ELSEVIER

Energy Policy 36 (2008) 1436–1447

ENERGY POLICY

www.elsevier.com/locate/enpol

More competition: Threat or chance for financing renewable electricity?

Sándor Szabó*, Arnulf Jäger-Waldau[1]

European Commission, DG Joint Research Centre, Via E. Fermi 1, TP 450, I-21020 Ispra, VA, Italy

Received 24 October 2007; accepted 14 December 2007
Available online 8 February 2008

Abstract

The paper examines how increased competition in electricity markets may reshape the future electricity generation portfolio and its potential impact on the renewable energy (RE) within the energy mix. The present analysis, which is based on modelling investor behaviour with a time horizon up to 2030, considers the economic aspects and conditions for this development with a particular focus on the photovoltaics. These aspects include pure financial/investment factors, such as the expected returns in the sector, subsidisation of certain RE resources and other policies focusing on the energy sector (liberalisation, environmental policies and security of supply considerations). The results suggest that policies aiming at the expansion of renewable energy technologies and strengthening the competition in the electricity markets have mutually reinforcing effects. More competition can reduce the financial burden of the existing renewable support schemes and consequently help to achieve the already established RE targets.

Keywords: Renewable energy; Liberalisation; Electricity generation portfolio

1. Introduction

The electricity sector investments represent a major share of the total investments in Europe. The IEA (2003) estimates that more than 1000 billion$ will have to be invested until 2030 in the European electricity sector. The diminishing capacity margins in most European countries call for substantial investment into new electricity generation capacities to replace the growing number of old power plants (UCTE, 2005; IEA, 2003). Despite this growing necessity, very limited new power capacity has been built since the second half of the 1990s, when the economics of the gas power stations were particularly compelling. One reason for this under-investment was that investors focused on mergers and acquisitions within the sector, as they offered not only higher returns in this period but also an option to postpone the decision between the new types of risks associated with the different power technologies. Nevertheless, the sector investors need to look for new opportunities because the low hanging fruits have already been picked. Investment opportunities with the highest yields that are responsible for having pushed up the return expectations have become more and more limited by now.

There are a number of uncertainties about the mix of electricity generation technologies that could be most appropriate for delivering current energy policy goals in the medium term. Although market-based instruments are the tools most often applied to efficiently managing these uncertainties, there are also framework policies at the European level concerning competition, security of supply and the environment that have to be taken into account in this analysis. The key factors affecting the new investment decisions are the high volatility and unpredictability of future fossil fuel, carbon and electricity prices; investor uncertainty about the form of the post-2012 European Emission Trading Scheme and the long-term policies concerning renewable energy targets. These uncertainties increase financial risk, making it more difficult for investors to compare the profitability of the different power plant investments.

Despite the portfolio composition is reflected in the electricity generation structure, the financial portfolio

*Corresponding author. Tel.: +39 3327 86582; fax: +39 3327 89992.
E-mail address: sandor.szabo@ec.europa.eu (S. Szabó).

[1]The views expressed in this paper are those of the authors and do not necessarily represent European Commission policy.

0301-4215/$ - see front matter
doi:10.1016/j.enpol.2007.12.020

theory (Brealey and Myers, 1991) is rarely applied in the studies analysing the effects of different power plants in the electricity generation (Awerbuch, 2003, 2004; Bolinger and Wiser, 2005). With a focus of one of these dimensions, the recent paper by Mitchell et al. (2006) compared the risk reduction potentials of the two mainstream policy mechanisms (renewable obligation and feed in tariff) affecting the investor's behaviour in the electricity sector. The paper analyses the effects of market opening on the future composition of electricity generation through modelling the changes in the investors' return expectation. The applied model simultaneously recalculates the optimal portfolio when there is a relative change in the technology and environment related costs due to different learning speed, load structure, demand patterns, fuel cost development and changing investors' preferences. Through the built in feedbacks of installed capacities and their cost trends, and due to the technical limits on lifetime, efficiency and resource availabilities the adaptation process approximates the dynamic investment decisions.

The paper is organised as follows. The introduction is followed by a short presentation on the specific features of the electricity markets and the description of the model (Sections 2 and 3). Section 4 presents the main results of the model including a brief description of the sensitivity runs. Section 5 concludes.

2. Specific features of the European electricity markets

Despite the standardised product, it is very difficult to characterise a single European electricity generation market because it does not exists as such. There are more than 20 segmented markets that are in the very beginning of the process of liberalisation and merging. The extent of isolation of these markets depends on the level of their interconnections with other markets.

There are special characteristics of these markets, which make them distinct from other electricity markets (US, Japan), but are shared by most of the European markets, which are important from our investigation point of view. These characteristics could be clustered into the following points.

2.1. Concentration and market power

The European Commission (DG COMP, 2006) launched an enquiry into competition issues in gas and electricity markets in 2005. The main findings of sector enquiry were the following. There are particular problems that include high levels of market concentration; vertical integration of supply, generation and infrastructure leading to a lack of equal access to, and insufficient investment in infrastructure; and, possible collusion between incumbent operators to share markets.

The non-discriminatory grid access, transmission tariffs or congestion management is far from being fully operational among the systems, clear rules on unbundling have not yet been put in place and these segmented markets can still be characterised by strategic behaviour of dominant actors. European surveys (DG COMP, 2006; DG TREN, 2005) revealed that in 21 countries the first three dominant generating companies in electricity generation have a market share of at least 60% (the exceptions are UK, Poland, Norway and Finland), and in 17 countries this figure is even above 75%.

The latest period of intensified company mergers between electricity producers have raised serious concerns about increasing market concentration and abuses of market power (Domanico, 2007). Electricity markets remain highly concentrated giving incumbent operators the potential for exercising market power and influencing prices. The market characteristics and the strategic behaviour have important consequences on the investment market of the industry: the expected return on investment (ROI) is higher than on a real competitive market.

Our analysis uses the changing ROI indicator as a proxy for the effects of increased competition to model the relationship between market concentration and sector investment. The most important financial consequence of the stronger competition is that it reduces the high prevailing rate of ROI (see Fig. 1).

The change in ROI has significant influence on the corporate financing investment decisions. It is a decisive factor on what projects the companies undertake. The decreasing ROI has manifold effects on the sector. *The first one of the direct outcomes* is that the difference in the net present values (NPVs) of investments with different cash flows decreases. When otherwise similar cash flows are differentiated by the relative weight of the initial costs, the one characterised by the high upfront costs becomes more competitive when lower discount rate is used in the project appraisal. This diminishing gap in the NPVs eliminates the barriers that disfavour the renewable electricity sources to the conventional sources.

