generation to end-use of electric power. Thus, in the standard way, the overall economic efficiency concept may be decomposed in sub-concepts or efficiency dimensions, e.g. as follows:[5]

- Static efficiency (operation)
    - Cost efficiency/technical efficiency; elimination of x-inefficiency.
    - Optimal use of total production and network capacity.
- Dynamic efficiency (investment and innovation)
    - Optimal dimensioning of production and network capacity.

[4] For a recent, stimulating discussion on the critical side by an economist, see Timothy J. Brennan (2007).

[5] For a more detailed discussion of efficiency concepts in relation to electric power markets and competition, see Hope (2005).

- Optimal mix of production technologies and composition of network system; optimal balance between capacity enhancing investment versus investment in flexibility in relation to demand.
- Optimal introduction of new technologies and products in the value chain; incentives and capacities for innovation.
- Facilitating integration of electricity markets by investment and regulation – spatially and across energy forms for electricity production – and also in relation to other energy sectors, thereby tapping the efficiency potential in the form of economies of scale and scope through market integration.
- Optimal investment in security of supply and system reliability of the electric power system.

In the public debate on power market reform, the focus has often been more on the income distributional or equity aspects, e.g. concern about the consequences of high electricity prices for consumers at different income levels, than on economic efficiency considerations. Such aspects are also alluded to in the formulation of the purpose of the Norwegian Energy Act above, and even more directly, e.g. in the UK Utilities Bill. However, we take economic efficiency as the general performance standard for the discussion in this paper.[6]

4. Potential sources of market failure for optimal electric power investment

A starting point for a discussion of the optimal, operational design of investment markets for electric power could be to ask the question: why should not investment decisions in decentralized markets lead to an efficient outcome along the efficiency dimensions outlined under section 3 above? The economic response to it would be to identifying potential sources of market failure for realizing optimal investment throughout the electric power value chain from generation to end-use. A standard classification system of potential causes of market failure is as follows; indicating potential causes for electric power markets in parentheses:

- Public goods aspects (security of supply, supply adequacy).
- Externalities in production and consumption (green house gas emissions).

[6] For some discussion of efficiency versus equity objectives, see Hope (2005).

- Market imperfections:
  - Economies of scale (natural monopoly of the transmission network).
  - Monopolization; exercising market power (market concentration, market dominance).
  - Missing markets, e.g. for capacity regulation or financial risk hedging; imperfectly functioning markets.
- Regulatory imperfections (weak or improper competition policy enforcement; weak or improper incentives for investment in regulatory policy regimes).
- Imperfect information (asymmetric information, e.g. between producers and consumers or between regulators and those being exposed to regulation).
- Uncertainty (long pay-back period for new investment; long-lived investment).

Electricity investment markets are prone to suffer from market failure over the whole spectrum of potential causes listed above. In the literature survey in section 5 we concentrate on investment properties of the market-based electricity system as such and not so much on the "surrounding" system, i.e. issues related to externalities, regulatory imperfections and other forms of policy intervention in the investment markets. There is also more emphasis on the power production and transmission parts of the value chain, and on relationships between production and transmission, than on the end-use of power part of the chain.

5. Investment in electric power systems: A survey of the literature[7]

A survey of the literature on investment in market-based electricity systems has, necessarily, to be selective. In this section we focus on investment in generation and transmission, respectively, on the assumption that they can be analyzed separately, while in section 6 we discuss interdependencies between generation and transmission.

[7] The section draws heavily on Skjeret (2008).

5.1 Investment in generation

Among the several factors that need to be taken into account when assessing optimal investment in electric power generation, five of the most important ones are discussed below.

5.1.1 Licensing

In order for an investor to be able to build a generation facility, licenses from public agencies are normally required. There are many aspects of the licensing procedures that we cannot go into, e.g. the capacity and the competence of the licensing agency to handle applications in a timely fashion so that unnecessary delays in the investment process do not occur. The licensing process for investing in generation capacity today may, however, be used as a tool for assessing future generation activities, not only because one can foresee intended investment plans, but also because one may learn about the profitability of different technologies in various regions.[8] This requires that the application for licenses actually describes the intentions of the investors. Further, the licensing process may be a valuable device for the system planner or operator[9] to govern the future investment process on the production side. This requires though that the system planner and the licensing agencies are closely connected.[10]

5.1.2 Profitability

Assuming that licensing is not an obstacle, private entities subject to competition must find a project profitable in order to invest in new generation capacity, and will therefore look at expected future prices and costs when determining their optimal level of generation capacity. Cases where firms first invest in a certain level of production

[8] The deregulation of the Norwegian electricity system has recently been evaluated in ECON (2007) and Hammer (2007), also in relation to licensing. For a more general evaluation of the experience with the liberalization of the Norwegian and Nordic electricity markets, see Bye and Hope (2006 and 2007).

[9] System operator is here used in a transmission system operator (TSO) sense, having direct influence over transmission investment, and not in an independent operator sense (ISO), where such influence is typically more indirect. In the Norwegian system the Norwegian the energy regulator, NVE, has the main responsibility for system planning, while Statnett SF is the system operator (TSO).

[10] ECON (2003) discusses the relationship between a transmission system operator (Statnett SF) and generators in an investment context.

capacity and in later periods maximise profits taking the investment choices for given (during the working life of the investment) was initially analysed in Johansen (1972).

Green (2006) discusses optimal investment in generation capacity using the framework of peak-load pricing. He argues that, within the framework of peak-load pricing, there are three reasons for investing in capacity. The first is the case when the market has a lower than optimal level of capacity of a particular technology. Second, if a plant is allowed to reach the end of its physical working life, it must be replaced. Third, plants need not be allowed to reach the end of their working life in equilibrium. If a more efficient plant type becomes available it may be profitable to replace the old plant type with the newer and more efficient one. Green (2007) also discusses the case of optimal plant mix in a generation market, noting that efficiency is not only restricted to the optimal level of total capacity, but also the optimal mix of the various generation technologies.

