

**SRU**



German Advisory Council  
on the Environment

# **Pathways towards a 100 % renewable electricity system**

## **Special Report**

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# 1 Introduction

The future of Germany's and Europe's energy supply is currently the subject of a political and social debate where energy policies are inextricably bound up with environmental and climate policies. In September 2010 the German government announced a new energy master plan that sets targets and defines numerous measures for 2050 and aims to bring about a far reaching transformation of Germany's energy supply system with a view to achieving an energy supply that is economically sustainable, reliable, and climate-friendly. This report also has to be seen in the context of the Commission Communications on a "Low Carbon Economy Roadmap 2050" (March 2011) and the respective Energy Road Map planned for late 2011.

It was with this overarching goal in mind that in October 2008 the German Advisory Council on the Environment (Sachverständigenrat für Umweltfragen, SRU) began work on the present expert report, since which time SRU has contributed to the professional discourse concerning the future of Germany's electricity supply system (SRU 2009a; 2009b; 2010a; 2010b). The report discusses the need for transformation of the electricity supply system, in light of the relevant technical, economic, legal and political factors, and with the goal of ensuring that Germany is able to establish a sustainable and decarbonised electricity supply system by 2050.

This report also addresses European aspects as far as they are relevant for the transition of Germany's electricity supply. The following text is a partial translation of the German original and focuses on those elements of the original report that might be relevant for an international reader. Furthermore this translation presents in an annex the results of some of the scenario runs for all European countries not yet completed by the date of the German publication in January 2011.

## 1.1 The issues

Our report currently centres around Germany's electricity supply system, concerning which major investment decisions are pending. A considerable share of Germany's current electricity generation capacities will need to be replaced over the next two decades, since many power plants will have reached the end of their lifetime by then. The investments that are made in the coming years will have a major impact on both the structure and emissions of the electricity sector for decades to come. This situation presents an opportunity to revamp Germany's power plant fleet in a manner that will be relatively inexpensive and that will constitute a far reaching structural change in the national electricity system.

In order to avert potentially catastrophic climate change by limiting global temperatures to 2 degrees Celsius above preindustrial levels, industrial nations such as Germany need to reduce their carbon emissions by 80–95 percent by 2050 (IPCC 2007). Emissions

reductions of this scope are also now a policy of both the European Union and Germany (Council of the European Union 2009; CDU et al. 2009) and enjoy broad support in Germany across the entire political spectrum. Inasmuch as, in the view of the European Commission, only a minute proportion of the attendant reductions can be achieved through implementation of flexible mechanisms outside the European Union, Germany and other EU states need to make major efforts to reduce their emissions.

In order for carbon emissions to be reduced by 80–95 percent, German power plants would need to be virtually emission free since for technical reasons, emissions cannot be reduced sufficiently by 2050 in other sectors such as agriculture and goods transport, or the costs of such reductions might be relatively prohibitive, whereas the requisite technological solutions are already available to power companies. Hence the electricity supply system is a touchstone of energy and climate policies.

In this report, the SRU lays out the reasons why a sustainable and climate friendly electricity supply can only be achieved using renewables. Using this principle as a starting point, the Council addresses the issue as to whether and under which conditions a wholly renewable electricity supply system can be established. Hence this report is in line with a series of recent studies that have investigated whether a largely or wholly renewables based electricity supply is achievable in Germany and Europe (PwC et al. 2010; ECF et al. 2010; Klaus et al. 2010; Öko-Institut and Prognos AG 2009; Nitsch and Wenzel 2009; FoEE and SEI 2009), and in so doing addresses the following issues:

- Is a wholly renewables based electricity supply technically feasible for and in Germany? Would such a system allow for security of supply that is on a par with today's?
- How much would a wholly renewable electricity supply and the transition thereto cost?
- What would be a realistic timeline for the transition to such an electricity supply and which measures would this transition entail?
- Which hurdles would need to be cleared in transitioning to a renewables based electricity supply? Which political and legal frameworks would need to be taken into account for such a transition in the European context and how much leeway do they allow?
- Which economic and statutory policy instruments could be used to bring about this transformation smoothly and efficiently?

The present report is based on a series of technical and economic scenarios concerning a wholly renewable electricity supply in Germany and Europe that were elaborated by the German Aerospace Center (DLR) and whose findings were published in a Statement in May 2010 so that the government could use them in elaborating its energy master plan (SRU 2010a). These findings are described here. After the publication of the original

report, final runs of one of the scenario families have been calculated for each EU member state, which are presented in the Annex. The SRU has also elaborated a series of recommendations, in light of the relevant political, economic, legal and social factors, as to how Germany's electricity supply could be transitioned to an entirely renewables based electricity system. In terms of climate protection objectives and the target energy mix, our concept goes further than the government's, since we take the view that transitioning to a wholly renewable electricity supply by 2050 is a realistic objective, whereas the government's master plan calls for a system where 80 percent of all electricity would be supplied by renewables. However, the recommendations are also relevant for the government's less ambitious objective. Inasmuch as base load oriented nuclear power and renewable energy development are mutually exclusive, SRU recommends pursuit of a strategy for transitioning to renewables that diverges completely from the government's. For further information in this regard, see our critical assessment of the government's energy master plan (SRU 2010b).

## **1.2 Overview of the report**

In chapter 2 we explain why Germany needs a wholly renewable electricity supply, which is the guiding principle for all of the analyses and scenarios presented in this report. To this end, we discuss the extent to which the available electricity generation options are sustainable.

In chapter 3, we describe the various scenarios that would allow for establishment of a wholly renewable electricity supply in Germany by 2050, and in so doing, by way of providing the necessary background we briefly survey the relevant German and international electricity sector development scenario studies that have been published. In chapter 3 we also discuss our scenario methodology, the basic attributes of the scenario models, and the models' assumptions concerning the potential and costs of renewables. Chapter 4 describes the putative timeline for transformation of the electricity supply system by 2050, based on the current situation; we also provide a cost estimate for renewable electricity during this period.

Chapter 5 surveys the history of renewables support schemes in the EU in terms of their key phases, and assesses the political probability that the EU will in fact be able to transition to renewables, also chapter 6 concerns itself with the political hurdles entailed by transitioning to a wholly renewable electricity supply with a strong European perspective, whereby the following issues are discussed in particular: the new EU energy and environmental policy competency framework pursuant to the Lisbon Treaty; the future of EU climate and energy policy; bilateral and multilateral cooperation; the policy conditions needed nationally to transition to a wholly renewable electricity supply.

In chapter 7 we argue that energy efficiency is a key precondition for transitioning to an affordable wholly renewable electricity supply. In chapters 8 and 9, using an analysis of the relevant regulations we recommend certain legal and political measures that we feel would help Germany to transition to a wholly renewable electricity supply. This chapter mainly concerns itself with the following: optimisation and expansion of the emissions trading framework and of the Renewable Energy Act (EEG); promoting public participation in and acceptance of a wholly renewable electricity supply; the regulatory aspects of an optimised electricity transmission grid planning process; and an analysis of economic incentives for electricity storage facility and grid expansion. An executive summary of this report can be found in chapter 10.

## **2 Sustainable electricity – the technological options**

### **2.1 Introduction**

Energy supply that meets future needs must be compatible with the tenets of sustainability and must at the same time set the stage for achievement main environmental objectives. This mission is indirectly enunciated in the German Constitution, whose Article 20a states that “Mindful also of its responsibility toward future generations, the state shall protect the natural foundations of life...”. Also Article 191 and Article 11 of the Treaty on the Functioning of the European Union (TFEU), the so-called Lisbon Treaty, contain more precise requirements to ensure a high level of environmental protection. Under this framework, the electricity supply system must fulfil its pivotal task of establishing a reliable supply of quality energy at an affordable price. Among the key references concerning the sustainability criteria and environmental objectives discussed below are the various treaties, programs and strategies which, by virtue of their official nature, are generally accepted and which we shall interpret and flesh out in light of the scholarly and scientific debate.

The discussion of the various electricity generation technologies is set against the backdrop of the aforementioned preconditions for sustainable energy development. No energy generation technology can hope to fulfill equally well all of the criteria and objectives entailed by sustainable electricity generation. And indeed, some forms of renewable energy – particularly if their development is unregulated – can also have a negative impact on the environment. Hence the decision to opt for one or more energy technologies always involves a process where the various factors are weighed against each other with the goal of arriving at an energy mix that represents the lesser evil, so to speak. But at the same time, certain energy technologies are completely incompatible with the criteria of sustainability, particularly over the long run – one example being new conventional coal fired power plants, which are incompatible with the government’s medium term climate protection objectives (SRU 2008, no. 218). The next section of this report focuses on the key problems that call into the long-term sustainability of such technologies. The main criterion applied in this regard was whether such problems are inherent to the technologies in question; or alternatively, whether the undesirable effects of such technologies can be averted or substantially minimised by altering the relevant frameworks.

In the following, we argue that particularly in light of this criterion renewable energy is the only potentially sustainable solution.

## **2.2 Objectives and criteria**

### **2.2.1 Sustainability criteria**

The concept of sustainable and eco-friendly development mainly stems from the international debate concerning the concept of sustainable development, as advanced in 1987 by the Brundtland Commission (WCED 1987) and whose definition of sustainability remains a generally accepted touchstone of the debate in this domain. According to this definition, development is sustainable if it “meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED 1987). This principle first gained broad international acceptance on being included in the Rio Declaration of 1992, in a similar formulation, as Principle 3.

Nonetheless, the ecological, economic and social worth and importance of sustainability are still being hotly debated by policymakers and academics alike, as is the interpretation of these various principles (Schutz des Menschen und der Umwelt. Ziele und Rahmenbedingungen einer nachhaltig zukunftsverträglichen Entwicklung, Enquete-Kommission 1998; SRU 2008 no. 1 ff; von Egan-Krieger et al. 2007; Ott and Döring 2004).

The federal government's second progress report on sustainable-development strategy (Bundesregierung 2008), which greatly helped to clear the air concerning such issues, placed particular emphasis on (a) how important it is, in terms of achieving other objectives, to durably safeguard the natural foundations of life; (b) our responsibility toward future generations; and (c) the principle of equal and fair resource usage rights. In so doing, the report addressed the basic elements of the principle of “robust sustainability” that has long been advocated in the literature (Ott and Döring 2004; von Egan-Krieger et al. 2007).

#### **Achieving sustainability**

The government's progress report lays down the following principle: “We simply need to accept that our planet's capacity to sustain human activity is finite.” The report then goes on to say the following: “Achieving sustainability for our planet is the absolute outer limit that comprises the framework in which we need to realise our various objectives” (Bundesregierung 2008, p. 21). The report is referring here to the problem of scale – namely that we need to avoid overuse of what is essentially finite natural capital (Daly 2007). The term “absolute limit” used in the report refers to the theory that owing to the complex systemic functional context in which it exists, natural capital cannot be replaced to an infinite extent by technical capital and that natural capital can be irretrievably lost as the result of overuse or human intervention (Ott and Döring 2004). According to a recent study that attempts to define exactly where this limit lies for ten key Earth system processes, these resource-use limits have already been exceeded to the point where mankind may be

facing sudden, irreversible or catastrophic effects in terms of climate change, biodiversity loss, and human intervention in the nitrogen cycle (Rockström et al. 2009).

By placing economic, ecological and social objectives on the same footing, the classic German sustainable-development triad fails to take sufficient account of the overarching nature of the ecological context (for a critical view see SRU 2002; 1994; Rehbinder 2009). But to achieve a state of ecological sustainability economic and social objectives need to be regarded as highly desirable icings on the cake of a robust and above all non-negotiable ecological framework. But while economic and social objectives may take a back seat to the ecological imperative, they nonetheless remain highly relevant.

#### Responsibility toward future generations

The government's progress report also underlines the importance of the principle of responsibility toward future generations, which has been generally accepted since the Rio Declaration and is also enunciated in Article 3 (1) of the UN Framework Convention on Climate Change. The guiding principle of the government's report is that "insofar as possible, resources and natural areas should be preserved as a legacy for future generations" (Bundesregierung 2008, p. 19). One of the key issues that has come up in the sustainability debate is how to fold the principle and practice of responsibility toward future generations into today's decisions. In this context, the economic concept of discounting – i.e. ascribing a lower value to assets than their current value – has generated controversy. If we are to achieve robust sustainability, we will need to ascribe the same value to both current *and* future environmental damage. Hence natural resources should only be used in such a way that their potential will be available to future generations. This concept is clearly expressed by the so called constant natural capital rule (Ott 2009).

#### Fair and equal usage rights

The government's progress report addresses the issue of fair and equal per capita rights to the use of natural resources by saying the following: "From an ethical standpoint, all human beings have an equal right to use resources, so long as they are not overused. (...) Unequal distribution of opportunities, rights, and duties in domains such as access to natural resources or education violates the sustainability related principle of responsibility toward future generations" (Bundesregierung 2008 p. 20).

These sustainability criteria are particularly relevant to climate protection and the preservation of biodiversity, but need further fleshing out in order to render them usable for assessing the possibility of establishing a sustainable electricity supply. The social justice aspect of sustainability strategies has far reaching implications for the allowable carbon emissions of industrial nations. But in light of the aforementioned principles, it is difficult to see how a strategy involving the long-term storage of power plant carbon and radioactive

waste can be reconciled with the principle of responsibility toward future generations. For even underground areas used for long term storage can and should be regarded as finite resources, one should scrupulously avoid burdening future generations with such hazardous substances (SRU 2009a).

### Sustainability and risk avoidance

Sustainability and the precautionary principle are inextricably bound up with each other, as is clearly enunciated by Principle 15 of the Rio Declaration: “In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.” This principle is likewise enunciated in other international treaties such as the UN Framework Convention on Climate Change, whose Article 3(3) calls for the treaty signatories to “take precautionary measures to anticipate, prevent or minimise the causes of climate change and mitigate its adverse effects.” But unfortunately, the discourse in this regard here in Germany barely makes any connection between sustainability and risk avoidance, despite the fact that precautionary measures are absolutely indispensable when it comes to meeting our responsibilities toward future generations (Birnbacher and Schicha 2001). As time goes on, the nature of future events will necessarily become freighted with ever growing uncertainty, whereby the decisions we make today will inevitably have a broad range of consequences. Risk avoidance means making decisions aimed at safeguarding our security. One of the key tenets of the precautionary principle is taking actions that mitigate the greatest possible damage, i.e. adopting a so called minimum-maximum strategy. In the view of one author, this tenet fleshes out the definition of sustainability advanced by the Brundtland Commission to the effect that we must not compromise “the ability of future generations to meet their own needs” (Ott 2009, p. 79). Hence avoidance of major risks, including extremely remote ones, can be regarded as a need that will be relevant for future generations (as it is in some cases for today’s) and that falls within the scope of the aforementioned sustainability principles.

## **2.2.2 Climate protection objectives**

Climate compatibility is one of the most important criteria when it comes to assessing the sustainability of energy and electricity supply technologies. The myriad and possibly catastrophic effects of climate change pose a threat to all species and species habitats, the dynamics of ecosystems, the livelihoods of millions of human beings, and international peace. One of the key challenges we now face in terms of climate protection is observance of the three principles of sustainability: usage limits; responsibility toward future generations; and per capita equality of natural resource use.

## Preventing dangerous anthropogenic interference with the climate (Article 2 of the UN Framework Convention on Climate Change)

According to Article 2 of the 1992 UN Framework Convention on Climate Change, the Convention's "ultimate objective" is as follows: "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

This provision of the Convention is to all intents and purposes a legally binding international-law framework that needs to be fleshed out – a goal that is particularly urgent in view of the scenarios we may well be facing according to scientific projections on climate change (IPCC 2007b). The technologies that are the key contributors to greenhouse gas emissions play a central role in the goal enunciated by Article 2 of the Convention (Ott and Döring 2004).

## Keeping global warming to below 2 degrees Celsius: a key international goal

Since the mid 1990s, international efforts have been underway to set a quantitative threshold limit for Article 2 of the UN Framework Convention on Climate Change. Already in 1995, the German Advisory Council on Global Change (WBGU) recommended that global warming be limited to a maximum of 2 degrees Celsius in the interest of keeping the risks and consequences of global warming within reasonable bounds (WBGU 1995; 2003, chapters 2.1 and 6.1; 2009a). This has also been the official climate protection goal of the EU since the European Council meeting that was held in Luxembourg in June 1996, has been strengthened in the interim, and has been widely accepted internationally since 2005 (see for example Council of the European Union 2005, p. 15). Moreover the 2009 Copenhagen Accord, which was signed by the heads of 120 nations (UNFCCC 2010, p. 5 f), also recognises this goal as the state of the art and a guidepost for each signatory state's emissions reductions – albeit without obligating the signatories to take the measures necessary to achieve this goal. The Copenhagen Accord is based on a so called pledge and review process, whereby the signatory states set their own mandatory emissions reduction objectives. Although according to current estimates the 76 binding obligations that had been announced as at April 2010 will contain the increase of global temperatures, in the best case scenario global temperatures will still rise by at least 3 degrees Celsius (WBGU 2010; Sterk et al. 2010; Rogelj and Meinshausen 2010).

## Emissions reduction obligations in Germany and Europe

In the interest of adhering to the 2 degrees Celsius limit, in the run-up to the 2009 Copenhagen Conference the heads of the EU member states reached an agreement (by way of a European Council declaration) to the effect that all industrial nations should promote halving of greenhouse gas emissions by 2050 by reducing their own emissions by 80 to 95 percent (Council of the European Union 2009). Hence this goal is also relevant for the EU. In the view of the European Commission, only a minute proportion of the attendant reductions can be achieved through implementation of flexible mechanisms outside the EU (European Commission 2010a). Even if the aforementioned European Council declaration was intended as a supporting instrument for the Copenhagen conference and thus was not binding upon the EU per se, it is nonetheless a highly significant document for European climate policy frameworks and should be regarded as a key climate policy benchmark. This benchmark is also consistent with the reductions that the Intergovernmental Panel on Climate Change (IPCC) regards as necessary in order to avoid exceeding a 450 ppmv concentration of carbon equivalent emissions (IPCC 2007a; Barker et al. 2007, p. 39).

However, in the interim the European Commission has stated that the EU goal of cutting greenhouse gas emissions by 20 percent of 1990 levels is insufficient. As adherence to this 20 percent target would necessitate considerable acceleration of emissions reduction rates after 2020, the 2050 goal might not be met (European Commission 2010a).

According to initial European Commission investigations, in order for carbon emissions to be reduced by 80 to 95 percent the electricity sector would need to be virtually emission free (Jones 2010); other multi-sector scenario simulations have reached similar conclusions (Öko-Institut and Prognos AG 2009; Edenhofer et al. 2009 p. 7). This decarbonisation requirement for the electricity sector is attributable to the fact that for technical reasons, emissions cannot be reduced sufficiently by 2050 in other sectors such as agriculture and freight transport, or the costs of such reductions would be prohibitive, whereas alternative technological solutions are already available in the electricity sector.

European climate objectives are of course also binding for Germany, whose objectives for 2020 exceed the EU's but have been set at the lower limit of the mandated target range for 2050. By way of supporting an international climate protection treaty after 2012, the German government plans to cut greenhouse gas emissions by 20 percent of 1990 levels by 2020. The government has also endorsed the goal of reducing greenhouse gas emissions in industrial nations by at least 80 percent by 2050 (CDU et al. 2009, p. 26).

## Acceptable per capita greenhouse gas emissions

Implementation of the three sustainability-strategy principles would nonetheless entail considerably greater emissions reductions than those referred to above. A study by the

German Advisory Council on Global Change (WBGU) calculated the per capita greenhouse gas emissions that would be compatible with global sustainability limits, responsibility toward future generations, and equal and fair per capita resource usage rights (WBGU 2009a).

According to the study, in order to achieve, with 66 percent probability, the goal of keeping global warming to below 2 degrees Celsius, global carbon emissions would need to be limited to *750 billion tons* between 2010 and 2050 (WBGU 2009a). If these total allowable emissions (excluding emissions trading) were subject to equable per capita distribution (the WBGU's "responsibility toward future generations" option), Germany's current approximately 11 tons per capita annual emissions would have to be reduced to practically zero by 2030. If emissions trading is factored into the calculation, real emissions could be around 1 ton per capita and year in the run-up to 2050. And even if this resulted in an increase in the allowable amount of carbon emissions, they would still need to be drastically reduced.

A reduction of this scope would entail curbing emissions by around 95 percent, as opposed to the "minimum of 80 percent" level advocated by the government. In light of what we have stated above, achieving such a goal would unavoidably mean that Germany's electricity system would have to be almost completely climate neutral.

### **2.2.3 Preservation of biodiversity**

Until recently the goal of EU biodiversity policies was to stop biodiversity loss, while the UN's goal was to significantly curb such loss (SCBD 2002, 2004). Neither of these goals has been reached (EEA 2009; European Commission 2009; Deutscher Bundestag 2009), and new goals for 2020 have now been set by both the EU and UN. At the tenth meeting of the Conference of the Parties to the Convention on Biological Diversity (CBD) in October 2010 in Nagoya, the goal of at least halving the loss of natural habitats by 2020 was set as part of a strategic plan, whose aims at the EU level are to stop the deterioration of ecosystem services in EU member states by 2020, restore biodiversity and ecosystem services insofar as possible, and at the same time step up EU efforts to avoid global biodiversity loss (SCBD 2010; European Commission 2010b).

Germany's biodiversity strategy calls for the setting of specific objectives aimed at protecting biodiversity and using it in a sustainable manner, with a view to preserving eco-balance functionality and durably ensuring the regeneration capacities of natural resources and the habitats needed by both plants and animals (BMU 2007a, p. 9). To this end, the strategy calls for the preservation of species, species habitats, and the genetic diversity of both wild and domesticated animal species. The strategy also stipulates development and other objectives for forests, coastal areas, wetlands and other habitats, with a view to

durably stabilizing them at a high quality level through measures such as the conservation of interconnected and unfragmented habitats. But the strategy goes even further, in that, based on these habitat objectives, requirements are laid down for the sectors that are largely responsible for biodiversity loss – in particular agriculture, energy generation, raw materials extraction, settlements and transport.

In terms of the substance inputs stemming from these sectors, the strategy sets a goal of adherence to critical load and level limits by 2020 for acidification, nutrients and heavy metals (eutrophication), and ozone, so as to ensure that vulnerable ecosystems can be durably protected (BMU 2007a, p. 54). Agricultural production methods play a pivotal role when it comes to reducing overfertilisation (SRU 2009b). As for land use attributable to settlements and transport, the biodiversity strategy calls for a reduction to a maximum of 30 hectares per day by 2020, via measures such as intensifying cooperation between municipalities in connection with residential and commercial zoning processes (BMU 2007a, p. 51).

Preserving biodiversity also means building ecologically compatible power generation facilities, to which end Germany's national biodiversity strategy recommends that measures be instituted in particular for renewable raw materials, and for renewable energy in general (2007a, pp. 76–78).

One of the main *raison d'être* for the national biodiversity strategy is the economic importance of ecosystem services, whose monetary value various authors have attempted to quantify. For example, the seminal study titled *The economy of ecosystems and biodiversity* (Sukhdev 2008) estimates that nature conservation areas of various types provide humanity with US\$4.4–5.2 trillion worth of ecosystem services annually, which exceeds aggregate annual automobile, steel, and IT industry sales revenues worldwide. The study estimates that the annual cost of properly preserving nature conservation areas amounts to around 1 percent per annum of their monetary yield. The ecosystem services that come into play in this regard include clean water and fertile soil, with one of the most important being an intake buffer system against environmental change such as global warming and the consequences thereof (Dister and Henrichfreise 2009; Vohland et al. 2008; SCBD 2007; Epple 2006). The absorption capacity, regeneration rate and response capacity of natural resources are determined by eco-balance functionality. Against this backdrop, climate change is making functioning, adaptable ecosystems an increasingly important commodity for both the agriculture and forestry sectors; and this in turn means that sustainability criteria need to factor in nature and environmental conservation measures. Protecting natural capital is one of the less expensive measures available when it comes to effective climate protection (McKinsey & Company 2009).

A sustainable electricity supply needs to build in biodiversity protection considerations from the get-go. Biodiversity is harmed by just about every aspect of the energy use and supply chain, including raw materials extraction, emissions resulting from energy conversion, interventions engendered by infrastructures, and disposal of combustion residues. There is a potential for major conflicts between renewables on one hand and biodiversity conservation objectives on the other, by virtue of the fact that renewables involve land use. However, such conflicts can be mitigated by the following: (a) defining geographic boundaries, setting priorities, and judicious siting (SRU 2007); (b) landscape and land use planning; and (c) careful and comprehensive site impact studies concerning environmental factors, and in particular biodiversity. Site and time related information needs to be available to all relevant decision makers in order to assess and mitigate any possible negative effects. This is particularly important in view of the fact that the biological impact on species and populations, as well as the physicochemical effects on water, soil and air resources are scale dependent. In this context, the environmental policy goals of the FFH Directive (92/43/EEC), the Water Framework Directive (2000/60/EC) and the attendant protection programs such as that promulgated by the Marine Strategy Framework Directive (2008/57/EC) should also be met.

#### **2.2.4 The energy policy target triangle**

In terms of both German and EU energy policy, the current energy policy target “triangle” (which in our view is outdated) comprising efficiency, security of supply, and environmental tolerability continues to be relevant (CDU et al. 2009, p. 6; European Commission 2008). The salient feature of this target triangle comprises the interdependency of three specific objectives, which according to this model should be given equal weight with a view to achieving a balance among them. However, in 2002 a parliamentary commission on sustainable energy stated that “nature’s barriers” should take priority over the other two objectives (Enquete-Kommission Nachhaltige Energieversorgung unter den Bedingungen der Globalisierung und Liberalisierung 2002, p. 71). This clearly defined hierarchical take on sustainability was also folded into the German government’s progress report, and SRU too endorses this view. But this position resulted in today’s governing parties having only a minority vote on the commission; and thus the commission failed to become a consensus building instrument. This partisan disagreement among the commission’s members clearly shows that safety, cost, and affordability are also key factors that will need to be taken into account if Germany is to successfully transition to a wholly renewable electricity supply – even if the main aim of this transition is to protect the environment by achieving the mandatory ecological and climate protection objectives.

## **2.3 Sustainability assessments of various energy generation options**

The lion's share of Germany's electricity is currently generated by nuclear power and coal, whereby renewables usage is on the rise and now accounts for 16 percent of the energy supply. In the sections that follow, the Council assesses the three most important sources of electricity – namely coal, nuclear energy, and renewables – in light of the criteria that previously has been discussed concerning a sustainable energy supply.

### **2.3.1 Coal**

#### Greenhouse gas emissions

Electricity generated using fossil fuels is a major contributor to global warming. The greenhouse gas emissions per kilowatt hour of coal are far higher than those of all other energy resources. Table 2-1 shows the amount of mean greenhouse gas emitted by various sources of electricity over the entire lifecycle of the attendant installations. The figures shown in the table take particular account of the relevant upstream processes and power plant construction materials. Specific greenhouse gas emissions for lignite fired power plants without waste heat recovery systems amount to 1153 g/kWh<sub>el</sub> and for hard coal are 949 g/kWh<sub>el</sub>. Although combined heating and power (CHP) plants allow for improved greenhouse gas performance, the specific emissions of these plants are still one order of magnitude higher than that of renewable energy and nuclear power. Gas power plants without CHP systems emit 428 g/kWh<sub>el</sub> of greenhouse gases, while the emissions for gas fired district heating power plants are only 49 g/kWh<sub>el</sub> thanks to the credits resulting from the heat they use (see the comment below Table 2-1).

The negative climate impact of power plants that use fossil fuel is a particularly important factor for the sustainability assessments discussed in this report.

Table 2-1

**Aggregate mean greenhouse gases  
emitted by various electricity sources**

Energy source/resource	Emissions in g/kWh <sub>el</sub>	
	Carbon equivalents	Carbon only
Nuclear power (import-mix uranium)	32	31
Nuclear power (Russian uranium)	65	61
Imported hard coal	949	897
Cogeneration fuelled by imported lignite	622	508
Lignite fired power plants	1.153	1.142
Lignite fired cogeneration plants	729	703
Gas and vapour turbine power	428	398
Gas and vapour turbine cogeneration	148	116
Natural gas district heating	49	5
Biogas district heating	- 409	- 414
Onshore wind	24	23
Offshore wind	23	22
Hydropower	40	39
Multi-crystalline solar cells	101	89
Solar energy imported from Spain	27	25

The figures above, which were computed by the organisation known as Öko-Institut using Gemis 4.4 software, take account of upstream processes and power plant construction materials. These calculations also presuppose that the energy needed for these upstream processes will be provided by a conventional mix of energy resources – which means that nuclear power plants and renewable energy power stations will also display a carbon footprint to some extent throughout their lifetimes. The assessments of combined heating and power (CHP) systems factored in heating generation as a credit. To this end total emissions for the CHP process (i.e. heating and electricity generation) were computed, and the emissions from a heating system that would provide the same amount of heating were then subtracted from this amount. Hence arithmetically negative emissions were obtained for biogas fired district heating power plants since the credit for CHP heating is higher than the total emissions for district heating power plants, which use carbon neutral biogas.

Source: Fritsche et al. 2007

**Additional health and environmental effects  
using fossil fuel to generate electricity**

The use of fossil fuel to generate electricity engenders other negative health and environmental effects apart from those mentioned above (SRU 2000; WBGU 2003). Coal

mining involves major interventions in the landscape, potentially necessitating the relocation of whole villages and provoking social conflicts. Moreover, coal mining is associated with high health and fatality risks for coal miners, depending on the working conditions in the country of extraction. Coal mining also causes ecological damage owing to effects such as habitat loss, groundwater quality degradation, and methane emissions.

Fossil fuel combustion results in not only CO<sub>2</sub> emissions, but also emissions of other air pollutants that have negative health effects and cause soil and surface water acidification, eutrophication, and ozone layer damage. Thanks to the use of filter and flue gas cleaning systems, power station air pollution has been greatly reduced in Germany over the past two decades (UBA 2009). However, the energy sector still remains one of Germany's largest emitters of both nitrogen oxide and sulfur dioxide emissions (UBA 2010). The substantial amount of water needed for condensation power stations constitutes an ecological disadvantage in many regions owing in large measure to the consequent higher water temperatures and exacerbation of water scarcity.

#### Use of non-renewable resources

Fossil fuel combustion for electricity generation purposes entails the use of non-renewable resources that are irretrievably lost to future generations. The importance of this factor for sustainability assessments in terms of our responsibility toward future generations depends on the total available reserves of the fossil fuel in question. Total known hard coal *reserves* worldwide (i.e. currently known reserves whose extraction is feasible from a technical and economic standpoint) amount to around 730 Gt. Assuming that coal reserve mining this resource remains at its current level of 5.5 Gt per year, these reserves will last for another 130 years (BGR 2009). As for coal *resources* (coal deposits whose mining is currently not economically viable and that are thought to exist based on geological indicators, but whose existence has not yet been proven), according to most estimates the amount is far higher (15,675 Gt for hard coal). However, some experts feel that these estimates are overblown, pointing out that coal deposits could begin to grow scarce sooner than expected. This view is based on (a) the fact that in recent years numerous countries have considerably lowered their coal reserve estimates but have for the most part yet to reclassify resources as reserves (Zettel and Schindler 2007); and (b) the current rapid depletion rate of known reserves (Kavalov and Peteves 2007).

However, coal is relatively abundant compared to energy resources such as natural gas or uranium. Inasmuch as coal use for power stations will be limited at an earlier point in time by the atmosphere's capacity to act as a sink for greenhouse gases from coal, the climatic effect of coal is the key criterion in assessing its sustainability as an energy resource. Extraction of less than half of the known oil, gas and coal reserves by 2050 is allowable,

providing that the admissible amount of greenhouse gas emissions is not exceeded (Meinhausen et al. 2009).

### Carbon capture and storage systems

One of the options being considered for mitigating the greenhouse effects of fossil fuel fired power stations is carbon capture and storage (CCS) technology, which is currently being developed and will probably not become commercially available until 2030. However, it seems doubtful that the use of coal CCS can be regarded as a sustainable form of energy generation.

CCS would greatly reduce but not completely nullify greenhouse emissions from coal. Carbon dioxide emissions reduce their efficiency and increase the amount of coal needed to run them. The greenhouse gas emissions of power stations that are slated to go into operation in 2020 could be reduced by around 70–90 percent for the process chain as a whole (Esken et al. 2010), although the attendant ecological risk entailed by long term carbon storage and the long term safety of carbon storage facilities have yet to be sufficiently studied (Blohm et al. 2006; BMWi et al. 2007). The use of CCS would not greatly mitigate the remaining environmental effects of coal mining and use. However, construction of the requisite CCS infrastructure, and in particular pipelines to transport carbon from power stations to storage sites, would entail additional interventions in the landscape and environment.

Another sustainability assessment factor for CCS is the potential impact of long term underground carbon storage. Here, the overriding consideration is that the use of underground areas for carbon storage purposes can only be classified as use of a non-renewable resource, since the available storage space is finite. According to the latest estimates from the Federal Institute for Geosciences and Natural Resources (Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)), German territory (underground) and the German sector of the North Sea exhibit aggregate storage capacity for 12 billion tons of carbon dioxide, 9.3 billion of which is represented by saline aquifers and 2.75 billion of which is located in empty natural gas fields (Knopf et al. 2010). This capacity equates to around 36 times the annual carbon emissions of Germany's large combustion plants, whereby plants of this type that are subject to emissions trading obligations (nominal output exceeding 50 MW) emitted 330 million tons of carbon in 2009 (Olaniyon et al. 2010). However, this figure does not encompass the entirety of German territory, and the BGR anticipates that additional storage capacity will be identified in regions that are awaiting investigation.

These figures, which are considerably lower than earlier estimates (May et al. 2005), are still freighted with considerable uncertainty. According to the Wuppertal Institute, potential saline aquifer carbon storage capacity may be considerably lower if more conservative

water displacement and compressibility assumptions are applied (Esken et al. 2010). Moreover, it may only be possible to use a portion of the available potential capacity owing to geological, economic, and/or ecological restrictions. For example, the geomechanical forces exerted by overlying rock resulting from decades of aquifer-formation water displacement could limit storage capacity use (Knopf et al. 2010). According to experts, it will not be possible to determine with certainty the storage capacity of certain geological formations until they are actually used for storage purposes. But at the same time, it goes without saying that the lower the actually usable storage capacity, the less cost effective establishment of a suitable CCS infrastructure in Germany would be. Consideration is also being given to the possibility of storing carbon from German power stations in neighbouring countries or in North Sea geological formations, although the issues raised by this option, particularly in terms of its technical, economic and legal feasibility have yet to be resolved (Esken et al. 2010). But be all this as it may, establishment of a CCS infrastructure would undoubtedly entail a high level of economic risk.

Another possible problem with CCS is that it could give rise to competition with other geological formation uses such as geothermal energy (SRU 2009a). In addition, the use of coal CCS would conflict with the use of CCS for industrial process emissions (Öko-Institut and Prognos AG 2009) or the use of CCS in connection with biomass combustion (SRU 2009a). While coal CCS would continue to engender emissions, albeit at a low level, combining biomass CCS would allow for the removal of carbon dioxide from the atmosphere – a solution which may become necessary in the latter half of this century in order to keep global warming below 2 degrees Celsius (IPCC 2007c).

Hence in the interest of leaving a maximum number of greenhouse gas reduction options open for future generations, it would probably be best to avoid using coal CCS.

#### Fossil fuel fired power station costs

It is safe to assume that the cost of producing electricity using fossil fuel fired power stations is set to increase on account of emissions trading and rising worldwide demand for electricity (Nitsch 2008). The extent of this cost increase will mainly be determined by the climate policy objectives that are set and the manner in which they are implemented. If CCS use reduces emissions trading certificate costs, it also ramps up electricity generation costs owing to the additional technology entailed by it. Presumably the cost of renewable electricity and coal CCS will be more or less the same at the time CCS becomes commercially available; whereby renewable electricity is likely to become cheaper thereafter. Hence from an economic point of view, there is no particular reason to prioritise CCS over renewables (Esken et al. 2010).

### 2.3.2 Nuclear power

Nuclear power has less of an impact on global warming than is the case with coal (Turkenburg 2004, p. 46), with greenhouse gas emissions per kilowatt hour during the lifetime of a nuclear power plant more or less equating to that of renewables (see Table 2-1). Nonetheless, nuclear power cannot be regarded as a sustainable energy source in view of the problem of nuclear waste disposal and the operational risks it entails.

#### Final storage of nuclear waste

The as yet unresolved worldwide problem of how to dispose of highly radioactive and heat-dissipating spent nuclear rods is a key issue when it comes to nuclear energy use (Pistner et al. 2009, p. 45). The environmental policy goal in this regard should be to find a solution that allows radioactive waste to be stored for at least several thousand years in a manner that will reliably seal off such waste from the biosphere. There is as yet no officially approved ultimate waste disposal site solution worldwide for the highly radioactive waste engendered by nuclear power plants; nor is a solution in sight in Germany, where such waste continues to be kept in temporary storage facilities (BMU 2008).

In view of the enormity of the challenge entailed by ultimate nuclear waste disposal, this problem is likely to persist; nor can it be resolved via scientific acumen or the ordinary powers of human judgement. High radioactivity and chemical toxicity and lengthy heat dissipation, as well as gas formation resulting from corrosion and microbial processes, pose major problems for the retention capacities of the barrier elements that might potentially be used for nuclear waste storage purposes (SRU 2000, p. 529). Hence assessments of the long term safety of ultimate waste disposal sites must necessarily be based on assumptions and simulations. The longer the projection period of such investigations, the more freighted with uncertainty they become. This in turn means that a given ultimate waste disposal site for highly radioactive and heat-generating waste will in fact exhibit the requisite safety attributes for the desired period. Nor is there currently any way to ensure that it will be possible to indicate to future generations the exact locations of ultimate waste disposal sites and the hazards attendant upon them. This means that the livelihoods of future generations could be catastrophically threatened by radioactive waste that is stored in the present day; and thus nuclear power cannot be regarded as a sustainable energy source in light of our responsibility toward future generations and the tenets of risk avoidance.

#### Risks entailed by nuclear accidents

Accidents that befall nuclear reactors or other elements of the nuclear fuel cycle can provoke the release of considerable amounts of radioactivity into the atmosphere, which in turn can cause severe problems for individuals, populations, economies, and the

environment. These risks are also heightened by the threat of terrorist attacks on nuclear power stations or uncontrolled proliferation of nuclear technology and/or radioactive byproducts, which could potentially be used for attacks of various kinds.

A probability based risk assessment of the type prescribed by law in most EU countries prior to the construction of a nuclear reactor leads to the following conclusions (Turkenburg 2004, p. 48):

- Catastrophic accidents involving a large number of victims and extremely serious social consequences over a lengthy period cannot be completely ruled out.
- Safety risk calculations are extremely inexact and freighted with great uncertainty, particularly in settings involving an accident that is very unlikely to occur but that would have catastrophic consequences.
- As the greatest risk of catastrophic nuclear accidents with today's nuclear reactors is entailed by improper use of this technology resulting from events such as a terrorist attack or human error, the validity or the attendant risk assessments is dubious.

Nor will this concern be eliminated by fourth generation nuclear reactors, particularly if safety standards need to meet the exigencies of economic efficiency (Pistner et al. 2009). Hence characterizing a risk by ascribing to it a determinable and low probability of occurrence and a determinable and high scope of loss and damage is now a superannuated approach, since neither the probability of occurrence nor the consequent loss or damage can be determined with exactitude. Moreover, nuclear power plant risk is characterised by a high level of persistence, ubiquity and irreversibility (WBGU 1998, p. 73).

#### The controversy surrounding nuclear risk

The risk structure of nuclear energy risk displays the following attributes: (a) a major accident is very unlikely to occur; (b) the exact probability of such an accident is extremely difficult to determine; and (c) spent fuel rods need to be stored for extremely lengthy periods (Diekmann and Horn 2007, p. 77). Owing to this unusual risk structure, assessing the risk of operating a nuclear power plant and disposing of its spent fuel rods – and thus assessing the external costs entailed by this technology – run up against limits that are in turn reflected by the limits placed on insurance coverage for major nuclear accidents. It is estimated that a major nuclear disaster could cost up to 5 trillion euros (Ewers and Rennings 1992, p. 163), subject to a 2.5 billion euro deductible per power plant (BMU 2007b, p. 28). Hence the current premiums for this type of insurance do not reflect the actual risk costs involved (Diekmann and Horn 2007, p. 77), whereby adequate insurance coverage for the catastrophic damage entailed by a nuclear accident would appear to be beyond the realm of possibility.

According to the principle of sustainability, averting such risks is a priority. If we are in fact facing the possibility of catastrophic effects arising from such risks, exactly which risks are involved and their financial cost can be empirically determined to a very limited degree only, whereby classic economic modelling methods do not provide an adequate basis for decision making in such cases (see the article by Paul Krugman in *The New York Times Magazine* of 7 April 2010). Instead, when it comes to avoiding major risk, the main criterion should be sustainability; and this in turn means that wherever possible electricity generation should be based on realizable and affordable technologies whose safety risk levels are considerably lower than is currently the case.

#### Environmental damage and health problems from uranium mining

The radioactive, heavy metal and chemical emissions attributable to uranium mining (virtually all of which occurs outside of Europe) provokes considerable local environmental damage, as well as health problems for uranium miners and the general public. The most important problem in this regard is the uncontrolled spread of radioactive dust and contaminated water (Lindemann 2010; Chareyron 2008). Many uranium mining areas are located in developing countries or on land inhabited by indigenous peoples. It is very difficult to determine whether social and environmental standards such as adequate protection for miners are being adhered to for imported uranium fuel, whose mining poses the further ecological problem of extensive groundwater use for the mines, as well as local destruction of plant and animal habitats.