The *second significant effect* of the declining ROI is that it may reduce the willingness to invest in the sector because

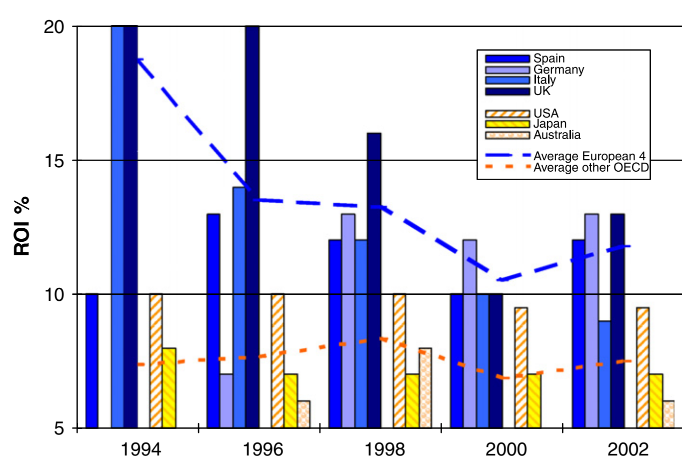

Fig. 1. Return on investment figures of the electricity companies in seven OECD countries (IEA, 2003).

of the diminishing freely available cash flow of the market players. This directs the investments towards the investment options that require smaller initial capital. However, it has to be mentioned that the investment rata of the sector has not been high in the last decade despite the fact that the ROI in Europe was much higher than in other regions, which indicates that a high ROI does not automatically bring about high investment rate (see Section 2.5).

2.2. Increased competition on the demand side

Driven mainly by the EU framework policies, almost all Member States opened up their electricity and gas market for large consumers, who can change their supplier, and from 2007 all EU countries all consumers should be eligible to enter the open market. A growing number of large European electricity companies have been responding to this changing environment by merging with electricity companies in other countries. This means that while some national markets may not look excessively concentrated, concentration at the European level has been growing (Green, 2006).

The picture becomes even less straightforward when the supply side deregulation and market opening effects are taken into account. The progress has reached very different stages in the various countries. The United Kingdom, the country that started the liberalisation process at the earliest in Europe (see Green and Newberry, 1992) has achieved a steady progress. The same is valid for Italy where the return of investment rate was exceptionally high at the beginning of the period shown in the figure. In Germany an opposite trend can be observed: the ROI increased throughout the period from a very low level to the highest among the European OECD countries. Since the German electricity companies represent a huge share in the capital value of the European electricity market (they own assets in the UK, Spain, in Central Europe) this increase has an even higher importance for the whole EU.

2.3. Reducing fragmentation of national markets

Because the size of the incumbent utilities is large relative to the national markets, the main track for liberalisation in Europe will be to merge the national markets into regional ones. This would enable more competition between more utilities without harming their acquired assets. This process leads to increased cross border trade and in the long term it enhances interconnections the lack of which is presently among the major barriers to the competition.

Some of the national power generation and distribution markets already merged into regional markets (for instance the NordPool covers Sweden, Norway, Finland, and Denmark), but most of them created electricity exchanges on national basis (i.e. EEX in Germany, UKPX in UK, OMEL in Spain, APX in Holland, etc.), while some of them chose other types of market mechanisms (such as bilateral contracts, public auction).

2.4. Decreasing supply and price security

In the long run, the resource potential, depletion and distribution are important factors for the future electricity production mix and the RE penetration (see a synthesised study on this subject by de Vries et al., 2007). It is even more valid for Europe, which becomes increasingly dependent on energy sources from outside its territory because of the insufficiency of its own resources. The share of the foreign-mainly Russian-natural gas (as results of increasing share of gas capacities) exceeds two-thirds in some Member States. The same tendency is valid for coal, where dependence on foreign-often overseas-resources is also increasing.

Using energy and fossil fuels more efficiently is a cost-effective method of both tackling emissions and increasing energy security. By reducing the demand for gas and oil, the exposure to security of supply and price volatility risks can be reduced, including the potential risks associated with imported energy. An important aspect in this context is that the fuel price volatilities are much lower for RE sources than for fossil fuel-based technologies. The higher share of low volatility sources in the portfolio decreases the exposure of consumers to electricity price changes.

A more diverse electricity mix and less reliance on imported fuel sources can also contribute to system reliability. The renewable sources also have to be diversified: in order to prevent fluctuating energy sources to undermine reliability, reasonable caps can be used on the specific sources.

2.5. Postponed investments, ageing generation portfolio

The European investment prospect became a big challenge for the sector as in the last decade the realisation of physical assets was lagging behind the level what was required to sustain the preceding safety reserve levels (IEA, 2003; UCTE, 2005; EIA, 2005). On the other hand, the delayed decision making of the investors means that there is still a unique opportunity to reshape the portfolios. The most significant capacities put in place in the period are characterised with flexible output that does not rule out any future portfolio changes. The new capacities put in place were mainly gas turbines, with their present economic and technical advantages, however their future growth within the portfolio would impose further price risk and supply security problems. Additional to the generation capacities, the network development is lagging behind as well (UCTE, 2005).

Introducing more favourable condition for new players to enter the market became the primary policy answer to this situation. This would also motivate investments from the incumbent producers and network operators.

The opening of the electricity and gas markets for increased competition has been given a high priority in the European policy for more than a decade.[2] The Lisbon

[2]See the 96/92/EC Directive on common rules for the internal market in electricity, and the subsequent EU regulations: the 1228/2003 Regulation

strategy with its emphasis on competitiveness and higher R&D share further enhanced this process. The results are still uncertain. On the one hand, all consumers will be free to choose among the service providers as of the end of 2007, on the other hand, the competitiveness is expected to increase on the production side, though this is less visible. Despite the growing need for new capacity installation in both the generation and in the transmission system (IEA, 2003, 2004) the statistics do not show new capacity boost: the increase in the net installed capacities has stayed around 1% (between 0.5% and 2.2%) in the last decade (Eurostat, 2006). Simultaneously, the ratio of investment to turnover has also been cut from 10.3% in 1998 to less than 5.5% in 2004 (Capgemini Consultancy, 2006). The postponement in capacity investments can only be partially explained by the uncertainties caused by fuel price volatilities and new regulations.