5.1.3 Market rules and operations

Joskow (2006) discusses incentives for investment in generation capacity, and in particular two potential impediments due to market rules and operational procedures.[11] Following Cramton and Stoft (2006), he argues that spot prices cannot be expected to be high enough to provide proper incentives for investors to invest in a cost-minimising portfolio of generation assets. This is referred to as the "missing money" problem. It is also argued that the rules governing the market may be used in a less than optimal way, for instance, price caps are regarded as detrimental for investments. A part of such reasoning may also be related to regulatory uncertainty about the future development of market rules, potentially affecting prices and also the expected behaviour of transmission system operators.

The second feature related to market rules and operations is the choice of how regional prices of electricity are determined. Prices are allowed to vary regionally in most

[11] Volatile prices – a third topic mentioned by Joskow – are in some instances argued to reduce the amount of investment on the generation side of electricity markets. The example in Varian (1992), page 42 (and in most other textbooks in economics) illustrates that – since profit functions are assumed convex – uncertainty in prices will lead to a non-negative change in profits. As noted by Joskow (2006): "I do not think much of the argument that price uncertainty per se deters investment".

deregulated electricity markets, and also access charges affect the cost of production according to where the facility is situated. The literature on regional pricing in electricity were initiated by the seminal work of Schweppe *et al* (1988). Following their work, Chao and Peck (1996), Cardell *et al* (1997) and Bushnell and Stoft (1996) apply models of Schweppe *et al* (1988) to study various economic aspects of transmission constrained electricity markets. The main conclusion from these models is that regional price differences will give private agents incentives to invest in areas of high prices (most likely excess demand areas), and potentially make investment in load in low-price areas. These models focus largely on how the price-mechanism in various markets (spot market, forward markets and ancillary markets) could best be organised in order to provide incentives for deregulated entities to behave competitively. Since any investment in transmission or generation (or demand) may affect regional prices, investors must also take into account the effect their investment has on prices. E.g. in Norway, zonal prices rather than nodal prices are applied. This has been analysed by Bjørndal and Jörnsten (1999) and Bjørndal *et al* (2002). Bjørndal *et al* (2002) also discuss various methods for congestion management and how these methods potentially affect prices and therefore the economic surplus of the various agents, including the system operator. They argue that the system operator may have incentives to affect the location of capacity constraints, thereby affecting the system operator's revenue.

Both arguments mentioned above ("*missing money*" and "*market rules*") rest on three characteristics of electricity markets that may well lead to a less than optimal level of investment on the generation side. The above-mentioned impediments to investing optimally in generation technologies are further examined in Joskow (2006) who investigates characteristics of i) certain production plants, ii) market operations, iii) demand side, and iv) flow of electricity over the grid. First, a fraction of the generation capacity in most thermal electricity markets is only used in periods of peak demand, thus the revenue required to cover both production and investment costs must be earned during only a few hours each year. These plants are naturally sensitive to the level of prices in the few hours when they are in operation, and price caps or public intervention during those hours (either on the demand or generation side) may reduce incentives to invest in these capacities.

Similar arguments can be used when analysing incentives to invest in generation capacity e.g. in the hydro based Norwegian power market, both in relation to wind power and hydropower production capacity. In a hydro based system one may reason similarly in relation to storage capacity, since one optimally must store water for dry years occurring only rarely. Second, it is argued that electricity generation capacity in any one hour must be higher than the demand for electricity, in order to provide reserve capacity. Accordingly, the combined electricity market must carry an "inventory."[12] When the reserve requirements are violated, system operators take measures to increase the reserve capacity. If these measures are not properly arranged and applied, firms may not have incentives to invest in a sufficient level of capacity. For example, reserve production capacity owned and operated by the TSO can be used to affect prices. Reserve production capacity should only be used in extreme situations to deter system breakdown, and not in order to reduce prices in periods of peak demand. Third, real time pricing is in use only partially and individuals may not have the proper incentives for responding in situations of scarcity.

Joskow and Tirole (2004) point up three reasons for why the demand side does not adjust consumption according to real-time prices in the wholesale electricity market. First, consumers may not have real-time meters installed. Second, if small consumers do have real-time meters installed, the cost savings from adjusting demand according to prices may be relatively small. Finally, some large consumers may find it very expensive to adjust its consumption in the short run, making them less flexible. Thus, short-term scarcity situations (in Norway, e.g. a very cold winter day) may not to a satisfactory degree reduce demand for electricity. Reliability of supply is therefore frequently in the very short term regarded as a public good (see for instance Hung-po Chao *et al* (2005) and section 7 in this paper). This problem may - in a hydro based electricity system – also

[12] There are in principle two ways of carrying this inventory, either by purchasing generation capacity or by purchasing the right to close down consumption units.

be relevant in the long term, when optimal storage of electricity must be determined months prior to when the scarcity situation sets in. Finally, electricity flows according to physical laws and re-directing the flow of electricity comes at a high cost. Thus, the system operator is not adequately able to differentiate between consumers with varying degrees of marginal willingness to pay for electricity and reliability.

The general impediments for investment in generation capacity will not be studied here per se; rather the implications for investment in generation will be discussed in relation to the planning of investment in transmission capacity. The general literature on investment in electricity is to a great extent concentrated to thermal production facilities; analyses of hydropower markets are found in Førsund (2007a).[13]

5.1.4 Access charges

A fourth factor affecting the decisions of investing in generation capacity is the charge required for getting access to the grid. One particular concern when it comes to providing incentives for an efficient electricity market is how generators optimally should pay for costs related to connecting new production facilities to the transmission grid. If new generation capacity is connected to the grid, all regional prices – and all relative prices – are potentially affected, and may require additional transmission capacity. Access charges must therefore be arranged so that proper incentives for generation firms to invest optimally are provided.