#### Use of non-renewable resources

In view of the fact that the uranium used for the fuel rods in nuclear power plants is a finite resource, nuclear energy is at best a solely transitional technology. According to current estimates, known uranium reserves equate to around 50 years of assured resources for the world's nuclear power plants. The world's nuclear power stations used around 65,000 tons of uranium in 2008, when around 44,000 tons of uranium were mined, with the remainder of demand being covered by stored and reprocessed uranium. Worldwide uranium reserves are thought to be around 1.77 Mt, which equates to 40 times the current annual amount mined. Worldwide uranium resources are put at around 14.2 Mt, which is more than 300 times the amount currently mined each year.

While the use of new technologies such as fast breeder reactors could greatly reduce uranium consumption, such solutions would necessitate more uranium reprocessing, plutonium generation, a higher risk of nuclear proliferation, and the misuse of nuclear materials for military or terrorist purposes (BMU 2009).

In view of the finite nature of uranium reserves, use of this non-renewable resource is likewise a criterion that needs to be factored into the sustainability assessment for this option.

## Costs

There is no way of predicting exactly how much nuclear energy will cost going forward. Assuming that Germany stops using nuclear energy (and in so doing perhaps extends the lifetime of existing nuclear power stations) and builds no new nuclear power plants, the main cost factor would be the cost of nuclear fuel and disposal thereof.

Although nuclear fuel supply bottlenecks will presumably drive up and heighten the volatility of uranium fuel prices from 2015–2030 (Deutsch et al. 2009), uranium prices play a relatively minor role in aggregate nuclear fuel costs. The economic costs of ultimate waste disposal are difficult to determine as no ultimate waste disposal sites exist as yet. The extent to which nuclear plant operators will incur additional costs after decommissioning nuclear power stations will be determined by who pays for maintenance and refurbishment of ultimate waste disposal sites, and whether claims by the government will be forthcoming for such activities in cases where operators' financial provisions do not cover actual disposal costs (Deutsch et al. 2009).

All in all, the cost of nuclear power is not only difficult to determine but may also entail a major discrepancy between the social costs on one hand and the costs incurred by nuclear power plant operators on the other. Moreover, these costs are unlikely to decrease.

### **2.3.3 Renewable energy**

The use of renewable energy also entails interventions in the environment that need to be taken into account in assessing the sustainability of renewable energy. In chapter 3.3, the renewable energy potential for Germany and the European-North-African region will be discussed, which then will be compared with the use of such energy according to the scenario simulations. In the present section, the environmental impact of the renewable energy technologies will be assessed that were investigated for this report.

The environmental impact of renewables is mainly attributable to the land use entailed by the attendant technologies, which all in all use more land than conventional energy resources since they of course use energy flows whose power density is lower than that of fossil fuel energy (Mackay 2009). This land use can have a negative impact on biodiversity, can conflict with other forms of land use, and can engender landscape eyesores. Hence the extent to which renewables have a negative impact on the environment and landscape is mainly determined by land use site, scope and quality; and this in turn makes siting a crucial factor.

Another problem with renewables is that they can potentially involve the use of scarce resources. Solar thermal energy, for example, may necessitate extensive water use, while the use of rivers for hydro power competes with other local water usage modalities, as well as shipping. In addition, the construction of renewable energy facilities involves the use of

non-renewable resources such as the rare metals and minerals used to make PV installations; but such resources are also used to realise the requisite electronic infrastructure (Behrendt et al. 2007; Angerer et al. 2009). However, unlike coal, these resources are not *consumed* but instead comprise an infrastructure element that is normally reclaimable.

Although renewables are not completely climate neutral from the standpoint of their life cycles, their greenhouse gas emissions are minute compared to those resulting from fossil fuel electricity (see Table 2-1). However, the carbon emissions from most renewables could be virtually eliminated (except for their process emissions) if the only energy resources used to manufacture the attendant installations were renewables. Life cycle analyses allow renewables to be produced in a more eco-friendly manner that also optimises resource use (Bauer et al. 2007).

Unlike conventional energy resources, whose environmental impact (apart from the effects of mining them) is largely unrelated to their location, renewable electricity installations offer more siting and planning leeway to avoid environmental impacts. Thus the environmental impact of such installations can be minimised if their siting is judiciously based on suitable land use and nature conservation criteria, and if the relevant technologies are combined in an optimised manner. In addition, while (with the exception of biomass plant cultivation) land use for renewable electricity ends with construction of the relevant installation, the nuclear power and coal entail ongoing land use owing to raw materials mining. The interventions in the eco-balance entailed by renewables occur over a finite period that normally coincides with the lifetime of the relevant installations and do not have the kind of long term impact, resulting from mining, nuclear waste storage and carbon sequestration, that is engendered by nuclear power and coal.

### Wind power

Wind farms use an extensive amount of land, and in rural areas can have a negative impact on the quality of life of local populations owing to factors such as noise emissions, light emissions, and changes in the landscape; in addition, they pose a risk for birds and bats (Krewitt et al. 2004, p. 12; BUND 2004; Sprötke et al. 2004; Höker et al. 2004). Moreover building access roads to the installation sites can potentially damage forest ecosystems (NRC 2007). Large wind farms whose sites are not judiciously selected can in particular have a negative impact on biodiversity (Ohlhorst 2009, p. 225).

However, the extent of such impact, which is largely determined by site attributes as well as installation design and size, can be greatly reduced by applying the relevant standards, standardised planning procedure, and land use planning regulations, and by taking account of site specific ecological attributes (Köck and Bovet 2008; NRC 2007; Mautz et al. 2008, p. 117). The negative impact on human populations, birds and bats could be

mitigated through the use of land use planning concepts, wind energy project installation configurations, and adherence to the minimum statutory distances between wind farms and residential areas.

Offshore wind farm construction and operation can have a negative impact on sea and migratory birds, as well as on marine ecology, a particularly serious problem in this regard being the impact of construction noise emissions on marine mammals (Siebert et al. 2007; SRU 2003; Weilgart (undated)). Here too, such risks can be largely mitigated through judicious siting, as well as the realisation of precautionary measures during the construction phase (Klinski et al. 2008). Wind farms should never be built in ecologically vulnerable areas.

Although the bans on fishing that are presumably imposed in wind farm areas have a negative impact on this activity, such bans also create de facto protected habitats for threatened fish species and populations, and in particular enable sea floor organisms to regenerate over the long term out of the reach of fishermen. However, studies concerning such positive effects are still in their infancy, and the results thus far have proven to be largely determined by the very specific attributes of the wind farm areas in question (Zettler and Pollehne (undated); Michel et al. 2007).

It has been shown that carbon emissions, including in light of the overall lifecycle of wind turbines, are far lower than for coal. The gray energy that goes into today's wind turbines is amortised during the first three to nine months of operation, depending on installation location and size (Jungbluth et al. 2005).

### Photovoltaics

The ecological impact of photovoltaics is mainly determined by the amount of space occupied by the attendant installation and thus by the nature of the installation site, with solar panels installed on or integrated into buildings constituting the most ecologically compatible solution. Ground-based PV installations may constitute eyesores or conflict with other installation site uses, and can potentially have a negative impact on biodiversity (ARGE Monitoring PV-Anlagen 2007). That said, German ground based PV installations are very unlikely to be built in key nature conservation areas or on sites that merit statutory protection, since under the Renewable Energy Act (EEG) the electricity generated by such installations cannot be sold back to the grid.

PV installation electricity generation results in neither solid, liquid, or gaseous byproducts nor non-renewable resources use. The amount of time it takes a PV installation to pay for itself via the energy it generates depends on the amount of annual solar insolation at the installation site, as well as the amount of energy used to generate the installation's

electricity. The amortisation periods of such installations range from 1.7–4.6 years (Wild-Scholten and Alsema 2006).

### Solar thermal energy

Although solar thermal energy likewise involves substantial land use, this technology is mainly suitable for use in desert areas (particularly in central Spain and the southern Mediterranean region) that are used for hardly any other purposes. Nonetheless, an environmental impact study should always be conducted for such installations so as to avoid undermining nature and biodiversity conservation goals in desert areas (Benabid 2000). Water cooling of solar thermal installations can provoke ecological damage, since this technology can only be used in high solar insolation and thus mainly arid or semiarid regions such as southern Europe and North Africa (Hollain 2009). Air cooling, which is also an option for such installations, can greatly reduce water consumption, but also reduces installation efficiency (U.S. Department of Energy 2007).

### Geothermal energy

Although the possibility that geothermal energy may cause environmental damage cannot be ruled out, this technology is nonetheless one of the most ecologically compatible forms of renewable electricity generation available today. The environmental impact, water consumption and heat dissipation of geothermal installations, which is largely determined by the type of installation used, are particularly low in cases where the heat dissipated by electricity generation can be captured for use in a combined heating and power (CHP) system (Kaltschmitt and Müller 2004, p. 9 f; Paschen et al. 2003, p. 88; BMU 2007c, p. 28 f). The impact of geothermal energy on flora and fauna is limited to the installation site and is very low since such installations occupy little space (Krewitt et al. 2005, p. 37). Geothermal energy carbon dioxide and hydrogen sulfide emissions are also very low compared to classic electricity generation technologies (Hunt 2000).

Seismic activity has been observed recently at geothermal installations. Such events in connection with deep geothermal installations are not completely avoidable, and can be triggered by the underground storage facility realisation process, as well as by operation of the installation. However, according to current knowledge, and compared with other anthropogenic events such as those provoked by potassium and coal mining, such geothermal events are of relatively minor scope and can be readily kept under control (Janczik et al. 2010), as can the input of pollutants in surface waters and aquifers, which also has been known to occur in connection with geothermal energy (Hunt 2000).

### Biomass

Biomass for energy applications can be realised by cultivating renewable raw materials such as wood, or can be obtained from biogenic residues. The use of cultivated biomass is

the only fuel based energy technology that differs qualitatively from all other renewable forms of renewable energy in that while wind and solar energy installation sites can to some extent be used for other purposes such as food crop cultivation, biomass plant cultivation on farmland precludes and is in direct competition with other uses of such land.

Biomass cultivation that necessitates prior modification of the land in question via measures such as moor drainage, forest clearing, or pastureland conversion can impact the eco-balance in ways that promote climate change (Righelato and Spracklen 2007; Wegener et al. 2006). Inasmuch as land use related greenhouse gas emissions resulting from fertiliser use, as well as carbon loss resulting from a change of land use modality, are often disregarded, it is crucial that life cycle analyses factor in all production processes and the attendant greenhouse gas emissions (WBGU 2009b, p. 180, 244; SRU 2007; chapter 3).

The growing use of farmland for biomass cultivation in recent years via for the most part intensive farming has had a negative ecological and landscape impact, particularly in terms of (a) biodiversity; (b) the water balance; and (c) increased land use competition in connection with fallow land, land that has been taken out of production, nature conservation areas, and biotope community planning (Schümann et al. 2009; SRU 2007; Doyle et al. 2007; Nitsch et al. 2008; Thrän et al. 2009). Increased biomass cultivation has also resulted in the following: loss of pastureland and fallow land; intensified agricultural and forestry activities; smaller harvests at the regional level; increased short-rotation (permaculture) activities at the local level; and weakening of ecosystem resilience – which in turn complicates the task of adapting to climate change.

Although low conflict modalities – namely the use of landscape management residues, paludiculture or extensive cultivation of perennial crops (Barthelemes et al. 2005 p. 1,462) – are available, such methods can make only a limited contribution to the establishment of a renewable electricity supply (Peters 2010). Furthermore the structure of Renewable Energy Act (EEG) bonuses sets the wrong priorities and incentives (see chapter 8).

The potentially negative impact of biomass cultivation in third countries should be taken into account in particular in connection with the importation of raw biomass and biomass fuels. The 2009 *Biomassestrom-Nachhaltigkeitsverordnung* (BioSt-NachV; Biomass electricity sustainability regulation), which fleshes out the Renewable Energy Directive (2009/28/EC) in Germany, is intended to balance out the positive and negative effects of increased biomass use (Ekardt and Henning 2009). Nonetheless, biomass producing states are likely to experience considerable direct and in particular indirect changes in land use modalities that may result in overcropping of valuable natural resources (SRU 2007, nos. 39 and 80).

Biomass use in the waste management sector (within the meaning of the law titled Kreislaufwirtschafts- und Abfallgesetz (KrW-/AbfG) and in connection with agricultural and forestry residues, which lies outside the scope of this law, offers significant potential for biomass use. Fermentation of liquid-manure fertiliser is a particularly effective way to reduce greenhouse gas emissions from methane and nitrogen monoxide. Another useful climate protection technique is installing fermentation upstream of composting installations, as this reduces carbon dioxide emissions during the composting process and at the same time allows for biogas use (Funda et al. 2009).

### Hydro power

Eighty percent of Germany's hydro power stems from run-of-river stations, with the remainder (14 percent) coming from storage hydroelectric power stations and natural inflows from pump storage systems. More than 90 percent of the output from Germany's roughly 7,000 hydro power stations stems from around 400 hydro power stations with more than 1 MW of output that are for most part operated by power companies. Renewable Energy Act (EEG) subsidies have greatly increased the number of small hydro power plants with output of up to 5 MW. Most such projects have involved the reactivation of existing installations whose operation the subsidies render economically viable (Nitsch et al. 2004, p. 25).

Greenhouse gas emissions (carbon dioxide and methane) from dams are mainly attributable to the following factors: the background concentration of organic carbon; the age of the dam; vegetation type; season; temperature; and local primary production. Such emissions decrease considerably after around ten years of operation as a result of the breakdown of the site's upstream organic materials. Thereafter, hydro power station greenhouse gas emissions mainly stem from organic material and are on a par with the emissions of natural water bodies in the relevant region (Eggleston et al. 2006).

There is an inherent conflict between energy generation and water resource management on one hand, and nature conservation goals on the other. Hydro power plant construction inflicts significant and in most cases irreparable ecosystem damage on rivers and their flora and fauna, since rivers display a type of habitat whose salient characteristics are dynamism and continuity that many aquatic organisms depend on for their existence. Apart from the impact of damming and the attendant loss of river continuity, hydro power stations also affect temperature and oxygen related conditions, as well as sedimentation processes. The ecological status of floodplains along rivers such as the Danube has been severely impacted by damming in conjunction with intensive hydro power use (BMU und BfN 2009).

The ecological modernisation measures promulgated by the Renewable Energy Act (EEG) allow for higher electricity feed-in tariffs. As a rule, body of water body development

activities are subject to Water Framework Directive requirements, which must also be observed in connection with hydro power station construction and operation.

### Costs of renewable energy technologies

It is safe to assume that the costs of the currently available non-fuel based renewable energy technologies – namely wind, solar, geothermal and hydro power – will decrease in the coming years as the result of improvements in the technologies per se (e.g. better efficiency, lower materials use), as well as economies of scale resulting from increased production figures. Although the fact that these cost reductions will occur is undisputed, estimates as to the scope and rate of these cost reductions differ (see: chapters 3 and 4).

As for biomass however, its price is likely to rise along with the prices of fossil fuels as a result of increasing competition for land and the fact that the agribusiness and energy raw materials market are likely to be more closely keyed to each other in the coming years (SRU 1007, p. 79 ff).

## **2.4 Overall assessment**

Technology related decisions in the energy policy arena need to be consistent with constitutional principles such as “protecting the natural foundations of life” pursuant to Article 20a of the German Constitution. Such decisions should also abide by the principles – which can be inferred from the principle of protecting the natural foundations of life, as well as international and EU environmental law – of instituting robust sustainability and averting hazards, which have also become a touchstone of the German government’s sustainability strategy.

The factors that come into play in this regard are compliance with the absolute compatibility and input limits of natural systems; and the principles of responsibility toward future generations and instituting equal per-capita usage levels for global public goods. The inherent and logical element of the first two of these principles in particular is mitigating the risk of irreversible or catastrophic events. In terms of climate protection, this means that we need to apply the three principles of sustainability across the board and make every possible effort to achieve fully climate neutral electricity generation by 2050 in a manner that is without prejudice to our national biodiversity strategy goal of preserving biodiversity. Moreover, transitioning to a renewables based electricity supply needs to be widely accepted by the general public and consistent with the classic energy policy goal of assuring a reliable supply of affordable energy.

There is no such thing as a fully environmentally neutral energy supply, for the eco-balance is bound to be altered in one way or another no matter how electricity is generated. Thus striving for a sustainable electricity supply must necessarily be a matter of opting for the lesser of two or more evils after weighing all the available options. Therefore saving energy

generally is the best option. However, all energy saving and energy efficiency methods that are instituted must be predicated on the principle that a high basic demand for electricity must be met at all times.

The SRU has come to the conclusion that, relative to all other available options, renewable electricity is the only possible approach that is genuinely sustainable.

The main goal in this regard is to completely decarbonise the electricity supply – a goal that is achievable through neither the use of carbon sequestration nor more efficient conventional coal technologies. Moreover, the use of coal entails to elaborate raw material extraction operations, which despite improved air purity efforts result in significant emissions. As for CCS, its use is limited by the available storage capacity and competition from other potential uses of this capacity.

Nuclear power is likewise not a sustainable electricity generation option; for despite the fact that gas emissions from nuclear power are far lower than for coal, the use of nuclear power entails the risk of accidents – an eventuality that cannot be completely ruled out and that could have repercussions for large areas and for extended periods of time – and poses the problem, which has gone unresolved for decades, of ultimate waste disposal for spent fuel rods. Moreover, nuclear power is unlikely to be a sustainable energy technology solution in view of the finite nature of uranium reserves.

But renewables have drawbacks as well, particularly biomass, since biomass crop overuse can result in environmentally harmful land use practices, eco-balance damage, and considerable environmental damage. Hence biomass use should mainly involve residues, as well as modalities entailing little or no conflict. Another factor that should be borne in mind is the resource use entailed by certain renewables, one example being the substantial amount of water needed for solar thermal power stations in arid regions; or the rare metals used to make such installations. Other renewables and the transmission and storage capacity expansion needed for them can also provoke conflicts in terms of onshore or offshore use.

But all things considered, the ecological problems entailed by renewable energies are far less serious and are far more amenable to mitigation than is the case with nuclear power and coal. Moreover, replacing fossil energies with renewables will make a substantial contribution to the reduction of greenhouse gas emissions. And thus renewables are the only potentially sustainable solution for electricity generation.

The environmental problems caused by nuclear power and coal are for the most part inherent to these technologies and are essentially the same no matter where such installations are sited. These problems will remain unresolved even if the highest possible environmental and safety standards are applied, and will need to be taken into account if

political leaders and the energy industry opt to continue using these technologies. Renewables, on the other hand, offer greater siting and engineering leeway, particularly if they are used in a setting where the actual demand for them is far lower than their nominal output potential. Ecological conflicts could be largely mitigated if power plant construction were supported by regional planning.

Another key factor here is that renewable-energy installations are normally smaller and easier to dismantle than the counterpart conventional facilities, and thus constitute more flexible infrastructure components. For example, after being dismantled solar and wind installations can be re-sited at a relatively low cost and with little risk. Whereas nuclear power and coal CCS are associated with long term consequential environmental damage and risk resulting from coal mining, nuclear waste storage, and carbon storage, the environmental impact of renewable energy is generally confined to the service life of the installation. Moreover, the environmental impact of solar and wind power is confined to the installation construction phase, whereas nuclear power and coal necessitate sustained land and natural resource use to mine the fuel needed. Renewables are sustainable in keeping with the precautionary principle and in view of the present uncertainties, since they can be adapted more flexibly to changing conditions and have a greater tolerance for error. Hence renewables are superior to conventional energy resources in terms of generational equality and risk avoidance, thus making renewables more sustainable.

Hence the comparative assessment of the various available energy options has led us to the conclusion that nuclear power and coal are indisputably non-sustainable, and at best could serve as transitional power sources for a strictly limited period of time. And while renewables are not without their drawbacks, their undesirable effects can be mitigated for the most part by giving careful thought to their siting, design, and planning. Hence renewables are the only modality that is viably sustainable.

According to Article 20a<sup>1</sup> of the German Constitution, the government is obligated to safeguard the natural foundations of life – a duty that encompasses not only climate protection but the environmental situation as a whole. And for all that the wording of Article 20a places the emphasis on whether rather than how the state will fulfil this duty, it can nonetheless be inferred from this provision that the State is also duty bound to optimise the foundations of life, rather than just protecting them. It therefore follows that the State is also obligated to ensure that all human activities can be realised in a manner that is as climate neutral as possible, by taking precautionary measures aimed at keeping potential risks from becoming outright hazards. And most important of all, the State's long term

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The relevant detailed legal analysis of the German Constitution has been skipped from the translation. Here, only the conclusion from that analysis is presented.

responsibility toward future generations is the objective correlative of the precautionary and sustainability principles.

It can be inferred from Article 20a of the Constitution that the Constitution prohibits overall environmental degradation relative to the state of the environment at the time the Constitution was drafted. Hence the more environmentally compatible path should be chosen whenever possible, insofar as such a path is available. From the principle of protecting the natural foundations of life pursuant to Article 20a of the Constitution the government's decision and project leeway is limited in terms of climate protection goals; from which a duty on the part of the government to avert climate change and any irreversible environmental damage resulting can be inferred. Thus climate protection measures instituted by the government should not violate Article 20a of the Constitution. And from this it follows that, for example, in determining the way forward for implementation of an electricity system that will make a major contribution to the fight against global warming, the government needs to opt for solutions that are maximally compatible with the sustainability and precautionary principles laid down in Article 20a of the Constitution. In light of these considerations, a energy policy that promotes anything other than renewable energy sources over the long term is at odds with the stipulations of Article 20a.

In the sections that follow, a number of scenario simulations will be discussed that shed light on how a wholly renewable electricity supply and the transition thereto might potentially unfold from a technical standpoint, and on how the performance profile of such a system would shape up in light of, and meet, the relevant social and economic criteria – namely competitiveness, affordability, and security of supply.

## **3 The objective: a low-carbon, sustainable electricity supply by 2050**

### **3.1 Introduction**

In this chapter we discuss a series of scenarios that the German Advisory Council on the Environment (*Sachverständigenrat für Umweltfragen, SRU*) elaborated with a view to shedding light on the possible attributes of a wholly renewable electricity supply in Germany. In the interest of enabling the reader to see how our approach compares with similar studies, we first give an overview of the most important long term scenarios for the electricity sector in Germany and the EU. One purpose of this analysis was to elaborate plausible assumptions concerning electricity demand in 2050, which we then used as a basis for our scenarios. Another objective was to determine which technology paths, emissions reductions, and costs have been presupposed by other studies. This analysis also reveals how differing methods and assumptions can in some cases lead to strongly divergent results.

Scenarios describe possible future evolutions that are characterised by different assumptions and framework conditions. Studies on the future of energy supply often compare a series of scenarios or scenario variants with each other so as to shed light on the factors that impinge on these scenarios or on leeway for decisions. This process involves the elaboration and application of different scenarios the design of which varies depending on the specific research question. The scenarios developed in this report are called target scenarios. Target scenarios, as the name suggests, take as their starting point a specific target – the target here being a wholly renewable electricity supply. The modeling results then show how and under which conditions the target can be reached. Alternatively, scenario simulations can also be used to investigate the impact of different framework conditions, such as energy policy measures, on specific variables relative to a reference case; this is referred to as an exploratory scenario. In the context of policy analysis, an exploratory scenario can, for example, address the question as to how the electricity system in question will evolve if a certain event occurs or if specific framework conditions change. In contrast, a target scenario investigates the extent to which the system in question can achieve a defined nominal (target) state, and the circumstances necessary to achieve this state. Both of these approaches often involve the elaboration of reference scenarios that are meant to provide a comparative metric for purposes such as determining additional costs. Reference scenarios normally assume that existing policies will remain in force and that defined obligations will be met, but that no policy measures above and beyond this will be carried out.

Scenario elaboration methodologies vary greatly. Computer models are often used to mathematically simulate the core structures and interactions of the complex real world and

specific changes in these elements. Widely varying types of models that exhibit specific advantages and drawbacks are used for these simulations. The main factors in determining which models are suitable for a specific simulation are the nature of the issue being investigated, the sectoral and regional focus of the investigation, and the nature and extent of the available data. Oftentimes it is useful to pair economic models with those that display a strong technological orientation. There are, on the other hand, also long term scenarios of a chiefly qualitative nature that define roadmaps for a specific development path thereby mapping out the economic, technological, and policy measures that need to be taken. Qualitative analyses are a useful complement to simulations in view of the fact that socioeconomic factors are not always amenable to modelling and in view of the great uncertainty surrounding the long-run evolution of certain quantitative variables. The scenarios discussed in this report fold in both technical and economic approaches, together with qualitative and quantitative analyses.

Scenarios should always be analysed and interpreted in light of the fact that they serve to gain insight into system dynamics. Scenarios aim to identify drivers of change, demonstrate possible development paths, elaborate required framework conditions and highlight synergies as well as trade-offs. However, scenarios are not a replacement for political decisions, nor do they aim to forecast future developments. As with all scenarios, those presented here should not be read as forecasts. Transitioning to a wholly renewable electricity supply should solely be regarded as one possible option that we consider worth pursuing. The scenarios described here are intended to demonstrate that such a transition is technically and economically feasible and to show the form such a system could take under technological and cost assumptions which appear plausible today. However, implementation of such a scenarios requires strategic policymaking, elaboration of the attendant measures, as well as careful planning and considerable cooperative effort.

## **3.2 German and international scenario studies on the development of the electricity sector**

### **3.2.1 Introduction**

There is a venerable tradition of studies concerning the long run evolution of the electricity and energy sector. Researchers have also been developing scenarios concerning the mitigation of energy-related greenhouse gas emissions for many years. More recently, however, efforts have been made to create models showing how the energy sector could become fully or nearly decarbonised over the long run with a view to contributing to a stabilisation of atmospheric greenhouse gas concentrations (Clarke et al. 2009; Fisher et al. 2006). Various studies have been published that discuss such scenarios at both the global level and for individual states and regions. They centre around issues such as the

extent to which the energy sector should institute measures that promote the achievement of overall greenhouse gas reduction goals; the technologies that could potentially be used for this purpose and the capital investments and energy costs entailed by such use; and the policy instruments and price signals that could set the stage for such a decarbonisation path (Anandarajah et al. 2009; Edenhofer et al. 2009; EREC and Greenpeace International 2010; Knopf et al. 2010; IEA 2009).

The scenarios developed for such studies are normally quantified, partly with the aid of complex calculation models. There are two basic types of energy models: top-down models, which are energy sector models that focus on overarching economic contexts; and bottom-up models, which are highly technically oriented energy system models. The advantage of bottom-up models is that they provide precisely detailed descriptions of energy generation and usage technologies, which in turn allows for differentiated analyses of both costs and potential cost and energy use reductions. The drawback of such models, however, is that they do not lend themselves to analyses of the feedback mechanisms arising from market and price adjustments (Clapp et al. 2009, p. 9). Top-down models, on the other hand, use macroeconomic indicators such as energy prices and elasticities to analyse the economic impact of policy instruments. Their advantage lies in the fact that their use does not entail the use of extensive data sets, although this also makes them unsuitable for detailed simulations of technical evolutions (Kahouli-Brahmi 2008). The fact that top-down models require little data partly explains why they are mainly used for global studies, whereas bottom-up models are frequently used in Germany for simulations at the national level. However, in view of the broad spectrum of differing approaches within each model group, the advantages and disadvantages of a modelling paradigm should be evaluated on a case by case basis. That said, more effort has been invested, particularly of late, in attempts to create hybrid models, i.e. the coupling of technical and macroeconomic models, with a view to combining the advantages of both approaches (Hourcade et al. 2006). Further methodological distinctions occur between short term and long term optimisation, between static and dynamic models, and in connection with the issue as to whether technical progress should be handled endogenously or exogenously (Clapp et al. 2009).

In the following, we summarise the key data and conclusions concerning the most important German and European studies concerning energy sector decarbonisation. This analysis centres around studies that investigate the electricity sector separately; discuss the electricity mix in a detailed and empirical fashion; and take all key electricity generation technologies into account. In line with the focus of the SRU scenarios, the analysis focuses on studies that describe the German or European electricity system examine the period until 2050. Studies that concern themselves with shorter timelines were disregarded.

In terms of the comparative analysis, it should be borne in mind that individual figures cannot always be compared head to head because the geographical boundaries of the regions under consideration vary to some extent (see Table 3-1) and because the individual variables are defined differently in some cases. For example, some studies factor line and conversion loss into electricity demand, while others do not. Nonetheless, as these discrepancies are limited in scope, it was still possible to analyse the approximate differences between these different studies as well as their commonalities. A comparison of costs, on the other hand, was possible only to a limited extent due to the large discrepancies between the indicators used in the various studies.

We reviewed the following nine studies that concern themselves with the EU as a whole:

- Energy Technology Perspectives, an International Energy Agency (IEA) report that discusses long run restructuring of the global energy system (IEA 2010);
- Adaptation and mitigation strategies: Supporting European climate policy (ADAM), a research project that was coordinated by the UK's Tyndall Centre for Climate Change Research and funded by the European Commission (Hulme et al. 2009; Knopf et al. 2010; Eskeland 2010);
- Report on Energy and Climate Policy in Europe (RECIPE), a study that was coordinated by the Potsdam Institute for Climate Research and funded by the World Wide Fund For Nature (WWF) and the insurance company Allianz (Edenhofer et al. 2009);
- Roadmap 2050: A practical guide to a prosperous, low-carbon Europe, which was published by the European Climate Foundation and was elaborated in cooperation with a consortium of research partners (ECF et al. 2010);
- Power choices: Pathways to carbon-neutral electricity in Europe by 2050, which was issued by EURELECTRIC (a European umbrella association of the electricity industry) and realised by the University of Athens (EURELECTRIC 2010);
- Re-thinking 2050: A 100% renewable energy vision for the European Union, which was issued by the European Renewable Energy Council and is partly based on projections by various member associations (EREC 2010);
- Energy [R]evolution – A sustainable global energy outlook, which was prepared jointly by Greenpeace International and the European Renewable Energy Council (EREC and Greenpeace International 2010);
- Europe's share of the climate challenge. Domestic actions and international obligations to protect the planet, a report that was prepared by the Stockholm Environment Institute at the behest of Friends of the Earth Europe (SEI 2009); and

- An engineering study that investigated the possibility of achieving cost optimised wholly renewable electricity by combining European and various Eurasian and African regions into a single so called supergrid (Czisch 2005).

Some of these studies concern themselves with Europe only (ECF et al. 2010; EURELECTRIC 2010; SEI 2009), while others are global in focus but also posit regional European scenarios (IEA 2010; Edenhofer et al. 2009; EREC and Greenpeace International 2010; Knopf et al. 2010). The IEA's *World Energy Outlook 2009* was only partly included in our analysis as its timeline extends to only 2030 (IEA 2009).

In addition to the various reference scenarios, we also analysed scenarios involving far reaching decarbonisation of the energy and electricity sector. For purposes of our comparative discussion of these studies, representative scenarios were analysed for studies that contain multiple individual scenarios (Edenhofer et al. 2009; Knopf et al. 2010).

The following studies concern themselves with Germany's energy and electricity system in the time frame until to 2050:

- Enquete-Kommission Nachhaltige Energieversorgung unter den Bedingungen der Globalisierung und Liberalisierung 2002;
- Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit: Leitstudie 2008 (Nitsch 2008) as well as a further elaboration of this study, Leitszenario 2009 (Nitsch and Wenzel 2009);
- Öko-Institut and Prognos AG: Modell Deutschland (Öko-Institut and Prognos AG 2009);
- Forschungsstelle für Energiewirtschaft e. V. (FfE): Energiezukunft 2050 (FfE 2009);
- ForschungsVerbund Erneuerbare Energien (FVEE): Energiekonzept 2050 (FVEE 2010a); and
- Umweltbundesamt (UBA): Energieziel 2050 (Klaus et al. 2010);
- Prognos AG/Energiewirtschaftliches Institut an der Universität zu Köln (EWI)/Gesellschaft für Wirtschaftliche Strukturforschung mbH (GWS): Energieszenarien für ein Energiekonzept der Bundesregierung (Schlesinger et al. 2010).

The key findings of these studies are briefly described in the next section and are summarised in Table 3-2. With the exception of the UBA study, the focus of all of the studies concerning Germany alone encompasses not only electricity but also the entire energy system including heating and fuel.

The German Parliamentary Study Commission known as *Nachhaltige Energieversorgung unter den Bedingungen der Globalisierung und Liberalisierung* (Study Commission on Sustainable Energy in the Context of Globalisation and Liberalisation issued its final report

in 2002 (Enquete-Kommission Nachhaltige Energieversorgung unter den Bedingungen der Globalisierung und Liberalisierung 2002). This study aimed to promote the establishment of robust, sustainable and future-proof development paths in the energy sector and to lay out policy measure options in light of the altered circumstances occasioned by globalisation and market deregulation. It characterised the current energy system as “non-sustainable” (Enquete-Kommission Nachhaltige Energieversorgung unter den Bedingungen der Globalisierung und Liberalisierung 2002, p. 43) and modelled a reference scenario along with the variants of three other scenarios – 14 development paths in all. The study’s reference scenario comprises the most likely evolution in light of the data available in 2000, while the other scenarios and variants thereof presuppose an 80 percent reduction in greenhouse gas emissions by 2050 relative to 1990. These target scenarios and their key attributes are as follows:

- The Umwandlungseffizienz (UWE; Conversion Efficiency) scenario: a strategy calling for a rapid increase in energy conversion and use efficiency and an end to nuclear energy use.
- REG/REN-Offensive (RRO): ending nuclear energy use by 2030; ending most fossil fuel use by 2050; a massive improvement of energy efficiency and massive development of renewables. A variant of this scenario called solare Vollversorgung (energy supply based solely on solar energy) models the manner in which a wholly renewable electricity supply could be achieved by 2050.
- The Fossil-Nuklearer Energiemix (FNE; Fossil-nuclear Energy Mix) scenario: continuation and expansion of nuclear energy use as a cornerstone of electricity generation; commercial use of carbon capture and storage (CCS) technologies.

These target scenarios were elaborated using two different calculation models (one developed by the Stuttgart University’s Department of Energy Resource Management and Rational Energy), and a second elaborated by the Wuppertal Institute) that use differing calculation methods and thus yielded different results. In addition, the baseline parameters were varied to some extent, resulting in multitudinous scenario variants.

The *Leitstudie 2009* scenario (Nitsch and Wenzel 2009), which was carried out in cooperation with the Department of Technical Thermodynamics at the German Aerospace Center (DLR), is primarily based on the *Leitstudie 2008* study (Nitsch 2008) but takes account of more recent developments concerning the renewable energy development, as well as more recent energy policy frameworks. The *Leitszenario 2009* study discussed a development path involving an 80 percent reduction in annual greenhouse gas emissions by 2050 relative to 1990 levels. The *Leitstudie 2008* study also described the following five variants of the study’s scenarios, based on various interrelated strategies:

- Variant E1 involves increased efficiency and expansion of combined heating and power (CHP) capacity.
- Variant E2 calls for further expansion of renewable energy capacity.
- Variante E3 calls for increased use of renewable electricity for electric vehicles.
- Variant D1 involves a further increase in energy productivity.
- Variant D2 calls for substantial use of coal.

The *Leitstudie 2008* scenario variants are exploratory in nature, while the *Leitszenario 2009* scenario involves a target scenario that presupposes that the desired emissions reductions will be achieved by 2050. This scenario was in the process of being revised while the present report was being prepared.

The *Modell Deutschland – Klimaschutz bis 2050* study, which the WWF commissioned from Öko-Institut and Prognos AG (2009), discusses a reference scenario and a so called innovation scenario, both of which are based on models. The reference scenario calls for implementation and optimisation by 2050 of current energy and climate policy instruments such as the German government's Integrated Energy and Climate Programme, while the innovation scenario is a target scenario that calls for annual greenhouse gas emissions reductions of 95 percent by 2050 relative to 1990 levels, subject to certain restrictions. Two variants were elaborated for each of these scenarios – one presupposing that CCS technology will not be commercialised by 2050, and the other premised on the assumption that this technology will be commercially available by 2020 and put to use.

The FfE's *Energiezukunft 2050* study (FfE 2009) focuses on three energy demand and production scenarios in Germany in the period up to 2050. The study goes into minute detail by, for example, considering virtually every relevant major form of energy for each energy demand sector and the attendant projections. This study discusses the following scenarios:

- Scenario 1 titled Referenzszenario (Reference Scenario) contains a projection concerning all relevant frameworks based on long term trends and expectations.
- In the scenario 2 titled Erhöhte Technischeffizienz (Increased Technical Efficiency), each of the available technologies is successively replaced by the best available technology.
- Scenario 3 titled Umweltbewusstes Handeln (Environmental Stewardship) presupposes the technology replacement called for by scenario 2 as well as a change in consumer behaviour.

Although the study provides detailed projections concerning final energy consumption applications such as lighting, building heating, process heating, mechanical energy and the like, the energy sources needed for these applications are not specified or are described

only partially. For example, the study indicates the final energy demand that would be entailed by the three scenarios in the run-up to 2050 but fails to indicate the attendant electricity demand, which is of course part of the overall energy demand. Hence this study has been omitted from Table 3-2.

The *Energiekonzept 2050* study (FVEE 2010a) is intended as a contribution to the government's energy master plan that was adopted on 28 September 2010. The FVEE study is predicated on institution of a wholly renewable electricity supply in 2050 – whereby the “dominant role” would be played by higher energy efficiency, as well as wind and solar power (FVEE 2010a, p. 5) – and is partly based on the aforementioned *Leitszenario* studies (Nitsch 2008; Nitsch and Wenzel 2009), the *Modell Deutschland* study (Öko-Institut and Prognos AG 2009), and the *SRU Statement No. 15* (SRU 2010), most of whose findings are described in the present chapter and chapter 4 of this report. The FVEE study (FVEE 2010a) mainly focuses on the functional aspects and costs of the envisaged system, rather than the quantification of energy demand and production. In addition, two sections of the study are devoted to research and development policies and activities, and provide detailed recommended course of actions in this regard. The study also discusses the potential conflicts between large thermal power plants and the substantial proportion of intermittent electricity supply.

The *Energieziel 2050: 100% Strom aus erneuerbaren Quellen* study (Klaus et al. 2010) concerns itself solely with the electricity sector. It represents a wholly renewable electricity supply by 2050. It mainly discusses the *Regionenverbund* (regional grid) scenario that was elaborated by the Fraunhofer Institut für Windenergie und Energiesystemtechnik (IWES), and revolves around the potential offered by regional renewable sources connected at national level. Other scenarios (albeit not published as yet) are the *International-Großtechnik* and *Lokal-Autark* (respectively: international large scale technology; local autonomy). The former concerns itself with the German energy system within the European grid, while the latter analyses the option of decentralised electricity systems.

In August 2010, Prognos AG, EWI and GWS issued the *Energieszenarien für ein Energiekonzept der Bundesregierung* (EEB) study (SCHLESINGER et al. 2010), which was intended to form the basis for the government's new energy master plan. As issuance of this study coincided with our own, we were unable to describe the study's energy scenarios comprehensively from a quantitative standpoint; and thus our treatment of this study is limited to a brief account of its main assumptions and findings.

The EEB study discusses nine scenarios which describe the development of the German energy supply system until 2050, covering electricity as well as transport and heating. In the reference scenario, which implies a continuation of current policies, gross electricity output in 2050 amounts to 488 TWh, 54 percent of which (264 TWh) are to be provided by

renewables. Greenhouse gas emissions are reduced by 62.2 percent relative to 1990 levels which implies that the emissions reduction target would not be met. The remaining scenarios are target scenarios (scenarios I–IV), each of them was run in two variants. All target scenarios have in common that they achieve a reduction of greenhouse gas emissions by at least 85 percent in 2050. This conclusion is mainly predicated on the assumption that the lifetime of existing nuclear power plants will be extended by anywhere from four (scenario 1) to 28 years (scenario IV). Each of the target scenarios was computed using two different data sets concerning the requisite nuclear power plant retrofitting costs. In addition, the scenarios assumed a minimum share of renewables for 2020 and 2050, and in some cases energy efficiency increases. In the target scenarios, by 2050 some 252–289 TWh of electricity, or 77–81 percent of gross electricity production, will come from renewables. All nine scenarios presuppose that Germany will be a net importer of electricity in 2050, whereby the net amount in the reference scenario and the target scenarios are 67 and 94–143 TWh respectively. However, the results of the reference scenario and the target scenarios lend themselves to comparison to only a limited degree as they are based on differing variables in terms of both generation (e.g. share of renewable and nuclear energy) and demand (e.g. electricity demand).

### **3.2.2 Study results**

#### **3.2.2.1 Electricity demand**

An assessment of the most important German and European scenarios for the development of electricity demand in the period until 2050 reveals a broad spectrum of possible demand levels, depending on the choice of assumptions and methodologies. These differences are in most cases not so much attributable to assumptions on population and economic growth, which are on a par in most of the scenarios. Rather, they result mainly from assumptions about the extent to which energy efficiency decouples economic growth and electricity demand and from the extent to which fossil fuels are replaced by other energy resources.

The electricity demand projected by the European reference scenarios for 2050 ranges from around 4,000–7,500 TWh, and in the European decarbonisation scenario from 2,750–6,900 TWh (see Table 3.1). Relative to today's electricity demand of around 3,325 TWh, this level corresponds to a minor reduction for the lowest case, and to more than a doubling of today's levels for the highest case. Interestingly, some studies assume that electricity demand is lower in the decarbonisation scenarios than in the reference scenario (EREC and Greenpeace International 2010; SEI 2009), whereas the reverse is the case in other studies (ECF et al. 2010; EURELECTRIC 2010). The first case (lower demand in the decarbonisation scenario) assumes that efficiency improvements will translate into lower

electricity consumption. Some studies see very large potentials for efficiency improvement, particularly in scenarios that presuppose the implementation of ambitious energy efficiency policies. It is also notable that scenarios based on bottom-up (i.e. technologically oriented) models tend to yield higher energy efficiency potential (Jochem and Schade 2009). In the second case (lower demand in the reference scenario) it is typically assumed that the potential for economically efficient energy saving is limited or that the electrification of other sectors (particularly transport) would over-compensate this effect, resulting in higher overall electricity demand.