2.6. Challenges and policy responses

The characteristics described above prompted policy makers to improve the framework conditions for the sector. Enhancing the functioning of energy market coupled with the expectation of better environmental performance became the combined focus of European policies. Recently, they were put together in one package, which signals a more holistic approach toward the sector. This includes further strengthening of the electricity market liberalisation, improving the EU emission trading scheme (ETS), and setting up mandatory renewable (differentiated by region) and biofuel targets.

In the policies addressing the open and well-functioning electricity markets, the European Commission puts emphasis on the following options:

- Develop proposals to increase the powers of EU regulators to the highest level and improve co-operation between regulators. At present EU regulators are only responsible for protecting national consumers and many have limited powers.
- Encourage effective unbundling. When one company owns energy production, supply and the transmission networks, it has an incentive to exclude new entrants to the market. The most effective way to prevent this situation is to ensure that the company, which owns and operates the network has no production or supply interests.
- Support consumer choice to ensure that all EU consumers have a real choice to choose their supplier.
- Increase transparency to enable greater cooperation between transmission system operators in Europe. Common network standards and access to transmission and distribution systems must be developed and made binding in order to increase network security across the EU.

(*footnote continued*)
on conditions for access to the network for cross-border exchanges in electricity and in the 2005/89/EC Directive on the safeguard security of electricity supply and infrastructure investment.

3. Description of the portfolio optimisation model

As policies concerning market opening and sustainable energy production became a part of one policy package, it became especially relevant to examine the interaction of these policies. An investment optimisation model was developed to assess the possible effects of the liberalisation on the renewable energy technologies in the electricity portfolio.

3.1. Model description

The applied model is an inter-temporal investment optimisation model using non-linear programming algorithm.[3] It consists of 25 multivariable equations and constraints, 19 electricity generation technologies, each defined by more than a dozen parameters and 13 variables for each model regions. The model optimises electricity supply on four aggregated EU regions by choosing the optimal portfolio of power capacities and by cost-minimising dispatching. As each regional model has one objective function, the investment behaviour is similar to a decision of a 'central planner' in each region. In reality, the investment decisions are made by a heterogeneous group of (mostly) private investors, so this approach is a strong simplification. With this simplification the model assumes homogenous knowledge (or expectation) about the future trends (including costs, fossil fuel prices, investment cost trends and so on) amongst the investors also facing similar constraints, in which case their 'aggregated' investment decisions would be similar to the used central planner approach.

The *model execution* is *sequential*. First, an aggregated version of the model covering the whole EU calculates the capacity cost trend defined by the global learning potential. Then these capacity cost trends are used as input parameters in the four regional[4] runs of the sub-models. In the regional optimization, the geographical and technical differences are taken into account, such as different financial expectations, local resource, capacity and demand characteristics. This sequentiality is necessary, as the capacity cost trends are determined on the more aggregated, and not on the regional level.

The *time frame* of the model is from 2005 to 2030 and solves by 5-year steps. Its standard objective function

[3] The model is written in GAMS and uses the CONOPT solver. A detailed technical description can be found on the following website: re.jrc.ec.europa.eu/refsys/

[4] The regions are:

- Western European countries group (Austria, Belgium, England, France, Germany, Netherlands).
- NordPool countries group (Denmark, Finland, Sweden, Norway).
- Mediterranean countries group (Greece, Italy, Portugal, Spain).
- Centrel countries (Czeh Republic, Hungary, Poland, Slovakia).

minimises the total discounted costs. During this process, the model simultaneously optimises the merit order to meet the load structure, taking account of possible capacity cost reduction by technological learning.

The model constraints can be classified into two categories. The first one consists of the *equilibrium conditions*, namely that electricity production always has to match demand in all blocks of the load curve. As a derived equilibrium total available capacity always has to cover the expected power requirement.

The model has several *technological* constraints, including capacity reserve requirements, limited capacity extensions over time (based on the theory of Hayashi (1982), see also McDonald and Siegel (1986) differentiated by technology clusters and limits on the production shares of the intermittent renewables technologies. To enable the model to run policy relevant scenarios, additional variables, such as CVs and subsidies were also introduced in the model.

The model does not include the number of companies operating in the various markets; it is not using market concentration indexes to account for possible market power behaviour. Instead a more general approach was followed and the competitive cost-minimisation behaviour was assumed for the producers. To account for the possible market power and its expected future adjustment is modelled through the change in the ROI, as the exercised market power is reflected in the expected return of the companies. This solution however has its drawbacks, namely that it allows only for exogenous treatment of the market distortions, and makes the behaviour homogenous amongst the generators (at least within the regions).

Three model characteristics have to be emphasised as they are distinct from other modelling approaches, and they describe crucial details from the model functioning point of view. The first one is the capacity differentiation by age of the different technologies (vintage by 5 years). The second one is the application of detailed load bands of the demand side, which is based on current national data. And the last one is the applied *parametric learning* function, which defines the relation between the unit investment cost reduction and cumulated capacities built in the model.

This last distinctive characteristic of the model structure is explained in the graph following a short reference to the concept of technological learning. There are numerous studies characterising the learning process in the sector (see, for instance, Ibenholt, 2002; Jensen and Andersen, 2004). The potential for technological learning for most energy technologies is reviewed by McDonald and Schrattenholzer (2001), and for wind and photovoltaics (PV), it is discussed in more detail by Neij (1997). The speed of learning depends on many factors: financing (i.e. what proportion of the cash flow can be invested in the technology), the growth of production capacities, etc. and other non-financial factors: plant size, module efficiency, raw material costs (Nemet, 2006). This study also identifies that factors of market dynamics like industry concentration, market power, and changes in elasticity of demand play important role in technological change (Fig. 2).

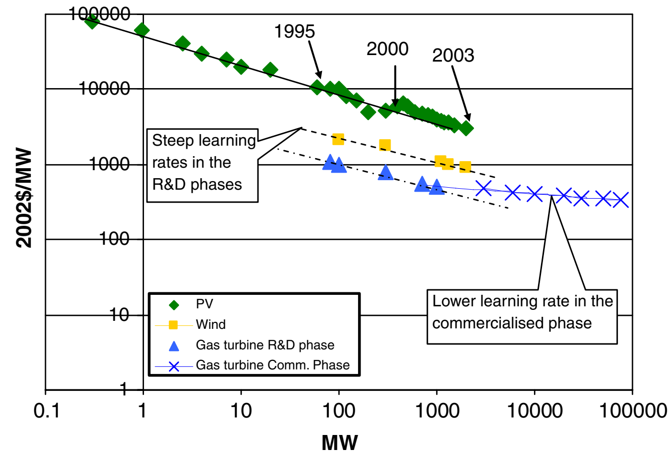

Fig. 2. Research and Development and the Commercialisation phases of learning for electricity generation technologies (Note the log scale! Gritsevskyi and Nakicenovic, 2000; Surek, 2004).