This is of general relevance for transmission grids as new production facilities are required to meet increases in demand. This is also relevant since authorities in many countries aim to give incentives for increasing the use of renewable electricity technologies in production. Of particular interest is the focus on providing incentives for the construction of wind farms located far from load centres. Access (to the grid) is a commodity that users of the grid should pay for. Since additional generation capacity affects the flow of electricity on the grid, there may be a need for strengthening the

13 See also Førsund (2005), von der Fehr (2005), Crampes and Moreaux (2001), Hoel (2004), and Garcia et al (2001).

transmission network. There are also costs to society (externalities) that the investor (generation-firm) does not take into account unless an access charge regime is in place. One may therefore argue that the costs to the network consists of several cost components that must be paid for, either by i) the new generating facility, ii) the consumers or iii) all entities demanding network services. Assume that the total cost of connecting a new production facility (TC) is given by:

$$TC = C_L + C_S + c_R + c_L + c_{RD}.$$

C_L gives the (local) fixed costs related to connecting the production facility to the network, while C_S is the (central) fixed cost related to network upgrades required in other parts of the network. As the production facility is connected to the grid, and production takes place, this entity also affects the reliability of the network. This component is described by c_R. What is more, the flow of electricity on the network will be altered and the losses in the network is altered, this is given by c_L. Finally, c_{RD} gives the costs related to redispatch. Note that only the fixed local investment cost is always positive.

The debate on access charges for new generation facilities is often analysed via two extreme versions of access charges, deep and shallow access charges. The former type of access charge implies that the generator must pay $C_L + C_S$ up front and also $c_R + c_L + c_{RD}$ during the life of the production asset.[14] The other extreme – the shallow access charge – takes a very different view. In this case, only the local fixed costs of connection are paid by the new generation facility, while all other costs are covered by a system charge.[15] The following table illustrates the alternative access charges:

Table 1: Access charging

	GENERATOR CHARGE	SYSTEM CHARGE

[14] A scheme similar to this is applied in the Pennsylvania-Jersey-Maryland electricity market, Hiroux (2004). Jamasb *et al* (2005) argues that there is an example in the Pennsylvania-Jersey-Maryland-market where the cost of connecting a new production facility to the network would equal the cost of building the generation facility.

[15] A version of a shallow connection charge is applied in the Danish electricity market, Hiroux (2004).

DEEP ACCESS CHARGE	$C_L + C_S + c_R + c_L + c_{RD}$	
SHALLOW ACCESS CHARGE	C_L	$C_S + c_R + c_L + c_{RD}$

If one assumes that the system operator is perfectly regulated, so that all charges are recouped either via producers or consumers (or both), the system operator may be indifferent between deep and shallow access charges. Two general results are readily available; first, when generators have to pay for all the connection costs, the access pricing regime provides high-powered incentives for localising production plants in regions where connection to the grid is favourable. Second, when the access charge is shallow, incentives are to a large extent rigged so that the cheapest production plants are being built. From a welfare maximising point of view, neither of the two extremes is necessarily desirable. On the one hand, shallow access charges may lead to an energy system with cheap electricity production entities in the wrong regions, while deep access charges may give expensive production facilities in favourable regions.

If nodal prices could be expected to bring about optimal investments on the generation side, these could be used as approximations of variable charges, and fixed charges would be required to be recouped by the system operator, for instance via taxation. Jamasb *et al* (2005) discuss several issues related to the design of optimal access charges for distributed generation plants, taking both theoretical and political issues into account. Among the issues discussed are:

- ✓ Deep versus shallow access charges
- ✓ Forward looking access charges
- ✓ Locational signals for load
- ✓ Differentiation between energy charges, capacity charges and fixed charges

5.1.5 Lumpy investments

A typical aspect of investments in the electricity sector (both transmission and generation) is lumpiness. In this section two issues related to lumpy investments are discussed.

Smeers (2006) argues that there is no common usable understanding of long-run marginal costs in the electricity market. He argues that cost allocation rules need not be the best way to proceed, and that such a framework need not provide the correct signals for investors looking far into the future when determining whether to invest in additional capacity or not. Using a model of integer programming, thereby allowing for lumpy investment in transmission, Smeers argues that the three criteria that are used when evaluating investments, i) economic efficiency, ii) cost reflectiveness and iii) non-discrimination, cannot simultaneously be obtained. However, one should not take all lumpy investments or non-convexities as problematic. Only in cases where the size of the lumpy investments are large compared to the overall market (or regional market when transmission constraints are present) does this pose a problem. This is similar to the traditional microeconomic argument of a large set of competitive firms described by both fixed and variable costs of production. Each and every firm has a U-shaped average cost curve. However, although individual firm's supply functions are discontinuous, the discontinuities are irrelevant in a large market.

5.2 Investment in transmission

In order to secure static efficiency, the system operator needs to see to it that the current transmission assets in place are used optimally. This can be seen in conjunction with the ability of the system to provide supply security. However, the transmission operator must also invest in transmission capacity and facilitating efficient investment in production capacity, so that supply adequacy is secured. This involves creating incentives for agents to invest in capacities necessary to meet future demand. Transmission adequacy is often taken to consist of two elements, sufficient capacity to balance load and generation, given known and unexpected outages, and sufficient capacity in order for firms to sell electricity at marginal cost, thereby securing an efficient electricity generation market. Thus, the first component is related to reliability, while the second is related to merchant aspects of the electricity market.

5.2.1 Licensing and public resistance

Building transmission lines in a deregulated market is a task for investors (or public agencies), but there are communities that may be adversely affected by these investments. In economic jargon, this implies that transmission investment imposes negative externalities on others. For instance, building a transmission line across a national park would most likely create a cost to society, in addition to the cost of the transmission line itself.

Fischbeck and Vajjhala (2006) analyse transmission externalities, using four indicators to quantify the difficulty of siting large transmission projects (and also other large electricity projects like wind power farms): public opposition, regulatory roadblock (projects that affects several jurisdictions), environmental constraints (the physical and environmental aspects of the site) and system barriers (requirements from other parts of the electricity system may reduce the viability of certain projects). They use formal models to quantify difficulties related to siting large projects in the USA. When large projects create externalities, it will lead to public resistance to the project which in turn makes the project a less likely candidate for investment. A similar reasoning is used when analysing the potential for wind production along the coast of Norway, where a large fraction of viable locations would be located in the very north. This is partly due to the fact that this region is more sparsely populated than the coastline in the south, Statnett (2004a).