Another important factor for the long-term development of electricity supply is electricity demand in North Africa. The global and European studies reviewed in this report do not provide a breakdown of demand figures for this region. The IEA, however, provides an estimation of electricity demand in North African countries (i.e. Egypt, Algeria, Libya, Morocco and Tunisia). The IEA reference scenario projects an annual increase in electricity demand by 3.2 percent until 2030 – i.e. a 171 to 402 TWh increase between 2003 and 2030 (IEA 2005). This scenario is predicated on population growth during this period from 145 to 209 million and GDP growth from US\$703 billion to US\$1.652 billion.

The electricity demand figures indicated in the scenarios for Germany are comparable to a limited degree only, since some of the scenarios are based not on gross electricity demand, but instead (e.g. in the case of the Parliamentary Study Commission target scenarios) on electricity demand in various end-use sectors, or on net electricity demand. Of the numerous electricity demand scenarios that have been elaborated for Germany, only the following four are reference scenarios. The reference scenario elaborated by the German Parliamentary Study Commission “Sustainable Energy in the Context of Globalization and Liberalization” puts gross electricity demand at 555 TWh in 2050, with the reference scenarios of Prognos AG, EWI and GWS indicating likewise. Both the Öko-Institute and Prognos AG reference scenarios set net electricity demand at 530 TWh in 2050 (see Table 3-2). The energy saving scenarios we reviewed posit electricity demand reductions of up to 380 TWh annually in the various electricity using sectors. On the other hand, high-demand scenarios that fold in electric vehicles assume an annual electricity demand of up to 773 TWh, with gross electricity demand being somewhat higher.

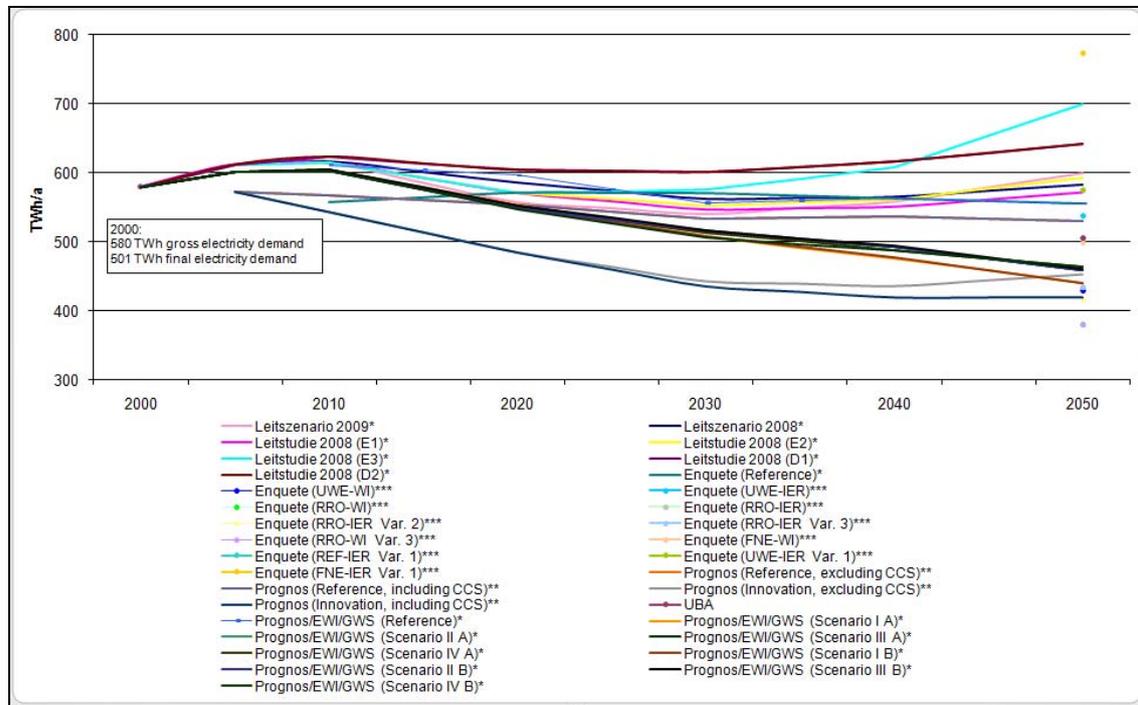
The electricity demand posited by most of the 31 scenarios or scenario variants we reviewed (excluding the four reference scenarios) ranges from around 430 TWh (demand in the end-use sectors) to 600 TWh (gross demand).

Based on the analysis of existing studies, the SRU scenarios assume for Germany in 2050 an annual gross electricity demand between 500 and 700 TWh which will have to be met from renewable sources.

We will now discuss in more detail our analysis of the available German and international scenarios in this regard.

Figure 3-1

### German electricity demand as projected by the scenarios analysed



Key: \*Gross electricity demand; \*\*Net electricity demand: \*\*\*Final electricity demand

Sources: Enquete-Kommission Nachhaltige Energieversorgung unter den Bedingungen der Globalisierung und Liberalisierung 2002; Nitsch 2008; Nitsch and Wenzel 2009; Öko-Institut and Prognos AG 2009; Klaus et al. 2010; BMWi 2010b; AGEb 2009; Schlesinger et al. 2010; own calculations

The reference scenarios of the Parliamentary Study Commission, as well as those of Öko-Institute and Prognos AG, assume an electricity demand ranging from 530–555 TWh annually in 2050. However, these projections are based on differing reference years (Enquete: 2000; Öko-Institut and Prognos AG: 2005) and population and economic growth rates. Inasmuch as the reference scenario assumptions appear plausible in light of current knowledge, we adjudge the electricity demand levels in the scenarios we reviewed to be realistic figures in terms of a policy path based on conservative assumptions. These demand levels represent a decrease relative to current electricity demand. In contrast, the FfE study's reference scenario assumes that electricity demand will "increase slightly" until 2050 (FfE 1009, p. 183), but does not attach a figure to this trend. The discrepancies between the electricity demand figures in the various reference scenarios are ascribable to their differing assumptions concerning electricity demand in the various consumer sectors. Growth of economic activity tends to ramp up demand while at the same the implementation of different energy efficiency measures decreases electricity demand. Conservative assumptions for both of these factors usually yield virtually constant demand. Hence a major change in either factor would result in higher or lower electricity demand.

The target scenarios and scenario variants that we analysed posit a much broader spectrum of net electricity demand for 2050, ranging from 380 to 773 TWh annually for the Enquete study's RRO-WI scenario and FNE-IER scenario variant 1 respectively. However, the highest figure assumes (among other things) that costs of nuclear power will be very low and that electricity will in large measure supplant other energy sources in the motor vehicle fuel and other sectors (Enquete-Kommission Nachhaltige Energieversorgung unter den Bedingungen der Globalisierung und Liberalisierung 2002, p. 679 f). Hence we treated both of the Study Commission's FNE-IER scenarios as outliers for purposes of our comparative analysis. The highest gross electricity demand in 2050 (699 TWh/a) posited by the remaining scenarios is found in the E3 scenario of the *Leitstudie 2008*. Thus depending on the scenario and the assumptions underlying it, projected electricity demand in 2050 is put at around one third higher or lower than for the reference scenario.

The *Leitszenario 2009* and the scenario variants for the *Leitstudie 2008* study posit gross electricity demand for 2050 ranging from 571–699 TWh/a. This discrepancy is attributable to differing assumptions concerning efficiency gains, renewable energy development, and expanded use of electric vehicles. According to FfE scenarios 2 and 3, 2050 electricity demand will be at roughly 2005 levels. The UBA *Energieziel 2050* study puts 2050 gross electricity demand at 507 TWh. The findings of the scenarios are summarised in Figure 3-1.

Likewise relevant here is the FVEE energy concept, which assumes 2050 electricity demand amounting to 764 TWh annually. However, this study is fairly descriptive in nature and cites our Statement *Stellungnahme Nr. 15* (SRU 2010) among other sources.

### **3.2.2.2 Emissions, technology paths and costs in Europe**

There is a broad consensus in the literature that greenhouse gas emissions in the electricity sector are more amenable to reduction than is the case in other sectors such as transport, manufacturing, and agriculture. Therefore, studies that model the energy system as a whole normally assume relatively early-stage and far reaching reduction in electricity generation emissions (IEA 2009; KNOPF et al. 2010; Edenhofer et al. 2009; ECF 2010). All of the international studies that we reviewed express the view that far reaching emissions reductions are achievable by 2050 (see Table 3-1). A number of scenarios in these studies even go so far as to posit virtually complete carbon neutral electricity generation by 2050.

However, the manner in which these results were arrived at differs greatly, principally as regards the extent to which energy efficiency can decouple economic growth and electricity demand. The technology paths that allow for the reduction of specific emissions likewise vary greatly from one study to another. Nonetheless, there is a general consensus that renewables will satisfy a major share of energy demand by 2050, with estimates in this

regard ranging from 34 to 100 percent (see Table 3-1). Noteworthy in this regard is that international reference scenarios likewise assume an increase in the share of renewable electricity from around 16 percent today to 20–42 percent in 2050. Most of the scenarios reviewed by the SRU also assume that fossil fuel power stations with carbon capture and storage (CCS) systems, as well as nuclear power plants, will account for a considerable share of electricity demand. Two of the studies conclude that it will be necessary to implement all three options, i.e. fossil fuel with CCS, nuclear, and renewables – or at least two of these – in order to reach ambitious emissions reduction targets (EURELECTRIC 2010). However, this partly refers to global emissions (KNOPF et al. 2010) and thus may not necessarily apply to each of the regions modelled. On the other hand, the technical and economic analyses realised for other studies attempt to show that neither nuclear power nor fossil fuel need be used to any great extent. In so doing they develop scenarios involving a wholly or nearly wholly renewable electricity supply (ECF et al. 2010; EREC 2010; EREC and Greenpeace International 2010; SEI 2009; Czisch 2005) and assume either moderate electricity imports from North Africa or other regions (ECF et al. 2010; EREC 2010; SEI 2009; Czisch 2005) or minor use of fossil sources for grid stabilisation purposes (EREC and Greenpeace International 2010). Based on extensive calculations, the European Climate Foundation (ECF) study found that the costs entailed by the various scenarios involving a 40, 60, 80 and 100 percent share of renewables differ very little from each other, and that therefore factors such as risk tolerance, technology development, the existing infrastructure, resource availability, and security of supply are far more important than costs when it comes to mapping out a technological path to a renewable electricity supply (ECF et al. 2010, p. 9).

The actual composition of the target energy mix depends not so much on the defined stabilisation objectives, but rather and above all on the modelling assumptions concerning technologies, learning curves, and resource prices (Knopf et al. 2010). This is partly attributable to the fact that the costs of the relevant technologies such as CCS, nuclear energy and wind energy in some cases differ very little from each other, which means that divergent assumptions can have a decisive impact on the technology that is ultimately selected (Anandarajah et al. 2009, undated), particularly in optimisation models.

Assumed aggregate electricity demand differs greatly from one scenario to another, with the result that in some cases similar absolute renewable energy figures yield widely divergent shares of renewables. For example, the roughly 3,000 TWh projection for renewable electricity generation in 2050 equates to 60, 91, or even 100 percent of total electricity production in various scenarios of studies concerning renewables. The aggregate amount of renewable electricity in 2050 estimated by the various scenarios we looked at ranges from around 2,000 to 5,000 TWh.

The methods used by most of the studies are not well equipped to analysing the extent to which electricity supply and demand are interrelated, The most commonly used international energy sector and system models exhibit only very approximate regional and timeline resolution. Hence these models do not allow for detailed investigations into how large amounts of wind and solar power can be fed into the grid or how site specific electricity from offshore wind farms and the like can be transported to demand centres. Hence while many of the studies we reviewed may mention the classic challenges faced by renewable energy, they do not analyse these challenges in detail (EURELECTRIC 2010; Knopf et al. 2010).

Although all of the international studies we reviewed discuss the economic implications of decarbonisation, the amount of detail such discussions go into varies from one study to another and some lack comprehensive cost calculations for their scenarios. Moreover, all of the scenarios cannot readily be compared with each other in a systematic fashion owing to the fact that they contain differing calculations of various types of costs such as the following: specific investments per installed capacity; additional investments relative to the reference scenario; cumulative scenario welfare loss; mean electricity generation costs; and total electricity generation costs. However, analyses of the various scenarios yield useful results nonetheless. Their cost estimates vary greatly from one study to another, and in some cases for the various models used within individual studies (Hulme et al. 2009, p. 17). Compared to general prognostic uncertainties, these differences between reference and decarbonisation scenarios are rather moderate (ECF et al. 2010; Edenhofer et al. 2009; EURELECTRIC 2010; EREC and Greenpeace International 2010; Knopf et al. 2010). The scenarios tend to assume an increase in capital expenditure in the decarbonisation path mainly during the short to medium term. This increase depends on investments in generation capacity (particularly for renewables, but also in some cases for nuclear and gas power plants) as well as in mitigation technologies (e.g. CCS) on the one hand and grid and storage capacity development on the other. But these investment costs will also result in durably lower operating costs, by virtue of the fact that this new electricity system will be largely unaffected by fuel and carbon certificate prices. Against the backdrop of this shift, some studies assume that electricity generation costs will decrease in the wake of an initial moderate rise. This holds true in particular for studies whose scenarios assume a high share of energy from renewable sources and lower medium term aggregate costs than for the reference scenario (ECF et al. 2010; EREC and Greenpeace International 2010). However, the extent to which these latter two effects will actually cancel each other out will be determined by long term costs, which cannot be readily forecast (particularly for fossil fuel and carbon certificates), as well as learning curves in connection with new technologies.

Table 3-1

### Suppositions and projected outcomes for various European scenarios in the run-up to 2050

Study	Scenario	Region	Mean GDP growth (in percent/year)	Gross electricity generation (TWh)	Renewable electricity (in TWh)	Share of renewables (in percent)	Share of fossil fuels (in percent)	Share of nuclear power (in percent)	Net electricity imports (in percent)	CO2 reduction (in percent per year)	CCS in electricity sector
IEA WEO	Today (2007)	EU-27		3,325	529	15.9%	56%	28.1%			
IEA WEO	Reference for 2030	EU-27	1.5%	3,968	1,330	33%	48%	19%			
IEA WEO	450 ppm in 2030	EU-27	1.5%	3,822	1,677	44%	26%	30%			
<b>Reference scenarios for 2050</b>											
Greenpeace/EREC	Reference	OECD (Europe)	1.4%	5,351	2,242	42%	46%	12%			no
IEA ETP	Reference	OECD (Europe)		4,819	1,908	40%	44%	17%			no
ADAM	M1-adaptation	EU-27	1.6%	4,300	1,600	38%	31%	27%			
ECF	Reference	EU+NOR+CH	1.8%	4,800	1,632	34%	49%	17%			no
Eurelectric	Reference	EU-27	~1.7%	4,650	1,600	34%	28%	38%			yes
ADAM	Reference	EU+NOR+CH	1.6%	7,000	1,400	27%	55%	18%			no
RECIPE	Base-IMACLIM	EU-27		7,500	2,000	27%	58%	15%			no
RECIPE	Base-WHICH	EU-27		5,800	1,500	25%	45%	30%			no
SEI	Reference	EU-27	1.5%	4,114	834	20%	60%	20%			no
<b>Decarbonization scenarios for 2050</b>											
EREC	Rethinking for 2050	EU-27		4,987	4,987	100%	0%	0%	yes (NA/NO)		no
Czisch	Reference scenario	Eurasia + North America		4,319	4,320	100%	0%	0%	yes		no
ECF	100% renewables	EU+NOR+CH	1.8%	4,900	4,900	100%	0%	0%	15% (NA)	95-100%	no
SEI	Mitigation	EU-27	1.2%	3,047	3,047	100%	0%	0%	7.5% (NA)	92%/1990	no
Greenpeace/EREC	advanced (r)evolution	OECD (Europe)	1.37%	4,119	3,995	97%	2%	0%		99%/2007	no
Greenpeace/EREC	energy (r)evolution	OECD (Europe)	1.37%	3,462	3,167	91%	9%	0%		95%/2007	no
ECF	80% renewables	EU+NOR+CH	1.8%	4,900	3,920	80%	10%	10%		95-100%/1990	yes
ADAM	400ppm-EuroMM	EU-27		2,750	2,050	75%	0%	25%	DE: 50%		modest
ADAM	450ppm-EuroMM	EU-27		2,800	2,050	73%	9%	18%	DE: 35%		
ECF	60% renewables	EU+NOR+CH	1.8%	4,900	2,940	60%	20%	20%		95-100%/1990	yes
RECIPE	450ppm-REMIND-R	EU-27		6,500	3,600	55%	15%	30%		~50%/1990	no
IEA ETP	BLUE Map	OECD (Europe)		3,636	2,007	55%	16%	29%	Variants		yes
RECIPE	450ppm-IMACLIM	EU-27		4,900	2,500	51%	28%	21%		~100%/1990	2040 onwards
Eurelectric	PowerChoices	EU-27	~1.7%	5,200	2,000	40%	31%	28%		89%/2005	yes
ECF	40% renewables	EU+NOR+CH	1.8%	4,900	1,960	40%	30%	30%		95-100%/1990	yes
RECIPE	450ppm-WITCH	EU-27		5,500	2,000	36%	14%	50%		~60%/1990	yes
ADAM	400ppm-POLES	EU+NOR+CH	1.6%	6,150	2,300	36%	27%	37%		89-103%/1990	yes
ADAM	450ppm-POLES	EU+NOR+CH	1.6%	6,900	2,350	34%	23%	43%			yes
Some of the figures in the table above are approximations obtained either from graphics or by rounding off existing figures.											
In some cases there are significant differences between the definition of specific indicators and the delineation of the electricity sector.											
Key to acronyms: CH: Switzerland; DE: Germany; NO: Middle East; EE: Renewables; CSP: concentrated solar power											

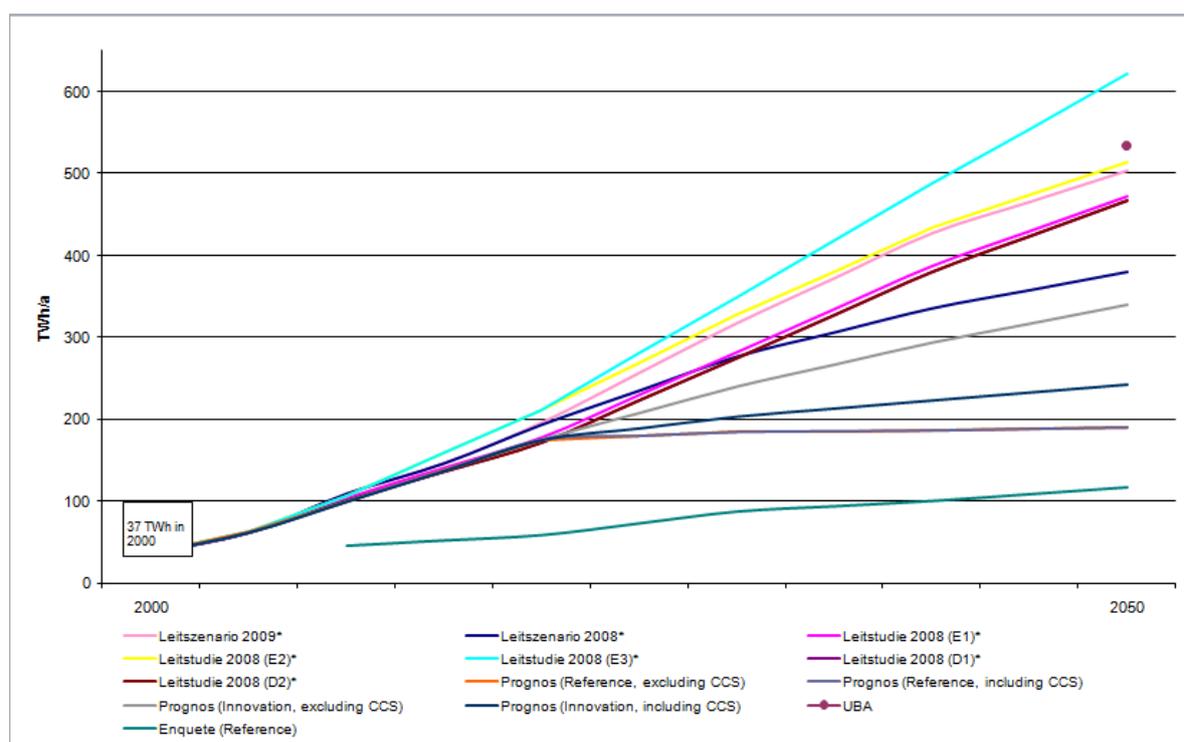
Sources: Hulme et al. 2009; EREC and Greenpeace International 2010; IEA 2010; SEI 2009; EURELECTRIC 2010; Edenhofer et al. 2009; EREC 2010; ECF et al. 2010; Czisch 2005; proprietary calculations

### 3.2.2.3 Emissions, technology paths and costs in Germany

The posited share of renewables varies greatly across the various German scenarios we reviewed (see Figure 3-2), in large measure due to the fact that differing reference years and cost suppositions were applied. The Study Commission and Öko-Institut/Prognos AG reference scenarios project that by 2050 117 and 190 TWh/a (respectively) of electricity will be renewable. Already in 2008 the actual figure (93.3 TWh/a) was on a par with the level which, according to the Study Commission scenario, will not be reached until the mid 2030s. However as the higher figures in this regard posited by the Öko-Institut and Prognos AG studies are based on a more current database that factors in recent dynamic developments, these figures would appear to be more plausible in light of the information available today.

Figure 3-2

#### Renewable electricity in Germany, including imports



Sources: Nitsch 2008; Nitsch and Wenzel 2009; Öko-Institut and Prognos AG 2009; Enquete-Kommission Nachhaltige Energieversorgung unter den Bedingungen der Globalisierung und Liberalisierung 2002; Klaus et al. 2010; BMU 2010; proprietary calculations

Some of the aforementioned target scenarios and variants thereof project a considerably higher share of energy from renewable sources for 2050. These include the following: the *Leitszenario 2009* study, which gives a figure of 503 TWh/a of which 379 TWh/a would be generated in Germany; the *Leitstudie 2008* study scenario variants give a figure ranging from 472 to 621 TWh/a; the Öko-Institut/Prognos AG innovation scenario, which forecasts 243 and 339 TWh/a of renewable electricity with and without CCS respectively; the

Enquete-Kommission's RRO-IER variant 2 projects an all-renewables electricity supply for 415 TWh/a of demand in 2050 (Enquete-Kommission Nachhaltige Energieversorgung unter den Bedingungen der Globalisierung und Liberalisierung 2002, p. 659); and according to the UBA's regional grid scenario, all electricity will be renewable by 2050, i.e. 506 TWh/a of renewable electricity, which is on a par with the figure indicated in the *Leitszenario 2009* study.

Save for the Study Commission's FNE scenarios, all of the scenarios that meet the mandatory emission objectives posit a massive expansion of renewable electricity installations. For the most part they assume that wind energy will play a prominent role (Nitsch and Wenzel 2009, p. 40; Klaus et al. 2010).

Table 3-2

**Suppositions and projected electricity sector outcomes for German scenarios in the run-up to 2050 Comparison  
of national scenarios: Assumptions and projected electricity sector outcomes in 2050**

German scenarios in the run-up to 2050			Socio-economic parameters		Electricity demand	RES production	Electricity mix			Imports of RES electricity	Reduction of GHG emissions	Cost	Technology
Study	Scenario	Reference year	Population (m)	GDP growth (%/a)	Total (TWh)	Incl. imports (TWh)	RES	Fossils	Nuclear	TWh	% (compared to 1990)	GHG prices (€/t CO2e)	CCS?
<b>Reference scenarios</b>													
Enquete	Referenz (IER)	2000	67.8	1.37 %	555*	117	21 %	79 %	0 %	0	31 %		No
Prognos/Öko-Institut	Referenz, without CCS	2005	72.2	0.70 %	530**	200	38 %	62 %	0 %	10	43 %	50	No
Prognos/Öko-Institut	Referenz, with CCS	2005	72.2	0.70 %	530**	200	38 %	62 %	0 %	10	49 %	50	Yes
<b>Target scenarios</b>													
Enquete	UWE-WI	2000	67.8	1.37 %	428***		~ 20 %		0 %		80 %		Yes
Enquete	UWE-IER	2000	67.8	1.37 %	538***		~ 20 %		0 %		80 %		Yes
Enquete	UWE-IER Var. 1	2000	67.8	1.37 %	380***		~ 20 %		0 %		80 %		No
Enquete	RRO-WI	2000	67.8	1.37 %	380***		> 50 %		0 %		80 %		No
Enquete	RRO-IER	2000	67.8	1.37 %	434***		> 50 %		0 %		80 %		No
Enquete	RRO-IER Var. 1	2000	67.8	1.37 %	431***		> 50 %		0 %		80 %		No
Enquete	RRO-IER Var. 2	2000	67.8	1.37 %	415***		100 %	0 %	0 %		95 %		No
Enquete	RRO-IER Var. 3	2000	67.8	1.37 %	434***		> 50 %		0 %		80 %		No
Enquete	RRO-WI Var. 3	2000	67.8	1.37 %	380***		> 50 %		0 %		80 %		No
Enquete	FNE-WI	2000	67.8	1.37 %	498***				> 0 %		80 %		No
Enquete	FNE-IER	2000	67.8	1.37 %	730***				> 0 %		80 %		No
Enquete	FNE-IER Var. 1	2000	67.8	1.37 %	505***				> 0 %				No
Enquete	REF-IER Var. 1	2000	67.8	1.37 %	574***						80 %		No
Prognos/Öko-Institut	Innovation, without CCS	2005	72.2	0.70 %	453**	339	75 %	25 %	0 %		88 %	50	No
Prognos/Öko-Institut	Innovation, with CCS	2005	72.2	0.70 %	420**	243	58 %	42 %	0 %		88 %	50	Yes
Leitszenario 2009	Leitszenario 2009	2008	75.1	1.12 %	599*	503	84 %	16 %	0 %		80 %	28 – 70	No
Leitsstudie 2008	Leitszenario 2008	2007	75.1	1.12 %	583*	472	82 %	18 %	0 %		79 %	28 – 70	No
FVEE	Energiekonzept 2050				764*	764	100 %	0 %	0 %		100 %		No
<b>Exploratory scenarios</b>													
Leitstudie 2008 (E1)	E1	2007	75.1	1.12 %	571*	472	83 %	17 %	0 %		81 %		No
Leitstudie 2008 (E2)	E2	2007	75.1	1.12 %	593*	514	87 %	13 %	0 %		83 %		No
Leitstudie 2008 (E3)	E3	2007	75.1	1.12 %	699*	621	89 %	11 %	0 %		85 %		No
Leitstudie 2008 (D1)	D1	2007	75.1	1.12 %	641*	467	73 %	27 %	0 %		62 %		No
Leitstudie 2008 (D2)	D2	2007	75.1	1.12 %	641*	467	73 %	27 %	0 %		60 %		Yes

\*) gross electricity demand

\*\*) net electricity demand

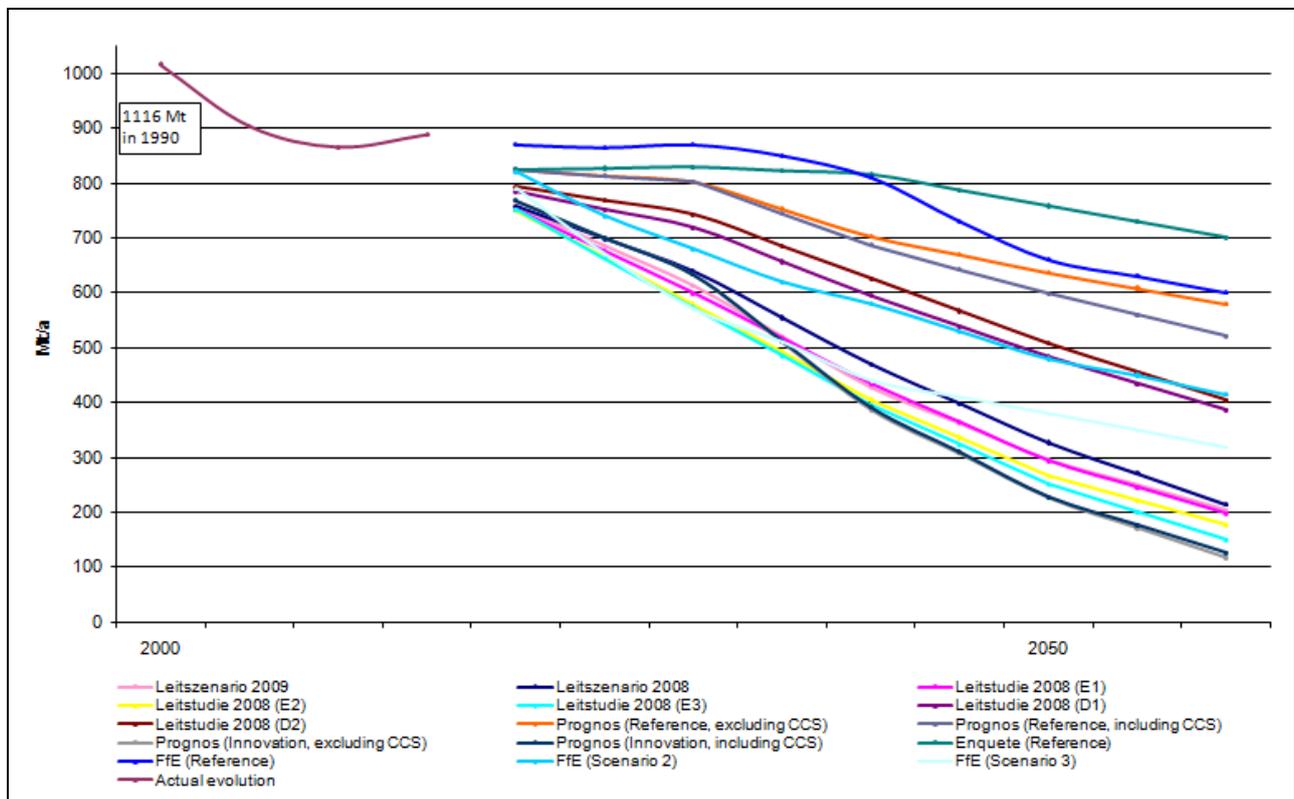
\*\*\*) electricity demand as final energy

Sources: Enquete-Kommission Nachhaltige Energieversorgung unter den Bedingungen der Globalisierung und Liberalisierung 2002; Nitsch and Wenzel 2009; Nitsch 2008; Öko-Institut and Prognos AG 2009; UNFCCC 2008; proprietary calculations

In addition to projecting electricity demand and the structure of electricity generation systems, some of the scenarios calculate the greenhouse gas emissions for each development path (see Figure 3-3). They can be used to evaluate the climate compatibility of this path, since these scenarios allow for an assessment as to whether emissions reduction goals will be reached. The data concerning greenhouse gas emissions are incomplete in some of the scenarios – for example in some cases methane (CH<sub>4</sub>) and nitrogen monoxide (N<sub>2</sub>O) emissions data are missing. In view of the fact that in Germany carbon dioxide (CO<sub>2</sub>) accounts for the largest share (88 percent) of greenhouse gas emissions (UBA 2009a) and that some of the studies we reviewed do not provide a breakdown of the various sources for the emissions indicated, the discussion that follows confines itself to carbon dioxide (CO<sub>2</sub>). The reference values used here come from the 1990 United Nations Framework Convention on Climate Change (UNFCCC).

Figure 3-3

### CO<sub>2</sub> emissions in Germany in selected scenarios



Sources: Enquete-Kommission Nachhaltige Energieversorgung unter den Bedingungen der Globalisierung und Liberalisierung 2002; Nitsch 2008; Nitsch and Wenzel 2009; Öko-Institut and Prognos AG 2009; BMWi 2010a; FfE 2009; UNFCCC 2008; proprietary calculations

The reference scenarios in the studies we reviewed fall far short of the annual greenhouse gas reduction target. Parliamentary Study Commission reference scenario: just under 31 percent (to 701 Mt/a); Öko-Institut and Prognos AG reference scenarios: 42 percent (580 Mt/a) and around 49% (521 Mt/a) with and without CCS respectively. Hence it is evident that the mandated emissions reduction objectives cannot be reached unless further energy policy measures are implemented.

On the other hand, the *Leitstudie 2008* study's scenario variants assume CO<sub>2</sub> emissions ranging from 150–404 Mt/a in 2050, an 85 and 60 percent reduction respectively. Although these lower values leave other greenhouse gas emissions such as CH<sub>4</sub> and N<sub>2</sub>O out of account, it can nonetheless be concluded from them that if the necessary energy policy measures were implemented total greenhouse gas emissions could be reduced by more than 80 percent until 2050. The same conclusion can be drawn from the Parliamentary Commission study's target scenarios, whose parameters are identical to those of the *Leitstudie 2008* scenarios. The regional grid scenario presented by the UBA study even goes so far as to project that all electricity will be renewable (i.e. emission neutral) by 2050. It should also be added here that the FVEE study reaches this same conclusion for the energy sector as a whole, referring to, *inter alia*, the *Stellungnahme Nr. 15* (SRU 2010).

#### 3.2.2.4 Costs

Most of the scenarios we reviewed contain cost calculations concerning the envisaged development paths, thus allowing for an economic assessment of these scenarios. The attributes of particular interest in this regard are (a) the manner in which aggregate costs shape up in the scenarios relative to a reference path; and (b) future electricity generation costs. Costs in these scenarios comprise power station and storage facility investment costs (capital costs), fuel costs (e.g. price of coal per tonne), operating costs (e.g. for maintenance), and CO<sub>2</sub> certificate costs, and are determined by other factors as well such as anticipated service life and capacity use. However, the costs indicated in the scenarios we reviewed should be regarded as an indication of order only, since even slight changes in the input figures could greatly alter the overall cost calculation outcome. All of the studies assume that renewable energy prices will decrease considerably in the coming years owing to the economies of scale resulting from robust expansion in Germany and elsewhere, which is expected to continue apace.

Although the 2002 Parliamentary Study Commission report contains no CO<sub>2</sub> certificate price estimates, the report attempted to fold these costs into its calculations and assessments since in the final analysis gas, nuclear power and coal will result in further external costs in the guise of investment, fuel, operating, and economic costs. However, differing assumptions were applied to these external costs owing to partisan disagreement among the Parliamentary Study Commission members resulting from a lack of valid figures.

In comparing the pros and cons of a renewable energy expansion versus continued use of fossil fuel for electricity generation, the *Leitstudie 2009* report came to the conclusion that if all of the external costs arising from fossil fuel electricity generation are factored in, already today a renewable electricity expansion would save €1.1 billion annually in loss and damage costs (Nitsch and Wenzel 2009, p. 65). In light of the fact that in this context the difference between renewable electricity and fossil fuel generation costs is chiefly determined by fossil fuel generation-related presumptions concerning fossil energy resource and CO<sub>2</sub> certificate prices and the anticipated cost decreases for renewable technologies, the *Leitstudie 2009* study investigated two price paths for

fossil energy sources. In so doing it concluded that (a) the envisaged renewable energy expansion would result in slightly higher short term energy costs relative to fossil fuels; (b) in the long term the “actual advantage” (Nitsch and Wenzel 2009, p. 67) of the renewables expansion path would become readily apparent; (c) this expansion would yield cost savings between 2022 and 2032 that would increase still further toward mid century relative to fossil fuels and that would outweigh in the long run the earlier additional costs of the renewables build-out; and (d) in the absence of a strategy that calls for an intensified expansion of renewables, in the period after 2030 (at the latest) Germany would be heading toward economic collapse.

The Öko-Institut and Prognos AG likewise conclude that the innovation path involving a high share of energy from renewable sources will involve lower long term costs than the reference path. Net additional costs will reach their maximum in 2024 (a cumulative total of €15 billion relative to 2007 (Öko-Institut and Prognos AG 2009, p. 368)), and by 2044 the savings will outweigh these additional costs.

Using cost calculations broken down by sector, the FVEE study reaches a kindred conclusion: Transitioning to a wholly renewable electricity supply will engender additional costs that would peak at €17 billion in 2015, savings amounting to €730 billion would nonetheless be realised by 2050 (FVEE 2010a).

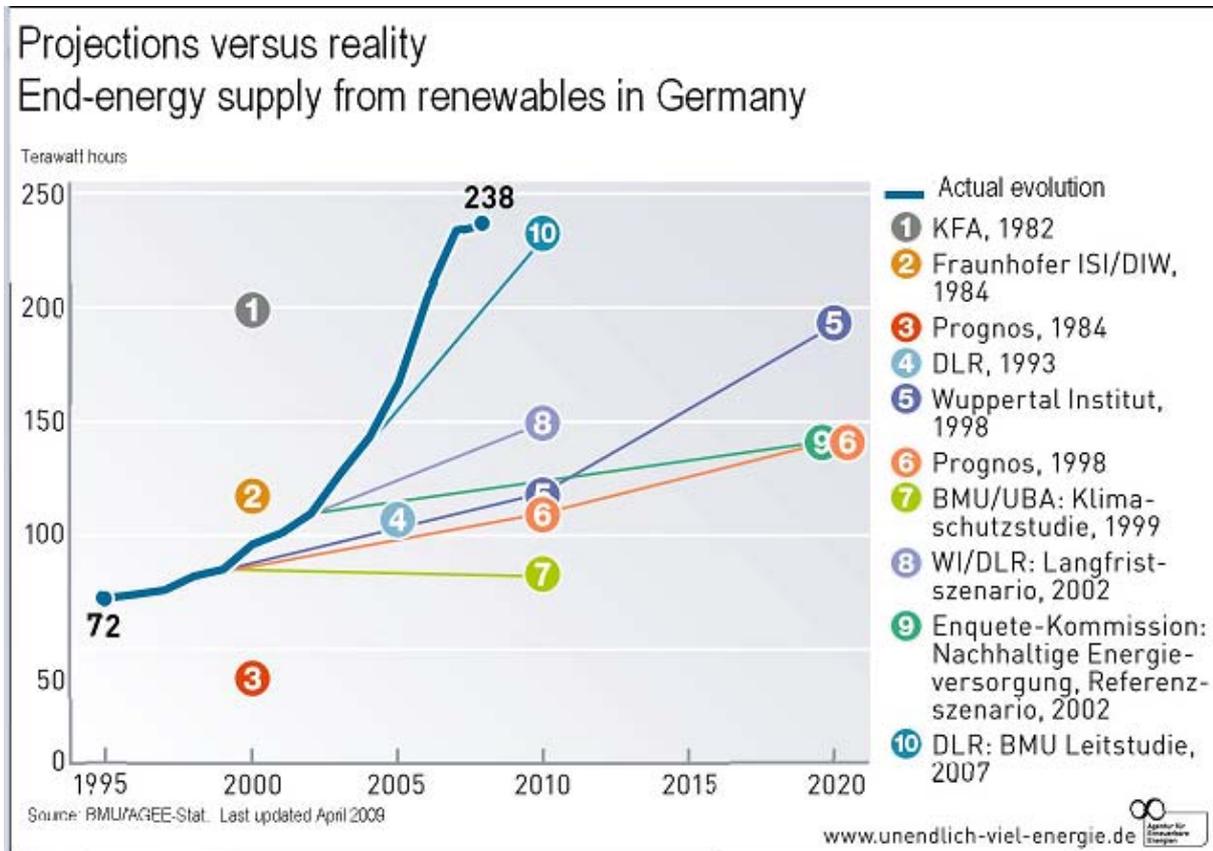
The FfE study contains no development path cost estimate. This also holds true for the UBA study, as it concerns itself solely with the technical aspects (Klaus et al. 2010).

### **3.2.3 The problem of systematic underestimation of renewables**

International organisations such as the European Commission and the International Energy Agency (IEA) have often been criticised for giving the economic potential of renewable energy short shrift in a manner that has a dampening effect on capacity expansion in this sector (Pieprzyk and Hilje 2009; Rechsteiner 2008). This underestimation contrasts with (a) the numerous analyses showing that this expansion has been far greater than anticipated by most studies not only for Germany and the rest of Europe but also worldwide; and (b) the fact that in some cases the renewables expansion projections made around a decade ago for 2020 have already been far exceeded (see Figure 3-4). For example, wind power growth was regularly underestimated during this period (see Figure 3-5).