The parameters of the function are defined in a way that the doubling of the cumulated capacity reduces the costs by nearly 20% (that is attainable by technologies with small initial capacity shares, like PV). With the further capacity addition the cost reductions level off at 10% values that are generally reported in the studies on the power generation technologies (for established technologies the capacity increase allow for 1–2% see also Figs. 5a and b).

3.2. *The reference and competitive finance scenarios*

To analyse the impact of increased competitiveness, the reference scenario is contrasted with an alternative one, where this increased competitiveness is modelled through the reduced expected returns of the investors. In the business-as-usual (BaU) and in the competitive finance (COMP) scenarios, the basic assumptions on the fuel costs, initial investment costs,[5] flat carbon prices (30 €/t of CO_2), were identical with the exception of the financial expectations.

The reference run assumes a gradual decrease in the ROI (it remains at the prevailing level, and only from 2020 it decreases from 15% to 12%). In the competitive financial option, the ROI starts to decrease rapidly and reaches the level of 9% in 2015 when it stabilises on that level.

4. Model results

4.1. *The portfolio impacts of the decreasing return expectations*

The model results show that the decrease in the investors' return expectation makes essential changes in

[5]For these parameters, the DG JRC Techpoles database reference values were used. For the detailed description see also re.jrc.ec.europa.eu/refsys/

the electricity generation mix. The following figure illustrates that the diminishing ROI used in the financial appraisals by the investors would change significantly the investments in the optimal portfolio. One of its most significant effects is to radically increase the share of PV, followed in a latter period by a significant increase in electricity from biomass. Wind and nuclear capacity installations take place earlier than in the BaU run, in which natural gas-based power dominates the overall investments (Fig. 3).

The decisions of investors' are primarily influenced by the market share of the different investment opportunities and the market growth for these options. In order to show the complex technology trends within the portfolio in a plausible way, the results are shown in a graphical representation for the years 2000 and 2030 (see Fig. 4). The dynamic development of the electricity generation market can be best described along two dimensions: the trends in available capacity and the shares in production. The following figures combine the historic capacity and production data of the European electricity sector (Eurostat, 2006) and the modelled trends in the BaU and the COMP scenarios. The technologies are labelled B and C on the chart referring to the BaU case compared to

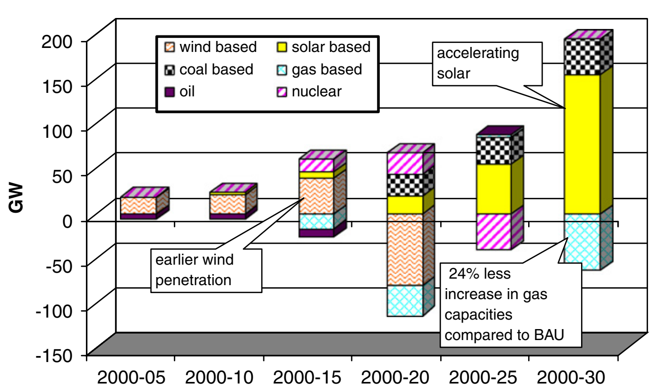

Fig. 3. Differences in the capacity investments in the two optimal portfolios caused exclusively by the more competitive financing.

the case with competitive financing due to fast track market opening. In the 2030 figure, only those technologies are presented that show significant difference between the two scenarios. The hydro, nuclear and the oil-based power generation capacities are not shown in the 2030 figure because they remain close near their historic values in both scenarios.

The two-dimensional plots are divided into four quarters. The four sections of the charts indicate the different choices of investors amongst the various technologies. Clearly, the portfolio composition is also influenced by technology requirements of the system, so it is not only shaped by financial considerations. These technical constraints are dealt in the model, so their fulfilment is always ensured in all scenarios. The matrix structure depicts the strategic response of the investors to the different market situations. This simple analytical tool associates the technologies that are utilised intensively and represents an already high market share as the preferred options of investors. Until the early 1990s, the coal-based technologies could be classified in this category. However, the strict emission regulation on sulphur and particulate matter changed the view on these technologies, while the mounting concerns about its global warming potential and the introduction of carbon pricing mechanism (ETS) has further deteriorated their position. In the 'dash for gas' period of the late 1990s, natural gas-based generators became the new favourites. Undoubtedly, they have their advantages, as the gas turbine technologies are flexible, and their efficiency is unreachable with the other fossil-based technologies.

As concerning the future developments, the high and volatile gas prices will not slow down the increasing pace of gas-based capacity installation in the modelled period, if the high return expectations prevail in the market as assumed in the BaU case. The most attractive options will be the various gas turbine technologies, and their increase will be accelerated again. In the COMP scenario however, the pace of the capacity increase would be curbed and most noticeably the utilisation rate of the gas capacities will fall.

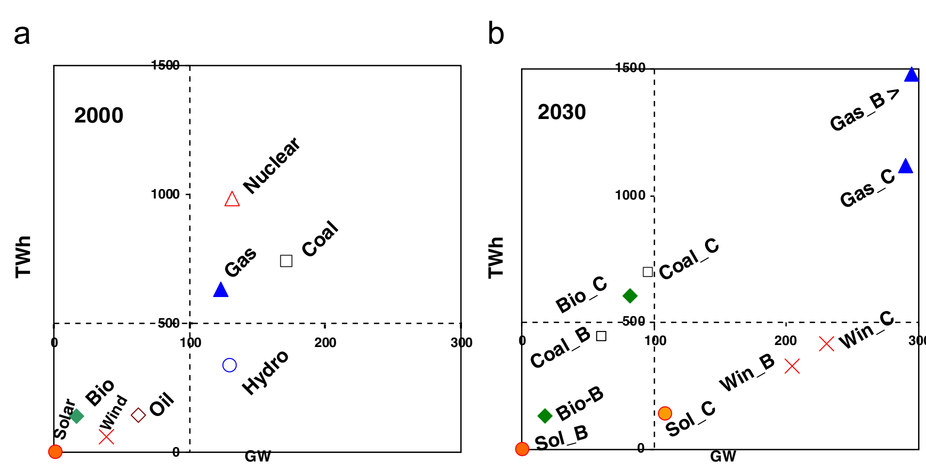

Fig. 4. (a, b) Changes to the projected portfolio in the electricity market 2000–2030 (Eurostat, 2006, model calculations).