5.2.2 Transmission investment and transmission enhancement

The general literature on investments in transmission capacity in electricity markets can roughly be divided into two categories, one focusing on the optimal regulation of transmission entities, while the other discusses whether investment decisions of transmission firms can be analysed, taking the economic model of perfect competition as a starting point.

The first strand of literature argues that there should be independent, regulated transmission operators investing in capacity, owning the lines and operating the network. In an early study of the deregulation of the electricity industry, Joskow and Schmalensee (1983) discuss various regulatory framework for the transmission system. More recently, this literature has analysed various regulatory regimes required to have the regulated transmission operators behave as desired. Vogelsang (2005) discusses performance-based regulatory mechanisms and their effects, related to short-run as well as long-run efficiency.[16]

The second strand of literature takes the opposite view, that transmission firms can be regarded as competitive entities, assuming that competitive forces between transmission firms may provide sufficient incentives for transmission investment (this framework is often referred to as the 'merchant transmission model').

Hogan (1992) studies how perfectly competitive environments may contribute to an efficient level of transmission capacity. Bushnell and Stoft (1996) study various ways to define transmission property rights and their impact on transmission investments, see also Bushnell (1999). Chao and Peck (1996) discuss how access and pricing policies affect efficiency in the market. Recently, this literature has been criticised by Joskow and Tirole (2005). They discuss several assumptions underlying the models mentioned above – assumptions that are hardly met in electricity markets – making the merchant transmission model less usable. In fact, they argue that the conjectures that profitable investment will be undertaken and unprofitable investment will not be undertaken may both be wrong.[17] Some of the factors listed by Joskow and Tirole are discussed below, since some of the factors will also affect generators' decisions regarding investing in production capacity, thus public transmission firms may face similar difficulties.

Lumpy investment: Investments in transmission capacities are not continuous, but rather restricted to various (largely) fixed sizes. In a path breaking, early study, Turvey (1969) discusses marginal cost pricing in such an environment, with illustrations from the electricity industry, while Turvey (2000) discusses access pricing in relation to lumpy investment (also in relation to electricity markets). Turvey (2000) discusses the relative merits of the American SMD-model (standard market design) and the British net-pool

[16] For an overview over recent theoretical advances in regulatory theory underlying much of the practical regulatory frameworks in electricity, see Armstrong and Sappington (2007).

[17] From the assumptions underlying the theories applied in this literature it can be shown that i) profitable investment, satisfying network constraints, will be undertaken and ii) unprofitable investments will not be undertaken, see Joskow and Tirole (2005).

arrangement, arguing that the use of system charges in the British model makes this framework “score highly with respect to long-run locational incentives.”

Asset specificity: Once an investment in transmission capacity has been undertaken, investment costs can be regarded as sunk costs. Williamson (1983) introduced the concept of asset specificity and also defined four types, i) physical asset specificity, ii) site specificity, iii) human asset specificity, and iv) dedicated assets, where the first two types are most relevant here. The analysis of asset specific investments highlights the fact that cost before and after investing may differ. When investing in transmission capacities in order to meet expected demand for transmitting electricity from new investments in generation to load regions, hold-up problems due to asset specificity may arise.

Nodal energy prices may not reflect willingness to pay for energy and reliability. Reliability of supply is to a large extent non-depletable in electricity networks and competitive market equilibria would most likely be held back by free-riding. Thus, reliability has public good characteristics and may therefore not be sufficiently incorporated in nodal prices.

Network externalities may not be internalised in nodal prices: When transmission capacities are added to an existing network, all flows of electricity are potentially affected and therefore also nodal prices (and price differences). Accordingly, investments in transmission impose externalities on all other agents (producers, consumers and other transmission owners). One way to overcome this problem would be to define a set of enforceable and tradable property rights so that investors internalise the effect their investments have on other agents. The optimal organisation of such property rights – and whether they can induce a welfare optimising outcome – is currently debated in the literature.

Transmission capacity is stochastic: The potential capacity of a line is determined by reliability measures (like N-1, N-2 or probabilistic tools). This implies that the potential flow over a line is determined by the probability of failure in other parts of the network or the potential failure of generation capacities.

Market power: In the models above, all generators are assumed to behave in a competitive manner. In quite a few electricity markets, market power among generators is seen as an important impediment to efficiency.[18] Accordingly, prices would not equal marginal cost of production. In relation to the debate on investments in transmission, market power is important since low transmission capacity between regions may increase regional market power exertion.

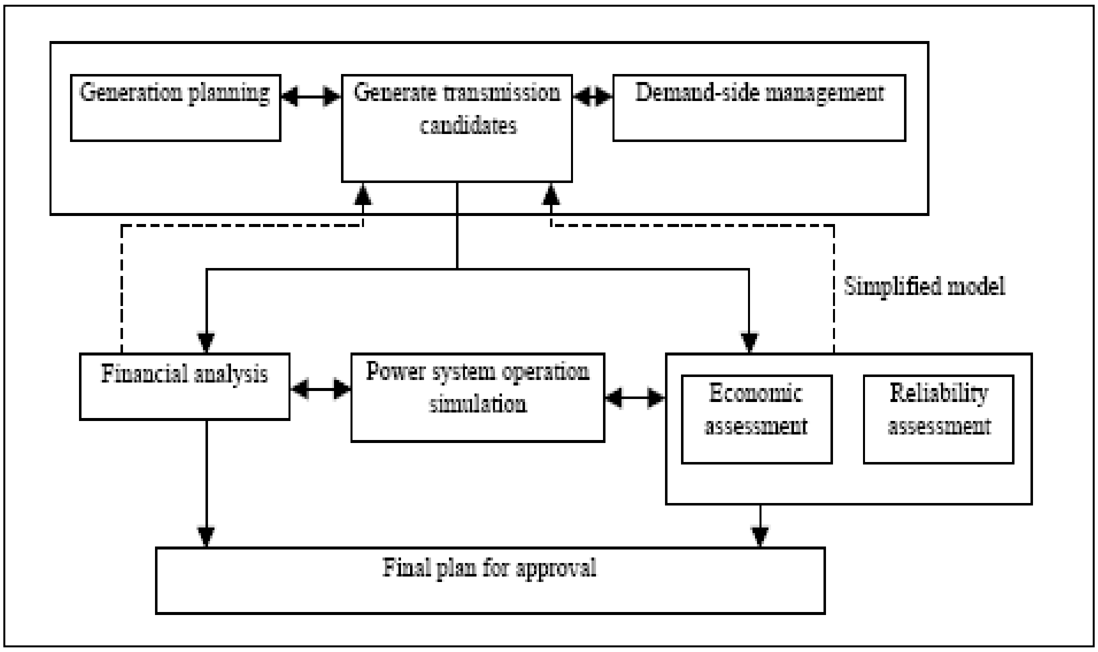
System operators may have discretion to affect transmission capacities: System operators have substantial leeway for affecting transmission capacity. In real electricity markets, system operators may reduce capacity on a transmission line due to congestion in another part of the system. Further, in extreme situations system operators may i) add to production and/or reduce demand. In some jurisdictions, system operators may also reduce the voltage-level, effectively reducing demand. Such measures may negatively affect incentives to invest in generation capacity if not handled properly.