Figure 3-4

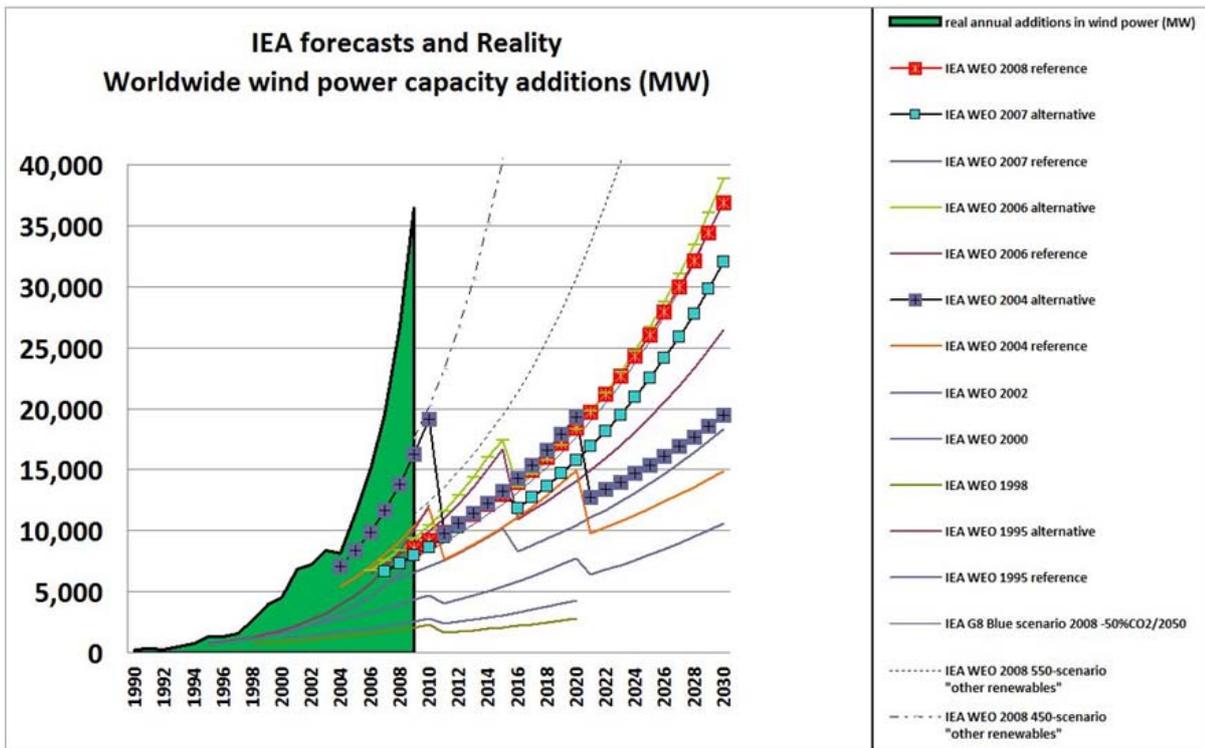
**Projected versus actual growth in the German renewable energy sector  
(expressed as final energy demand provisioning in TWh)**



Source: Pieprzyk and Hilje 2009

Figure 3-5

**International Energy Agency (IEA) scenario versus actual annual expansion of worldwide wind power capacity (in MW)**

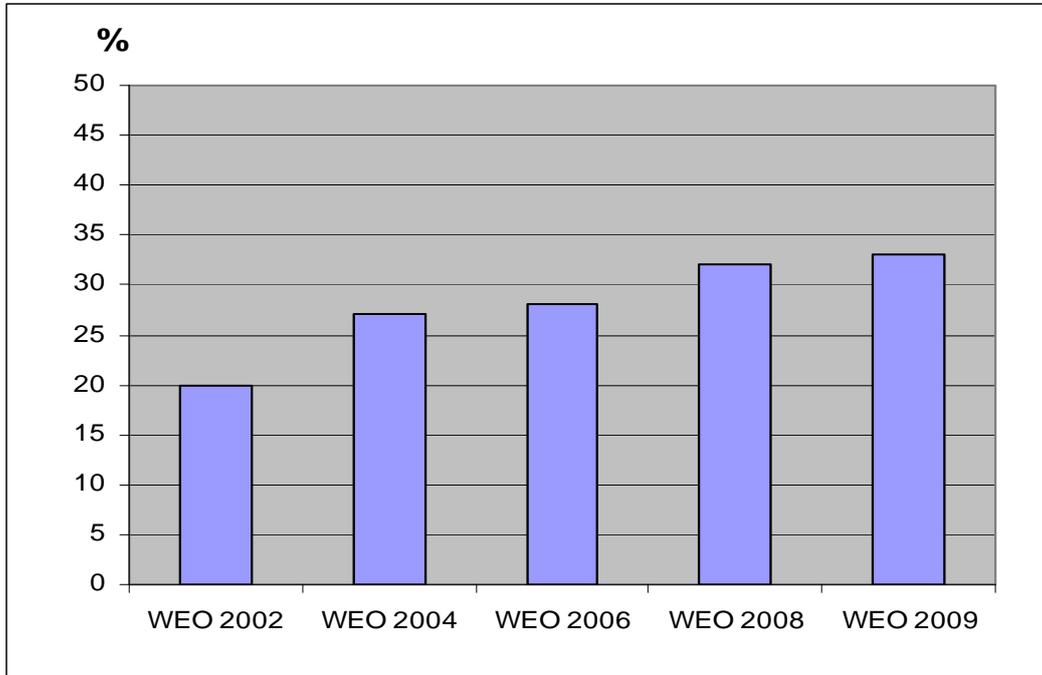


Source: Rechsteiner 2008

It is also noteworthy in this regard that renewable energy development assumptions have been steadily revised upward in recent years. One example of this is the World Energy Outlook’s reference scenario’s projection that renewables will account for 20 percent of European electricity output in 2030 (IEA 2002), which has since revised upward to 33 percent (IEA 2009; see Figure 3-6), by virtue of the fact that the 20 percent mark was already reached in 2009 (see Figure 3-7). According to a projection by the European Commission’s Joint Research Center, if this trend continues, up to 1,600 TWh of Europe’s electricity will be renewable by 2020 (Bloem et al. 2010). This figure represents between 45 and 50 percent of total demand. However, according to five of the European scenarios we reviewed the 50 percent mark would not even be reached by 2050.

Figure 3-6

**Share of renewable energy relative to gross electricity demand in the EU in 2030, as projected by the World Energy Outlook reference scenarios of the International Energy Agency (IEA)**

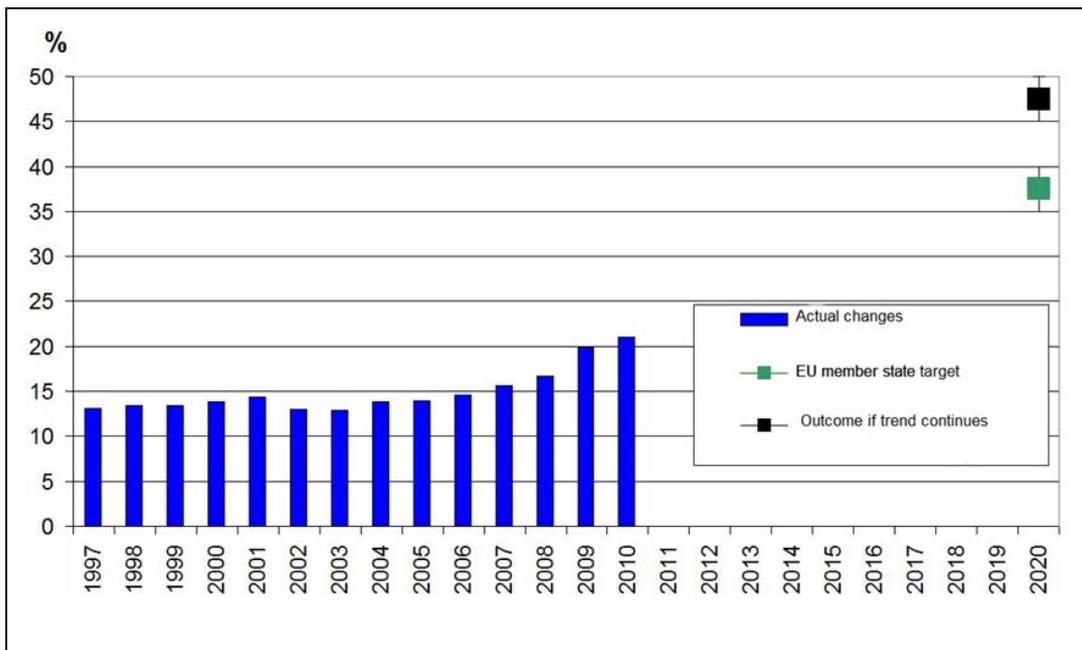


Note: 2002: EU-15, 2004–2006: EU-25, 2008 onward: EU-27

Source: IEA 2002; 2004; 2005; 2006; 2008; 2009

Figure 3-7

**Share of renewable energy relative to EU electricity generation: actual development; objective; results if trend continues**

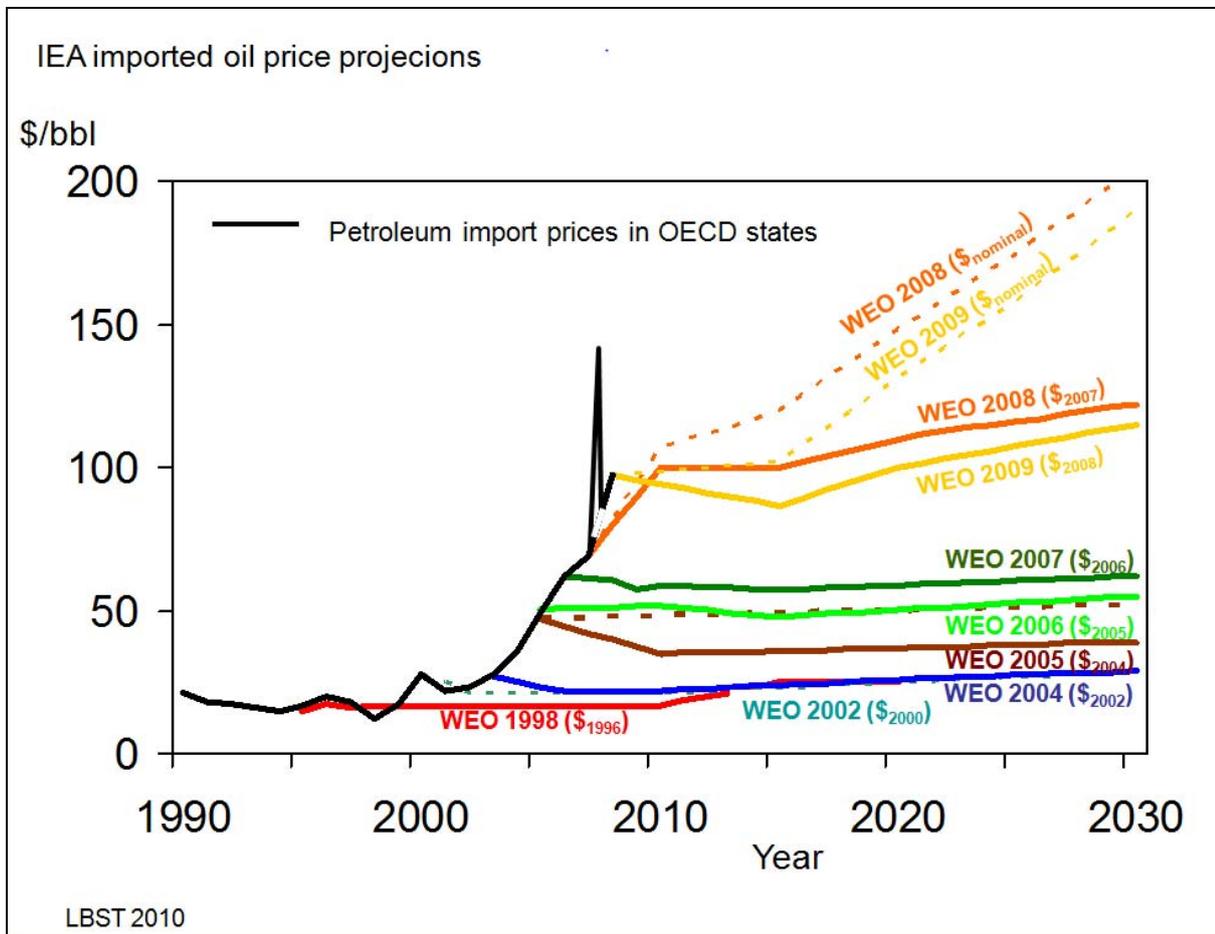


Source: Bloem et al. 2010; EuroStat 2010

The numerous reasons for the fact that the economic potential of renewable energy is constantly underestimated cannot be discussed here in detail. One thing, however, is clear: energy scenarios tend to very strongly reflect the situation that prevails at the time of their elaboration. This can be seen, for example, in the realm of fossil fuel cost projections, which have a major impact on the economic competitiveness of renewables. During the era of moderate oil prices that extended from around the mid 1980s to around 2004, it seemed reasonable to assume that fossil fuel prices would remain stable. But such projections have been revised substantially upward in recent years, during which prices have risen sharply (see Figure 3-8), whereby only a minute proportion of this increase is attributable to inflation.

Figure 3-8

**International Energy Agency (IEA) 1998–2008 oil price projections versus real prices**



Key: WEO = The IEA's World Energy Outlook  
 Source: Zittel 2010

Underestimates of the scope of renewable development are also partly attributable to the methodology used. Most modelling studies in this domain – a somewhat broader reach in some cases notwithstanding – mainly focus on ways to optimise greenhouse gas reductions from an economic standpoint. Other decision-making criteria such as job creation or secondary environmental benefits are referred to only in a marginal way (e.g. in the context of sensitivity

analyses), if at all. Although renewable energies also pose problems in terms of ecological impact and public acceptance, they offer multiple ancillary advantages over other emissions reduction technologies. Hence the narrow focus of many economic studies on CO<sub>2</sub> reduction costs can make it seem as though renewables are in fact less advantageous than other technological options. This focus on the economic optimisation of greenhouse gas reductions also results in technology paths being deemed economically optimal whose implementation may seem to be not a realistic prospect in political terms. This may hold true for scenarios that assume evolutions such as the mining of new lignite deposits, extending the lifetime of existing nuclear power plants and building new ones, and widespread use of CCS technologies (Edenhofer et al. 2009).

In addition, macroeconomic studies tend to posit development paths with a relatively conservative structure, in that such studies are based on existing technologies and are not very open to radical and systemic innovation. For example, some solar and wind power cost studies figure in extensive backup capacity costs that are intended to compensate for fluctuating input levels (IER et al. 2010). While this assumption seems reasonable in light of the relevant technologies in their present state, it leads to renewable energy cost projections that are unduly high in light of the fact that such technologies may well become less cost intensive over the long run. Technological breakthroughs such as the establishment of smart grids and the load balancing options that such grids could potentially open up are difficult to model.

And finally, the political climate has also changed, as the latest scientific findings clearly indicate how urgently needed are measures against global warming. As a result, many states have begun investing heavily in renewables; the EU has also set ambitious goals aimed at increasing the share of European energy from renewable sources. Incentives aimed at promoting renewable electricity development, particularly in terms of selling electricity back to the grid, are on the rise outside of the EU as well. Ambitious infrastructure projects involving large companies are in the works, e.g. developing the electricity grid in the North Sea and North African solar energy with a view to interconnect it with Europe. Such developments are only just beginning to be reflected in recent studies, which increasingly focus on cost efficient grid integration of wind and solar energy since in such scenarios the level of intermittent sources would exceed the integration capabilities of existing grid systems.

### **3.2.4 Conclusions**

The review of the most important energy and electricity scenarios for both Germany and Europe shows that numerous development path options are available in terms of electricity demand and expansion of renewable capacity for electricity generation. The most relevant findings for the present report are as follows:

- For the Europe-North Africa (EUNA) region covered by the SRU scenarios, it seems realistic to assume that electricity demand in 2050 will amount to around 5,400 TWh (with 500 TWh demand in Germany) or around 7,450 TWh (with 700 TWh demand in Germany).

- It likewise appears realistic to assume that annual gross electricity demand in Germany will be around 500 TWh in 2050, which would necessitate stringent energy saving and efficiency optimisation measures for traditional uses of electricity, while still allowing enough capacity for electrifying private transport (in the order of half of today's transport volume). Higher demand amounting to around 700 TWh/a would also be realistic in the event ambitious energy efficiency strategies are not implemented and electricity is substituted for some or all fossil fuel use in sectors such as transport, heating energy, and process heating.
- The baseline thesis of this report – namely that the electricity sector needs to be completely or almost completely decarbonised by 2050 in order for the German and European climate protection objectives to be reached – is overwhelmingly supported by the multi-sector studies we reviewed as well as the fact that greenhouse gas reductions in the electricity sector would be far less cost intensive than in other domains.
- The studies we reviewed show that this objective could be reached via manifold technical and economic options, whereby the possible technology paths include those based on fossil fuels with CCS technology, nuclear energy and renewables, as well as paths involving a completely or largely renewable electricity supply. Which technologies a given scenario favours is also largely determined by the methodology and suppositions that form the basis for the scenario. However, more recent studies tend to presuppose a higher share of energy from renewable sources than older studies.
- Most of the studies we reviewed fail to take load management sufficiently into account, which is a problem in that a long-term electricity supply scenario can only be viable if it also addresses the challenges posed by the oftentimes fluctuating levels of wind and solar power generation. An issue closely related to that of load management and that is likewise given short shrift in most studies is the economic and technical compatibility of such intermittent energy sources on one hand, and base load electricity generation technologies on the other. It is also noteworthy in this regard that the path we advocate – the use of Norwegian pump storage systems – is not mentioned by any of the studies, despite the evident economic and technical advantages of this solution.
- The studies we reviewed likewise fail to sufficiently address the legal, political, and social factors that would (or would not) allow for the implementation of various technological options. Any given decarbonisation scenario is bound to contain elements whose implementation can potentially run up against insurmountable obstacles that have nothing whatever to do with their technical or economic feasibility. This applies in particular to large scale power plants, carbon storage facilities, and electricity grids, but also to smaller installations and efficiency measures.
- Although the cost calculations in the studies we reviewed are freighted with extreme uncertainty, one thing is clear: a more heavily renewables based technology path will entail higher short to medium term investments, but will cost less in the long run. The differences in aggregate cost between a renewable and non-renewable energy supply path in the run-up to

2050 appear to be relatively small, but cannot be reliably forecast owing to the inherent difficulty of predicting costs. The studies also show that energy efficiency and energy saving can help to significantly reduce costs.

### **3.3 Options for an electricity based upon 100% renewable Sources**

#### **3.3.1 Introduction**

The scenarios in the following sections describe the dynamics of a wholly renewable electricity supply in Germany and in Europe and the steps that would need to be taken to implement it.

Scenarios are not intended to be a substitute for hard decisions concerning priorities and goals; all scenarios can hope to do is identify the conditions that would allow specific evolutions to occur and render the impact of the relevant factors more transparent.

The scenarios presented here posit a possible future state of the German electricity supply system based on a predefined level of electricity demand in the year 2050, and in so doing demonstrate the following:

- that a wholly renewable electricity supply (a) is achievable in Germany on its own, or via an inter-regional electricity supply network encompassing North African and neighbouring European states, based on technical potential; and (b) would provide a fully reliable electricity supply round the clock year round,
- the specific elements and their composition that such a system would comprise, assuming that (a) the attendant costs were optimised by 2050; and (b) these costs evolve in a manner that appears to be plausible based on today's knowledge,
- the probable order of magnitude of the costs of such a system,
- how the makeup of the system components, as well as system costs, would vary according to the design of the different scenarios.

These findings were then used to determine how the available electricity generation, transmission and storage capacities would need to evolve in order to achieve the defined target state by 2050. Based on the characteristics of the existing power plant fleet, we show how conventional generation capacity could be replaced incrementally by renewable energy. Here we made a conscious decision to forego a putative optimisation of the generation mix for each individual year, since the exact costs entailed by the various renewable and conventional electricity generation options will vary greatly over time and even a relatively minor change in the relative costs could greatly alter the results of any such optimisation.

As with all scenarios, those presented here should not be read as projections that may or may not come true. Transitioning to a wholly renewable electricity supply, as is proposed here, should

instead be regarded as an option – one we feel is well worth pursuing – whose implementation will necessitate targeted policymaking, strategic measures, careful planning, and considerable effort.

The scenarios presented here show (a) that such a transition is well within the realm of possibility; and (b) the form such a system would take, based on what currently appear to be plausible assumptions concerning technological and cost evolutions.

### **3.3.2 The German Aerospace Center's REMix model**

Various wholly renewable electricity supply scenarios were simulated mathematically, at our behest, by the DLR's Department of Technical Thermodynamics using the REMix energy model. The DLR has extensive experience in the field of research into technology development and cost trends in the realm of renewable energy and thus participates regularly in studies concerning the future of Germany's energy supply system (see Nitsch 2008; Nitsch and Wenzel 2009). Although the REMix model can be regarded as the best available German model for simulations of hour-based optimised electricity supply scenarios for Germany and Europe, it should be borne in mind that the results presented here are based on a series of *assumptions*. We feel, however, that all of these assumptions are plausible and reasonably represent the best available knowledge, even if, for example, our cost and price estimates concerning conventional energy resources and technologies for the use of renewable energy resources extending over a four decade period are subject to significant uncertainty.

The basic characteristics and principles of the REMix model will now be described. Further information concerning this model and the attendant assumptions will be published separately (DLR 2010a).

Having first analysed the potential of renewable energy resources, the REMix model uses the results of this analysis to determine a cost optimised (i.e. lowest cost) constellation of energy resources for the defined conditions.

The potential analysis is based on a GIS database, which provides detailed information concerning the electricity generation potential for renewable energy resources in Germany, Europe and North Africa, via a high resolution grid (grid cell size 10 km x 10 km) (see Figure 2-1).

The REMix model takes account of the following ten renewable electricity options:

- Photovoltaic solar energy,
- Onshore wind,
- Offshore wind in the German portion of the North Sea and Baltic Sea,
- Gaseous biomass with and without combined heat and power generation (cogeneration, CHP),
- Solid biomass with and without cogeneration,
- Geothermal energy with and without CHP,

- Run-of-river hydro power,
- Storage hydroelectric power stations,
- Pump storage systems,
- Compressed air energy storage.

The REMix model also takes account of concentrated solar power (CSP) potential. However this energy resource is available solely in regions with a greater amount of solar radiation such as North Africa and thus was only factored into the scenarios that included Southern European and North African states.

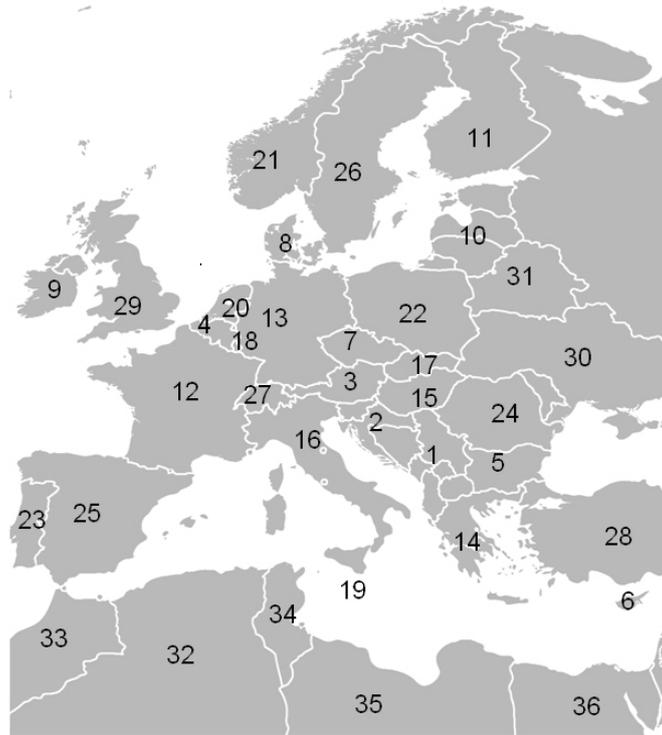
The REMix model's potential data for intermittent wind and solar energy resources were broken down by hours (DLR 2010a).

The analysis of potential was based on coverage types for areas available as GIS maps. Various assumptions were made in this regard as to which areas are suitable for use of a specific technology and which portion of these areas are available for such use in light of the main area use restrictions such as inhabited areas, ecological considerations, or competing land use forms.

Table 3-3- summarises, for the various energy resources, the underlying data and assumptions, as well as the areas that were excluded from consideration. Such exclusions were based on the presence of specific ecological or technical conditions that ruled out the area in question for use in connection with a specific energy technology. Thus for example all nature reserves are excluded, and solar energy (photovoltaic and concentrated solar power (CSP)) can only be used in gently sloping areas. Some areas are characterised by competing forms of use whose geographic boundaries cannot be clearly defined. Hence a maximum area utilisation rate was defined for the area in which each technology can mainly be used. These rates, which are based on the sustainability criteria defined by Germany's Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) (BMU 2004) and Quaschnig (2000), normally yield conservative estimates of potential. The area utilisation rates were set in such a way that aggregate potential could be determined, including in the presence of competing use forms (i.e. not subject to multiple uses) (see Table 3-3). For example, non-cultivated desert areas could potentially be used for concentrated solar power (CSP), wind energy and photovoltaic energy, to each of which the REMix model allocated 33 percent of the available area as the maximum useable area.

Figure 3-9

### REMix model countries



No.	Country (region)	Abbreviation	Area coverage	No.	Country (region)	Abbreviation	Area coverage
1	Albania	AL_CS_MK	1	17	Slovakia	EC	1
1	Serbia			18	Luxembourg	LU	1
1	Macedonia			19	Malta	MT	1
2	Bosnia	BA_HR_SI	1	20	The Netherlands	NL	1
2	Croatia			21	Norway	NO	1
2	Slovenia			22	Poland	PL	1
3	Austria	AT	1	23	Portugal	PT	1
4	Belgium	BE	1	24	Romania	RO	1
5	Bulgaria	BG	1	25	Spain	ES	1
6	Cyprus	CY	1	26	Sweden	SE	1
7	Czech Republic	CZ	1	27	Switzerland	CH_LI	1
8	Denmark	DK	1	27	Liechtenstein		
9	Ireland	IE		28	Turkey*	TR	0.80
10	Estonia	EE_LT_LV	1	29	Great Britain	UK	1
10	Lithuania			30	Ukraine	U_MD	1
10	Latvia			30	Moldavia		
11	Finland	FI	1	31	Belarus	BY	1
12	France	FR	1	32	Algeria	DZ	0.31
13	Germany	DE	1	33	Morocco*	MA	0.73
14	Greece	GR	1	34	Tunisia*	TN	0.99
15	Hungary	HU	1	35	Libya*	LY	0.18
16	Italy	IT	1	36	Egypt*	EG	0.13

\*A portion of this country/region is located outside of the area under investigation. Note: area coverage indicates the percentage of the region's surface area that lies within the area under investigation.

Source: SRU 2010; based on DLR 2010a, pp. 2-3

The utilisation rates indicate the maximum potential for each area, whereby the REMix model simulations indicate the amount of each such area that is usable in the various scenarios.

Based on the cost assumptions for the various technologies, the REMix model was used to determine the share that these technologies would have in a generation mix and which transmission and storage capacities would have to be installed. The estimated electricity generation costs for the various technologies are based on installable capacity and electricity generation potential in conjunction with specific investment costs, fixed and variable operating costs, and the lifecycles of the reference power plants. Future costs were estimated by projecting current costs into the future via learning curves. The DLR's assumptions concerning the timelines for specific electricity generation costs were based on Nitsch et al. (2004) and Krewitt et al. (2005) and have been subject to continuous updating ever since in light of new findings. These putative costs, which are consistent with those posited by a 2009 Federal Environment Ministry (BMU) study (Nitsch and Wenzel 2009), are based on a presumed 6 percent interest rate and are summarised in Figure 3-10. These costs are also based on so called learning rates, according to which doubling the production of a given technology (e.g. the number of wind turbines manufactured annually) will yield a cost reduction amounting to X percent. Such cost curves, which can be observed for numerous technologies, are primarily based on improvements in the technology per se (e.g. higher efficiency for a facility, reduced material use) and cost reductions resulting from higher production (efficiencies of scale). Although the existence of such effects has been scientifically proven and is undisputed, experts often disagree on the extent to which costs can be reduced in the future. The cost reduction potential posited by the DLR is subject to significant uncertainty since the attendant calculations relate to the next four decades. However, technology based cost reduction potential is subject to less uncertainty than are the prices of oil, coal, or natural gas over the same period.

Table 3-3

**Regions and renewable energy source potential in German, Europe and North Africa taken into account by the German Aerospace Center's REMix model**

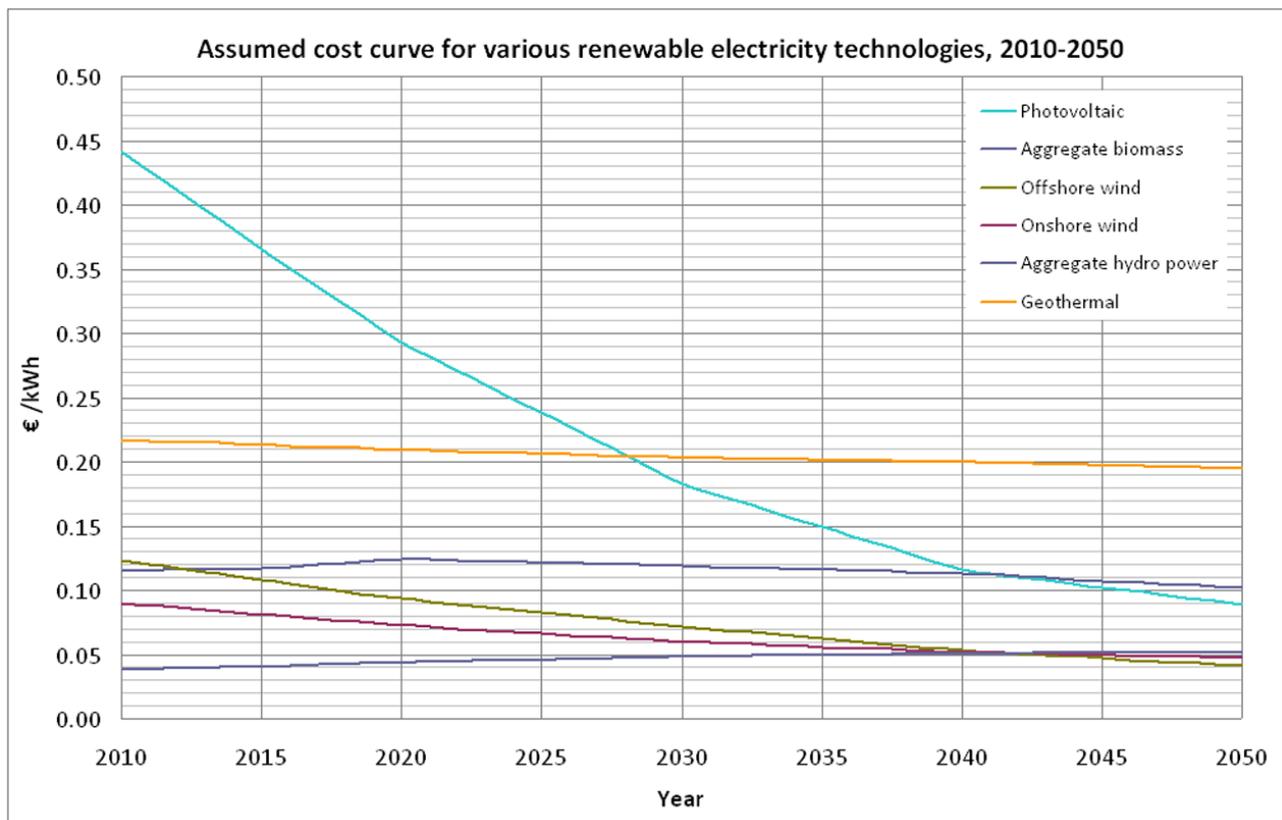
	Resource data	Excluded areas	Area distribution parameter	Area utilisation rate	Comments
<b>Photovoltaic energy in inhabited areas</b>	Global horizontal incidence solar radiation and direct normal incidence (DNI) solar radiation <sup>2</sup>		Inhabited areas <sup>3,4</sup>	Roofs: 0.775%; building facades: 0.48%; miscellaneous: 1.17% <sup>1</sup>	Orientation distribution in accordance with <sup>1</sup>
<b>Photovoltaic energy in non-inhabited area</b>	Global horizontal incidence solar radiation and DNI <sup>2</sup>	Protected areas with a slope exceeding 2.1%	Farmland <sup>3,4</sup>	0.03% <sup>1</sup>	Southern orientation without solar tracking
			Pastureland <sup>3,4</sup>	0.03% <sup>1</sup>	
			Uncultivated and sparsely covered areas <sup>3,4</sup>	33% (NA)/ 0.03% (EU)	
<b>Concentrated solar power (CSP)</b>	DNI <sup>2</sup>	Protected areas with a slope exceeding 2.1%	Uncultivated and sparsely covered areas <sup>3,4</sup>	33%	North-south orientation with east-west solar tracking and DNI exceeding 1,800 kWh/(m <sup>2</sup> *a)
<b>Onshore wind</b>	Wind velocity 116 meters above sea level <sup>6</sup>	Protected areas <sup>5</sup>	Uncultivated and sparsely covered areas <sup>3,4</sup>	33%	
			Pastureland <sup>3,4</sup>	3%	
			Bush <sup>3,4</sup>	3%	
			Mosaic areas (grass, bush, trees)	3%	
			Farmland <sup>3,4</sup>	3%	
			Forests <sup>3,4</sup>	0%	
<b>Offshore wind</b>	Wind velocity 116 meters above sea level <sup>6</sup>	Protected areas <sup>5</sup>	Entire exclusive economic zone, 5 km from the coast at a depth of less than 300 meters	16%	
<b>Geothermal energy, only for electricity generation</b>	Temperatures at a depth of 2, 3, 4, and 5 km <sup>7,8</sup>	Protected areas <sup>5</sup>	All areas	100%, minus geothermal and CHP potential	
<b>Geothermal power-CHP</b>	Temperatures at a depth of 2, 3, 4, and 5 km <sup>7,8</sup>	Protected areas <sup>5</sup>	Required heat demand more than 0-4 GWh/square km	Limited by absolute heat demand	European heat demand map; proprietary source
<b>Run-of-river hydro</b>	Installed capacity; <sup>9</sup> annual electricity generation potential; full load hours <sup>10</sup>		Installed capacity; <sup>9</sup> hypothetical hydro power potential <sup>11</sup>	100%	Top down approach
<b>Hydro reservoirs</b>	Installed capacity; <sup>9</sup> annual electricity generation potential; full load hours <sup>10</sup>		Installed capacity <sup>9</sup>	100%	Top down approach
<b>Biomass</b>	National biomass potentials <sup>12, 13, 14</sup>	Protected areas <sup>5</sup> with a slope exceeding 60%	Forest, farmland, pastureland, inhabited areas <sup>3,4</sup> , population density <sup>15</sup>		Top down approach
1	Quaschnig, V., Systemtechnik einer umweltverträglichen Elektrizitätsversorgung in Deutschland für das 21. Jahrhundert. 2000. Düsseldorf: VDI Verlag GmbH. 0-188.				
2	DLR, Direct Normal Irradiance and Global Horizontal Irradiance. 2007, Deutsches Zentrum für Luft- und Raumfahrt.				
3	EEA, Corine Land Cover 2000. E.E. Agency, Editor. 2005.				
4	JRC, Global Land Cover 2000. 2003, European Commission, Joint Research Center.				
5	WDPA, World Database on Protected Areas, <a href="http://www.wdpa.org/">http://www.wdpa.org/</a> 2006.				
6	DWD, Windgeschwindigkeiten und Bodenrauigkeit aus dem Lokalmmodell Europa, D. Wetterdienst, Editor. 2007, Deutscher Wetterdienst: Offenbach.				
7	Hurter, S.H., R. , Atlas of Geothermal Resources in Europe. 2002, Office for Official Publications of the European Communities: Luxemburg.				
8	Hurtig, E., Cermak, V., Haenel, R.; Zui, V., Geothermal Atlas of Europe. 1992,				

9	Hermann Haak Verlagsgesellschaft mbH, Geographisch-Kartographische Anstalt: Gotha.
10	PLATTS, PowerVision, datacut hydropower Europe. 2008, PLATTS (McGraw-Hill Companies): London.
11	WEC, 2007 Survey of Energy Resources, in Survey of Energy Resources, W.E. Council (ed.) 2007,
12	World Energy Council: London.
13	Lehner, B.C., G.; Vassolo, S., Europe's Hydropower Potential Today and in the Future. EuroWasser.
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15	EUROSTAT, epp.eurostat.ec.europa.eu.
	FAOSTAT, faostat.fao.org.
	Dobson, J.E., E. A. Bright, P. R. Coleman, R.C. Durfree; B. A. Worley, LandScan: A Global Population Database for Estimating Populations at Risk. Photogrammetric Engineering & Remote Sensing 2000. Vol. 66 (No. 7): pp. 849-857.

Source: DLR 2010a, p. 6

Figure 3-10

### Projected cost curve for the various renewable electricity generation technologies until 2050



Source: SRU 2010, based on DLR 2010a, p. 41 ff.

Changes in the costs of renewable and conventional electricity technologies may have a substantial effect on the portion of each technology simulated in the model, as well as on overall system costs. In our view, the DLR's assumptions are plausible and not unduly optimistic in light of other studies involving similar timelines, particularly in view of the interim results of the Intergovernmental Panel on Climate Change (IPCC) concerning the potential role of renewable electricity in fighting climate change. This study reviewed the results of all key international studies to date concerning the use of renewables. The learning rates indicated in the literature range from 4 to 32 percent, whereby Lemming et al. (2009, p. 35) cite Neij (1997; 1999; 2008) as the most reliable source for wind energy learning rates, which according to Lemming et al. (2009, p. 35)

range from 9 to 17 percent based on the aforementioned publications by Neij. Neij's latest findings (Neij 2008, p. 2209) prognosticate a range of 10 to 20 percent. Based on the renewable electricity expansion defined for Germany in our scenarios, a backward projection of the presumed costs indicates that the DLR learning rates are 11.5 percent for onshore wind farms and 18.6 percent for offshore wind farms. According to one author, the historical learning rate for photovoltaic energy is 20 percent (Surek 2005, p. 294). However this author also assumes that such high learning rates for crystalline silicon photovoltaic modules cannot be maintained over the long term (Surek 2005, p. 303). Neij (2008, p. 2209) predicts that photovoltaic costs will decrease by 15 to 25 percent by 2050. Backward projection of the costs indicated by the DLR reveals a putative learning rate of 26 percent, which would appear to be highly optimistic. The putative learning rate of 2.2 percent for biomass can be regarded as relatively conservative in view of the 0 to 10 percent range for this parameter indicated by Neij (2008, p. 2209). Geothermal energy may be a special case in this context. The latest DLR figures (not included in the present findings) indicate that geothermal energy costs could be subject to a far greater decrease than that prognosticated by the DLR calculations. If this is the case, geothermal energy could potentially play a larger role than that indicated in the scenarios presented here.

Even if the cost reduction potential posited in the present report would prove to be unduly optimistic, this would not alter the results of our calculations indicating that wholly renewable electricity supply is achievable; but it would equate to higher climate protection costs than those indicated by the scenarios.

The REMix model includes Europe and North Africa, where our scenarios allow for electricity interchange across specific national borders as well as for specific maximum interchange levels. This approach allowed for the analysis of country groups of varying sizes, as well as individual countries.

The REMix model calculated total system costs as well as mean per kWh cost for each scenario, and in so doing determined the necessary transmission capacities between the states concerned and the attendant total transmission costs. However, the incidental costs arising from electricity transmission via a grid expansion within an individual country were handled differently. Although technical potential was determined using a high spatial resolution during the simulations, some geographical information was lost in this process since it was necessary to aggregate technical potential for specific regions for reasons of limited computing capacity. Hence the total renewable electricity potential of each country was treated as aggregated. The REMix model did not take account of the grid expansion needed in Germany and elsewhere, particularly in terms of integrating offshore wind farm capacity and transporting it to the consumption centres – a process that also drives up electricity supply system costs. In view of this fact, we estimated the costs of the grid expansion within Germany separately.

Inasmuch as the model uses one hour time intervals, it can correlate annual electricity generation with electricity demand down to the hour. A condition was defined whereby each scenario must

allow for a completely reliable and secure electricity supply, which means that the technologies deployed must have the capacity to satisfy fluctuating electricity demand at all times via concurrent generation of renewable electricity or the use of stored electricity. The optimal makeup of a electricity generation mix was determined by extrapolating the load curve for a past year to the posited target year (2050) demand level of 509 or 700 TWh/a, whereby it was presumed that the demand curve during that year will be similar to the annual curve in Germany to date. We are well aware of the fact that, in the absence of a better estimate of electricity demand in 2050, the prognostication arrived at here is only an initial rough estimate. However this method very probably posits higher requirements for installed capacity and speed of changes in generation than what will actually be the case in 2050. Moreover, many of the efficiency optimisation technologies such as dispatchable loads and smart devices that may well be implemented between now and 2050 for climate protection reasons will allow for grid load balancing and reduced demand peaks.

Inasmuch as the model also takes account of fluctuating availability over time down to one hour intervals, it was also possible to determine the hourly requirements for production capacity and equalisation solutions using storage systems. This in turn allowed for computation of the costs associated with each of the various scenarios based on the calculations for the relevant generation and storage technologies, as well as the posited cost functions, and in such a way as to take account of all of the inherent imponderables.

The model takes account of three key storage modalities, namely pump storage systems, compressed air energy storage, and the use of hydrogen as an electrical energy storage medium. None of the optimised solutions yielded by the REMix model call for the use of hydrogen as an electricity storage medium due to the relatively high system loss and consequent elevated costs associated with this technology, although the model allows for its use. All of the calculations factored in the relevant conversion and line losses for long distance transport, but disregarded the distribution losses that occur in the current German electricity grid. However, such losses will continue to occur if conventional electricity generation remains in use.

### **3.3.3 Scenarios**

The SRU used the German Aerospace Center's REMix model to analyse various scenarios for a wholly renewable electricity supply for Germany and Europe, whereby various conditions were posited in respect to energy demand in 2050 and the possibility of cross-border electricity interchange. A total of eight scenarios were modelled so that a relatively broad range of requirements and options could be taken into account. These scenarios fall into three different scenario groups, whose main characteristics are shown in Table 3-4.

All of the scenario groups differentiate between a variant with stabilised electricity demand and one with substantially increased demand. The paradigm entailing national (i.e. German) electricity self sufficiency, a relatively small regional network and a far larger scale Europe-North African network were compared with each other. This approach took account of a broad range of solutions for a

wholly renewable electricity supply, while at the same time shedding light on the impact of various strategy options on costs, the constellation of renewable energy sources used, and storage capacity requirements.