In this case gas-based capacities would only be used to meet the peak load where in fact they can outperform the other technologies, while its contribution to the middle load reduces. Therefore, one major effect of the declining ROI on the electricity portfolio is to prevent the use of natural gas in meeting the base and middle load and creates opportunities to invest into other technologies, mainly renewables.

The technologies characterised with high market share but lower utilisation rate can be found in the upper-left quarter. These are characterised by high-income generation potential compared with their relatively low investment needs. The coal-based technologies are shifted into this category: the owners have been utilising the remaining plants without further investment in the sector. This is shown by the sharply decreasing capacities, while the production level of the remaining stations decline proportionally less. The future investment structures offer two very different pathways for the development of this technology: even with stagnant carbon prices, the high return expectations would direct away investment funds that would cut its share further. However, when the ROI expectations decrease fast, new coal technologies (fluidised bed and gasification) would become attractive enough to reverse the declining trends and more investments would be available.

Parallel to the reallocation of fossil-based energy carriers, renewable energy sources gain the largest share with the investment market opening: the faster deployment of wind capacities is one of the most visible results. Not least importantly, there is a substantial change in the marginal role the PV would play in the BaU scenario with the prevailing financial structure. In the COMP case the PV technology can reach capacity levels that yields significant investment cost reductions. The biomass energy sources will also gain higher market shares in the portfolio with the more competitive investment. In the BaU, with no change in the financial structure, both PV and biomass electricity capacities would remain near the marginal corner of the matrix discouraging further investments in these technologies.

In summary, the more competitive structure brings much more innovative power technologies into the least cost electricity generation portfolio. This does not only produce a portfolio of much more diversity, but it offsets most of the increase in the natural gas-based power generation. Without this diversification due to the changing decisions of the investors, the future electricity generation portfolio would be more dominated by natural gas-based generation technologies.

4.2. Technology learning

In order to capture the technology learning effect, an aggregated (on the whole EU level) and four regional versions of the model were built. The aggregated model allows for capturing better the ‘learning by doing’ effects, as it accounts for the cumulated capacities more reliably. At the same time, the regional models give more realistic pictures on the geographic differences. The two capital cost trend displays the following patterns for the BaU and the COMP scenarios (Fig. 5).

The contrast between the resulting technology cost trends described in Figs. 5(a) and (b) is remarkable. In order to make the cost dynamics of technologies comparable, time series are provided here. However, it must be kept in mind that the cost decrease is the function of the level of installed capacities, and not of time. The dissimilarity in the technical progress depicted in the figures is solely attributable to change in the capital cost development (the faster the decline in the ROI): the rest of the variables remained unchanged in the model runs.

4.3. Regional analysis

The regional executions of the model allow not only to monitor the effects of the regionally differentiated inputs,

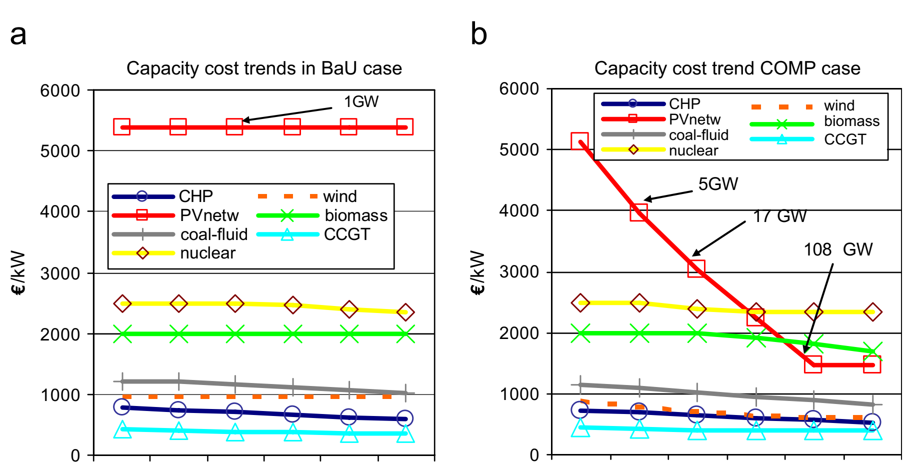

Fig. 5. (a, b) Dynamic capacity cost trends allowed by learning and lower capital costs.

but it can also answer whether the European RE targets achieve the competitive environment and what RE shares will be attained in the different regions. It also helps to answer the question whether the implementation of a uniform target is cheaper or whether allowing some regional variation with burden sharing is a better option?

Though stronger competition will bring about higher degree of convergence in the financial expectations, the period examined will be still characterised by diverse groups of investors. The increasing number of independent power producers, the different regional risk levels and resource availability have to be taken into account in the energy policy design. The accesses to capital from financial institutions are now completely free in the regions examined; however, there is still a distinctive risk premium associated with the different regions. The diverse weights of the different fuels in the regions also represent a huge difference in the portfolio optimisation. The cheapest way to change the existing power structure can only be achieved by gradual adjustments (by replacement of old generation, decreasing use of the capacities becoming more expensive). Therefore, the initial capacity shares in the regions are essential to project the regional portfolio changes.

The regional executions were differentiated on the basis of

- geographical isolation (limited cross border transmission),
- resource diversity and availability (different fossil fuel mix, hydro, wind resources and solar irradiation) and
- differences in financial structures (regionally differentiated return trends).

The model was executed for four defined regions in the second phase for regional optimisation. It was assumed that the capacity cost trend derives from the capacity installation (that is not only research but the learning by doing effects that are of equal importance in the cost reduction). Therefore, the regional executions were based on differentiated regional capacities, but the capacity cost figures were derived from the European level model run.

The following graph displays the regional distribution of the capacities (in GW) in the least cost portfolio and the shares of electricity production from RE sources are indicated (as a percentage of total TWh produced) (Fig. 6).