6. Interdependencies between investment in production and transmission

In section 5 we discussed optimal investment in electric power production and transmission separately, emphasizing, though, that the two parts of the electricity system are closely interrelated and interdependent. The transmission system is of fundamental importance as a vehicle to facilitate market-based transactions and efficient price formation in competitive electricity markets, and new investment in the system may change the efficient functioning of it in this regard, if this relationship is not sufficiently understood and taken into account by the transmission system planner or by the system operator. Likewise, investment on the production side may change the composition of the

[18] See for instance Green and Newbery (1992), Amundsen and Bergman (2002), von der Fehr and Harbord (1993) and the references therein. Skaar and Sørgard (2006) and Johnsen (2001) discuss market power in the Norwegian electricity wholesale market. For a comprehensive survey of market power and market dominance in electricity markets, see Hope (2005).

power generation mix over different generation technologies or the regional distribution of the production system. E.g.
investment in generation facilities may change the ratio of production to demand significantly in one region, demanding increased export capacity from that region, or alternatively, relieving congestion. Public policies toward renewable technologies, e.g. wind power, may add to variations in regional production-demand ratios, not only by contributing to investments in generation capacity in one region, but also by reducing incentives for investment in other regions.
In order to overview and integrate interdependencies between investment in power production and transmission, one needs to undertake a full system design approach to the electric power



system. An example of such an approach is Wu *et al* (2006). Their figure 2 summarizes neatly the aspects that have to be considered and analyzed when deciding on an optimal investment or optimal investment plan for the transmission system, due to interdependencies between generation and transmission.

Any additional generation capacity connected to the network will to a certain extent affect both the price of electricity and the flow of electricity on potentially all transmission lines on the grid. However, it is not only the increase in total generation capacity that matters, but also, as mentioned, the effect of a given investment in generation on the composition of the production system across generation technologies as well as the impact on the regional distribution of generation capacity in relation to capacity of the transmission network. Therefore, such aspects should, in principle be taken account of in an optimal investment plan for the power system as a whole, as illustrated above in the figure by Wu *et al*. Likewise there may be several investment alternatives in the transmission network to accommodate a given demand for new network capacity, so that the composition mix of new investments adding optimally to the increase in transmission capacity has to be considered. We will not go into such issues in this survey, but concentrate on the "vertical" interdependency between power production and transmission.[19]

As noted repeatedly above, investment in transmission capacity has impacts on investment in generation. Both reliability of supply and the potential for transmission constraints would affect generators' profitability, either positively or negatively. Investment in transmission capacity affects all relative prices and most likely the expected level of prices in electricity markets. Also, optimal access charges for connecting to the grid will affect the decision to invest. Thus, generators must foresee investment in transmission when determining optimal generation investment. The planning regime that is in use by the transmission operator is thus an important tool for generators when determining how much to invest in a specific technology and in a specific region.

[19] For an overview of some aspects, particularly with regard to investment in wind power or other intermittent power technologies, see Skjeret (2008). For a discussion of generation technology mix in competitive electricity markets, see Glachant (2006).
Contributions from other strands of literature, *e.g* real option and contract theories, to the analysis of investment in market-based electric power systems, incorporating the inherent uncertainty underlying investments decisions and the interdependencies between investments in such systems, requiring a dynamic framework of analysis, are not covered here. For an application and discussion of real option theory in relation to electric power investment, see e.g. Botterud and Korpås (2005), Kjærland (2007) and Stoft (2006). For an overview of contract theory, see Bolton and Dewatrapoint (2005).

Increased transmission capacity may also contribute to increased reliability of the overall transmission system. As discussed in Joskow and Tirole (2005), this may reduce the uncertainty related to stochastic transmission capacity thereby increasing the incentives for investments in production capacity. As a consequence, investing in transmission capacity for enhancing reliability of the transmission network reduces the uncertainty facing generators, thereby potentially increasing incentives to invest. What is more, transmission capacity affects market power exertion, most likely negatively. Thus, the potential of being capped from the market – as in Cardell *et al* (1997) – is most likely reduced when transmission investments are undertaken.

Sauma and Oren (2006) also study how investment on the transmission side potentially affects investment on the generation side. They use a three-stage model to analyse how transmission investment affects incentives for investment in generation capacity. In the first stage, investment in transmission is undertaken, then generating firms choose their optimal level of investment in generation capacity, and finally, the generation firms compete in the spot market for electricity, where the spot market is characterised by nodal pricing. One of their main conclusions is that investment in transmission capacity has potentially large distributional impacts. They apply their framework for the Chilean market (32 node system), illustrating that proactive planning differs from reactive investment decisions even in a three-period model of an electricity system.