The DE 100% SV scenario group assumes for Germany to develop a wholly self-sufficient renewable electricity supply – meaning that Germany’s entire electricity demand would be satisfied via domestic renewables and there would be no cross-border electricity interchange. And in keeping with the exigencies of such a scenario, all electricity storage would also have to be realised on German territory. Although such a scenario would appear to be neither necessary nor desirable in view of (a) the fact that Germany currently imports roughly 60 percent of its resources required for domestic electricity generation and (b) European market integration, the technical and economic feasibility of such a solution was assessed nonetheless for purposes of cost and technology comparisons with other scenarios. Chapter 3 solely presents the key results of the assessment of this scenario group.

In the DE–DK–NO scenario group, Germany was modelled as part of a network structure comprising Germany, Norway and Denmark. These scenarios investigated the impact of Norwegian pump storage system potential use on renewable electricity in Germany. Denmark would act as a transit country to Norway in this network and also offer considerable wind power potential for the system as a whole.

Four scenarios were analysed for this network. The first, DE–DK–NO 100% SV, presupposes that on the average Germany can achieve complete self sufficiency for its domestic electricity demand, i.e. the amount of electricity generated will satisfy 100 percent of domestic demand. However, unlike the DE 100 % SV scenario, the DE–DK–NO 100% SV scenario allows for up to 15 percent of annual output to be interchanged between Germany and its network partners. This would notably give Germany access to Norway’s pump storage system capacity to compensate for temporary discrepancies between electricity demand and generation. A second scenario (DE–DK–NO 85% SV) allows Germany to import 15 percent of its net electricity from Sweden and Denmark, thus reducing Germany’s self sufficiency rate to 85 percent. This straightforward tripartite cooperation yielded extremely clear analyses, unlike pan-European electricity exchanges, where some changes are difficult to classify owing to overlapping effects; moreover, the role of Germany and certain other states is far more difficult to assess.

The DE–DK–NO 100% SV scenario can be regarded as a relatively close approximation of a complex but realistic evolution of Germany’s electricity supply system, since (a) considerable electricity is already interchanged between Germany and other European countries; and (b) Germany is a net electricity exporter. This scenario is the main focus of the discussion of a possible transition from our current electricity system to the putative 2050 system.

A network comprising Sweden and Germany and involving the use of Swedish hydro power for electricity storage purposes is also an option. However, Norway, with its roughly 84 TWh of capacity, has Europe’s largest storage potential, which is far larger than Sweden’s roughly 36 TWh

(see Nord Pool ASA 2010). These two countries, along with Switzerland, Austria, France and Italy will undoubtedly be offering considerable pump storage system capacity at some point down the road. All of the calculations described below presuppose that Germany and Norway will form an electricity storage partnership in view of Norway's substantially higher storage potential and the relatively rudimentary power transmission lines between the large wind energy potential in the German North Sea and the storage potential in southwest Norway.

Table 3-4

### Wholly renewable electricity supply scenarios

Scenario group	Characterisation	Demand in 2050: 500 TWh/a	Demand in 2050: 700 TWh/a
1	Complete self-sufficiency in Germany	Scenario 1.a DE 100% SV-500	Scenario 1.b DE 100% SV-700
2	Complete self-sufficiency in Germany in terms of annual production Interchanging of up to 15 percent of annual output with Denmark and Norway	Scenario 2.1.a DE-DK-NO 100% SV-500	Scenario 2.1.b DE-DK-NO 100% SV-700
	Up to 15 percent net import of electricity from Denmark and Norway (plus interchanging of up to 15 percent of annual output)	Scenario 2.2.a DE-DK-NO 85% SV-500	Scenario 2.2.b DE-DK-NO 85% SV-700
3	Up to 15 percent net import from Europe-North Africa (EUNA) allowed (plus interchanging of up to 15 percent of annual output)	Scenario 3.a DE-EUNA 85% SV-500	Scenario 3.b DE-EUNA 85% SV-700

Source: SRU 2010

The third scenario group, DE-EUNA, describes an expanded network structure comprising North Africa and all of Europe. In these scenarios, as in the aforementioned ones, each of the member states could import up to 15 percent of its annual output so as to achieve an optimally reliable electricity supply. This larger-scale network would allow access to far greater renewable energy potential and would more efficiently offset regional output fluctuations, particularly in terms of wind power.

For all of the aforementioned scenario groups, total German demand (gross electricity demand) was set at 500-700 TWh (more precisely: 509-700). Moreover, all of the scenarios were subject to the requirement that all electricity in all participating states must be generated from renewables.

### 3.3.4 Electricity demand

Based on our analysis of various studies, it is safe to say that annual (net) electricity demand in Germany can be stabilised at around 500 TWh (e.g. Öko-Institut and Prognos AG 2009; UBA 2009; Barthel et al. 2006; Enquete-Kommission Nachhaltige Energieversorgung unter den Bedingungen der Globalisierung und Liberalisierung 2002; Nitsch 2008). This would (a) require stringent energy saving and efficiency optimisation measures are implemented for classic electricity uses, and (b) allow roughly half of Germany's auto fleet to go electric. Using this

assumption as a starting point, 2050 electricity demand in Germany amounting to 500 TWh was initially defined for all of the scenario groups based on the scaled hourly-interval annual load curve.

A second variant involving 2050 electricity demand amounting to 700 TWh in Germany was analysed. Demand could potentially rise to this level if we fail to implement ambitious efficiency measures and if most of Germany's auto fleet goes electric; demand would increase by an additional 100 TWh/a (see Wietschel and Dallinger 2008) if the entire fleet goes electric. On the other hand, such a 700 TWh/a scenario where energy efficiency measures have been successfully implemented would enable electrical power cover (a) a large portion of heating energy demand in 2050; and (b) a more substantial proportion of industrial process heat demand, in addition to auto electrification.

Our comparison of the 500 and 700 TWh/a scenarios sheds light on how total electricity demand affects system costs and energy resource constellations in a cost optimised electricity mix.

Although we feel that electricity demand stabilisation at the lowest possible level should be an avowed government policy goal with a view to keeping electricity costs as low as possible, the 700 TWh/a scenarios reveal that considerably higher demand could be satisfied using renewable energy – which of course means that demand ranging from 500 to 700 TWh/a could also be met. For example, if all possible energy efficiency and savings potential were used in a scenario where Germany's entire auto fleet goes electric, aggregate electricity demand would amount to roughly 550 TWh.

### **3.3.5 The transition process**

In chapter 4 we propose, for scenarios 2.1.a and 2.1.b (see Table 3-4) a timeline for the transition from Germany's current electricity system to a wholly renewable electricity supply as per the REMix model

This proposed solution presupposes only very minor expansion of the conventional power plant fleet and in so doing calculates, based initially on conservative assumptions concerning average conventional power plant lifecycles, the phase-out timelines for such power plants.

We then extrapolated from these phase-out timelines the scope of expansion of renewable electricity generation capacity that would be necessary by 2050 to satisfy residual demand. The scope of annual expansion of installed capacity for the various technologies was defined in such a way that a cost optimised energy mix would be achieved for the scenario simulations by 2050. However, the posited annual expansion was not itself based on optimisation calculations. Thus in periods when an unusually large number of conventional power plants is being phased out for age related reasons, safety margins for the expansion of renewable electricity generation capacity were factored in to a limited degree. The transition process described in chapter 4 comprises only one possible strategy that would allow Germany to achieve its goal of a wholly renewable electricity supply by 2050, without jeopardizing supply reliability during any phase of the transition. Moreover, in chapter 4.3 we explain why it would be essential for the expansion of renewable electricity

generation capacity in Germany to go hand in hand with incremental development of electricity storage potential in Germany and Norway and the requisite grid expansion.

### **3.4 Wholly renewable electricity supply options**

#### **3.4.1 Renewable electricity potential**

##### **3.4.1.1 Potential in Germany**

Renewable electricity potential in Germany was determined using the REMix model as per the methodology described in chapter 3.3. An average wind year equates to renewable electricity generation potential in Germany amounting to 839 TWh/a, roughly 612 TWh of which can be generated at the cost entailed by peak price kilowatt hours amounting to 0.096 euros per kWh (see Figure 3-11).

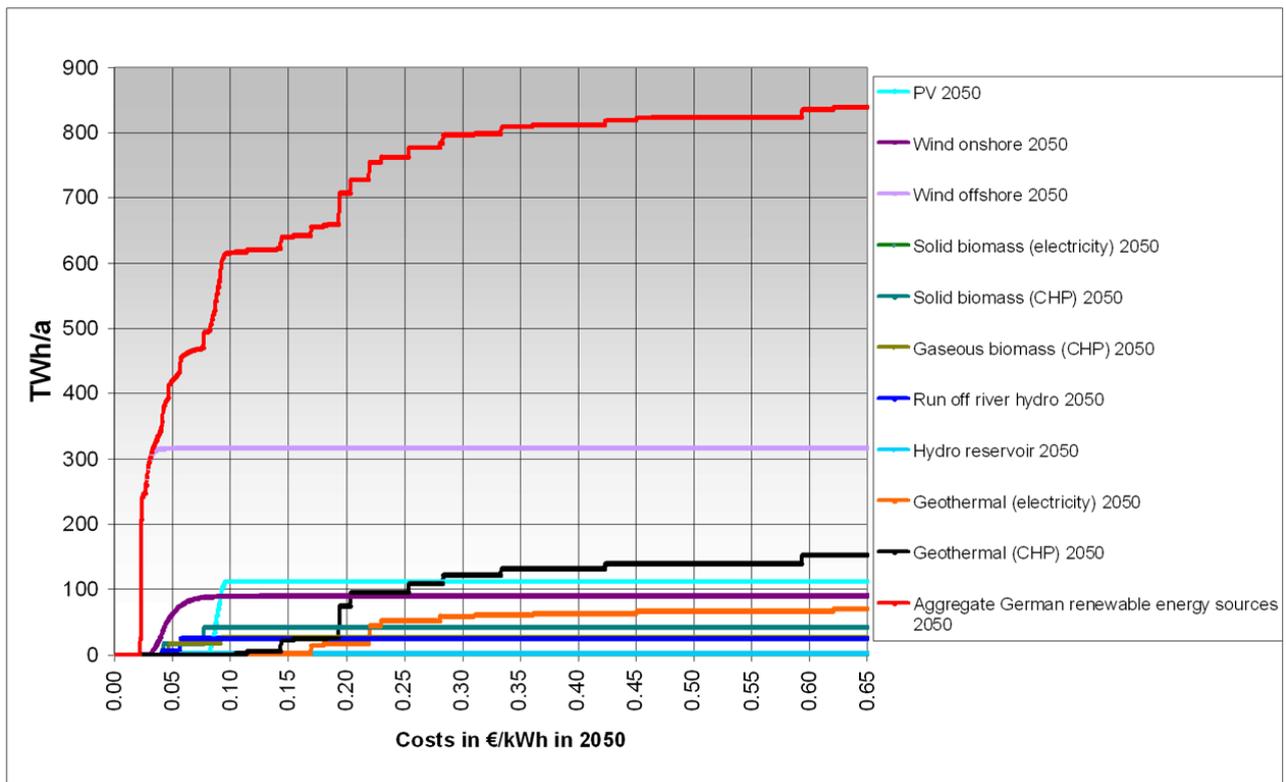
As noted in chapter 3, the German Aerospace Center determined the costs for the various technologies based on quantity dependent cost reduction functions for the target year in terms of 2009 prices (see DLR 2010a, p. 13 ff.). The lowest cost potential here is offered by onshore and offshore wind energy (roughly 407 TWh/a) and hydro power. However, hydro power potential for electricity generation in Germany is limited to about 28 TWh/a for orographic reasons. The use of biomass, which compared to geothermal energy is relatively inexpensive at 0.081 euros/kWh, is likewise limited (to approximately 71 TWh/a). Biomass electricity use may also be further restricted by competing demand for biomass from the fuel and heating sectors. The SRU presumes that biomass could be used optimally in power plants that generate both heat and power. In the scenarios presented below which assume a moderate electricity demand in Germany (509 TWh in 2050) and cross-border electricity interchange, only about half the total amount of biomass is used for electricity generation and in this constellation would be used almost exclusively in cogeneration (CHP) systems. Only in the hypothetical scenario that cross-border electricity interchange is ruled out (see scenarios 1.a and 1.b) would the entire potential be used for electricity generation – and in such a case mostly in peak demand periods without CHP. Although the potential for photovoltaics is greater (about 110 TWh/a), its use would increase the marginal costs to 0.096 euros per kWh. Although geothermal electricity generation potential is high (an additional 220 TWh), the cost of developing this potential is high as well, ranging up to 0.062 euros per kWh. However, according to recent findings that only became available after the modelling was completed, the long term costs for geothermal electricity would be substantially below those indicated by our calculations. However, these possibly lower costs would only be relevant in the those scenarios where a high demand (700 TWh) is largely met using domestic resources (scenarios 1.b and 2.1.b).

All renewables can be used round the clock except for run-of-river stations, wind turbines and photovoltaic plants. The potential of the latter two energy resources is subject to substantial fluctuation secondary to variations in wind speed and insolation respectively. This fluctuation translates into wind and solar power generation capacity potential in Germany amounting to

approximately 190 GW under favourable conditions (see Figure 3-12) and only about 39 GW under unfavourable conditions, which should be viewed against the backdrop of peak demand of 81 GW, minimum load of 35 GW, and annual demand of about 500 TWh. However, minimum grid load and minimum generation potential periods do not always coincide, as can be seen in Figure 3-12, which shows that most of the time renewable electricity potential substantially exceeds annual demand (i.e. the load curve) amounting to 500 TWh.

Figure 3-11

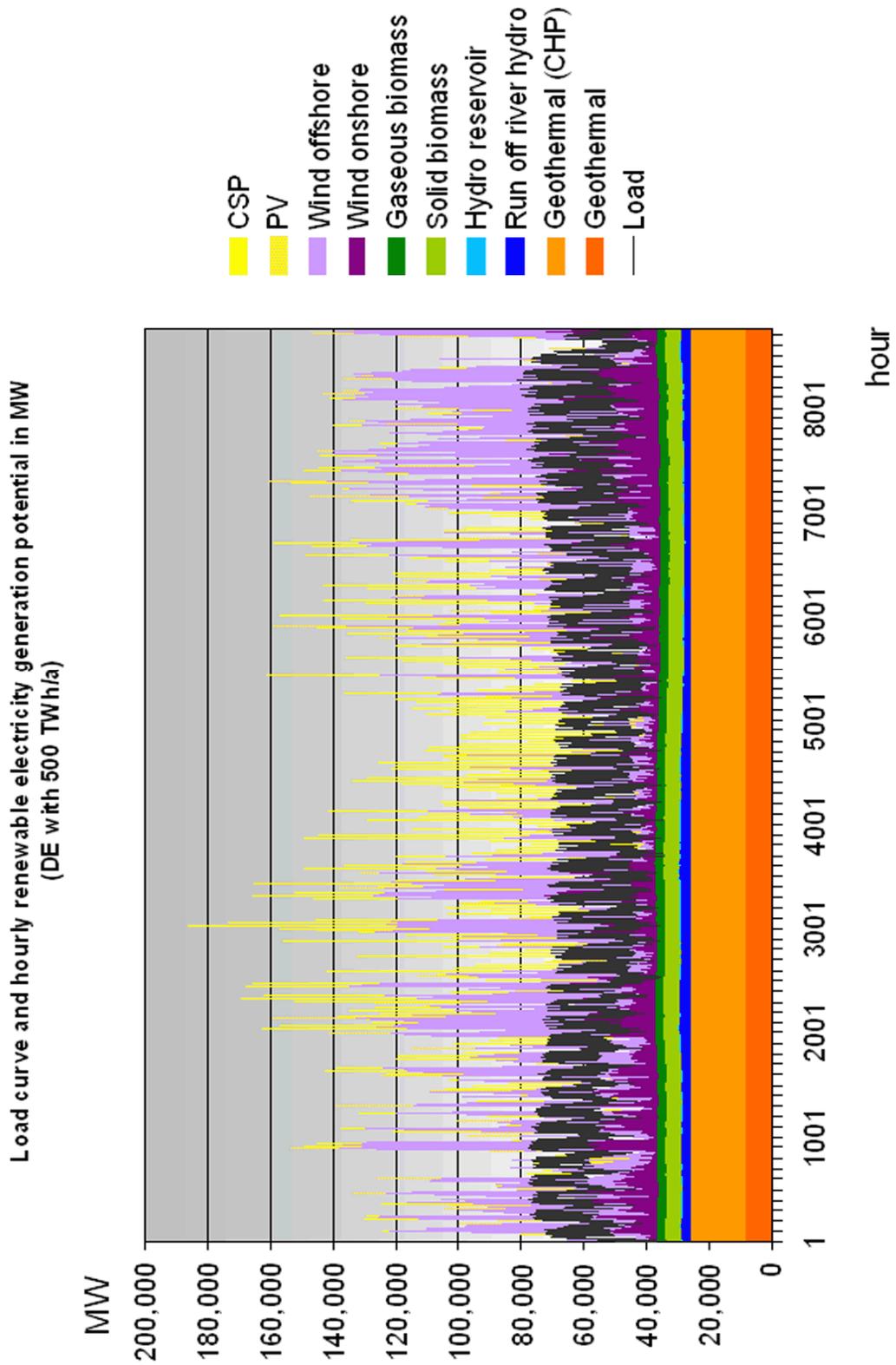
### Renewable electricity potential in Germany, in TWh/a as a function of per kWh costs



Source: SRU 2010, based on DLR 2010a

Figure 3-12

**Load curve and hourly renewable electricity generation potential in MW  
(DE with 500 TWh/a)**



Source: SRU 2010, based on DLR 2010b

Figure 3-13.a

**Load curve and hourly renewable electricity generation potential in MW  
(DE with 500 TWh/a, month of January)**

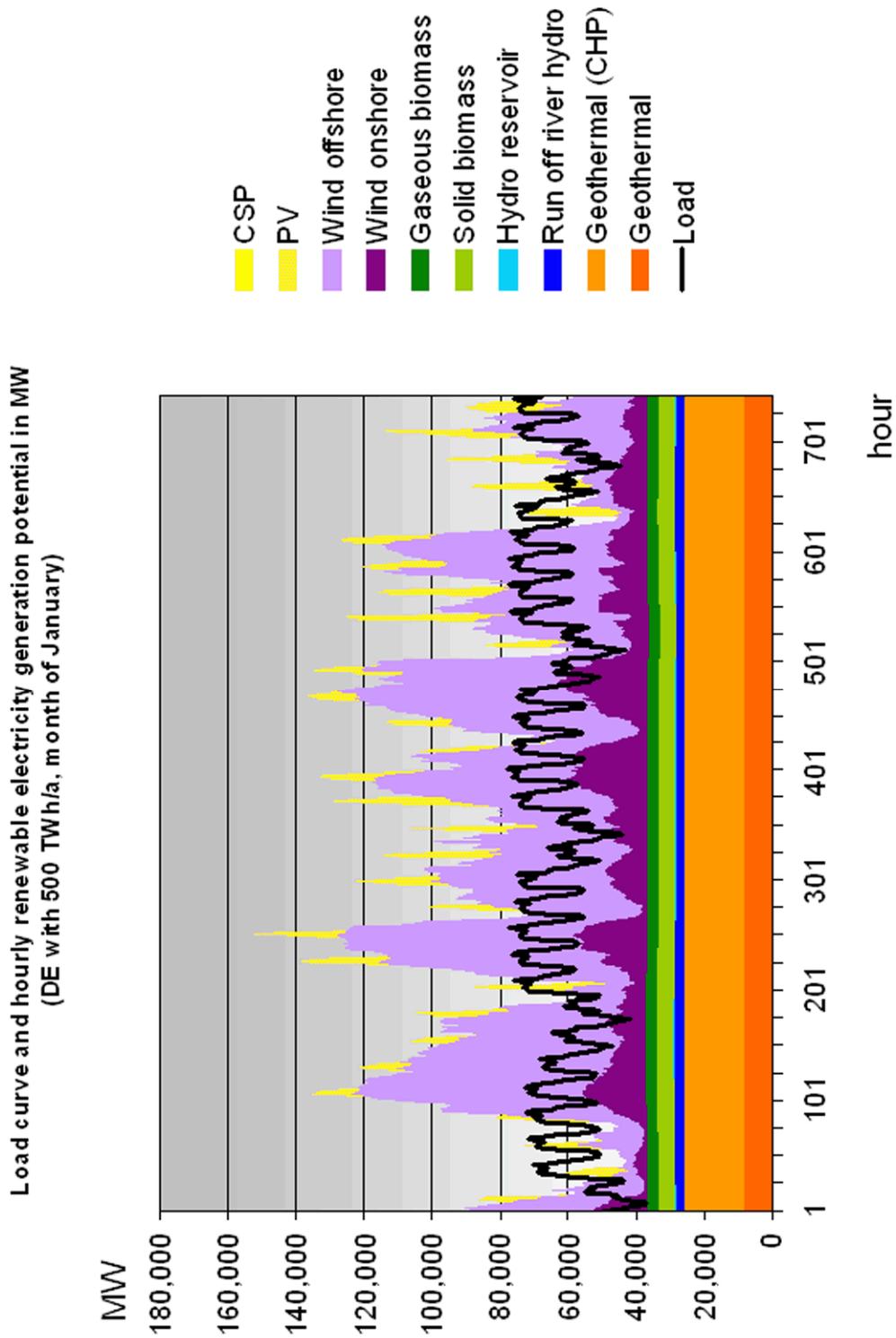
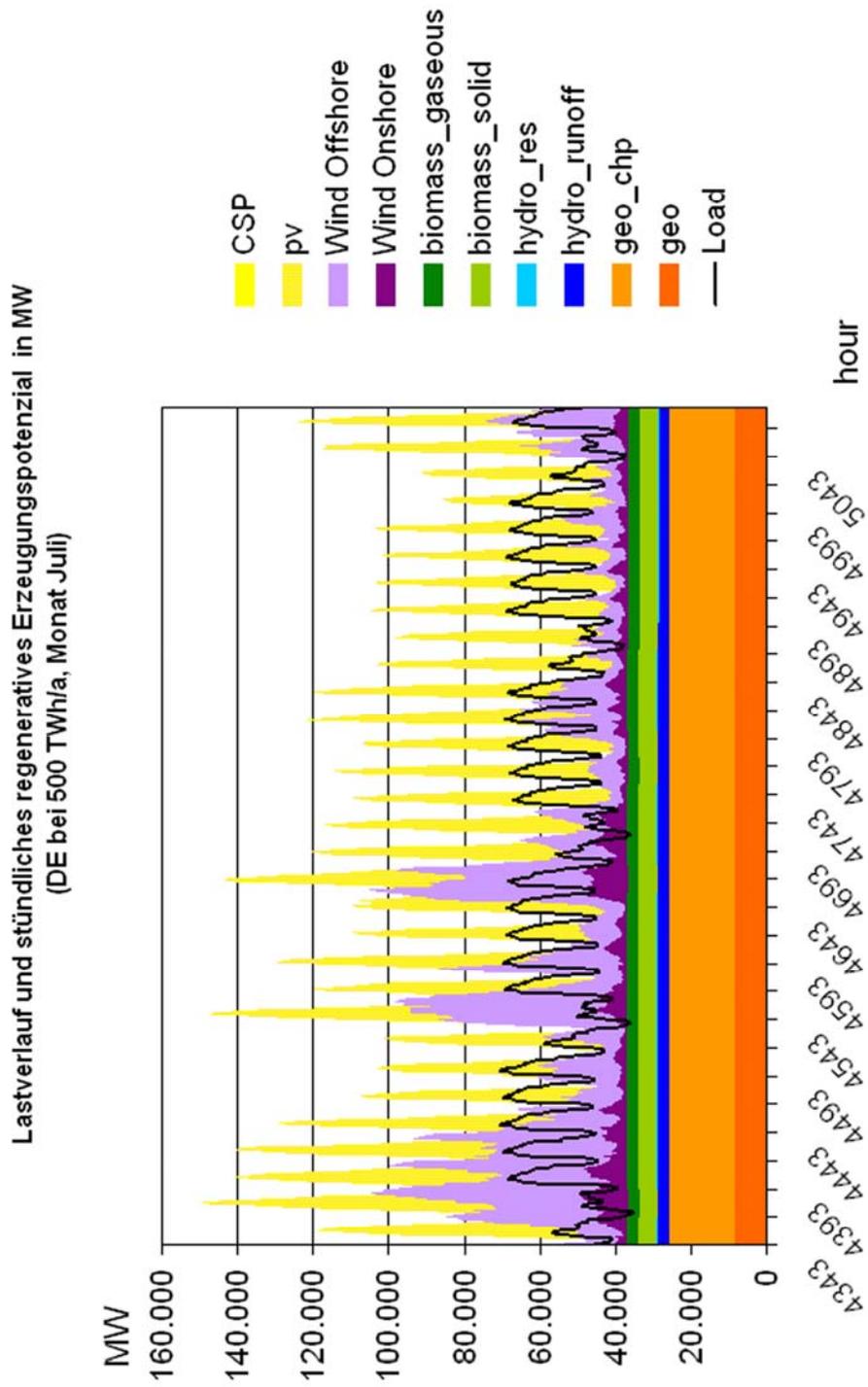


Figure 3-13.b

**Load curve and hourly renewable electricity generation potential in MW  
(DE with 500 TWh/a, month of July)**



Source: SRU 2010, based on DLR 2010b

If the fluctuations in putative electricity production are analysed in a higher (hourly) resolution (see Figures 3-13.a and 3-13.b, where the months of January and July are used as examples), shortfall periods appear to be a relatively rare occurrence. These graphics also show the load curve (500 TWh/a) relative to hourly electricity potential. In both months, brief generation shortfalls occur infrequently, whereas potential surplus production occurs far more frequently. From the perspective of this higher resolution, it becomes readily apparent that annual renewable electricity generation would amount to about 840 TWh for an anticipated annual demand of 500 TWh. Annual demand amounting to 700 TWh (which would arise from a combination of relatively minor efficiency optimisation and Germany's auto fleet going electric) would constitute a far less favourable scenario necessitating considerable storage capacity if Germany supplies all of its own electricity.

The analyses of the various scenarios based on hourly values provide precise comparisons of generation potential and electricity demand.

As these scenarios show, the extent to which satisfying hourly electricity demand would entail the use of relatively cost intensive generation potential such as geothermal and biomass energy would largely depend on the scope of total demand, storage capacity and cross-border electricity interchange.

### **3.4.1.2 Renewable electricity potential in the Europe-North Africa region**

The renewable electricity potential of the Europe-North Africa region (as territorially defined in the DLR REMix model (see Figure 3-9) would amount to approximately 105,000 TWh/a, which surpasses German generation potential by a factor of more than 100. This would allow for the generation of more than 47,000 TWh/a at a cost (in 2050) of 5 euro-cents per kWh. The least expensive electricity would come from offshore wind farms, as well as photovoltaic plants in sunnier regions (see Figure 3-14).

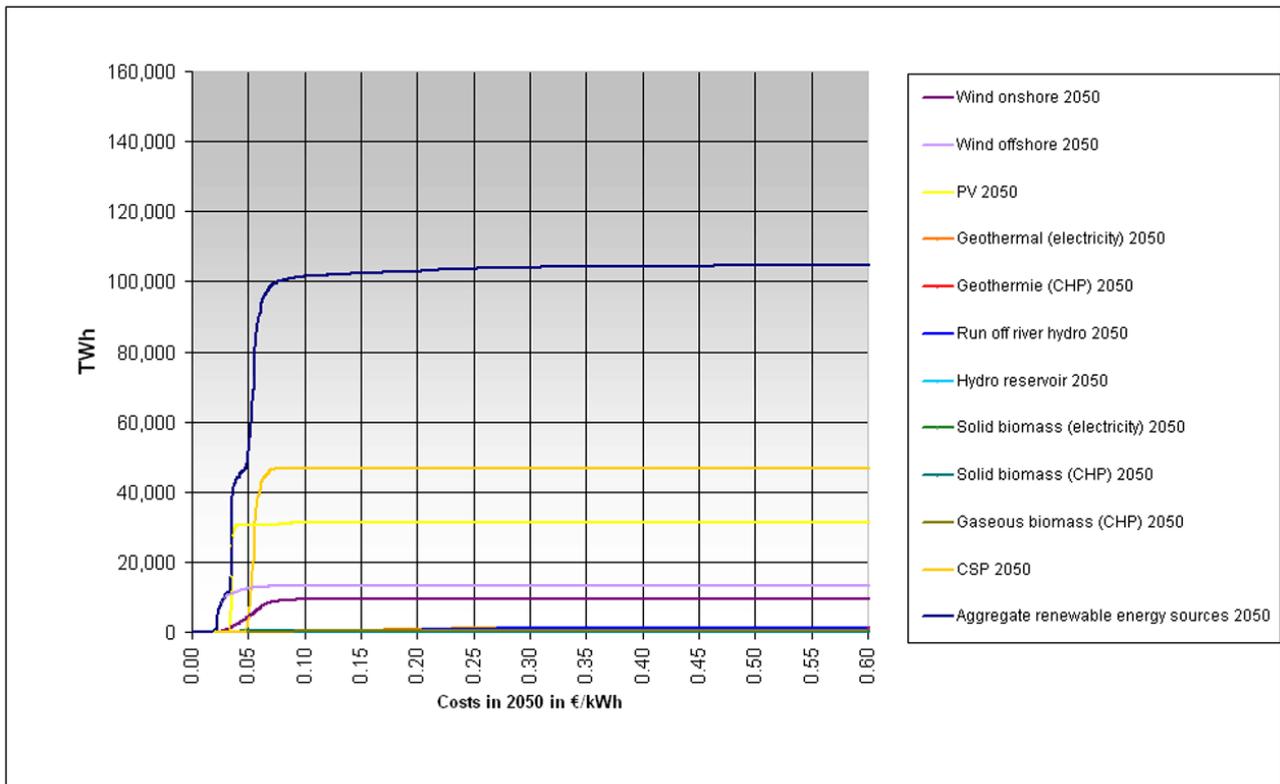
If Europe and North Africa are regarded as a potential energy supply network, a maximum grid load (demand) there would amount to approximately 840 GW (peak load in the entire region for a scenario that equates to German electricity demand amounting to 500 TWh/a and German peak load amounting to just over 80 GW), whereas renewable electricity potential would be in the neighbourhood of 39,800 GW.

Even on the day with the lowest wind turbine output of the year, the 1,609 GW available in the middle of the night far exceeds peak annual load. A full-fledged network in this region would theoretically require no electricity storage capacity at all, although it is doubtful that this would be an economically viable solution. How optimal resource use should be arranged, however, cannot be determined without more precise computation, as described in chapter 3.3. The fact that renewable electricity potential greatly exceeds demand in the Europe-North Africa region is clearly shown in Figure 3-15 whose scale ranging up to 50 million MW indicates total renewable electricity

potential; whereby the annual load (demand) ranging from 420,000 to 840,000 MW (only 1-2 percent of renewable electricity potential) is so low as to be almost indiscernible.

Figure 3-14

**Renewable electricity potential in the Europe-North Africa region  
as a function of per kWh costs**



Source: SRU 2010, based on DLR 2010a

Moreover, as Figure 3-15 shows, solar energy (33,800 GW) offers far and away the greatest renewable electricity potential, whereby a more detailed analysis of the German Aerospace Center calculations reveals that the lion's share of this capacity is accounted for by maximum concentrated solar power (CSP) capacity amounting to 20,000 GW, with photovoltaic solar energy providing an additional 13,800 GW of capacity. However this tremendous capacity could only be used during daylight hours unless storage systems are also installed.

The resource that provides the second highest renewable electricity potential is wind, whose maximum potential is around 5,500 GW, which is about evenly divided between offshore and onshore wind farms (2,700 and approximately 2,800 GW respectively). The advantage of wind power is that it provides minimum capacity of around 700 GW even during low wind periods.

Geothermal energy is in third place in terms of renewable electricity potential. Unlike solar and wind energy, geothermal energy is available without interruption, but is also relatively expensive. Geothermal electricity potential in the Europe-North Africa region amounts to roughly 275 GW.

The fourth highest renewable electricity potential in this region is hydro power, whose putative capacity ranges from 109 to 224 GW, depending on the season. The Europe-North Africa region's hydro power, which would chiefly come from run-of-river stations, would make a significant contribution to enabling renewable electricity to satisfy overall electricity demand. Hydro power also has a special role to play in terms of short and medium term storage in pump storage systems.

Biogas and solid biomass in accordance with nature conservation and environmental protection requirements would play a relatively minor role since the potential factored into the DLR calculations defined severe restrictions in terms of biomass crop cultivation. Thus the lion's share of this potential would necessitate the use of residual agricultural and forest materials. Biomass potential amounts to approximately 71 GW, assuming usage distributed evenly across the entire year. Inasmuch as solid biomass such as forestry smallwood ideally lends itself to storage, and since large amounts of biogas and natural gas can be stored seasonally in depleted gas fields, these renewables will mainly be used during periods when solar and wind power is at a low ebb.

It can be concluded that supplying the Europe-North Africa region with electricity from renewable sources could be achieved there using a mere 2 percent of renewable electricity potential.

In the hypothetical scenario under which Germany is fully self-sufficient in terms of electricity supply, the supply from renewable sources can – in the very unlikely case of demand exceeding 800 TWh/a and given the rather restrictive modelling assumptions imposed by the DLR - reach its limits. However, Germany's integration into an international renewable electricity supply network – a project that is already in the works – would satisfy German electricity demand in any imaginable scenario. It seems unlikely that this would require the use of North Africa's solar energy potential, but the integration of this potential would probably decrease mean electricity generation costs.

### **3.4.2 Three scenario groups involving a wholly renewable electricity supply**

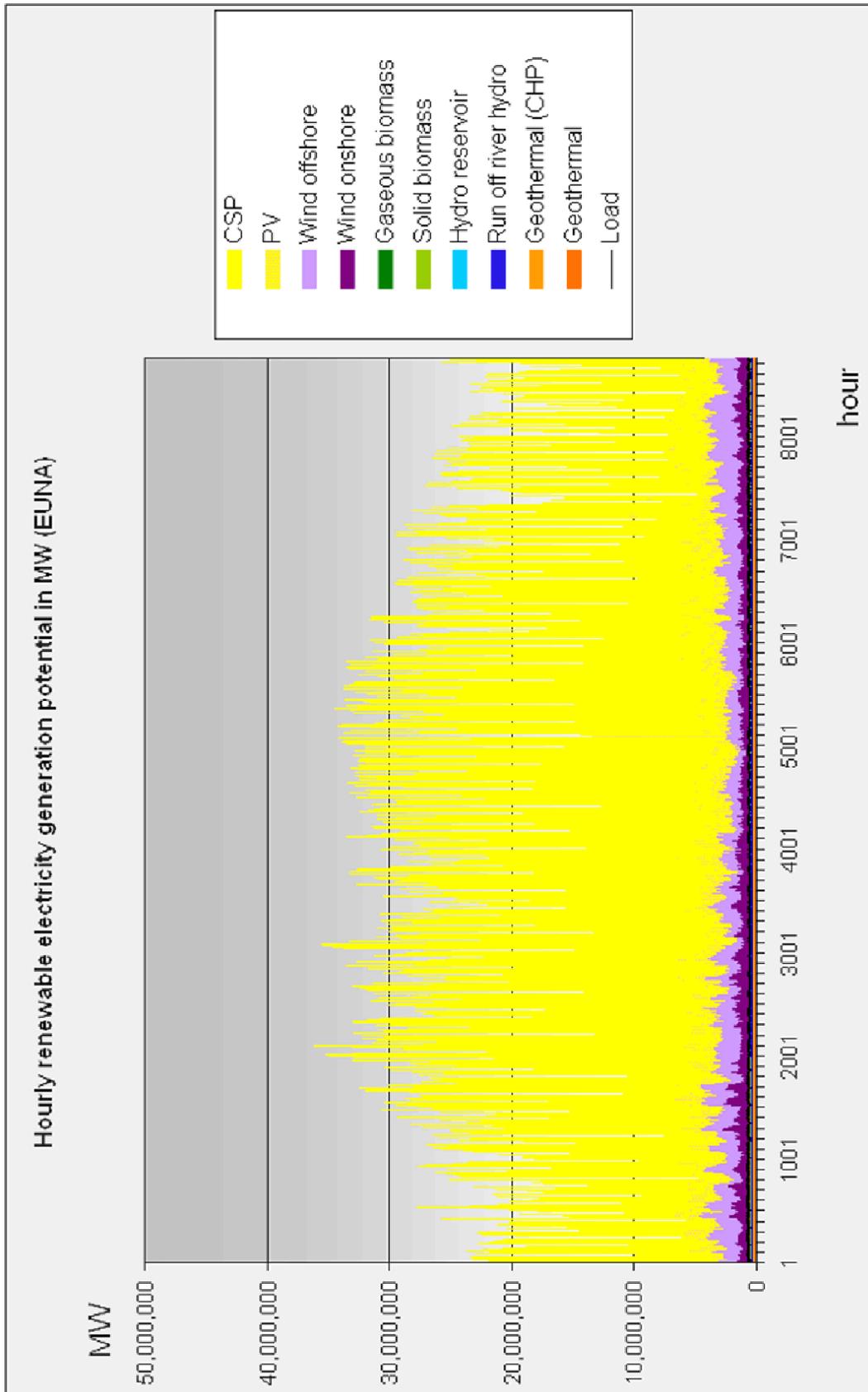
As shown by our analysis of renewable electricity potential in section 3.4.1, a wholly renewable electricity supply would be achievable in Germany even if Germany's renewable electricity potential were the sole renewable energy resource. However, this would be relatively cost intensive and would entail extensive use of various storage systems to balance the severe fluctuations in electricity generation. As noted, supplying the Europe-North Africa region with renewable electricity would necessitate the use of only 2 percent of the region's usable electricity generation potential and thus would not come anywhere near exhausting such potential. But as likewise previously pointed out, use of the entire region's potential would entail the integration of some politically unstable Eastern European and North African states. A simpler solution – one that would obviate the problems entailed by the exclusive use of German electricity generation resources, as well as the problems that could potentially arise from an inter-regional Europe-North Africa network – would be a trilateral German-Danish-Norwegian cooperation, which would be endowed with (a) considerable additional low cost renewable electricity potential in terms of wind

power; and (b) thanks to Norway, the best electricity storage potential in Europe. Against this backdrop, we feel that it would be worthwhile to shed light on the options entailed by a wholly renewable electricity supply, via the following three scenarios groups:

- A wholly renewable electricity supply based solely on German potential (scenarios 1.a and 1.b).
- A wholly renewable electricity supply involving a German-Danish-Norwegian network (scenarios 2.1.a, 2.1.b, 2.2.a and 2.2.b).
- A wholly renewable electricity supply via a large-scale network comprising the Europe-North Africa region (as territorially defined by the DLR) (scenarios 3.a and 3.b).

Figure 3-15

### Hourly renewable electricity generation potential in MW (EUNA)



Source: SRU 2010, based on DLR 2010b

The specifications for each of the various sub-scenarios can be found in Table 3-4 and section 3.3.3. As we see it, the German-Danish-Norwegian solution is a particularly promising option inasmuch as, relative to the 100 percent German self sufficiency of scenarios 1.a and 1.b, it would allow for substantial cost reductions by avoiding surplus capacity and its implementation would entail relatively little political or technical effort. Moreover, such a cooperative network structure could potentially set the stage for incremental integration of additional states without the need for a large number of states to reach a pre-implementation agreement and/or consensus. The scenarios described in the following only take technical and economic factors into consideration, to the exclusion of legal considerations, which will be addressed in a subsequent report.

### **3.4.2.1 The least likely solution: a wholly renewable electricity supply based solely on German renewables**

Unlikely though the prospect of Germany going it alone by implementing a wholly renewable electricity supply involving absolutely no international electricity interchange may be, this admittedly hypothetical scenario would entail the highest requirements in terms of achieving a wholly renewable electricity supply and thus constitutes the toughest test for our assumption that Germany could achieve a wholly renewable electricity supply by 2050. If it can be shown that such an electricity supply is achievable in Germany using the renewables available solely within our borders, then it stands to reason that any scenario that includes other states and posits the same restrictions would be easier to implement since a larger region entails additional generation and storage potential as was shown in our discussion of the available potential in the Europe-North Africa region. Since, as noted, the German energy self sufficiency scenario is more of a thought experiment than a plausible option – and one whose legal issues have yet to be analysed – the results of scenarios 1.a (DE 100% SV-500) and 1.b (DE 100% SV-700) will be described only briefly here. Moreover, in view of the fact that many of the assumptions we made apply to all of the scenarios, they will be described in our discussions of scenarios 1.a and 1.b.

The basic scenario for a wholly renewable electricity supply in Germany defines a reference demand amounting to 509 TWh/a in 2050. Based on DLR documentation for other target 2050 scenarios, in the interest of keeping the computing resources needed for the simulations within reasonable bounds we presupposed that German electricity demand will reach 509 TWh/a by 2050. Electricity demand was modelled for all of the scenario simulations based on the characteristic historical annual load curve in all of its hourly segments. Using the DLR's REMix model, and factoring in storage capacity and the cost assumptions in chapter 2, an optimal electricity mix was determined for the satisfaction of hourly demand. In terms of storage capacity, we assumed that in Germany compressed air energy storage capacity equating to an electrical storage volume of up to 3.5 TWh could be provisioned. This assumption, which was based on the work of Ehlers (2005) who analysed the availability of salt formations for the creation of storage caverns, needs further confirmation via additional investigations.

Only 1 GW of Germany's 7 GW of pump storage system capacity was folded into the storage of intermittent inputs as it was assumed that most of this capacity will be used for grid functions such as minute reserves and frequency stabilisation. This assumption can be regarded as being extremely conservative in view of the practice, already in place today, whereby pump storage systems are used for peak load provisioning.