At European level the 20% RE target includes heating and fuel for transport. Since the transport sector is aiming

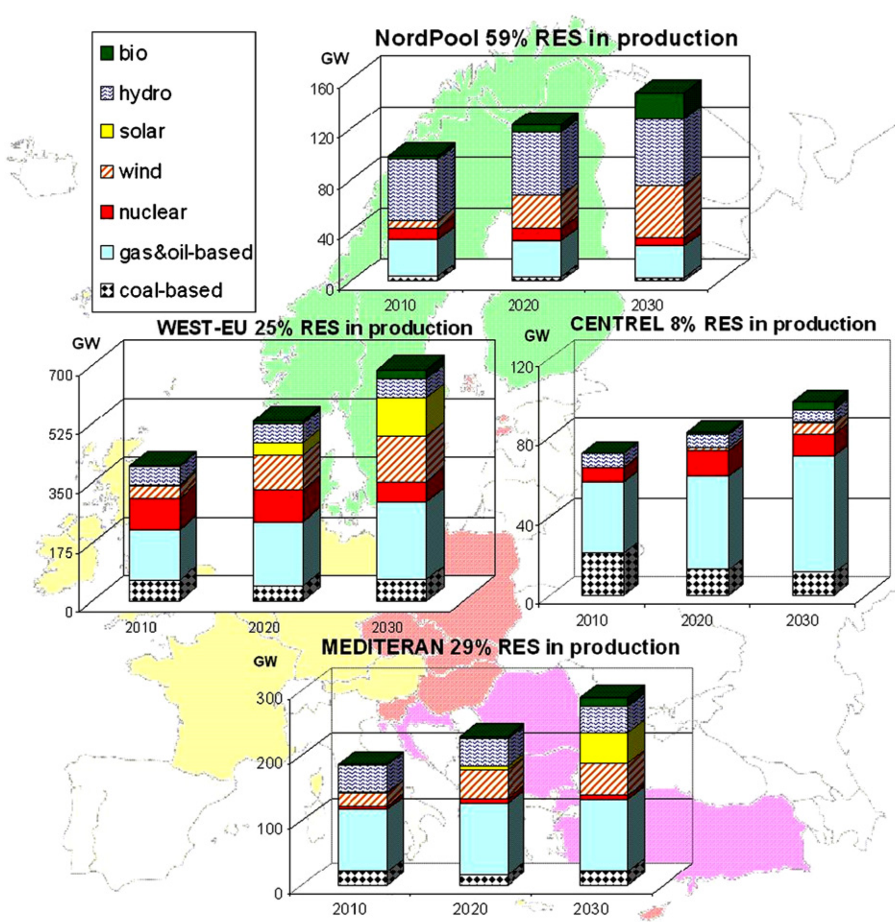

Fig. 6. Development of electricity capacities by regions in the competitive finance portfolio (note the different scale of the graphs!).

at 10% biofuel share, the RE target is only achievable if the electricity sector reaches 27–28% portion. The model shows that in contrast to the BAU case, the target could be met in the competitive case, however very imbalanced distribution can be observed in the least cost portfolios. In the former Centrel countries, the proportion of the electricity produced from RE sources would not reach the proposed share unless there are additional support mechanisms introduced. The differences of the resulting regional portfolios can serve as a basis for a future burden sharing agreement. Therefore, a cost-effective policy option must contain differentiated targets for the various regions (a reduced one for the Centrel countries), or some additional support measures to be introduced to these countries.

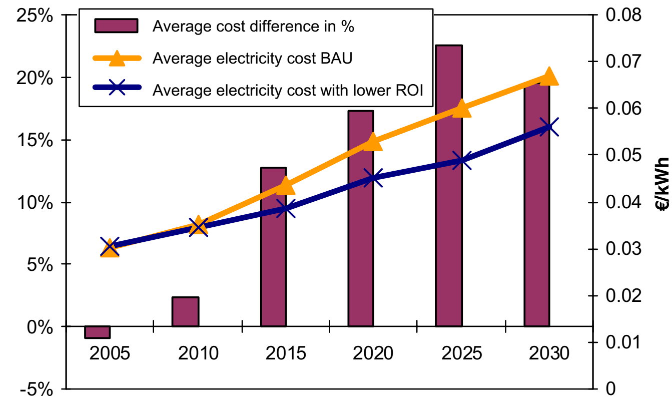

Fig. 7. Curbing effect of the more diverse portfolio on the weighted average cost increase.

4.4. Production cost trends

The model results suggest that the increase in electricity production costs will be unavoidable when considering a longer time horizon in Europe. In the price development there are two counteracting driving forces. On the one hand, a market that functions better with higher number of participants; a more diverse fuel portfolio; the increasing share of almost zero fuel costs and the continuous technical learning moves towards cost reduction. On the other hand, even the conservative fuel price projections, the higher upfront cost of RE technologies and the carbon market is predicted to push the costs upwards. The model results show that the former driving forces cannot compensate for the effects of the latter ones. The question is to what extent can the higher competition offset the increases in the costs. The advancement of the prevailing financial structure of the power sector to a more competitive one allows smoother price increase on the electricity market and a less-expensive support scheme for PV technologies.

The marginal producers are in both cases gas and oil-based capacities (the oil and conventional gas capacities disappear from the peak generation portfolio and a mixture of gas turbine and combined cycle gas turbine becomes dominant). The main difference to the average production price trend is that the marginal cost rises more rapidly in the reference scenario than in the COMP scenario. The difference between the two average production costs reaches 23% already in 2025 (compare the resulting 5 and over 6 €cents/kWh in Fig. 7).

4.5. Efficiency improvement of the support scheme for PV

The more competitive financing structure results in a smaller increase in the marginal costs, and create opportunity to design a more efficient support scheme for PV.

In the next figure, the two lines explain the difference between the subsidies required to cause a boom effect in PV (a capacity deployment enough to trigger the capacity cost reduction to a competitive cost range) in the two different

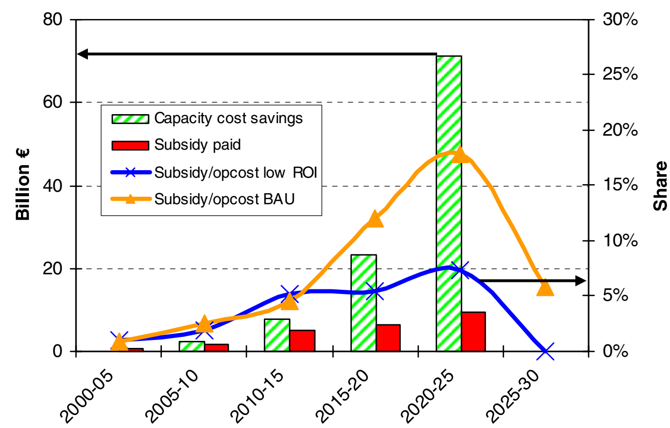

Fig. 8. Improved performance of the support scheme facilitated by the more competitive financial structure.

financing environments. In the competitive financing scenario, the amount of subsidy is 3.3% of the overall operation costs on average (the sum of 2005–2030 subsidy/2005–2030 sum of operation costs) of the portfolio (reaching 7% at it highest level in 2025). If the present structure prevails, the required support peaks at 18%. Without the reduced return expectation caused by market opening the policy that would support PV to attain the same market share could cost three times more compared with the reference case, probably making it an unfeasible option. The dark columns show the amount of subsidy that is paid under the improved finance structure. The striped columns show the savings achieved in the model through the accelerated capacity cost reduction for PV. The difference between the two columns clearly indicates that the cost of supports is overcompensated by the gains in potential capacity cost savings that would be significantly higher. Nevertheless, these savings arrive in the long term and the declining cost path of the PV technology is a critical prerequisite in addition to the progress in ROI (Fig. 8).