Joskow (2006) examines alternative institutional arrangements in relation to the governance, operation, and maintenance of networks. He considers investment in transmission capacity in relation to opportunities and incentives to reduce congestion losses and investment rationalised by reliability criteria. He argues that reliability rules play a much more important role in transmission investment decisions today than do economic investment criteria as depicted in standard economic models of transmission networks. However, he also states that economic and reliability-based criteria for transmission investment are fundamentally interdependent. If these interdependencies are ignored, it will have adverse effects on the efficiency of investment in transmission infrastructure, undermining the success of electricity market liberalization. He draws two implications: “(a) we need to better understand the economic justification (costs and benefits) for these reliability criteria and (b) economic models of transmission investment need to take into account the factors that create a need for reliability criteria and the impacts of reliability criteria that are applied in practice.”

7. Will optimal investment occur? Some reflections

The literature survey in sections 5 and 6 has identified several potential causes why investment in a market-based electric power system will not necessarily be optimal in terms of a) capacity expansion, b) composition of the production mix of generation technologies in relation to the structure and variability of demand, c) location of new production facilities in relation to the transmission network, d) the composition of the portfolio of transmission network assets to secure reliability of delivery of transmission services and e) the optimal functioning of the transmission network as a “market” in relation to competitive electricity markets, including e.g. the handling of transmission network constraints in the short run and optimal investment in the elimination or reduction of such constraints in the long run. Some lessons and insights can be drawn from such a survey with regard to market and system design and implementation to achieve optimality, but a survey cannot, of course, in itself assess how much, in a given situation, the actual flow of new investment deviates from the optimal flow. This requires an empirical efficiency analysis of investment behaviour in a specific case.

In this section we will reflect on some lessons and experiences that may be drawn with regard to optimal investment in electric power systems, partly on the basis of the literature survey, but also on some potential causes for market failure in power markets and systems that are not specifically covered in the survey. This will necessarily have to be done in a summary fashion. We start with the production and end-user parts of the power value chain, or competitive parts, and then the network part, recognizing the interdependences between them, as discussed above, and then some remarks on investment for energy security and system reliability purposes.

7.1 Investment in competitive power markets

Four issues or causes of market failure seem to be of particular importance here, i.e. a) economies of scale in generation technologies and economies of scope in the composition of the production mix of generation technologies, b) exercise of market power, c) externalities in the production and use of electricity, and d) information asymmetries on the end-user side.

7.1.1 Economies of scale and scope

Economies of scale as a potential market failure factor is dependent upon the size of the relevant power market area in relation to the optimal scale of the investment in question, which again is dependent upon the form and degree of market integration, where the power network capacity and facilities spanning the market play a crucial role. The accommodation e.g. of the new 1600 MW Finnish nuclear power plant into the market, on the assumption that 1600 MW is the optimal scale of plant, will have to be assessed quite differently from an investor and economic efficiency perspective whether this investment is considered in relation to an isolated Finnish power market or to a fully integrated Nordic market or even to a wider integrated European market. In general, economies of scale in power production, considered in isolation, do not seem to an important source of failure in power investment markets under the present degree of market integration.[20]

Economies/diseconomies of scope with regard to the composition of generation technologies in the overall production system has gained increased importance and attention as a consequence of the push for introducing new renewable power technologies, e.g. wind power, into the system, driven to a large extent by environmental concerns and political stimuli. Because of the inherently intermittent nature of such production technologies, their introduction into the power system raises a number of long term investment as well short term operational issues with regard e.g. to the size, form and location of the investment (e.g. clustering of wind farms in a location), generation scheduling, frequency management, stranded costs or the decommissioning of assets in

[20] For some discussion see e.g. Leveque (ed.) (2006) and Jamasb et al (eds.) (2006).

the established system as a consequence of the introduction of the new renewable technologies, etc, which basically is a question of economies or diseconomies of scope across generation technologies in the optimal composition of the production mix in relation to demand.[21] However, it is also a question in relation to the structure and regulation of the transmission network, e.g. regulated access charges to the network to facilitate the introduction and use of renewable power; see Subsection 7.2 below.

7.1.2 Exercise of market power

Exercise of market power is a serious potential source of market failure in electric power markets, because of the properties and characteristics of electricity in market terms and the generally high degree of market concentration in electricity markets.[22]

In investment power markets the exercise of market power can take many different forms. It can be used strategically to block or pre-empt entry to the market in the form of competitive new investment from market entrants, it can be used to withholding capacity to raise prices and then also lowering them strategically to deter entry, it can be used to distort the optimal composition of the production system by exercising market power discretionally between generation forms, e.g. between thermal and hydro power, it can be used under vertical integration, without full unbundling between generation and network activities, to distort competition and investment by cross-subsidization, to mention some forms.[23]

While the scope for the potential exercise of market power may be a serious cause of market failure in power markets, is the actual exercise of such power a problem in the short term for power markets in general and in the long term for investment power markets in particular? In the end, this is a question whether there is a “policy failure” in the design and efficient enforcement of the competition policy regime in relation to electricity markets. E.g. if the actual enforcement is not sufficiently strong and active to prevent the exercise of market power in the relevant market, or the enforcement power of

[21] For an overview and discussion, see Skjeret (2008).
[22] For an overview and discussion, see Hope (2005).
[23] For a discussion of (ownership) unbundling, see Pollitt (2007).

the competition policy regime is split up or insufficiently coordinated among (national) jurisdictions in an integrated, common electric power market, this may result in weak policy enforcement.[24]

7.1.3 Environmental effects of production and consumption of electricity (externalities)

This is a huge and complex area and probably the one that is most in focus in the political and public debate. In the present context one set of issues relates to the identification and valuation of environmental costs of production and consumption of electricity in investment analysis and decision making. Another set of issues concerns the design and selection of instruments and mechanisms, and their properties, for the efficient handling of environmental effects of power production and use; in particular, the design and operation of environmental markets, like emission quota markets and "green" certificate markets, and their properties in relation to other environmental policy instruments, e.g. environmental taxes. A third set relates to more long term investment issues, e.g. how to realize a future low-carbon electric power production and consumption system, mainly because of potential harmful environmental effects of green house gas emissions from the use of fossil fuels in electricity production, by means of environmental policy stimuli.[25]