As Figure 3-16 shows, German electricity demand can be satisfied at all times using the renewable electricity potential within our borders combined with compressed air energy storage systems, and without importing a single kWh of electricity. This could be accomplished via the following combination of technologies: 33 GW of installed offshore wind power, which would generate 76 TWh/a of electricity; 73 GW of installed onshore wind power, which would generate approximately 317 TWh/a of electricity; 86 GW of installed photovoltaic capacity, which would generate approximately 88 TWh/a of electricity; and biomass whose installed capacity of 33 GW would equate to 71 TWh/a of electricity. This "thought experiment" scenario involving German energy independence uses all available biomass potential for electricity generation purposes. Here, solid biomass, which exhibits high capacity but relatively few operating hours (1,660 equivalent full load hours (EFLH) per year), would be used for peak load situations (see Figure 3-16), owing to the fact that while biomass lends itself to storage, additional storage facilities are in short supply. Hydro power, for which virtually no expansion is currently in the works, accounts for just under 25 TWh/a via approximately 4.5 GW of installed capacity. A summary of the scenario 1.a (509 TWh/a) and 1.b (700 TWh/a) results can be found in Table 3-5.

Scenario 1.a entails the generation of 580 TWh/a in Germany for demand amounting to 509 TWh/a. Of this output, approximately 51 TWh/a would be kept in compressed air energy storage facilities; and after allowing for storage and conversion loss, 34 TWh/a would be available to satisfy demand on a deferred basis. Pump storage systems, which would also be used here, would allow for the storage of approximately 1.2 TWh/a and for reclaiming of an additional 1 TWh/a. This scenario results in surplus production amounting to more than 53 TWh/a, which can normally be avoided by shutting down wind turbines. Peak load amounts to approximately 81 GW during peak demand periods, whereas total primary installed capacity is 230 GW, with 32 GW of secondary capacity from hydro reservoirs. The electricity supply cost in this scenario, including annual capital costs, amounts to € 45.9 billion annually in 2009 prices – which equates to a mean annual generation cost of 0.09 euros per kWh or € 90 per MWh. An overview of all scenario 1.a and 1.b assumptions concerning capacity, generation, annual costs, and specific costs can be found in Table 3-5.

The most exacting scenario that was analysed on the basis of these assumptions – scenario 1.b – was obtained by increasing gross electricity demand to 700 TWh/a and scaling up the load curve accordingly. However, such elevated electricity demand would occur in 2050 only if current energy saving efforts achieve only limited success, if Germany's individual motor car fleet will be

completely electrified (see Wietschel and Dallinger 2008) and if the electricity needed for this evolution is derived from domestic renewable energy only.

The potential cost curve in Figure 3-11 for renewable electricity in Germany indicates that electricity demand amounting to around 700 TWh/a would also entail more expensive options such as the use of geothermal electricity. This is confirmed by the analysis based on hourly optimisation (Figure 3-17). Geothermal energy would be used nearly year round to ramp up power generation, and would generate 147.1 TWh/a via 18.3 GW of installed capacity. At 202 euros per MWh, this far exceeds the mean generation costs in the 509 TWh/a scenario. As a result, overall capacity would rise from 230 GW in the 509 TWh/a scenario to 283 GW in the 700 TWh/a variant, in order to meet the considerably higher demand with a peak load of more than 112 GW. Apart from the new geothermal capacity needed to satisfy this increased demand, the following other technologies would be similarly affected: photovoltaic capacity would rise from around 86 to around 110 GW; wind onshore turbine capacity would rise from around 33 to around 39 GW; and biomass capacity would rise from around 33 to around 38 GW. The biomass capacity increase would not, however, translate into a rise in production owing to the fact that the biomass capacity limit amounting to 71 TWh/a was already reached in scenario 1.a. This additional (solid) biomass would solely be used for relatively high peak loads. In scenario 1.b, usage would decline from approximately 1,660 equivalent full load hours (EFLH) to approximately 1,450 hours per year, with compressed air energy storage capacity increasing from 32 to 37 GW. As a new major electricity generation resource, geothermal energy generation is considerably higher in scenario 1.b than in scenario 1.a (509 TWh/a) (see Figure 3-17). However, despite this substantial generation capacity increase, surplus production decreases from 53 TWh/a in scenario 1.a to 45 TWh/a in scenario 1.b.

Total annual costs increase from just over 46 billion euros to just under 81 billion euros, with geothermal electricity generation accounting for the lion's share of the increase (30 billion euros) and per kWh costs rising from 0.09 to 0.115 euros due to the necessity of including very cost intensive electricity.

### **3.4.2.2 A wholly renewable electricity supply in a German-Danish-Norwegian network**

#### **3.4.2.2.1 A wholly renewable electricity supply in Germany with cross-border load balancing in a German-Danish-Norwegian network**

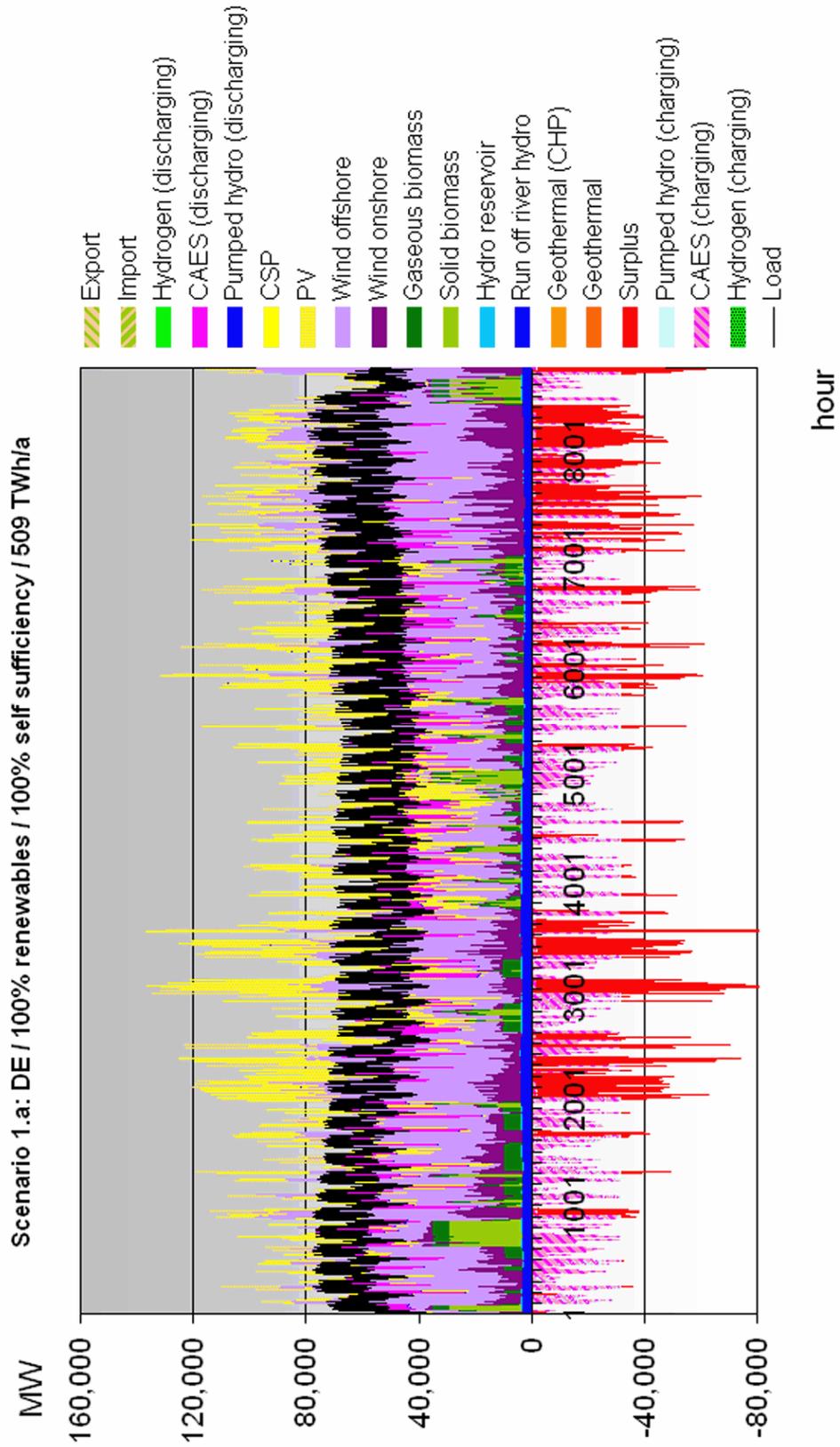
In view of the international cooperation in the European electricity generation sector already achieved today, scenarios that would allow for a wholly renewable electricity supply for and produced within Germany appear to far exceed the necessary goal of energy security. Hence scenarios 1.a and 1.b suggest that even extremely ambitious energy security objectives can be reached if solely renewables are used. However, it appears to be far more likely that Germany will continue to interchange electricity with its neighbours. A simple model for such cooperation is an energy supply network comprising Germany, Denmark, and Norway (or Sweden), whose interchange and reciprocal dependency even

the most hardened skeptics would have to admit will entail little or no risk in terms of ensuring a reliable electricity supply. Hence the scenario group 2 scenarios were analysed as an initial phase in the relaxation of the regional restrictions entailed by scenario group 1, for a wholly renewable electricity supply in a German-Danish-Norwegian system. In so doing, we assumed for scenarios 2.1.a and 2.1.b (a) that each of the three states in this network will produce all of its own electricity over the course of any given year; but (b) that these states will be permitted to interchange up to 15 percent of their total output so as to avoid a situation where each state is required to produce all of its own electricity round the clock. This set of circumstances was in turn analysed for total German demand amounting to 509 TWh/a (scenario 2.1.a) and 700 TWh/a (scenario 2.1.b), which equates to approximately 650 TWh/a (scenario 2.1.a) and approximately 895 TWh/a (scenario 2.1.b) of the aggregate demand of the three participating states. A complete overview of all of the scenarios we investigated can be found in Table 3-5.

In scenario 2.1.a (509 TWh/a in Germany), electricity generation costs in Germany are reduced from 0.09 to 0.07 euros per kWh by virtue of the fact that electricity interchange and particularly the use of Norwegian pump storage system capacity equates to the following reductions in Germany: generation capacity from 230 to 163 GW; surplus production from 53 TWh/a to approximately 0.8 TWh/a; compressed air energy storage capacity from 32 to 18 GW. A noteworthy evolution here is that the installed capacity of cost intensive power technologies would be reduced (biomass and photovoltaic 27 and 47 GW lower respectively), but at the same time German onshore wind capacity would rise 6.4 GW to the maximum potential posited by the model amounting to 39.5 GW, by virtue of the Norwegian pump storage system capacity that would be used for equalisation purposes within the framework of the German-Danish-Norwegian network. However, German use of installed compressed air energy storage capacity would decline relative to the counterpart scenario 1.a, resulting in an increase in specific storage costs from 0.109 to 0.276 euros per kWh. The lower degree of capacity utilisation in Germany is due to competition from cheaper Norwegian pump storage systems. This also means that biomass does not have to be used for storage purposes as was the case in the German self sufficiency scenarios 1.a. and 1.b. In scenario 2.1.a, solid biomass is used solely for cogeneration plants, whose equivalent full load hours (EFLH) increase to 6,840.

Figure 3-16

**Scenario 1.a: DE/100% renewables/100% self sufficiency/509 TWh/a**



Source: SRU 2010, based on DLR 2010b

Table 3-5

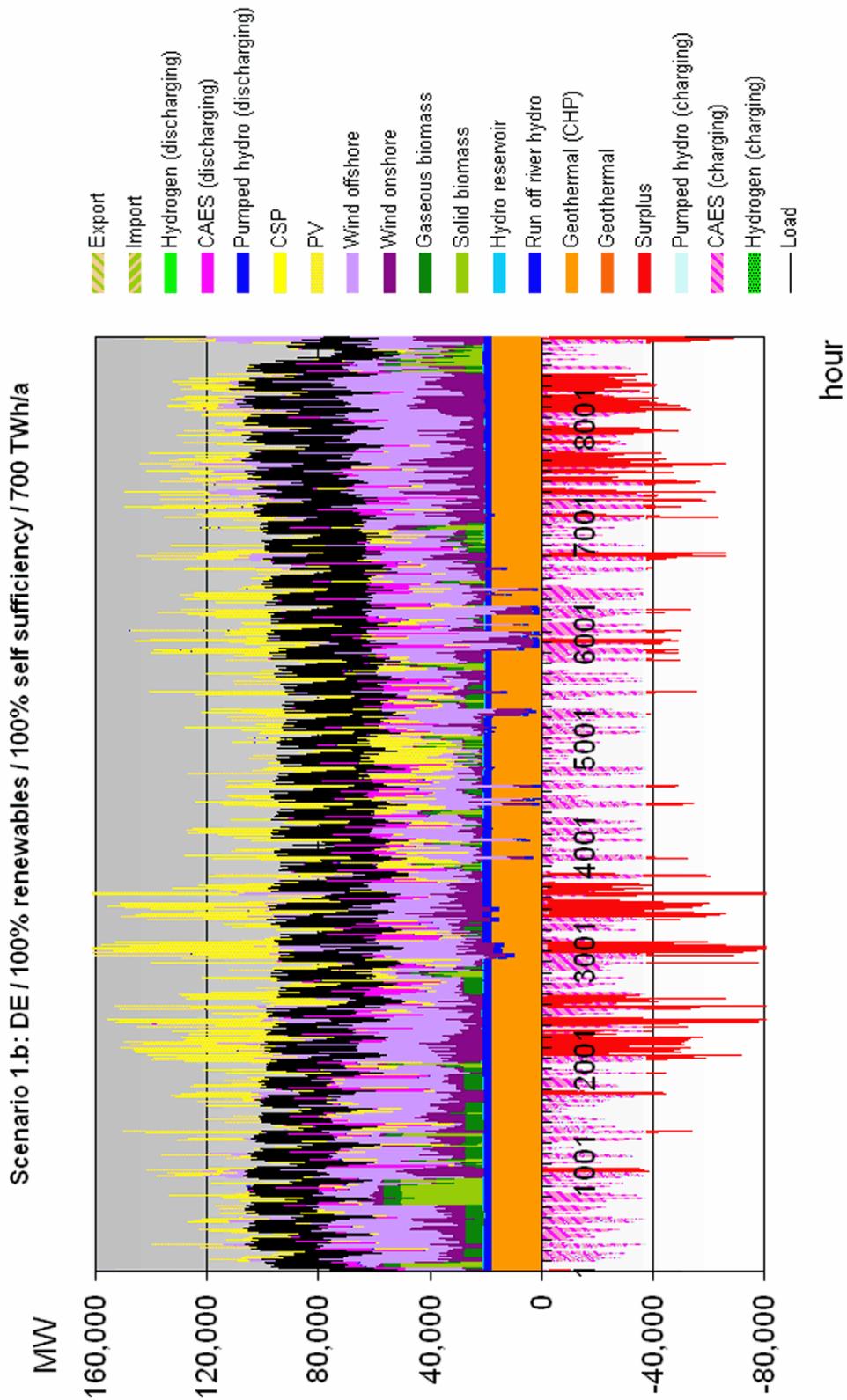
**Capacity, electricity generation, and annual and specific cost assumptions  
used  
for scenarios 1.a and 1.b**

	Capacity used		Electricity produced		Costs			
	Max. GW		TWh/a		Millions of euros per year		Euro-cents per kWh	
Energy source/technology used for scenario...	1.a	1.b	1.a	1.b	1.a	1.b	1.a	1.b
Photovoltaics	85.9	109.6	87.9	112.2	7,798	9,957	8.9	8.9
Solar thermal								
Onshore wind	33.1	39.5	76.0	90.6	3,578	4,267	4.7	4.7
Offshore wind	73.2	73.2	316.9	316.9	13,056	13,057	4.1	4.1
Geothermal								
Geothermal with CHP	0.0	18.3	0.0	147.1	0	29,696	0.0	20.2
Solid biomass	26.8	30.8	44.5	44.5	11,664	12,734	26.2	28.6
Solid biomass with CHP	0.0		0.0					
Biogas	0.0		0.0					
Biogas with CHP	6.6	6.7	26.6	26.6	4,687	4,745	17.6	17.8
Run-of-river hydro	4.1	4.1	25.3	25.3	1,337	1,337	5.3	5.3
Hydro reservoir storage	0.4	0.4	2.3	2.3	119	119	5.3	5.3
<b>Totals/average (gross)</b>	<b>230</b>	<b>283</b>	<b>579.5</b>	<b>766</b>	<b>42,239</b>	<b>75,911</b>	<b>7.3</b>	<b>9.9</b>
Electricity imports	0	0	0.0	0	0			
Electricity exports	0	0	0.0	0	0			
Electricity storage								
Pump storage ( storage)	0.5	0.6	1.2	1.4				
Pump storage (generation)	0.5	0.6	1.0	1.1	68	85	7.1	7.7
Compressed air (storage)	32	37	50.5	60.3				
Compressed air (generation)	32	37	33.5	39.7	3,654	4,660	10.9	11.7
Hydrogen (storage)	0	0.0	0.0	0.0				
Hydrogen (generation)	0	0.0	0.0	0.0				
Storage loss			17.2	21				
<b>Total demand/costs</b>	<b>81</b>	<b>112</b>	<b>509.0</b>	<b>700</b>	<b>45,960</b>	<b>80,656</b>	<b>9.0</b>	<b>11.5</b>
Surplus capacity/production	181	209	53.3	45				

Source: SRU 2010, based on DLR 2010a

Figure 3-17

**Scenario 1.b: DE/100% renewables/100% self sufficiency/700 TWh/a**



Source: SRU 2010, based on DLR 2010b

A summary of the results of scenarios 2.1.a and 2.1.b can be found in Table 3-6. It should be noted here that the losses attributable to cross-border transport and storing electricity outside of Germany for re-import purposes was computed in such a way that these losses were offset by additional electricity generation outside of Germany. The posited re-import costs include international cross-border transport in both directions, the cost of storing electricity in Norwegian pump storage systems, and the cost of generating electricity (via Norwegian wind farms) to compensate for the losses.

Figure 3-18 shows the dynamics of electricity generation in the German-Danish-Norwegian network structure in 2050. Noteworthy here are is high proportion of electricity generation accounted for by pump storage systems and the oftentimes high storage capacity of such systems, virtually all of which comes from Norway. Wind energy is the predominant primary electricity generation modality.

As can be seen in Figure 3-19, scenario 2.1.a entails extensive short-term electricity interchange, and high wind turbine capacity translates into higher generation peaks than in scenario 1.a, thus substantially reducing biomass and photovoltaic capacity. Figure 3-19 also reveals that electricity is exported during peak production periods and is re-imported a short time later, as soon as wind power generation falls off substantially. German compressed air energy storage capacity is used far less than is the case in scenario 1.a.

Table 3-6

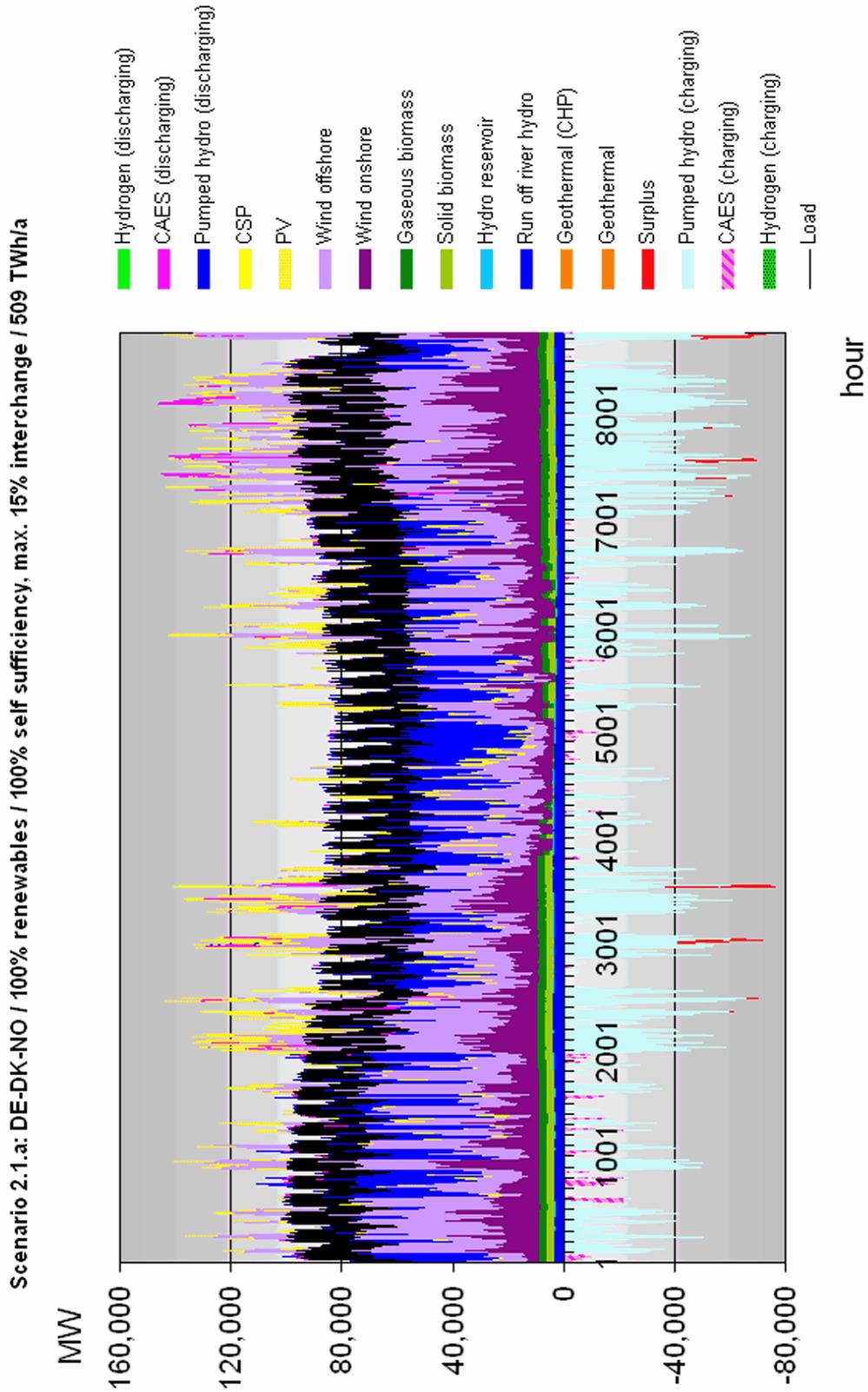
**Overview of capacities used, electricity generated, and annual and specific costs in scenarios 2.1.a and 2.1.b**

	Capacity used		Electricity produced		Costs				
	Max. GW		TWh/a		Millions of euros per year		Euro-cents per kWh		
	Scenario	2.1.a	2.1.b	2.1.a	2.1.b	2.1.a	2.1.b	2.1.a	2.1.b
<b>Energy source used</b>									
Photovoltaics	40.9	109.6	41.9	112.2	3,714	9,957	8.9	8.9	
Solar thermal		0.0		0.0		0			
Onshore wind	39.5	39.5	90.6	90.6	4,267	4,267	4.7	4.7	
Offshore wind	73.2	73.2	316.9	316.9	13,057	13,057	4.1	4.1	
Geothermal		0.0		0.0		0			
Geothermal with CHP		14.4		119.8		23,314			19.5
Solid biomass		0.0		0.0		0			
Solid biomass with CHP	2.5	3.0	17.1	17.1	1,983	2,249	11.6	13.2	
Biogas		0.0		0.0		0			
Biogas with CHP	2.4	2.9	17.1	17.1	1,495	1,741	8.7	10.2	
Run-of-river hydro	4.1	4.1	25.3	25.3	1,337	1,337	5.3	5.3	
hydro reservoir	0.3	0.3	2.3	2.3	92	92	4.0	4.0	
<b>Totals/average (gross)</b>	<b>162.9</b>	<b>247.0</b>	<b>511.2</b>	<b>701.3</b>	<b>25,944</b>	<b>56,013</b>	<b>5.1</b>	<b>8.0</b>	
Electricity reimporting	0.0	0.0	76.4	103.1	8,406	11,304	11.0	11.0	
Electricity storage									
Pump storage (storage)	1.2	1.2	1.0	0.8					
Pump storage (generation)	1.2	1.2	0.8	0.6	171	170	21.4	28.3	
Compressed air (storage)	18.1	23.5	5.7	4.0					
Compressed air (generation)	18.1	23.5	4.3	3.0	1,189	1,466	27.6	48.9	
Hydrogen (storage)	0.0	0.0	0.0	0.0					
Hydrogen (generation)	0.0	0.0	0.0	0.0					
Storage loss			1.6	1.2					
<b>Total demand/costs</b>	<b>81</b>	<b>111</b>	<b>509.4</b>	<b>700.1</b>	<b>35,709</b>	<b>68,953</b>	<b>7.0</b>	<b>9.8</b>	
Surplus capacity/production	101.2	160.7	0.2	0.0					

Source: SRU 2010, based on DLR 2010b

Figure 3-18

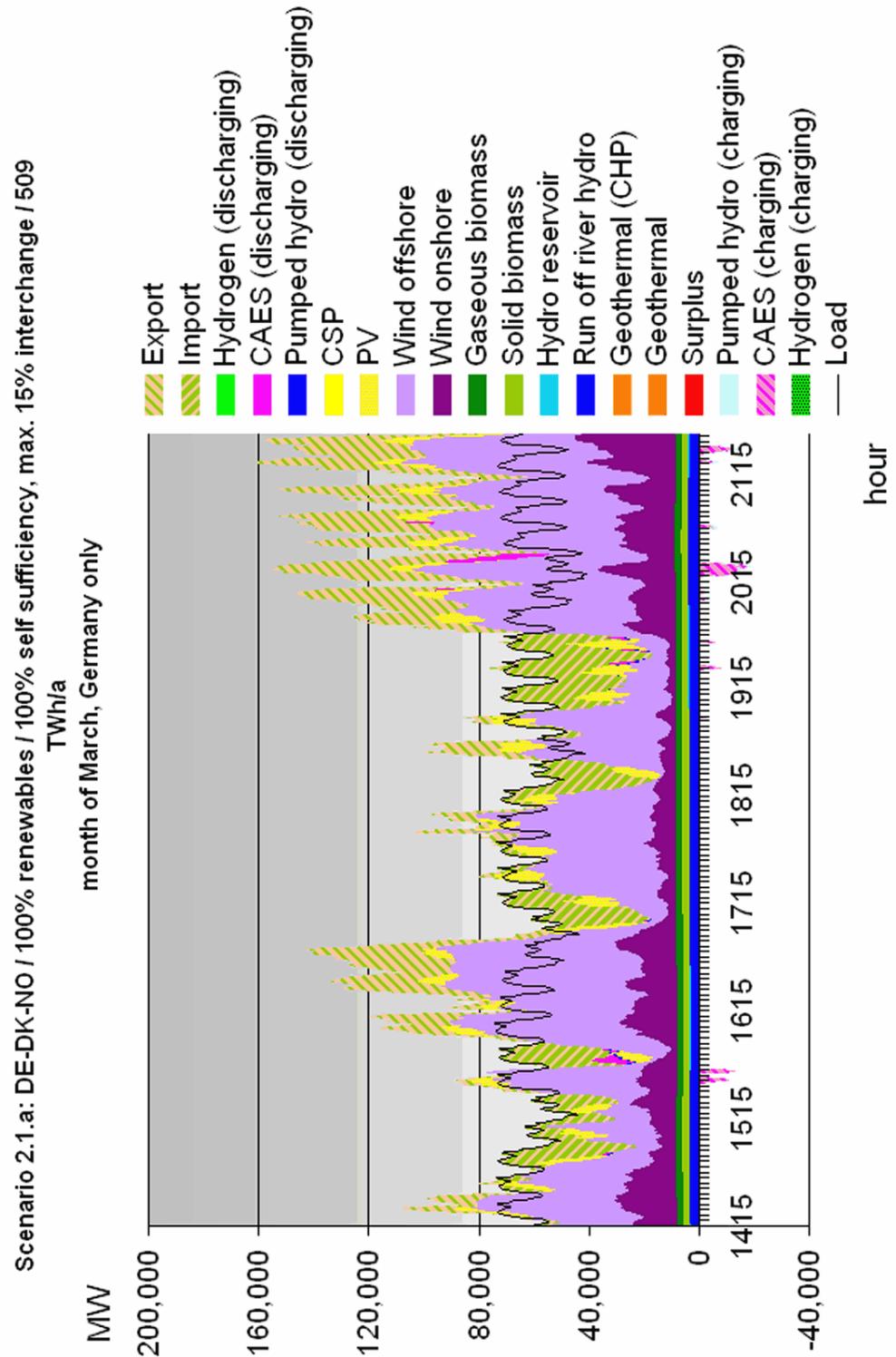
**Scenario 2.1.a: DE-DK-NO /  
100% renewables/100% self sufficiency, max. 15% interchange/509 TWh/a**



Source: SRU 2010, based on DLR 2010b

Figure 3-19

**Scenario 2.1.a: DE-DK-NO /**  
**100% renewables / 100% self sufficiency, max. 15% interchange / 509 TWh/a,**  
**month of March, Germany only**



Source: SRU 2010, based on DLR 2010b

In scenario 2.1.b, as in scenario 1.b, electricity demand in Germany increases to 700 TWh/a, whereby electricity interchange for only up to 15 percent of demand is allowable for the three participating states, each of which must produce 100 percent of the electricity for its annual demand. An increase in German electricity demand to 700 TWh/a equates to an increase in aggregate demand amounting to approximately 895 TWh/a in these three states, which results in an increase in average electricity costs to 0.098 euros per kWh. However, electricity costs are 0.017 euro per kWh lower than in scenario 1.b (German electricity generation self sufficiency with demand amounting to 700 TWh/a). The cost increase relative to scenario 2.1.a (509 TWh/a) is primarily attributable to the following: (a) the fact German geothermal capacity amounting to approximately 14.4 GW is included to allow for the generation of additional electricity; and (b) the necessity of ramping up photovoltaic generation capacity from 41 to 110 GW. It is also necessary to increase German compressed air energy storage capacity from 18.1 to 23.5 GW, although this leads to a less efficient use of this capacity. The data concerning capacity use, electricity generation, and total and specific costs can be found in Table 3-6.

#### **3.4.2.2.2 German electricity supply with allowable net electricity import amounting to 15 percent**

Scenarios 2.2.a and 2.2.b eliminate the restriction on the German-Danish-Norwegian network requiring that 100 percent of each member state's electricity must be produced within its borders, whereby each state is permitted to import 15 percent of total output from either of the other two partners. Scenario 2.2.a assumes again a German electricity demand of 509 TWh/a (and a demand of 650 TWh/a in all three countries), whereas scenario 2.2.b investigates a German electricity demand amounting to 700 TWh/a (895 TWh/a in the tripartite system).

As can be seen in Table 3-7, the scenario 2.2.a costs decrease from 0.07 euros per kWh only slightly to 0.065 euros per kWh as compared to scenario 2.1.a (net import barred, interchange allowed), although installed generation capacity in Germany decreases from 163 to 107 GW. This is mainly attributable to the elimination of photovoltaic generation capacity (41 GW) and the reduction of installed onshore wind energy capacity to 25 GW. However, since imported renewable electricity, including all storage expenses, is relatively expensive (0.148 euros per kWh), the avoided investment costs in Germany barely reduce overall costs.

A comparison of Figure 3-21, which shows aggregate generation in the German-Danish-Norwegian network, and Figure 3-18 (scenario 2.1.a) shows that no solar energy is needed to satisfy electricity demand, and that relatively expensive photovoltaics are replaced by additional wind energy and storage.

If the assumed demand is increased to 700 TWh/a under these same conditions (i.e. Germany importing 15 percent of its electricity from the two other cooperating states), the conditions for scenario 2.2.b are obtained. As is shown in Table 3-3, in order to provide 85 percent of this electricity output (595 TWh/a) in Germany, generation capacity would have to be raised to 234

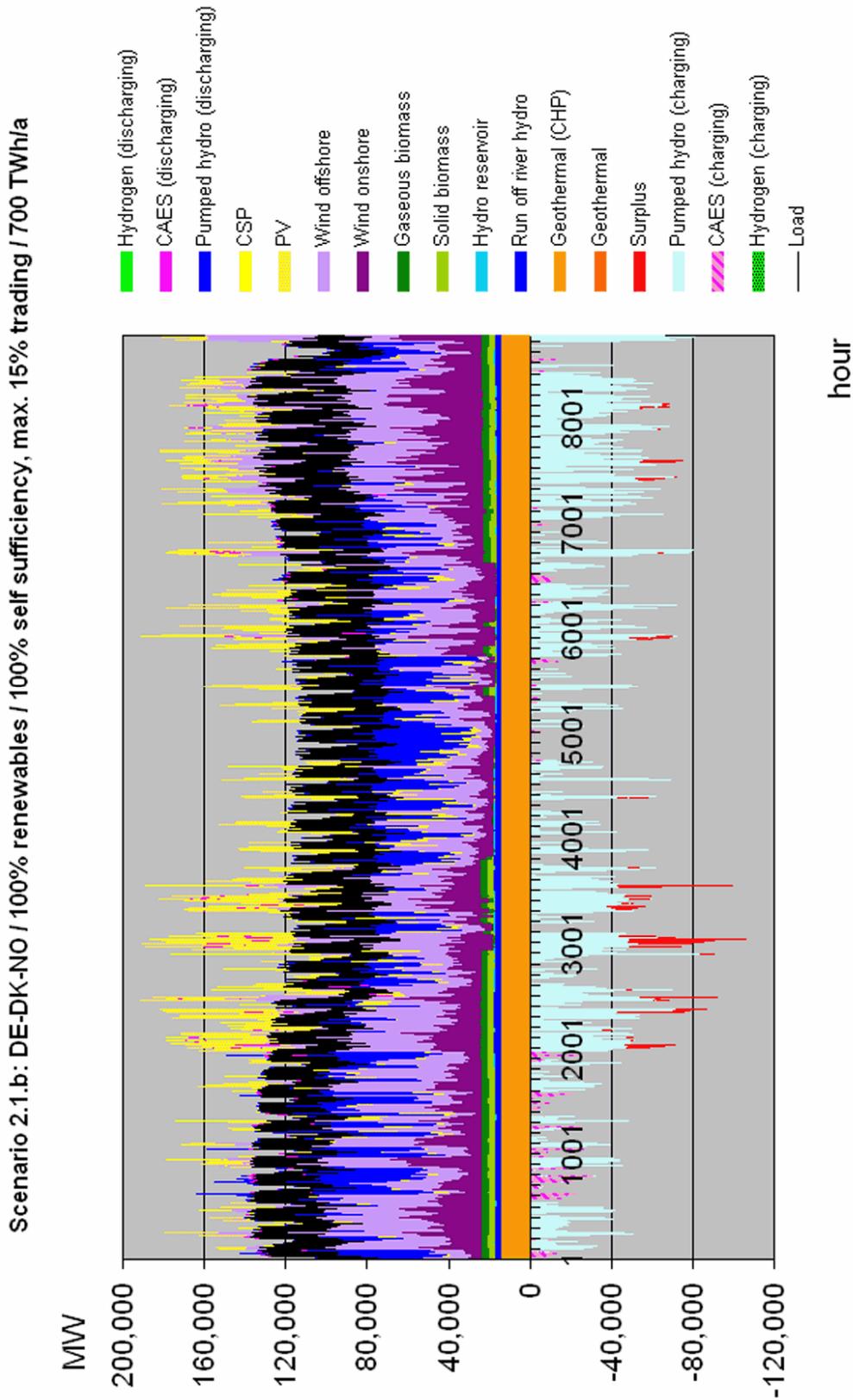
GW, which is more than twice the 107 GW in scenario 2.2.a. However, German electricity production would only have to be increased by 161 TWh/a, from 435 to 596 TWh/a. This capacity increase would be realised by expanding photovoltaic capacity to 110 GW (up 110 GW), expanding onshore wind capacity to 39.5 GW (up 15 GW) and by geothermal capacity amounting to 1.8 GW. This would translate into an aggregate cost increase from 0.065 euros per kWh in scenario 2.2.a to 0.072 euros per kWh.

However, relative to scenario 2.1.b, which disallows electricity import and only allows electricity interchange, scenario 2.2.b costs decrease substantially, from 0.098 to 0.072 euros per kWh, mainly due to substantially lower geothermal energy transmission capacity (down 12.6 GW), which in scenario 2.2.b is replaced by imports. As can be seen by comparing Figures 3-22 (scenario 2.2.b) and 3-20 (scenario 2.1.b), geothermal energy is no longer a mainstay of electricity generation.

In the four Table 3-8 scenarios, electricity transmission between the three cooperating states would necessitate a substantial increase in line capacity, which was factored into the electricity supply costs. The transmission capacities in the present report presuppose that all electricity transmission between Germany and Norway would transit through Denmark. However, in reality these transmission lines would traverse the Danish exclusive economic zone in the North Sea, whereby only a minute portion of these lines would be installed onshore in Denmark. This arrangement would necessitate line capacity ranging from 42 to 69 GW (see Table 3-8). These figures show that electricity interchange amounting to 15 percent of annual electricity production (but excluding net imports) (scenario 2.1) would also necessitate up to 54 GW of transmission capacity between Denmark and Norway (scenario 2.1.b), 48 GW of which, however, would be accounted for by electricity transit between Germany and Norway. Raising the allowable amount of imports would necessitate increased transmission capacity, but only 10 percent more than in the scenarios that exclude net imports.