Table 1
Input parameters for the sensitivity analysis

Input parameters	Period	Minimum value	Reference value	Maximum value
Carbon value (€2000/tC)	2005–2030	2005 55	2005 110	2005 165
(110 €/tC = 30 €/t CO_2)		2030 55	2030 110	2030 165
Investment cost of PV in 2030 (€2000/kW)	2030	1100	1716	2300
PV limit on production share (%)	2005–2030	8	10	15
Wind limit on production share (%)	2005–2030	8	10	15
Expected return on investment (ROI) (%)	2005–2030	2005 15	2005 15	2005 15
		2020 8	2020 9	2020 12
		2030 7	2030 9	2030 11
Demand growth rate (%/year)	2005–2030	1	1,5	2
Change in the load structure (MW)	Peak	354,000	394,000	430,000
	High	312,000	318,000	324,000
	Medium	293,000	290,000	290,000
	Low	242,000	228,000	208,000
Natural gas price (€2000/mill MBtu)	2000	2,68	2,68	2,68
(Present US NY price 5,4 €/mill MBtu)	2015	3,69	5,36	8,38
	2030	4,69	9,41	14,07
Subsidy level on PV (€2000/MWh)	2010	40	40	40
	2020	17	23	26
	2030	0	6	12

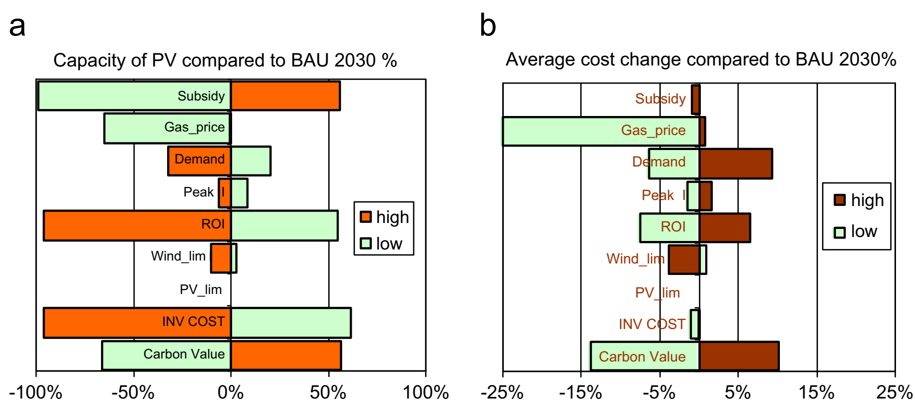

Fig. 9. (a, b) Sensitivities of the PV share and the average cost to the input variables.

4.6. Sensitivity analysis

The aim of the sensitivity analysis was to identify the key parameters and their potential impact on the model results.[6] By doing so, it fulfils two tasks. It gives indication on the functioning of the model, if the economic logic maintains on a wider range of operating environment described by the parameters. Additionally, it also helps to identify policy relevant aspects, e.g. which the parameters are that are decisive form a certain policy view, in this case in the promotion of photovoltaic technology.

By changing the parameter the model reallocates the new investments reshaping the whole generation portfolio. The impact could be measured on many variables of the model, but in order to keep the analysis concise this study focuses on the photovoltaic capacity shares and on the average cost developments (Table 1).

The results are presented in the following two figures. The first one shows the range of PV capacity shares compared with the reference run in 2030. Positive values mean an increase as compared with the reference share, while negative numbers indicate a reduction. Thus 0% means no change compared with the reference value (6.4%).

Fig. 9(a) highlights that the crucial parameters from the PV penetration point of view are the future investment costs of the technology (its capacity for learning—or cost reduction) and the level of subsidy given to it. This result coincides with earlier analyses, as most of the studies dealing with the question highlight the importance of technology learning and the vital role of the long term and predictable subsidy scheme. What more remarkable is the role of the expected ROI in the penetration of PV.

[6]The detailed input parameters and results of the sensitivity analysis can also be found at following web site: re.jrc.ec.europa.eu/refsys/

According to the sensitivity results, it also has a fundamental function in the progress of PVs. The positive developments of these three factors (Investment cost, subsidy and ROI) are indispensable conditions for a future development of the PV, but on the other hand they also represent threats to the PV development, as can be seen using the lower values. Early drying out of support to the scheme, less than expected technology learning and delayed results of the liberalisation policy (represented by the continuing high ROI) could interrupt its presently strong development.

The sensitivity analysis results also show that the climate policy (through the carbon price) and the expected future gas prices also play an important role in the development of the PV sector. The figure also reveals that these factors do not only mean a threat to achieving a significant share of PV technology in the future electricity portfolio, but also give opportunities to even further developments of the PV technology drawn in our scenario.

As concerning the other parameters, the figure suggests their minor importance and they signal that the model functions plausibly. An interesting signal from the Wind limit is the indication of the competition that exists between wind and PV, allowing for higher portion of wind energy that could reduce the PV share; however, this impact seems to be limited.

Fig. 9(b) shows the change in average cost values compared with the reference scenario in 2030 (2020). The figure gives a snapshot of the future electricity market from another angle. Looking at the cost of the whole system, the subsidy and the future investment cost of the PV is not a key concern for the sector, even a substantial development of the PV technology would mean limited increase in the costs (mainly in the 2015–2025 period). The most important factors are the future gas price developments, the carbon value and again the expected ROI in the sector. Nevertheless, it has to be noted that already in the reference path a significant cost increase is projected in the sector, being around 100% between 2005 and 2030. The impacts shown in the figure represents the additional effects of the different sensitivity runs.