The design and implementation of existing environmental markets, like e.g. the European Emission Trading Scheme (ETS) and the Swedish certificate market[26] for renewable power, have been subject to flaws and problems in the formative stages, resulting in inefficient performance. However, the performance seems to be improving due to various regulatory interventions and design improvements.[27]

More important than imperfectly functioning environmental markets to explain why the environmental policy towards GHG emissions and other environmental effects of energy use in the electricity sector may have fallen short of stated policy objectives, however, has been a lack of consistency and stability over time in the environmental policy

[24] The Nordic competition authorities have recently published jointly a comprehensive and interesting report on investment for an efficient Nordic electricity market. See Nordic Competition Authorities (2007). See also Nordic Competition Authorities (2003).

[25] See e.g. Jamasb et al (2008).

[26] A common Swedish/Norwegian certificate market was planned, but has not realized yet. Discussions between Swedish and Norwegian authorities have, however, been resumed.

[27] See a.o. various reports and documents from the EU Commission wrt the ETS, e.g. Ecofys (2006).

framework, resulting in uncertainty and in lack of predictability for investors with regard to investment cost and timing and form of investment. A relevant case could e.g. be the Norwegian policy approach to investment in gas fired power plants and the various solutions advocated for CO2 sequestration and storage in connection with the investments, where policy consistency and predictability over time have been relatively weak.

7.1.4 End-use investment

The analysis of investment in competitive power markets has to a large extent been concentrated on the production side, while the potential for efficiency gains from new investment and innovation may be even larger on the end-user side. There are two main issues or problem areas to be considered here in relation to optimal investment.

One set of questions relates to improving the design and operation of retail electricity markets and activating the demand side to make it more responsive to changes on the supply side, e.g. in relation to supply shortages or obtaining better capacity utilization of production facilities. Relevant measures could be to implement real time pricing mechanisms, developing risk-sharing contracts between producers and consumers, investing in two-way communication systems between producers and consumers, investing in smart metering technologies,[28] etc. Investment in decentralized, small-scale production systems for electric power close the consumers, e.g. micro-generation, would also fall within this area.

A second set of issues relates to various kinds of information barriers for the optimal flow of investment on the end-user side, which can be grouped under imperfect information barriers and asymmetric information barriers between producers and consumers, respectively. These information barriers are to a large extent due to the long-lived nature of many types of investment on the end-user side, e.g. in houses/buildings, where the economic lifetime of such investments typically is much longer than the planning time horizon of the end-users, and where investment in energy/electricity facilities, and their

[28] See e.g. Owen and Ward (2007).

operating costs, account for a relatively small share of the total investment and operating costs of such buildings.

Many developments are taking place in this area, partly with the purpose of improving information to end-users and partly by promoting the energy performance of buildings by introducing various forms of energy efficiency standards and measures. This can be exemplified with two EU Directives issued by the Commission, i.e. the Energy Performance and Buildings Directives (EPBD) (2003) and the Energy End-Use Efficiency and Energy Services Directive (ESD) (2006)[29], respectively.

The EPBD is designed to promote the energy performance of buildings in Member States through: a) the introduction of a framework for an integrated methodology for measuring energy performance; b) the application of minimum energy performance standards in new buildings and certain renovated buildings; the energy certification and advice for new and existing buildings; and c) the inspection and assessment of boilers and heating/cooling systems. The purpose of the ESD is to encourage energy efficiency through the development of a market for energy services and the delivery of energy efficiency programmes and measures to end-users. There are a number of problems with the implementation and enforcement of the Directives, but they represent interesting efforts and approaches to cope with information barriers with regard to investment and operation of information services for energy on the end-user side.

7.2 Investment in electric power networks

Even though they are interrelated, a distinction can be drawn between the optimal structure and organization of the electric power network on the one side and the optimal regulation of the network as a natural monopoly on the other.[30] The literature survey in sections 5 and 6 covered many questions and issues relevant for optimal network investment decisions with regard to both network structure and regulation. In this section we will list in a summary fashion some factors and issues that have to be taken into

[29] The ESD has a wider coverage than just buildings, but is highly relevant for them.
[30] See von der Fehr, Hagen and Hope (2002).

consideration, primarily when deciding on investing in the optimal structure and organization of the network, while Subsection 7.3 will be devoted to a brief discussion of the relationship between security supply of power and regulation of electric power networks in liberalized power markets.

7.2.1 Network structure and organization

- The network as a natural monopoly
    - Technical properties and characteristics of network functions and services, physical power flows, network externalities, system effects, etc.
    - Identification and demarcation of natural monopoly functions; relationship between natural monopoly services and ancillary network services
    - Extent of natural monopoly in network; one monopoly or hierarchy of natural monopolies
- Network organization
    - Overall network structure and planning system
    - Division of labour and responsibility between overall network planning system and network investment and operation decisions
    - Degree of decentralization of network functions and investment decisions in the network organization
    - Ownership of network assets and facilities; public versus private ownership; merchant transmission investment; allocation of property rights; investment decision criteria
    - Transmission system operator (TSO) versus Independent system operator (ISO) organization; implications for investment decisions
    - Network organization in regionally integrated (multi-country) power markets; overall regional network planning and decision-making system
    - Network organization for the integration of other energy networks with the electric power network; multi-utility network organization.
- Network functions
    - Identification of network capacity constraints in meshed networks

    - Methods for the handling of network capacity constraints; properties of different methods; relationship between capacity constraint handling and capacity investment. Harmonization of principles and rules for the handling of capacity constraints in spatially integrated networks and power markets
    - Methods and criteria for evaluating optimal network investment; short-term versus long-term considerations and decisions
    - Location decisions with regard to generation capacity in relation to network load and demand for power
    - Implementation of an optimal investment programme for the total network; division of labour and responsibility in decision making between involved parties, vertically and horizontally, and also for spatially integrated power markets
- Network regulation
    - Choice of regulatory mechanism with desired properties, short and long term, and timely revision of the regulatory model under changing circumstances, with special attention to the incentive properties of various mechanisms to contribute to optimal investment in the electric power system as a whole
    - Harmonization of regulatory models and procedures in spatially integrated power markets
    - Choice of "global" regulatory model to facilitate the integration of the electric power network with other energy networks, e.g. natural gas, if desired.