Figure 3-20

**Scenario 2.1.b: DE-DK-NO /**  
**100% renewables/100% self sufficiency, max. 15% interchange/700 TWh/a**



Source: SRU 2010, based on DLR 2010b

Table 3-7

**Overview of capacities used, electricity generated, and annual and specific costs in scenarios 2.2.a and 2.2.b**

Energy source used for scenario...	Capacity used		Electricity produced		Costs			
	Max. GW		TWh/a		Millions of euros per year		Euro-cents per kWh	
	2.2.a	2.2.b	2.2.a	2.2.b	2.2.a	2.2.b	2.2.a	2.2.b
Photovoltaics		109.6		112.2		9,957		8.9
Solar thermal								
Onshore wind	24.6	39.5	56.5	90.6	2,663	4,267	4.7	4.7
Offshore wind	73.2	73.2	316.9	316.9	13,057	13,057	4.1	4.1
Geothermal								
Geothermal with CHP		1.8		14.6		2,842		19.5
Solid biomass								
Solid biomass with CHP	2.5	2.6	17.1	17.1	1,960	2,035	11.5	11.9
Biogas								
Biogas with CHP	2.3	2.5	17.1	17.1	1,471	1,545	8.6	9.0
Run-of-river hydro	4.1	4.1	25.3	25.3	1.37	1,337	5.3	5.3
Hydro reservoir	0.3	0.3	2.3	2.3	89	89	3.9	3.9
<b>Totals/average (gross)</b>	<b>107.0</b>	<b>233.6</b>	<b>435.2</b>	<b>596.1</b>	<b>20,576</b>	<b>35,128</b>	<b>4.7</b>	<b>5.9</b>
Net electricity imports			76.4	105.0	11,298	14,091	14.8	13.4
Electricity storage								
Pump storage (storage)	0.5	0.9	1.1	0.4				
Pump storage (generation)	0.5	0.9	0.9	0.3	76	125	8.4	41.7
Compressed air (storage)	18.7	23.1	7.0	3.5				
Compressed air (generation)	18.7	23.1	5.2	2.6	1,228	1,352	23.6	52.0
Hydrogen (storage)								
Hydrogen (generation)								
Storage loss	0.0		2.0	1.0				
<b>Total demand/costs</b>	<b>81.0</b>	<b>111.4</b>	<b>509.4</b>	<b>700.0</b>	<b>33,178</b>	<b>50,697</b>	<b>6.5</b>	<b>7.2</b>
Surplus capacity/production	45.2	146.2	0.5	0.1				

Source: SRU 2010, based on DLR 2010b

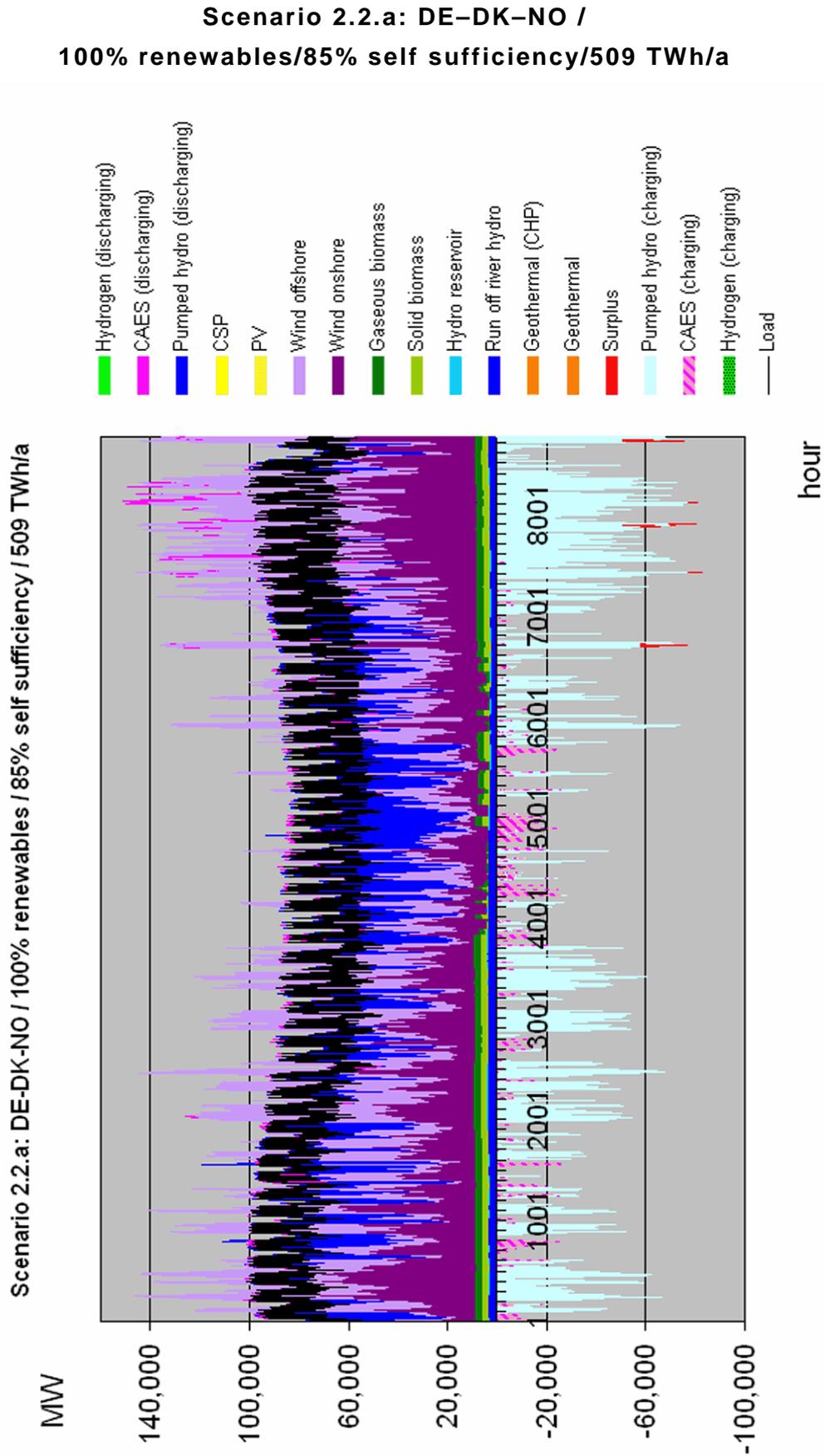
Table 3-8

**Electricity transmission capacities (in GW) within the German-Danish-Norwegian energy supply network for the various scenarios**

Network states	Scenario			
	2.1.a	2.1.b	2.2.a	2.2.b
	100% self sufficiency/509 TWh	100% self sufficiency/700 TWh	85% self sufficiency/509 TWh	85% self sufficiency/700 TWh
DE-DK	41.9	48.5	47.1	61.6
DK-NO	46.0	54.2	50.0	68.8

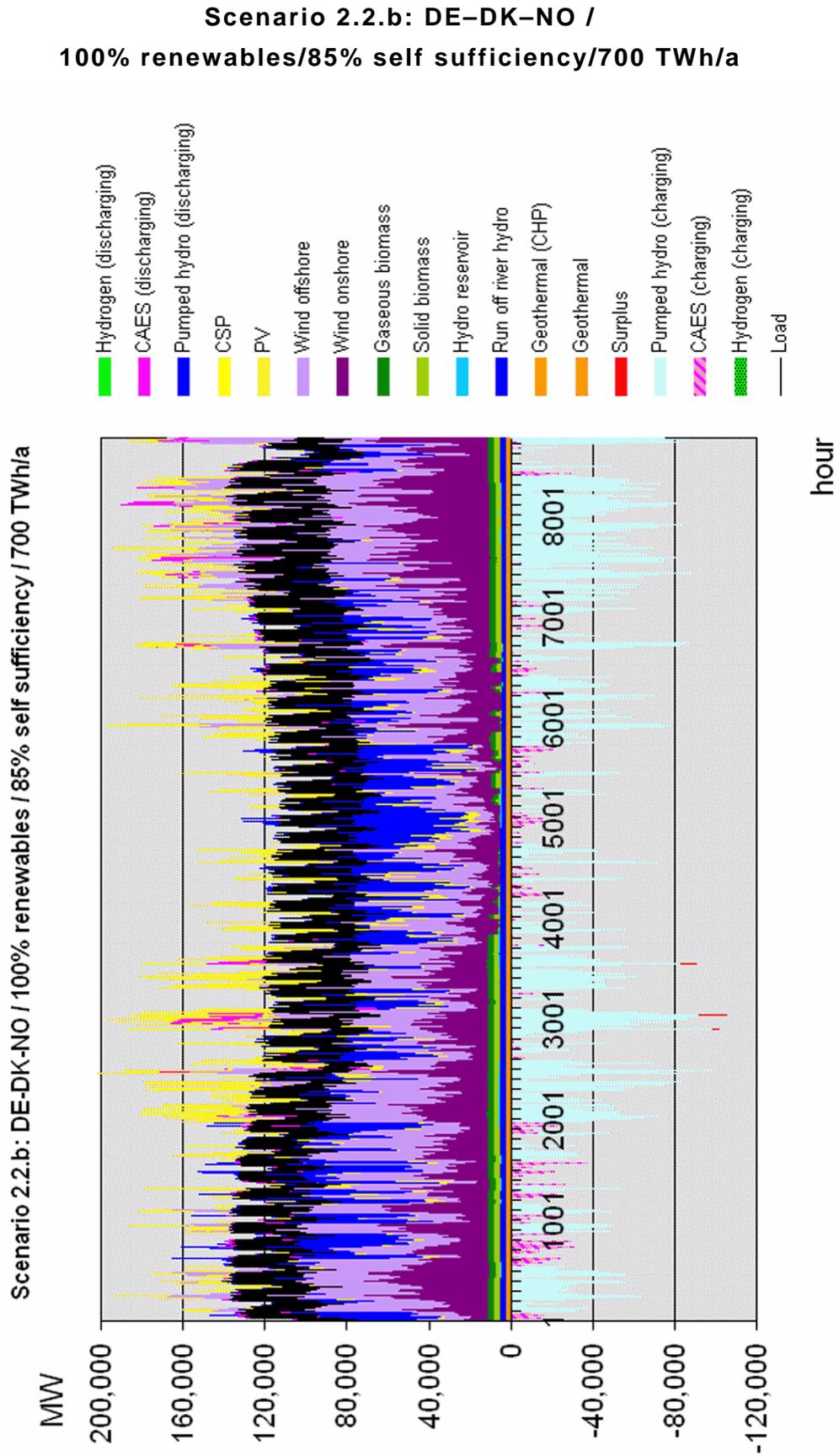
Source: SRU 2010, based on DLR 2010b

Figure 3-21



Source: SRU 2010, based on DLR 2010b

Figure 3-22



Source: SRU 2010, based on DLR 2010b

### **3.4.2.3 A wholly renewable electricity supply in an inter-regional Europe-North Africa network**

Inasmuch as the exploitable renewable energy potential for a Europe-North Africa network exceeds foreseeable demand by a factor of 20, in scenario group 3 we investigated the impact such an inter-regional network would have on German electricity supply in 2050. Here again, it was assumed that each network state will cover at least 85 percent of its electricity demand via renewables over the course of a year and that maximum net imports of 15 percent are allowable. These scenarios also admit electricity interchange (export and re-import) for electricity storage purposes abroad. Scenario 3.a assumes a German electricity demand in 2050 amounting to 509 TWh/a, which corresponds to an aggregate demand in the network zone amounting to approximately 5,400 TWh/a, whereas scenario 3.b. assumes a German demand amounting to 700 TWh/a in this same year. Correspondingly for each other country a low demand scenario is calculated as presented in the Annex of this report.

In view of the fact that modelling the optimisation solution for a 36 state/region network for the 8,760 hours comprising a year would entail a monumental amount of computing resources, the scenario 3.a and 3.b simulations were run for every second hour over the course of a year and for five intervals of equal length, so as to keep the requisite computing resources within reasonable bounds. Despite these measures, each simulation took days or even weeks to run. In view of the fact that, as at the April 2010 cut-off date for the present report, the scenario 3.b simulation results were available for only three of the five aforementioned intervals, this scenario will not be discussed in depth here.

In the enlarged network entailed by scenario 3.1, the costs for a wholly renewable electricity supply in Germany are the same as for scenario 2.2.a (0.065 euros per kWh). As Table 3-9 shows, relative to scenario 2.2.a installed German generation capacity increases by 3 GW to 110 GW due to the increase in installed onshore wind power from 24.6 to 28 GW, whereas offshore wind power amounting to 73.2 GW remains unchanged. Installed capacity and electricity generation from biomass and hydro power differ little relative to scenario 2.2.a. Noteworthy here is that installed German compressed air energy storage capacity increases from 18.7 to 20.7 GW, which equates to the generation of 11.8 TWh/a from 15.7 TWh/a of stored electricity over the course of a year. Owing to the multiplicity of transmission lines in a complex network comprising 36 states, it cannot be determined exactly which state produces or stores electricity for which other state. Nonetheless, it is noteworthy that the maximum Norwegian pump storage system capacity used (in TWh) in the Europe-North Africa network is lower than in the German-Danish-Norwegian system. Expanded Norwegian pump storage system capacity, the use of new compressed air energy storage facilities, and the equalisation effect of such a large scale network structure (without any pump storage system capacity increase in any other participating state) allow for a wholly renewable electricity supply in Europe on a 24/7/365 basis. It is also safe to assume that an analogous expansion of the already considerable capacity of hydro reservoirs will occur, certainly in Sweden, but also in

France, Italy, Switzerland and Austria. The present report did not allow for this possibility, since many such expansion projects necessitate the prior construction of lower lakes, which experience has shown can provoke considerable opposition.

As in the German-Danish-Norwegian network, wind power is the predominant energy source in here, accounting for more than 3,400 TWh/a (63 percent) of the more than 5,400 TWh/a of demand. However, the presence of southern Europe and North Africa in this grid also yields relatively low cost solar power potential, amounting to 1,080 TWh/a for concentrated solar power and 575 TWh/a for photovoltaic energy, or 31 percent of this network's aggregate electricity generation – a substantial contribution, particularly during the summer months. Figure 3-23 shows how hourly demand is satisfied via electricity generation in the inter-regional Europe-North Africa network, where primary generation capacity amounting to just under 1,380 GW is installed for an annual peak load amounting to 840 GW. Apart from this, compressed air energy storage capacity amounting to more than 230 GW and pump storage capacity amounting to more than 100 GW would be needed for a fully reliable round the clock electricity supply in this wholly renewables based system.

As can be seen in Table 3-9, the basic supply situation in Germany would change very little in the Europe-North Africa network relative to scenario 2.2.a (DE–DK–NO 85% SV). And in terms of satisfying hourly demand, as is shown in Figure 3-24, wind energy and imports of stored surplus electricity would account for a substantial portion of Germany's electricity supply. The corresponding data for the other European and North African states will be presented in the Annex.

In view of the fact that the Europe-North Africa network is only marginally more advantageous than the German-Danish-Norwegian network and would take considerably longer to implement owing to the large transmission line distances involved, Germany should move quickly to establish a cooperation with Denmark, Norway and possibly Sweden. For even if Austria and Switzerland have substantial storage hydroelectric power station capacity amounting to just under 30 TWh/a at present, the Scandinavian potential amounting to more than 120 TWh/a is four times as large. Moreover, this potential is utilised by far fewer states than is the case with Austria and Switzerland on account of Scandinavia's far greater distance from centres of electricity demand.

Table 3-9

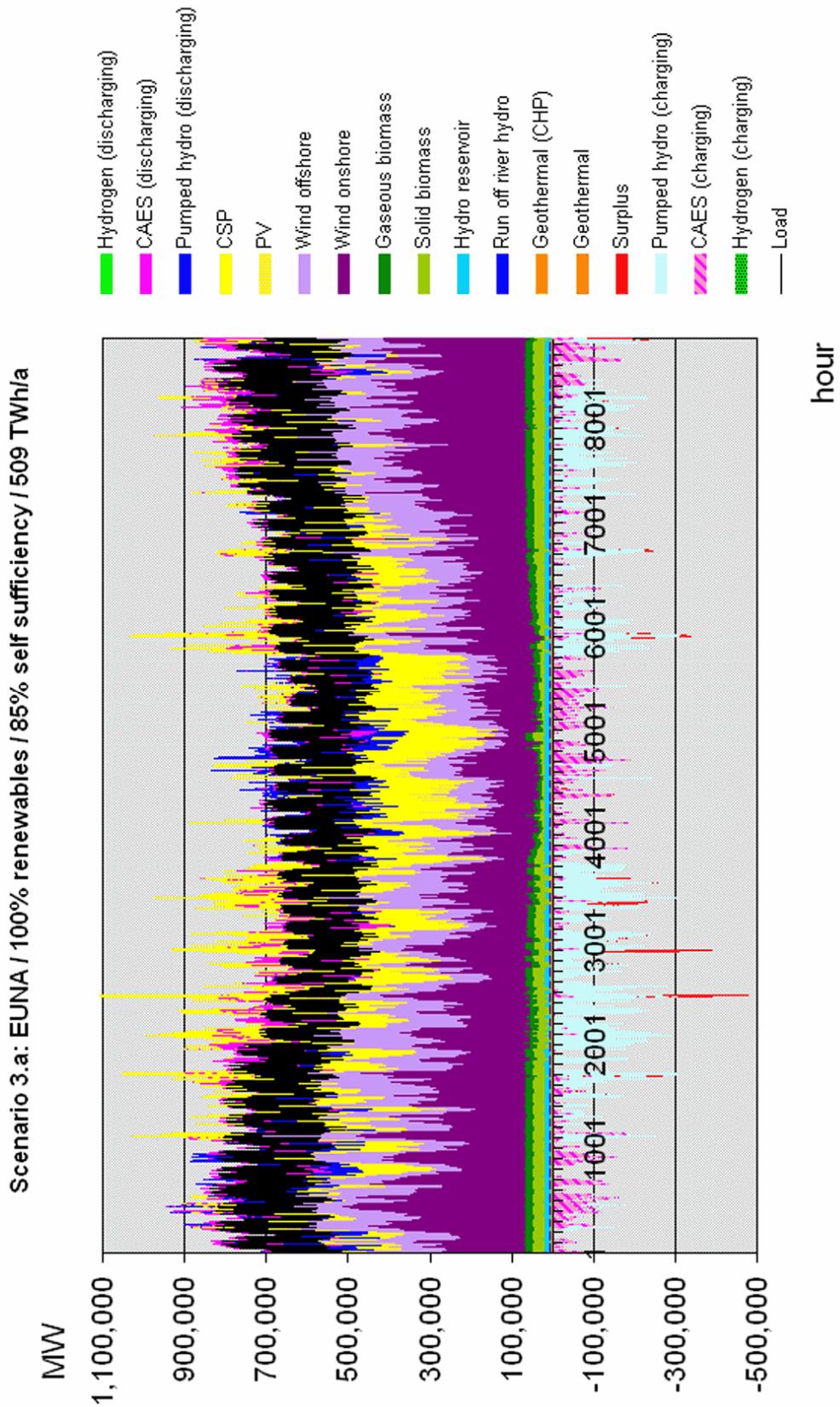
**Overview of capacities used, electricity generated,  
and annual and specific costs in scenario 3.a**

Scenario	3.a	Germany 509 TWh/a, 85% self sufficiency, German interchange with the Europe-North Africa region		
		Capacity used	Electricity produced	Costs
	Max. GW	TWh/a	Millions of euros per year	Euro-cents per kWh
<b>Energy source used</b>				
Photovoltaic				
Solar thermal				
Onshore wind	38.3	63.7	4,142	6.5
Offshore wind	73.2	316.9	13,057	4.1
Geothermal				
Geothermal with CHP				
Solid biomass				
Solid biomass with CHP	2.6	17.1	1,986	11.6
Biogas				
Biogas with CHP	2.4	17.1	1,489	8.7
Run-of-river hydro	4.1	20.2	1,337	6.6
Hydro reservoirs	0.3	2.3	107	4.7
<b>Totals/average (gross)</b>	<b>120.9</b>	<b>437.2</b>	<b>22,117</b>	<b>5.1</b>
Electricity imports		76.4	11,298	14.8
Electricity storage				
Pump storage (storage)	0.8	1.5		
Pump storage (generation)	0.8	1.2	115	9.3
Compressed air storage)	30.6	15.7		
Compressed air (generation)	30.6	11.8	1,474	12.4
Hydrogen (storage)				
Hydrogen (generation)				
Storage loss		4.7		
<b>Total demand/costs</b>	<b>81.0</b>	<b>509.4</b>	<b>35,004</b>	<b>6.9</b>
Surplus capacity/production	71.3	0.1		

Source: SRU 2010, based on DLR 2010b

Figure 3-23

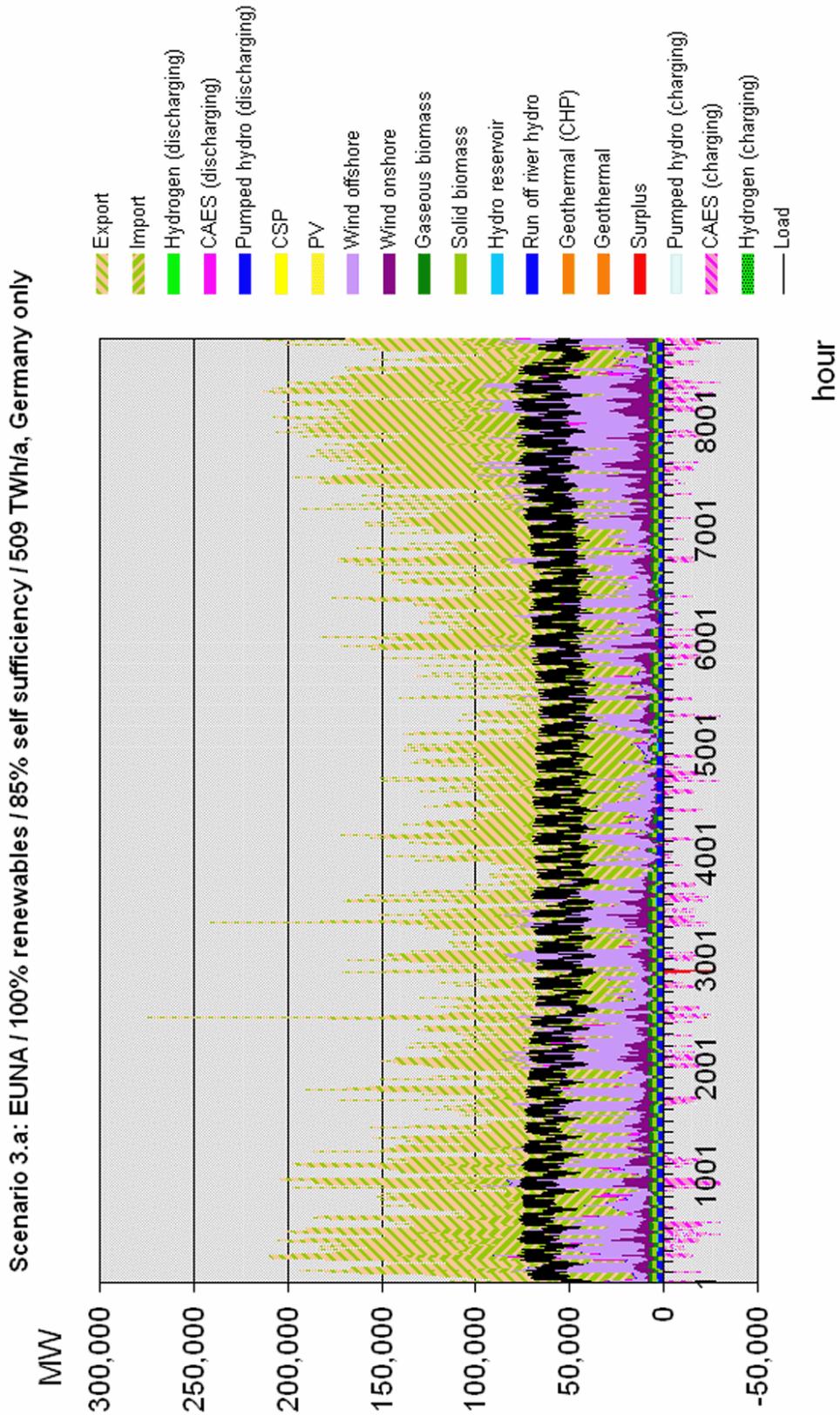
**Scenario 3.a: EUNA / 100% renewable / 85% self sufficiency / 509 TWh/a**



Source: SRU 2010, based on DLR 2010b

Figure 3-24

**Scenario 3.a: EUNA/100% renewables/85% self sufficiency/509 TWh/a, Germany only**



Source: SRU 2010, based on DLR 2010b

## **4 The technical development roadmap and the decisions needed for it**

### **4.1 Capital-stock timeline**

Chapter 3 aimed to show that a wholly renewables-based sustainable electricity supply is achievable by 2050. The question nonetheless arises as to which roadmap would allow for realisation of such a scenario in light of Germany's current electricity supply situation. Our aim here is not to predict how the current electricity supply situation will evolve in light of current conditions, but rather to show which pathway can ensure that the objectives are reached.

This roadmap takes as its starting point Germany's current power plant fleet and the evolution this fleet is slated to undergo as the result of various German power plants being decommissioned at the end of their technical or economic life time. Each year between now and 2050 will be characterised by a specific residual power plant fleet, the attendant aggregate capacity resulting from the age of the power plants involved and their projected mean service life thereof, and can be represented graphically. Inasmuch as a power plant's life cycle can extend over 50 years, these graphics of these cycles extend a number of decades into the future. Multiplying the capacity of the current power plant fleet for each year by a posited mean annual service life, which is expressed as equivalent full load hours (EFLH), yielded the amount of electricity that can be generated annually with the existing power plant fleet. This production potential was then compared with the assumed future electricity demand for each year. It should be noted in this regard that conventional power plants are prone to considerable internal consumption and that transmission of their electricity to customers entails a certain amount of power loss. In cases where electricity generation potential would undercut future demand, it is necessary to ramp up generation capacity or import electricity in order to avoid supply shortfalls.

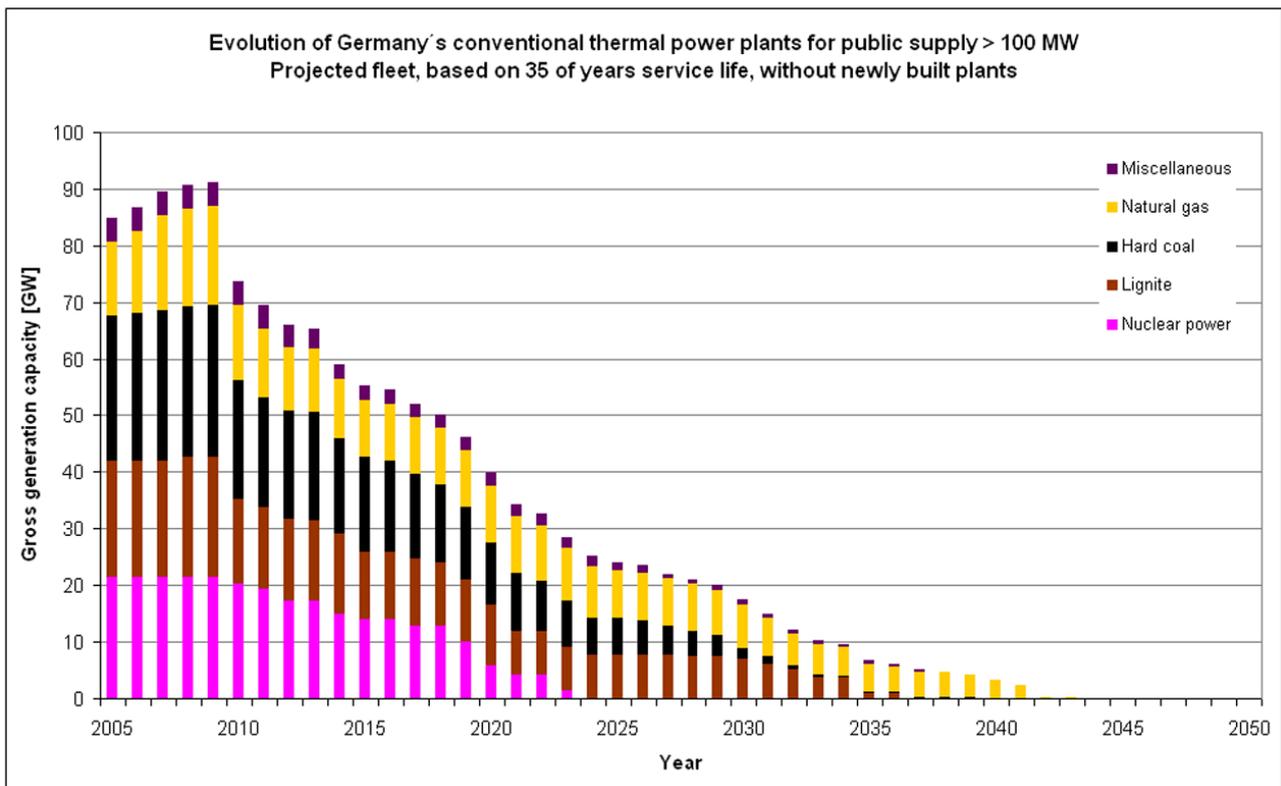
Life spans ranging from 30 to 50 years were assumed for conventional thermal power plants. However, the actual life spans of German power plants tend to be longer than the nominal service life indicated by the manufacturer, and can be extended by an additional 20 to 25 years if they are overhauled. Life spans ranging from 35 to 45 years were assumed for coal fired power plants (Loreck 2008, p. 4; Marketwitz et al. 1998, p. 40), and life spans ranging from 30 to 35 years were posited for gas power plants, which, however, oftentimes remain in operation for up to 50 years (Dena 2010, p. 9).

The equivalent full load hours (EFLH) per year indicated in the literature for various types of power plants differ greatly, depending on how they are used. Moreover, power plant operating hours vary considerably over time according to annual load and power plant fleet availability. For example, fewer operating hours for nuclear power plants can substantially ramp up the operating hours for coal fired power plants. Moreover, the extent to which wind energy is fed into the grid can have a major impact on the number of full load hours for a conventional power plant, particularly in the medium load range.

Relatively short life spans amounting to 35 years for all available and under construction thermal power stations were defined for the 2010-2050 road map simulation of our target scenario, as was also done in a published basic scenario (Marketwitz et al. 1998, p. 40). The term conventional thermal power plant refers to virtually all fossil fuel powered power plants and nuclear power plants to the exclusion of hydro power plants. The assumption that conventional power plants have a relatively short life span means that the scope of renewable energy sources will have to be expanded with all due speed and makes the transition to a wholly renewable electricity supply particularly challenging. The evolution of the German power plant fleet in terms of capacity, assuming a power plant life span of 35 years, is shown in Figure 4-1. No assumptions have been made concerning the political climate surrounding nuclear power plant operation in Germany. Hence a 35 year life cycle was likewise defined for these facilities. This means that the last conventional thermal power plant currently in operation would be decommissioned in 2041 (see Figure 4-1.a).

Figure 4-1.a

**Evolution of Germany’s conventional power plant fleet (thermal power plants) as at 2009 for the years 2009-2050**



Source: SRU 2010, based on UBA 2009a

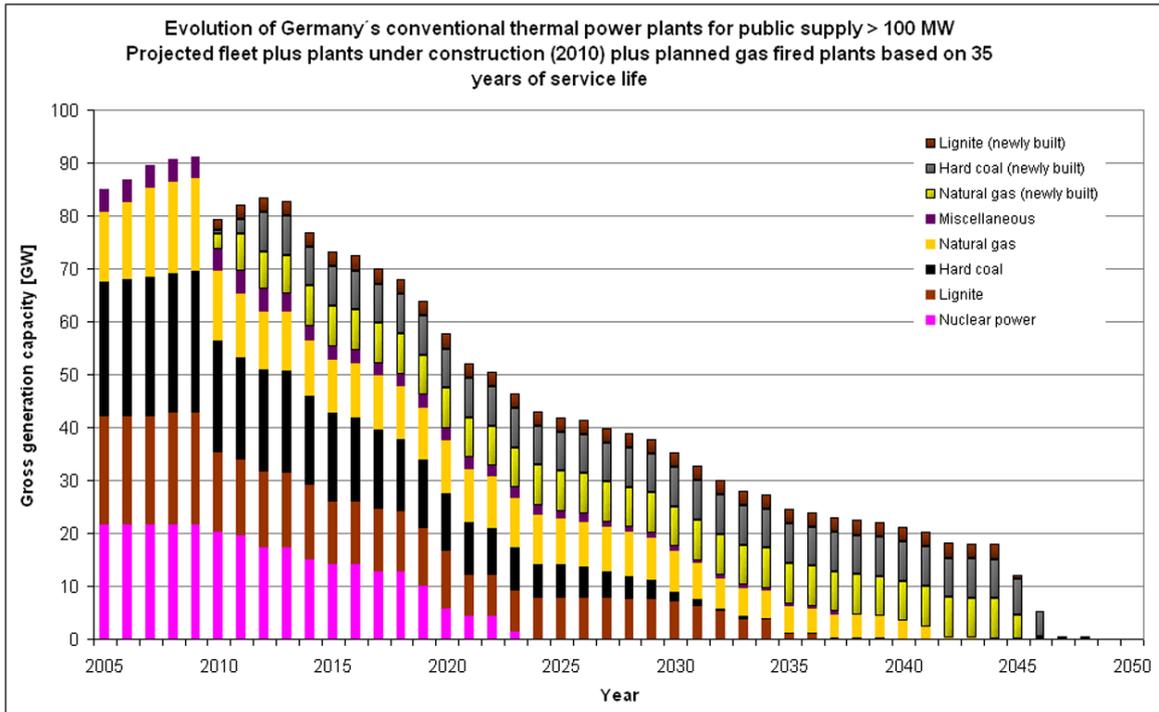
The severe capacity reduction from 2009 to 2010 is attributable to the fact that in 2009 a series of power plants were in operation that were more than 35 years old at that time were eliminated from the simulations as at 31 December 2009. However, actual power plant life cycles are considerably longer, which means that the capacity reduction indicated in Figure 4-1.a for 2010 would in fact be distributed across a number of years.

Factoring in coal fired power plants that are currently under construction as well as gas fired plants that are in planning or under construction equates to a considerable increase in the scope of Germany's installed power plant capacity amounting to around 15 GW (see Figure 4.1.b). In view of the fact that gas power plants lend themselves to particularly flexible supplementation of large portions of fluctuating input from renewables and exhibit the lowest carbon emission levels of all fossil fuel fired power plants, we presumed that all gas power plants that are currently under construction will be completed and that all such facilities that were in the planning stages as at January 2010 will be built. On the other hand, in view of the high carbon emissions of coal fired power plants, we presumed that only those facilities that were under construction as at January 2010 will be completed. Based on these assumptions, the last of the newly rolled out thermal power plants will be decommissioned in 2048.

If, however, a 45 year life cycle is posited for coal fired power plants, such facilities that are currently under construction will not be decommissioned until 2055-2077. For these conventional power plants, this 45 year life cycle would mean that approximately 10 KW of power plant capacity would still be in operation in 2050 (see Figure 4-2). If all coal fired power plants plans whose construction had been announced as at February 2010 are included, a 45 year life cycle would translate into additional capacity amounting to more than 20 GW, excluding the suspended planning process for the coal fired power plants in Kiel (800 MW), Dörpen (900 MW), Lubin (1,600 MW) and Mainz (760 MW). This in turn would mean that the last conventional thermal power plant would not be decommissioned until 2059. Figure 4-3 shows the evolution of Germany's fleet of conventional thermal power plants from 2005-2050, including coal fired power plants that are in the planning stages.

Figure 4-1.b

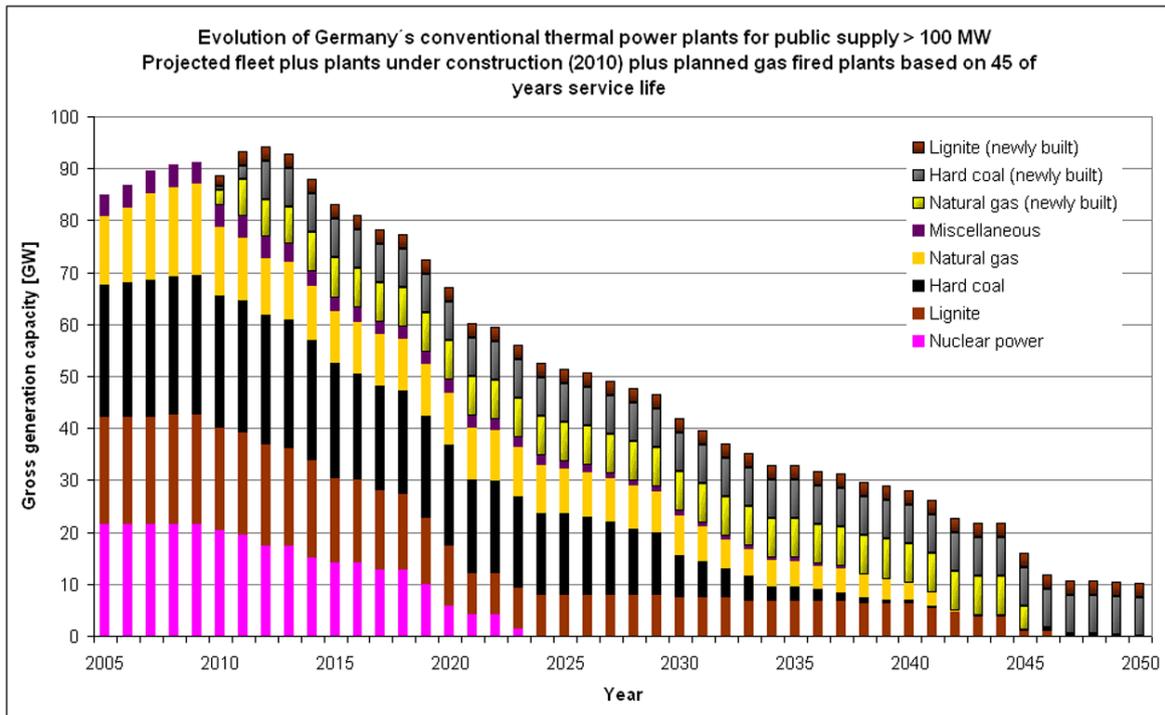
**Evolution of Germany's conventional thermal power plant fleet, including coal fired power plants that are under construction and gas power plants that are in the planning stages, and assuming a 35 year life span for all power plants**



Source: SRU 2010, based on UBA 2009a; BDEW 2008a

Figure 4-2

**Evolution of Germany's conventional thermal power plant fleet,  
including coal fired power plants that are under construction  
and gas power plants that are in the planning stages  
(assuming a 45 year life span for coal fired power plants  
and a 35 year life span for all other types of power plants)**



Source: SRU 2010, based on UBA 2009a; BDEW 2008a

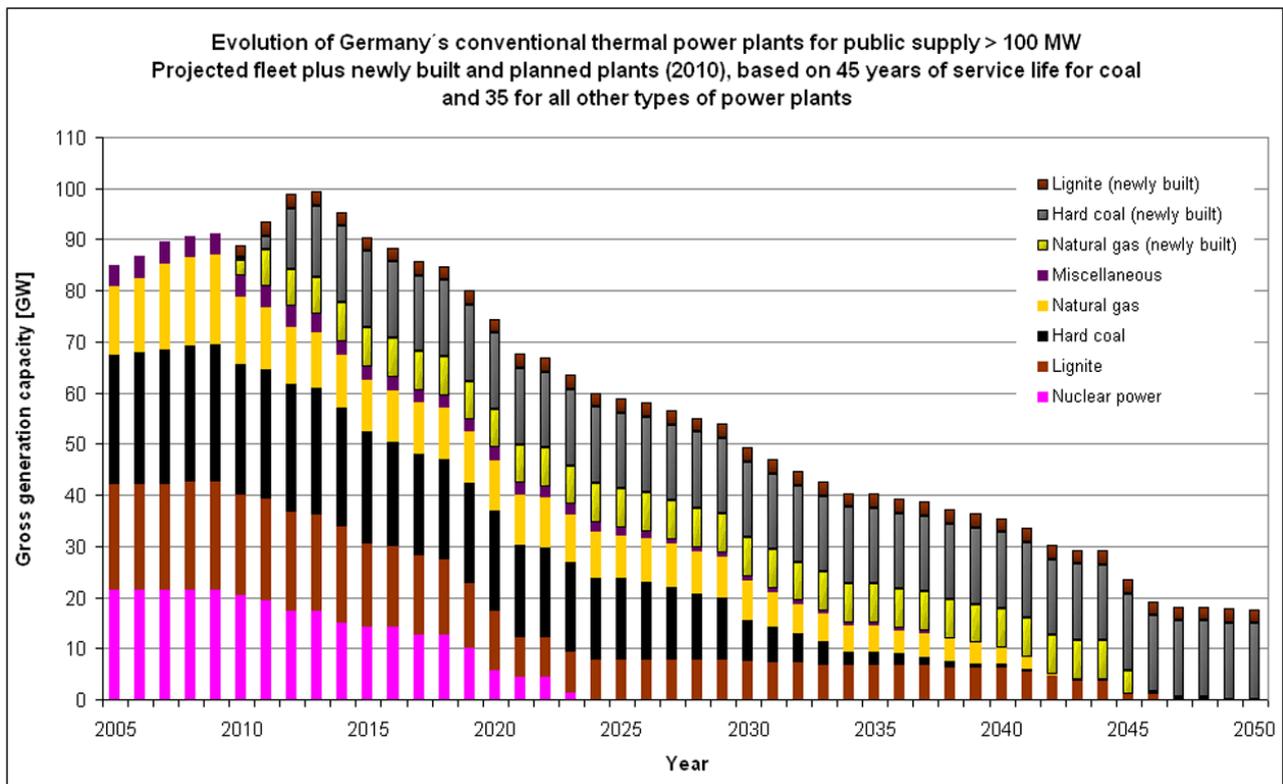
Carbon emissions in 2050 would amount to roughly 100 megatons/year, assuming that all coal fired power plants that are in the planning phase are built and remain in operation for 45 years. However, the 80 percent greenhouse gas reduction goal for 2050 allows for only around 65 megatons/year of power plant carbon emissions by this date. If further reaching reduction objectives of up to 95 percent were achieved, power plant carbon emissions could be reduced to just over 16 megatons per year. Thus even just the coal fired power plants that are currently in the pipeline (under construction or in the planning stages) would far exceed these emission limits, but would only satisfy some 25 percent of electricity demand. A large portion of coal fired power plants that are currently in the pipeline would – if run for a period of 45 years – have to be retrofitted with carbon capture and storage (CCS) systems which experts unanimously agree will be far more cost intensive than installing this same technology in new power plants (see IPCC 2005, p. 152). Moreover, CCS technology requires an infrastructure for transporting the captured carbon and storing extremely large quantities of it safely. Efforts to find underground carbon storage sites were met with firm opposition in 2009 on the part of the populations living near such sites. In our view, CCS is a possible, but not a sustainable and not a necessary strategy for the reduction of power plant greenhouse gas emissions and has a very limited overall capacity (SRU 2009, p. 9). The

systematic expansion of the scope of renewable energy sources will obviate the need to keep conventional power plants in operation for 45 years and to use CCS technology for such facilities. However, if the coal fired power plants currently under construction are still in operation in 2050 and have not been retrofitted with CCS systems, the roughly 10 GW of coal fired power plant capacity they represent would equate to approximately 50 megatons of carbon emissions annually. Hence only a small proportion of these power plants could still be operated if an ambitious carbon reduction goal amounting to 15 megatons per year were promulgated.

All of our other simulations were based on the 35 year life span scenario shown in Figure 4-1.b. The assumption of such a relatively short conventional power plant life span translates into the most challenging scenario in the shorter term, both in terms of capacity (GW) and annual generation (TWh/a). If it can be shown that it is possible to move to a wholly renewable electricity supply under these conditions, this will also prove that such a transition is feasible for longer conventional power plant life spans as well.

Figure 4-3

**Evolution of Germany's conventional thermal power plant fleet,  
including power plants that are in the pipeline  
(assuming a life span of 45 years for coal fired power plants  
and of 35 years for all other types of power plants)**



Source: SRU 2010, based on UBA 2009a; BDEW 2008a

Even if the simulations described below are based on a strict life span of 35 years for all types of power plants in the interest of rendering the transition scenario calculations unequivocal and

readily understandable, the real world scenarios will offer far greater flexibility. For example, if renewable energy sources come into greater use at a more rapid pace than that posited by our simulations, it may well be possible to decommission conventional power plants sooner, as has in fact sometimes been the case in recent decades (Markewitz et al. 1998, p. 40). But if the process of implementing renewable energy is delayed (for example offshore wind farm installation and commissioning can easily be delayed by six to nine months by early autumn storms; or electricity transmission line installation can be delayed by protests from local residents), normally the life cycle of conventional power plants can be extended beyond 35 years without undue additional expense. Hence the transitional scenarios discussed below that presuppose a 35 year life span for all types of power plants in fact allow for considerable generation capacity flexibility for the process of transitioning to renewable energy.

In view of the fact that annual hours of use for the various renewable energy resource technologies vary greatly, in addition to replacing conventional generation capacity it is also necessary to ensure that the generation capacity needed to meet electricity demand is available at all times in an electricity system that relies heavily on renewables. This in turn necessitates the installation of considerable storage capacity in conjunction with the envisaged generation infrastructure. To this end, it is crucial to determine beforehand how much electricity (a) is likely to be generated each year by the remaining conventional power plant fleet; and (b) will need to be generated in connection with increased use of renewables to generate electricity.

Our conventional power plant calculations in this regard were based on 2008 annual full load hours for conventional power plants in the public grid (according to BDEW 2009; see Table 4-1). Multiplying the power plant fleet for each year by the presumed number of full load hours yields electricity generation by conventional thermal power plants.