5. Conclusions

The model results confirm that in the context of the renewable energy technologies the energy market liberalisation and the energy related climate change policy represent two mutually reinforcing policies: without liberalisation RE support would become too expensive and would prevent achievement of the established targets. In fact, the financial burden of introducing more RE sources in the electricity portfolio has been solely borne by the physical investors. This burden was increased by the following factors: risk associated with the duration of such projects, investors were effectively excluded from the market, limited experience on the performance of RE technologies over the lifetime. More competitive financing can efficiently separate the financial burden between the pool of physical and financial investors and the consumer. The physical investors can synchronise the payments to the cash-flow generated by the projects. The co-financing institutions are willing to give more competitive financing due to reduced risks. The consumers can choose different level of contribution (additional green tariffs or compulsory feed in tariff).

Without the reduced return expectation caused by market opening the policy subsidising PV would cost three times more, probably making it an unfeasible option.

The most significant basic requirement in the design of sustainable RE support policy is the achievement of the capital cost reduction needed to create a level playing field with the other power technologies. To accomplish this task, an effective RE support policy presumes the existence of a more competitive market structure.

The lower ROI weigh up the subsequent operation and fuel cost in the cash-flow, and consequently encourage investments in RE technologies characterised with high up-front costs. Since the reduction in the expected return produces a significantly more diverse power generation portfolio with a higher share of renewable energy sources, the market opening could have a positive effect on the electricity production from RE. These synergies can be achieved through

- encouraging the use of financial time horizon that corresponds better to the lifetime of the assets and
- ensuring public access to resource plans and related financing has to be ensured by a regulatory or supervisory body.

The sustainability of any support policy requires that the PV capacity cost reductions should be monitored, as it is one of the crucial prerequisites for the subsidy. As the investment cost reductions are realised, the subsidy in connection should be reduced as well to offer an additional incentive for faster market penetration. This parallel cutback, however, should be made clear for the investors in advance, to make the scheme predictable.

Based on the model results, the cost-effective support scheme for the PV technology has the following criteria:

- The support given must be defined in advance to the period corresponding to the lifetime of the technology.
- The amount of subsidy should be linked to the cost performance of producers: with a time delay, the support level has to be decreased as bigger market share results in capacity cost reductions. This would give the proper indication to the investors not to delay the investment in the production lines. The first movers gain higher support, while those investors access the market later have to invest in the lower cost facilities to maintain the market dynamism.

To find a cost-effective way to attain the European RE targets, some kind of 'burden sharing' could be advantageous, as the regional differences indicate the different potentials of the various regions. Market-based economic instruments (e.g. tradable RE quotas) could also help to achieve an efficient allocation of the cost burden of the renewable target on the European level. The model also shows that including some additional measures (regional differentiation, local supplementary incentives) the overall target can be achieved at lower costs. The results of the regional runs also indicate that the existing target level set for the EU is attainable with some regional differentiation.

References

Awerbuch, S., 2003. The True Cost of Fossil-Fired Electricity in the EU: A CAPM-Based Approach. IEA.

Awerbuch, S., 2004. Portfolio-Based Electricity Generation Planning: Policy Implications for Renewables and Energy Security. SPRU Energy Group.

Bolinger, M., Wiser, R., 2005. Balancing Cost and Risk: The Treatment of Renewable Energy in Western Utility Resource Plans, Ernest Orlando Lawrence, Berkeley National Laboratory LBNL 58450; 〈http://eetdlbl.gov/EA/EMP〉.

Brealey, R.M., Myers, S.C., 1991. Principles of Corporate Finance, fourth ed. McGraw-Hill, New York.

Capgemini Consultancy, 2006. European Energy Markets Observatory. Available at: 〈http://www.capgemini.com/industries/energy/eemo/〉.

de Vries, B.J.M., van Vuuren, D.P., Hoogwijk, M.M., 2007. Renewable energy sources: their global potential for the first-half of the 21st century at a global level: an integrated approach. Energy Policy 35, 2590–2610.

Domanico, F., 2007. Concentration in the European electricity industry: the internal market as solution? Energy Policy 35, 5064–5076.

Energy Information Administration, 2005. Planned Nameplate Capacity Additions from New Generators, by Energy Source, EIA/DOE, Available at: 〈http://www.eia.doe.gov/cneaf/electricity/epa/epat2p4.html〉.

European Commission, DG Competition, 2006. Report on Energy Sector Inquiry, Available at: 〈http://ec.europa.eu/comm/competition/sectors/energy/inquiry〉.

European Commission: DG TREN, 2005. Annual Report on the Implementation of the Gas and Electricity Internal Market, Available at: 〈http://ec.europa.eu/energy/electricity/benchmarking/doc/4/com_2004_0863_en.pdf〉.

Eurostat, 2006. Dataset on Infrastructure—Electricity—Annual data. Product code: NRG_113A. Available at: 〈http://epp.eurostat.ec.europa.eu〉.

Green, R., 2006. Electricity liberalisation in Europe—how competitive will it be? Energy Policy 34, 2532–2541.

Green, R.J., Newberry, D.M., 1992. Competition in the British electricity spot market. Journal of Political Economy 100, 929–953.

Gritsevskyi, A., Nakicenovic, N., 2000. Modelling uncertainty of induced technological change. Energy Policy 28, 907–921.

Hayashi, F., 1982. Tobin's marginal *q* and average *q*: a neoclassical interpretation, econometrica. Econometria 50 (1), 213–224.

Ibenholt, K., 2002. Explaining learning curves for wind power. Energy Policy 30, 1181–1189.

International Energy Agency, 2003. World Energy Investment Outlook 2003 Insight. OECD/IEA.

International Energy Agency, 2004. World Energy Outlook. OECD/IEA.

Jensen, S.G., Andersen, P.D., 2004. Experience curves in prospective studies. In: Proceedings of the EU-US Seminar: New Technology Foresight, Forecasting and Assessment Methods.

McDonald, A., Schrattenholzer, L., 2001. Learning rates for energy technologies. Energy Policy 29, 255–261.

McDonald, R., Siegel, D., 1986. The value of waiting to invest. Quarterly Journal of Economics 101, 707–727.

Mitchell, C., Bauknecht, D., Connor, P.M., 2006. Effectiveness through risk reduction: a comparison of the renewable obligation in England and Wales and the feed-in system in Germany. Energy Policy 34, 297–305.

Neij, L., 1997. Use of experience curves to analyse the prospects for diffusion and adoption of renewable energy technology. Energy Policy 25 (13), 1099–1107.

Nemet, G.F., 2006. Beyond the learning curve: factors influencing cost reductions in photovoltaics. Energy Policy 34, 3218–3232.

Surek, T., 2004. In: Proceedings, Third World Conference on PV Solar Energy, Osaka.

UCTE, 2005. System adequacy forecast 2005–2015. Available at: 〈http://www.ucte.org/publications/systemadequacy/〉.