The list could have been made even longer, but covers the main factors that have to be considered from the network side with regard to the structure, organization and regulation of the electric power network to facilitate optimal network investment.

7.3 Security of supply and regulation

A number of different definitions and conceptions of security of supply of energy (electric power in this context) have been presented in the literature and in official policy documents, often focusing on security of physical supplies and often with reference to the upstream part of the power system (production).[31] Related concepts to security of supply are system reliability and supply adequacy.[32]

Security of supply of a defined electric power system has characteristics of a public good. There may also be *global* public goods aspects of the production and use of electric power, e.g. global climate change effects of GHG emission from fossil-fuelled electricity plants, or global security issues over and above energy security from nuclear power production, e.g. resulting from the handling internationally of nuclear material as input to and waste from nuclear power production. These aspects will not be discussed in the present context.[33]

The optimal provision of security of supply will not be secured and some form of regulation is required. How should this regulation be designed for liberalized electric power markets and, in particular, what role will the power network and the regulation of the network play in achieving security of supply?[34] We will make a few observations on this question.

Egenhofer et al (2004) suggest that, in liberalized energy markets, the role of government, companies, and consumers change and, therefore, supply security should rather be redefined in terms of risk and associated costs. "In this logic, security of supply becomes a risk-management strategy with a strong inclination towards cost-effectiveness,

[31] For an overview, see Egenhofer at al (2004), who also propose definitions of security of supply for market-based electric power systems.

[32] A Working Group of the CEER (2005) defined security of supply as: "Customers have access to electricity at the time they need it with the defined quality". Reliability is defined as: "System operation without interruption and disturbance within the defined period." For definition of supply adequacy, see section 5 above.

[33] For discussion of global public goods in an energy context, see Barrett (2007). For a more general exposition, see Sandmo (2007).

[34] Many of the recent power system failures in the form of blackout or brownouts have come from the network side, e.g. in Italy in 2006.

involving both the supply and the demand side". In this context the strategic role of the electric power network and its regulation becomes important.

The primary role of regulation of networks in improving security of supply in market-based power systems are (section 3): a) attracting sufficient investment, b) promoting adequate maintenance of existing facilities, c) promoting efficient operation of network infrastructure, and d) ensuring adequate rewards for innovation and technological progress, by building into the regulatory model incentives for such outcome. However, because the security of supply concept under the above approach becomes a multi-dimensional concept, regulators have to make choices about incentives which may have precise impacts on some of the components of security of supply but not on others.

A case in point may be the introduction of capacity payments for generation capacity in some electricity markets, e.g. the PJM market in the US[35] and access charges for intermittent renewable power.[36] The access charging methodology is important for the allocation of network access and usage costs between the existing and new connections that have to be established e.g. for the introduction of new renewable power into the system.

Two factors seem to be of particular importance with regard to achieving acceptable and cost-effective solutions for security of supply through network regulation:

- Design of regulatory mechanisms with incentives to stimulating innovation and technological progress in the power network. Technological progress has been relatively slow in the electric power network, but many interesting innovative developments are now taking place. Decentralized power systems with multiple small scale sources of generation like micro-generation, location of new generation capacity in relation to the network, smart meters, two-way communication systems, as mentioned above, are examples of such innovations.[37]

[35] See e.g. Joskow (2006) and Bowring (2008). In the UK auctions have been introduced for peaking capacity at times of maximum electricity demand; see e.g. JESS (2006) for the UK. In Norway the regulation capacity market represents an interesting case, taking account of capacity factors on both the supply and demand sides.

[36] See section 5.

[37] See e.g. Patterson (2007) for some discussion of the potential for network innovations.

On the other hand, the macro security of the network should always be considered, because failures or breakdowns in the high-level parts of the network can have very serious consequences for system security and stability.

- Integration of different energy networks (electricity, natural gas, systems for distributed gas, district heating networks, etc) and "global" regulation of the networks on a common basis are important for securing energy security for the energy system as a whole.

Will this perspective on security of supply and innovations taking place in the network change the public goods aspect of security of supply to the extent that it can be left to the energy markets to set the level of security of supply, without network regulation in this regard, also taking into account that regulation will never be perfect in relation to stated regulatory objectives? At the present state-of-art, this is definitely not so. However, the "core" of natural monopoly in the network seems to be shrinking due to these developments so that well-functioning energy markets will gradually have a larger role to play in securing energy security.

8. Concluding remarks

A state-of-the-art research paper will, necessarily, have to be "static" in the sense that it is supposed to take a bird's eye view of the state of the art of scientific analysis and thinking within a given area at a point in time. Optimal investment in market-based electric power systems is one of the most complex and challenging set of issues presently facing us in energy economics research and also with regard to the operational implementation in market design and regulation. Therefore, a brief state-of-the-art research paper like this cannot do proper justice to all the issues and problems that have to be considered. However, we hope that the paper has shed some light on the issues and has helped to identify some of the most important factors and aspects that have to be taken into account in research design to make further knowledge-based progress in this area, as well as for improvements in market and regulatory designs to secure optimal investment.

Progress is indeed taking place. We end by quoting a statement by Michael Pollitt to the book edited by Fereidoon Sioshansi (2008). This collection of studies was published in February 2008, which also represents the time of closure of this state-of-the-art research study.

"Electricity liberalization continues to be one of the longest running and most interesting of multi-country microeconomic experiments. While most of these market reform initiatives are ongoing, some are mature enough to no longer be experiments, and many others have been running long enough to give rise to preliminary results. Economic analysis is well served by well-informed and detailed analyses of these experiences, such as appear in this volume."

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