Table 4-1

**Posited annual full load hours for conventional power plants**

<b>Fuel</b>	<b>Annual full load hours</b>
Lignite	6,710
Hard coal	4,320
Natural gas	3,430
Nuclear energy	7,690

Mean annual full load hours in 2008 for conventional power plants for public supply with more than 100 MW of electrical capacity.

Source: BDEW 2009

Our simulations were based on the assumption that (a) the level of hydro power use in Germany will remain relatively stable for the foreseeable future since most of the available environmentally compatible potential has already been developed; and (b) all necessary investments will be made to keep available hydro power capacity operational.

## 4.2 Renewable electricity generation: the way forward to 2050

It is safe to assume that, as various studies have shown, if energy saving efforts are implemented successfully, German electricity demand in 2050 will amount to around 500 TWh/a, which will be satisfied by the necessary gross electricity generation. However, in our estimation if such efforts fail and but Germany's auto fleet goes electric in the meantime, gross electricity generation may be as high as 700 TWh/a by 2050. The simulations described below for the process of transitioning from our current electricity system to the putative 2050 structure were based on (a) our scenario simulations for 2050; and (b) presumed electricity demand amounting to 509 and 700 TWh, depending on the scenario.

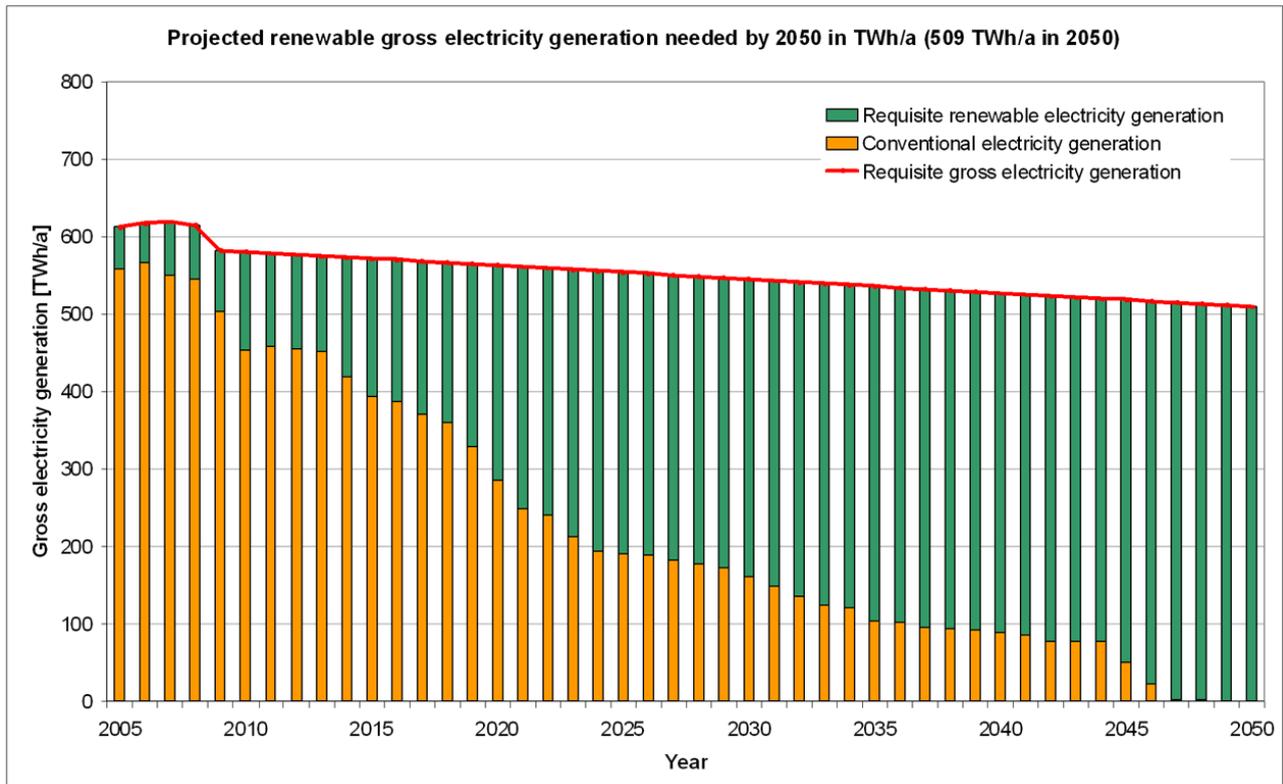
The transition scenarios for the 2010-2050 period were based on the generation structures posited for scenarios 2.1.a and 2.1.b, which allow for electricity interchange within a German-Danish-Norwegian network, but are based on an equitable electricity export balance of "trade" and require that total annual German electricity demand be satisfied using domestically generated electricity. However, the electricity interchange in these scenarios allows for equalisation during low electricity output phases in Germany (i.e. in low wind periods) via electricity imports and via exports during particularly high domestic production phases. The underlying structure of these scenarios is largely consonant with the evolution of German electricity generation in the past in that while Germany in general has always generated sufficient electricity to satisfy demand, we use our connections with the European power grid to compensate for short term domestic production shortfalls and surpluses.

If, congruent with 2009 gross electricity generation in Germany amounting to around 582 TWh, gross electricity generation declines to a posited 580 TWh in 2010 and to approximately 510 TWh by 2050, annual demand for renewable electricity can be determined by factoring in the electricity generated by existing conventional thermal power plants and presupposing that demand will decrease in a linear fashion until 2050. Greater use of renewable energy sources will virtually close the gap between gross electricity generation and demand by 2050, since renewable electricity obviates the internal electricity consumption that is associated with conventional power plants. The amount of renewable gross electricity generation equates to the difference between future annual gross electricity generation and the electricity generated by conventional power plants (see Figure 4.1.a).

Figure 4-4 shows the evolution of gross electricity generation in this context and the amount of renewable electricity needed to fill the gap left by conventional power plants that are decommissioned, assuming gross electricity generation amounting to 509 TWh/a by 2050 (in accordance with scenarios 1.a, 2.1.a, 2.2.a and 3.a). As from 2021, the requisite proportion of renewable electricity generation amounting to 310 TWh/a will account for more than 50 percent of gross output. It will be necessary to transition to a wholly renewable electricity supply by 2049.

Figure 4-4

**Renewable gross electricity generation needed by 2050 in TWh/a  
(509 TWh/a in 2050)**



Source: SRU 2010, based on UBA 2009a; BDEW 2008a

Assuming that electricity demand increases steadily to approximately 700 TWh/a by 2050 in accordance with scenarios 1.b, 2.1.b, 2.2.b and 3.b, the amount of renewable electricity needed will rise accordingly (see Figure 4-5). Development of the requisite renewable energy sources will evolve in essentially the same manner

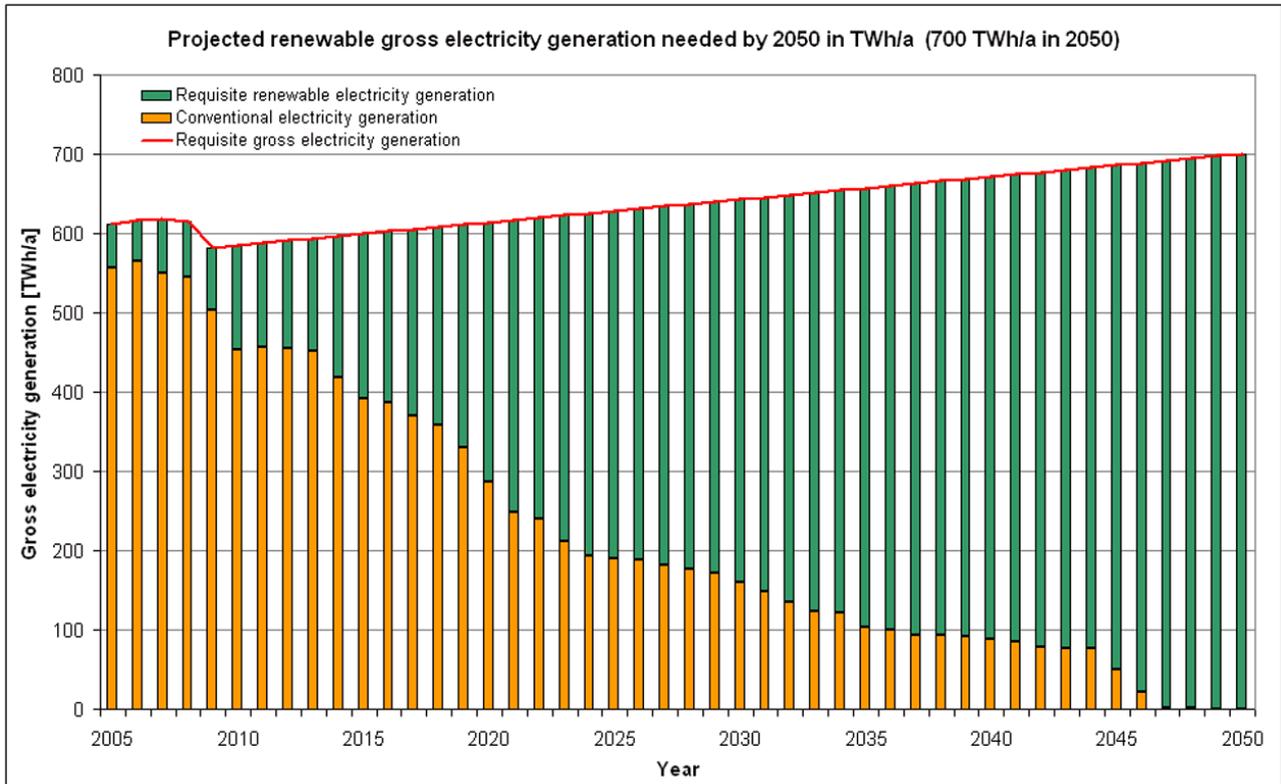
as for 509 TWh/a demand (in 2050), except that overall generation capacity will rise more rapidly. This means that the goal of generating 50 percent of all electricity using renewables (just under 330 TWh/a) will have to be reached in 2020 rather than 2021.

The two roadmaps for transitioning from the electricity system of 2010 to that of 2050 described in the following (and referred to below as transition scenarios) show how the requisite expansion of renewable electricity generation capacity can be achieved by 2050 for both the 509 and 700 TWh/a gross electricity generation scenarios. A deliberate decision was made to forego economic optimisation of the expanded electricity generation technologies, except in the 2050 target scenarios, since our main aim here was to show how the requisite amounts of electricity can be generated by expanding the capacity of various renewables without requiring that the extent to which the specific technologies are used be drastically increased. This approach allows for continuous expansion of production and construction capacity for the various technologies and is expected to minimise obstacles to technical realisation. The scenarios presuppose that the

necessary storage and transmission capacities will be expanded in concert with renewable electricity generation capacities.

Figure 4-5

**Renewable gross electricity generation needed by 2050 in TWh/a  
(700 TWh/a in 2050)**



Source: SRU 2010, based on UBA 2009a; BDEW 2008a

**4.2.1 Transition scenario 2.1.a (509 TWh/a in 2050)**

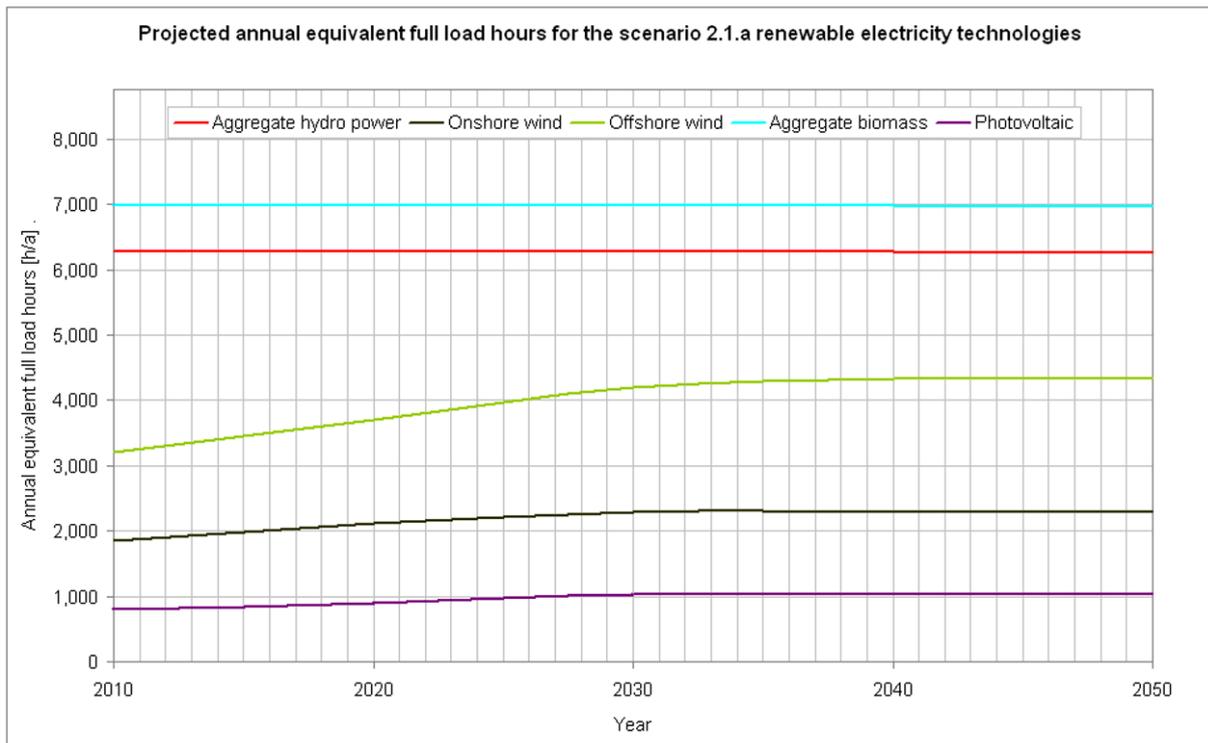
Transition scenarios 2.1.a (509 TWh/a in 2050) and 2.1.b (700 TWh/a in 2050) allow for a maximally smooth transition from today’s energy generation system to the generation structures of target scenarios 2.1.a and 2.1.b for 2050. In this context, it should be borne in mind that the efficiency of, as well as the number of annual full load hours for, the various technologies involved, will improve over time. The assumed curve for annual full load hours is shown in Figure 4-6, whose baseline values constitute currently realisable annual equivalent full load hours (EFLH) and whose end point values constitute the DLR suppositions for the target scenario simulations that was carried out by the DLR. If the suppositions that form the basis for these scenarios are unduly optimistic (a possibility that cannot be excluded), higher capacities than indicated may be needed to satisfy electricity demand, particularly as the curve nears 2050. This evolution would mainly have a cost intensifying effect.

The scenario simulations attempted to provide for expansion of the various renewable energy technologies via an annual installation expansion rate that seems plausible from a technical and

production standpoint against the backdrop of current evolutions. Figure 4-7 shows the consequent gross electricity generation curve for 2005-2050, during which period in some years it is necessary to compensate for the widely varying decommissioning rate of conventional power plants on account of their heterogeneous age structure. Hence the scope of renewable energy source use is expanded in the years leading up to each year where this compensation is deficient owing to a particularly high decommissioning rate, so as to prevent expansion “clumping” during individual years. This in turn can temporarily result in the generation of minor amounts of surplus electricity, which can be used for export purposes. However, a reliable electricity supply in terms of both quantity and demand is achieved via the year in and year out interplay between the capacity expansion timeline discussed in chapter 4.3 and the transmission grid build-out. Cooperative arrangements and electricity interchange in the German-Danish-Norwegian network structure will allow for a fail-safe supply reliability with only moderate capacity expansion.

Figure 4-6

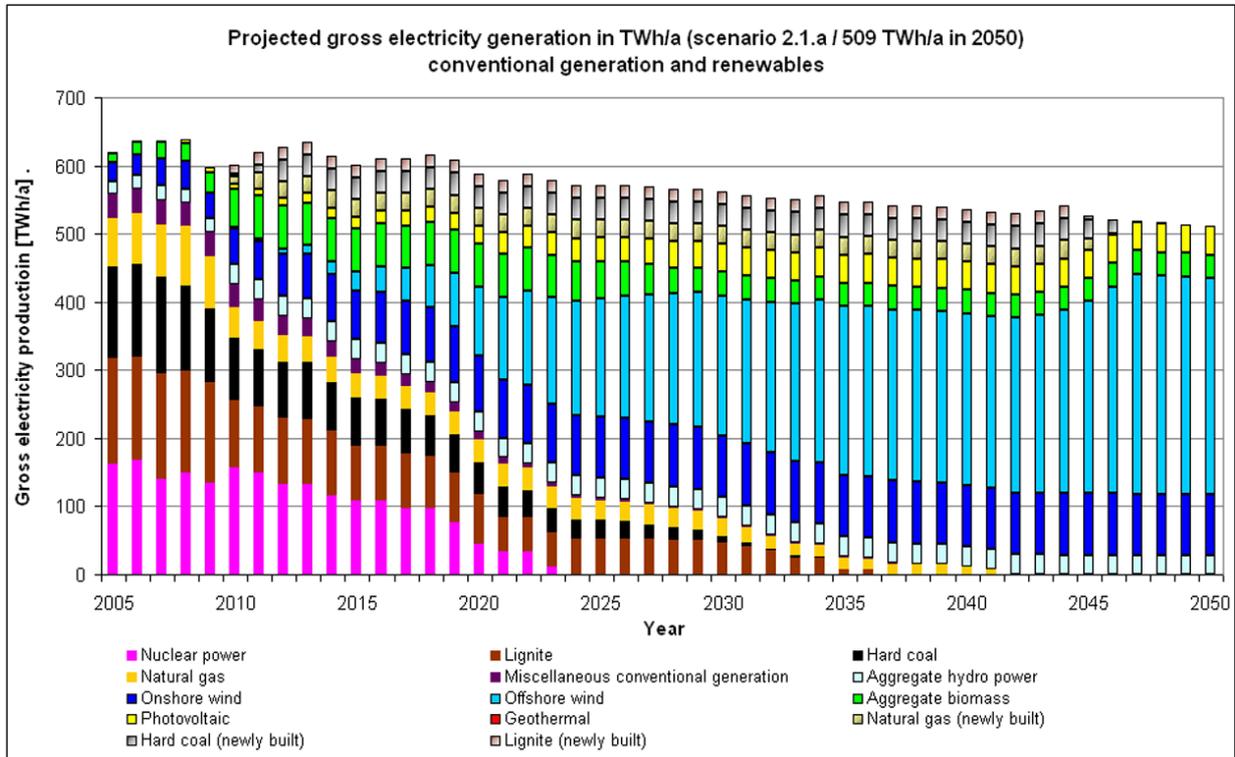
**Projected annual electricity demand equivalent for the scenario 2.1.a renewable electricity technologies (EFLH)**



Source: SRU 2010

Figure 4-7

**Projected gross electricity generation in TWh/a  
(scenario 2.1.a/509 TWh in 2050)**



Source: SRU 2010, based on UBA 2009a; BDEW 2008a

The expanded scope of renewable electricity generation capacity as from 2010 will allow for a steady increase in renewable gross electricity generation to roughly 390 TWh/a by 2024 (see Figure 4-8). The expansion rates needed in this context are comparable to those that were observed from 2005-2008. Despite a steady capacity increase prior to 2009 (see Figure 4-9), electricity generation in that year was considerably lower than would have otherwise been the case, on account of reduced hydro and wind power generation resulting from extreme weather conditions. Our scenarios for 2010 and thereafter presuppose that average weather conditions will prevail. This explains the sharp rise in electricity generation in 2010 relative to the prior year. A considerable increase in renewable electricity generation from 2010-2024 is followed by an only minor rise over the succeeding five years (2025-2029) due to a reduced conventional power plant decommissioning rate. However, biomass use for electricity generation, which is a significant driver of the short term rise in renewable electricity generation between 2010 and 2020, falls off sharply from 2025-2029 due to non-replacement of decommissioned conventional power plants and is replaced by expanded use of offshore wind energy. Rates of biomass use level off between 2030 and 2035, whereas renewable electricity generation rises to approximately 425 TWh/a secondary to further expansion of offshore wind farm use, remaining at virtually this same level until 2041. Following decommissioning of the last conventional power plants in 2042, in 2047 renewable gross electricity generation increases to roughly 515 TWh/a, declining to 509 TWh/a by 2050 secondary

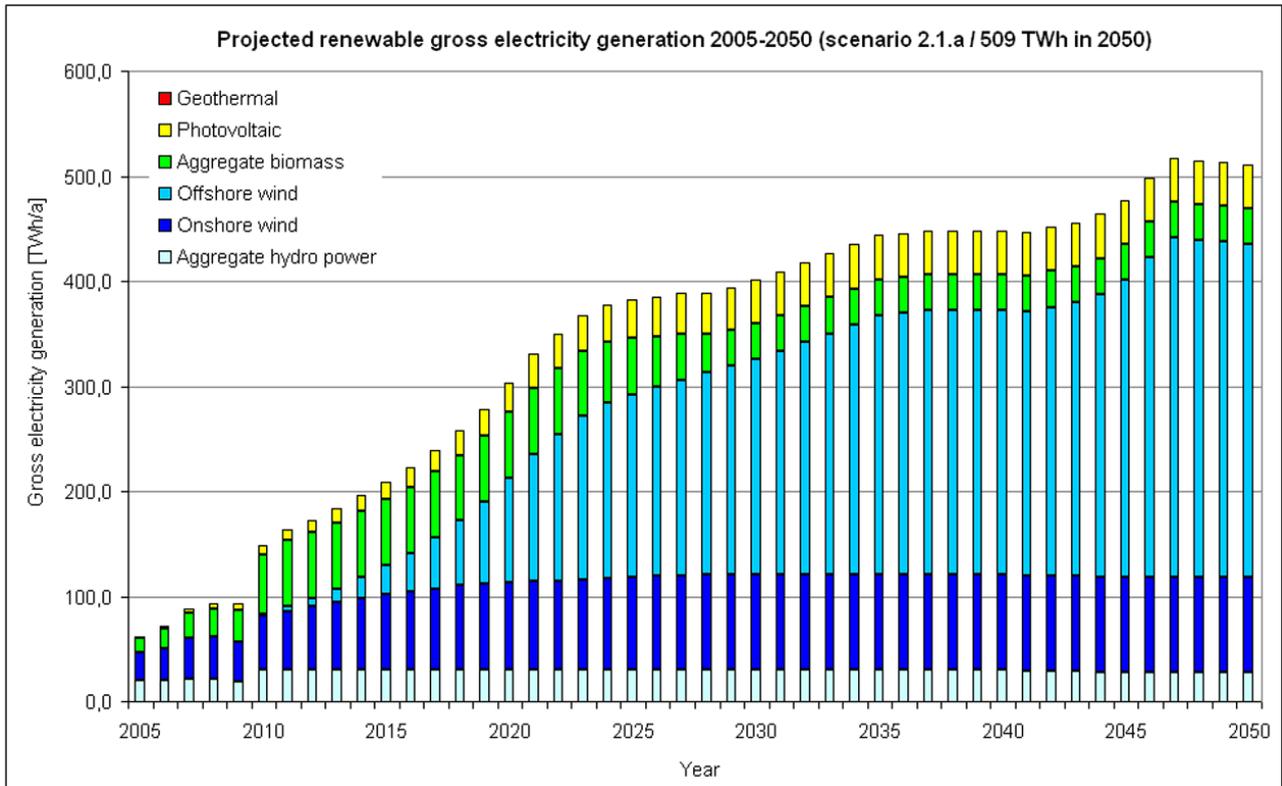
to decreased demand. The proportional share of onshore wind turbine generation rises relatively quickly, reaching its definitive level in 2025. Offshore wind energy production increases steadily until 2036, reaching its full potential in 2047.

The generation capacities for the gross electricity generation shown in Figure 4-8 vary greatly due to the fact that the various renewable electricity technologies require widely varying capacities to generate a terawatt hour. This explains why biomass and geothermal electricity can exhibit extremely high annual operating hours (full load hours). Offshore wind farms can currently achieve full load hours ranging from 3,500-4,500 per year, whereas the figure for German onshore wind farms is only 1,500-2,500 and for photovoltaic electricity generation less than 1,000. The projected annual EFLH for the various renewable electricity technologies is shown in Figure 4-6. Figure 4-9 shows the renewable electricity capacities that will be needed. Figure 4-10 shows the consequent evolution of aggregate electricity generation capacities for transition scenario 2.1.a, including conventional power plant capacity.

The increase in photovoltaic energy generation, which is highly disproportionate to gross electricity generation, is accompanied by steady expansion of renewable electricity generation capacity until 2023 at a rate slightly higher than for 2005-2009 (see Figure 4-10). The expansion of renewable electricity generation capacity necessitates no rise in the requisite expansion rate, even if expansion from just over 40 GW in 2009 to just over 120 GW in 2023 entails mean expansion amounting to 6 GW per year. To all intents and purposes, this expansion rate is not unusual for the industries concerned. For example, in the run-up to 2008 the highest annual wind power expansion rate in Germany was 3.2 GW (in 2002); the figure for photovoltaic facilities was 1.9 GW (in 2008); and for biomass electricity 0.9 GW (in 2007) (BMU 2009, p. 12). In fact, German potential for manufacturing and installing such facilities already exceeds the annual installation rate of 6 GW. Inasmuch as a production capacity expansion amounting to more than 25 percent per year is, as noted, not unusual for the industries concerned, appreciably ramping up such capacity over the next decade would pose little or no problem. Solar cell manufacturing output is currently undergoing a great leap forward. Until recently standard production volumes equated to 0.03 GW of capacity, whereas thin layer solar cells are now being made at a rate of 1 GW per facility and year.

Figure 4-8

**Projected renewable gross electricity generation in TWh/a  
(scenario 2.1.a/509 TWh in 2050)**



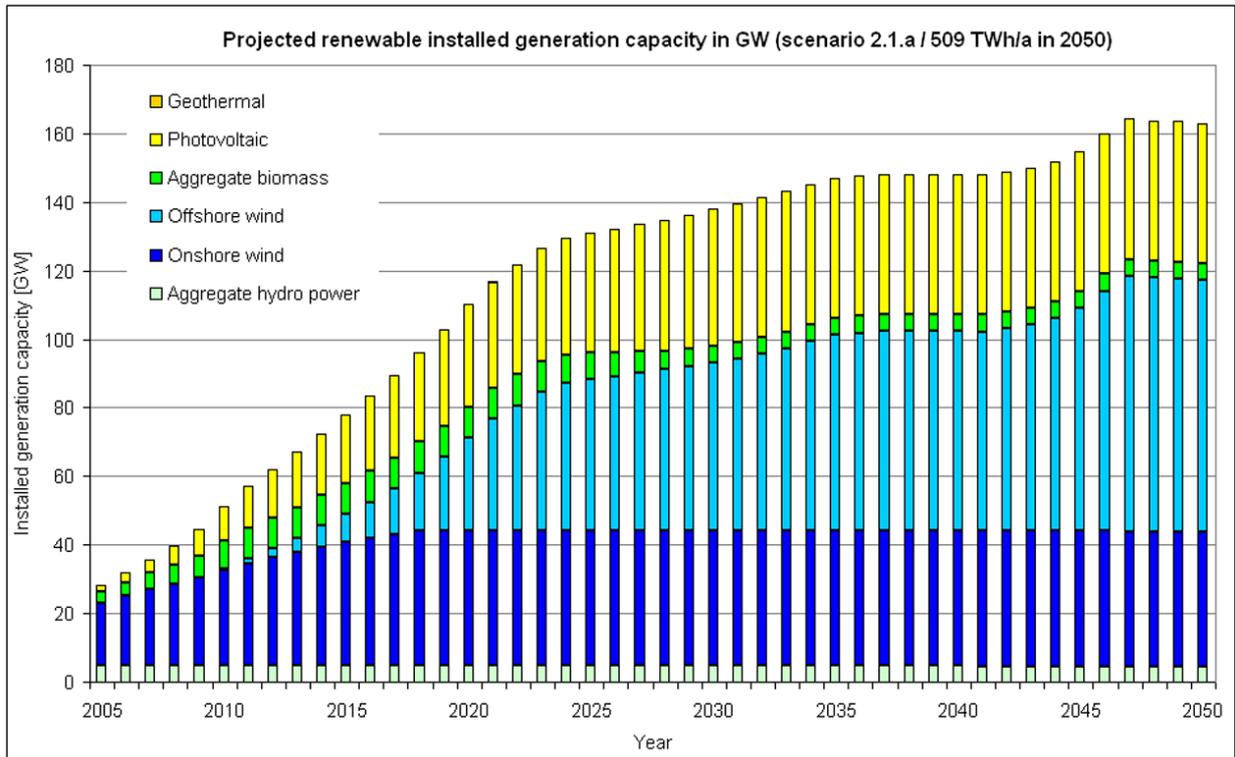
Source: SRU 2010

On the other hand, multiple GW wind power expansion in the North Sea poses a new challenge for the German parties involved. Nonetheless in January 2010 the Crown Estate, Britain’s authorising body in this domain, concluded exclusive development agreements with various consortiums for the construction of offshore wind farms with roughly 30 GW of capacity (The Crown Estate 2010). Although Germany only has one North Sea offshore wind farm, according to government information (Deutscher Bundestag 2010) licenses have been granted for 1,894 offshore wind farms, and the authorisation procedures for an additional 5,178 are in the pipeline. This means that as of March 2010, assuming wind turbine capacity ranging from 3-5 MW, offshore wind farm capacity ranging from 5.7 to 9.5 GW has been given the go ahead and authorisation for an additional 15.5 to 25.9 GW is in the pipeline. This equates to approximately 35 GW of offshore wind capacity (since 5 MW turbines are normally used for such facilities), which would be achieved in transition scenario 2.1.a, in 2022. Although offshore wind farms are in their infancy in Germany, the leading vendors in this domain such as Siemens and Vestas have up to 18 years of experience in wind turbine development and manufacture. It is unlikely that the expansion volume suppositions posited for transition scenario 2.1.a will pose any major unsolved problem for the wind turbine industry. Moreover, the takeover of small wind turbine vendors by major players such as General Electric, Siemens, Suslon and Areva (which have respectively acquired Tacke, Bonus, Repower and Multibrid) ensures that (a) these vendors will have the capital needed for rapid production

capacity expansion and to cover the difficult to predict guarantee risks entailed by the initial phases of massive investments in offshore wind farms; and (b) the extremely dynamic evolution that is necessary in this domain will not be subject to delays or resource shortfalls.

Figure 4-9

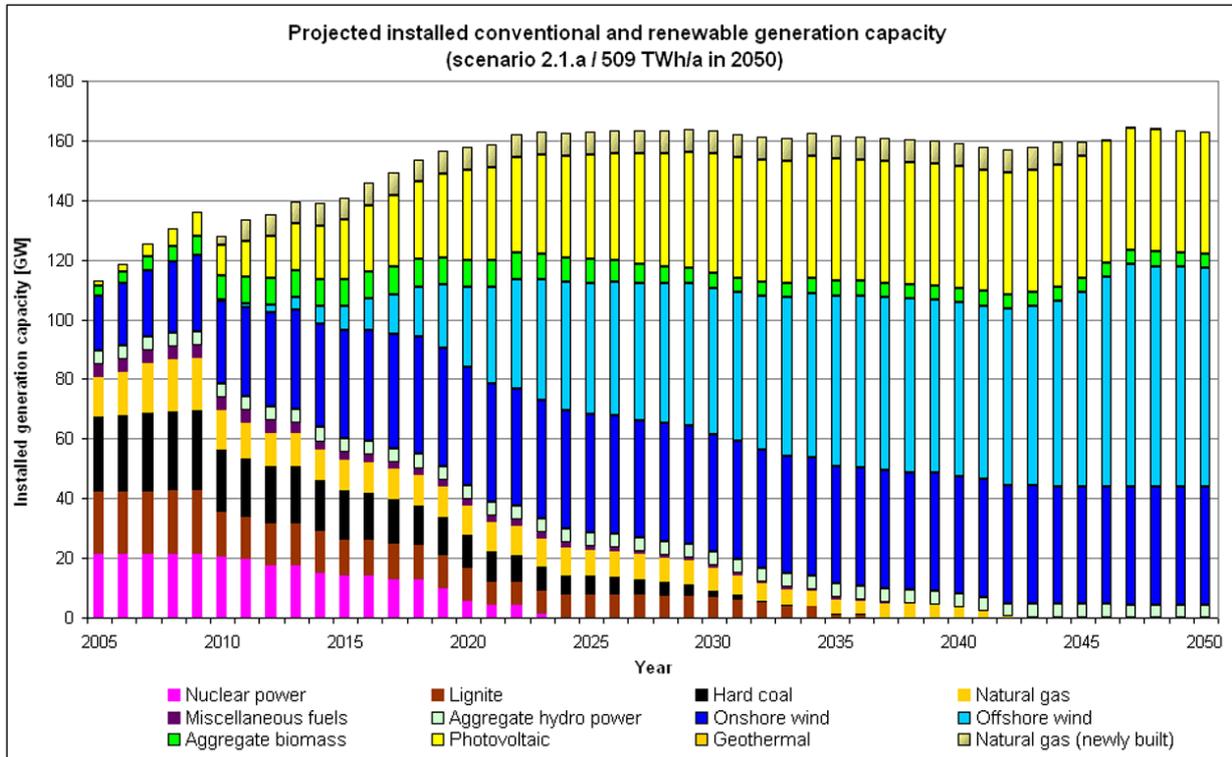
**Projected renewable electricity generation capacity in GW  
(scenario 2.1.a/509 TWh in 2050)**



Source: SRU 2010

Figure 4-10

**Projected aggregate electricity generation capacity in GW  
(scenario 2.1.a/509 TWh in 2050)**



Source: SRU 2010, based on UBA 2009a; BDEW 2008a

Aggregate installed generation capacity for conventional power plants and renewable energy will increase from just under 140 GW in 2009 to roughly 174 GW in 2026, tapering off to just over 160 GW by 2050. This is an amazingly small increase in installed capacity in view of the unavoidable fluctuations in wind and solar energy output, which will in any case have to be supplemented by a substantial expansion of energy storage capacity (pump storage mainly in Norway, and advanced adiabatic compressed air energy storage (AA-CAES) in Germany) in order to satisfy demand round the clock.

**4.2.2 Transition scenario 2.1.b (700 TWh/a in 2050)**

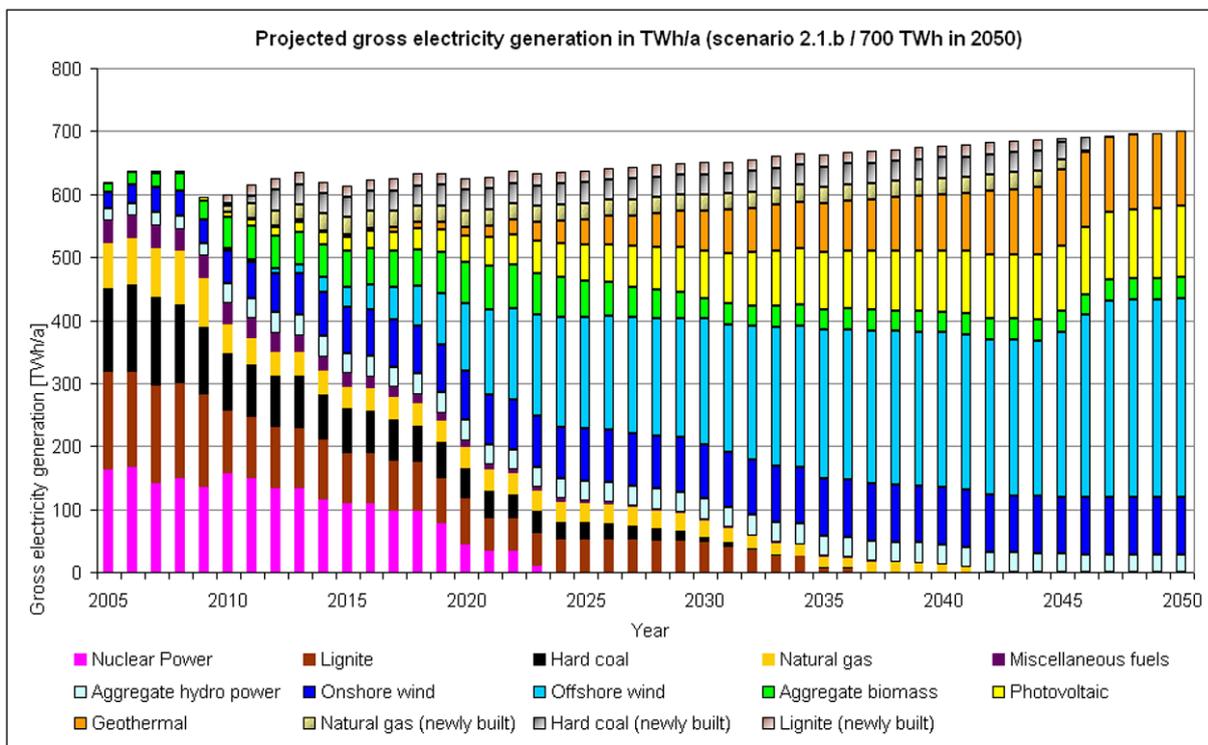
The eventuality that energy efficiency measures will not be implemented in a timely manner and that at the same time the replacement of other energy sources by electricity will be farther reaching than expected is addressed by scenarios 1.b, 2.1.b, 2.2.b and 3.b, which allow for electricity generation amounting to 700 TWh/a in 2050. These scenarios are also relevant for a situation where energy efficiency targets are reached, but at the same time a substantial portion of the greatly reduced heat demand, in addition to transport, is substituted by electricity. Scenario 2.1.b, which illustrates the putative transition in this regard, allows demand amounting to 700 TWh/a to be met in Germany, and at the same time allows for electricity interchange and the use of Danish and Norwegian pump storage system capacity within the German-Danish-Norwegian network.

Figure 4-11 shows projected gross electricity generation in scenario 2.1.b, which calls for a long term increase in electricity generation and replacing conventional generation capacity with renewable energy sources.

Noteworthy here is the substantial proportion of electricity generation accounted for by geothermal energy relative to scenario 2.1.a (see Figure 4-12), where geothermal energy is not used on account of its elevated generation costs but is needed to satisfy the high level of demand in scenario 2.1.b (700 TWh/a).

Figure 4-11

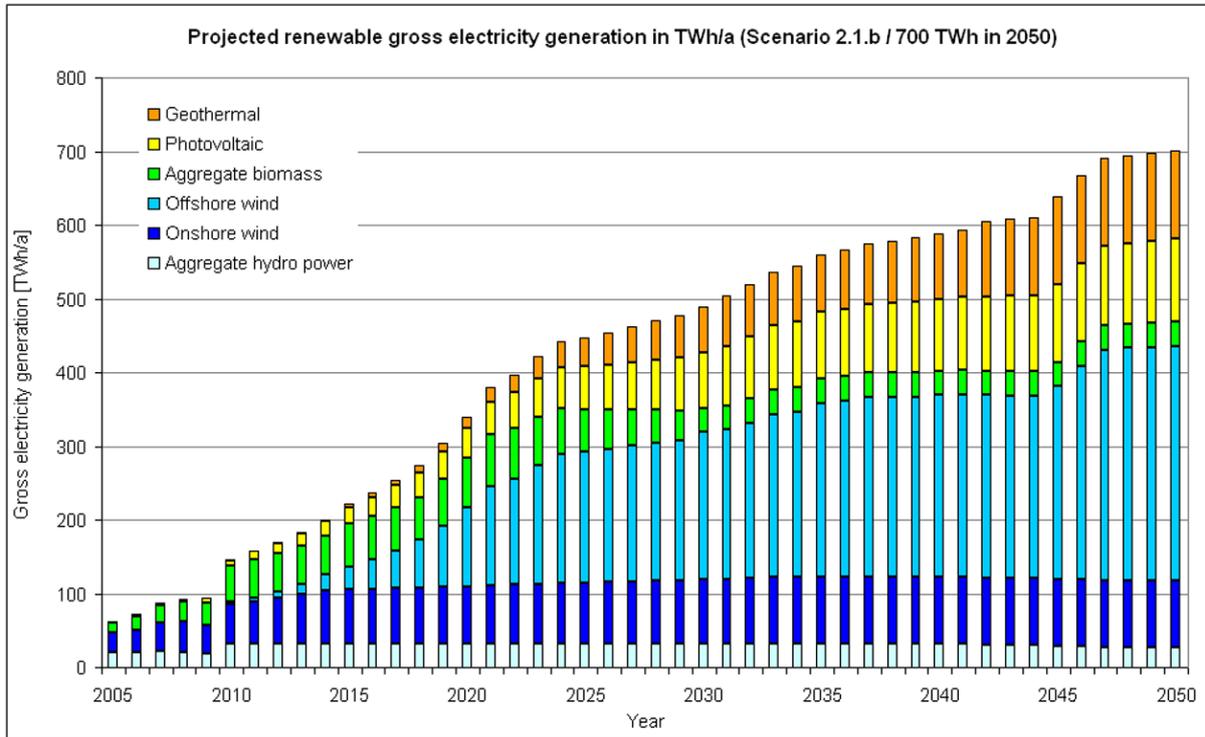
**Projected gross electricity generation in TWh/a  
(scenario 2.1.b/700 TWh in 2050)**



Source: SRU 2010, based on UBA 2009a; BDEW 2008a

Figure 4-12

**Projected renewable gross electricity generation in TWh/a  
(scenario 2.1.b/700 TWh in 2050)**



Source: SRU 2010

The requisite capacity expansion for renewable electricity slightly exceeds the trend of recent years, ultimately reaching installed capacity of just over 150 GW by 2023 (see Figure 4-13). To reach this goal, it will be necessary to expand capacity at a rate of just under 8 GW per year; though 2 GW higher than in transition scenario 2.1.a, this is fully realizable in light of the expansion rates that have been registered in the relevant industries in recent years.

The lion's share of the increased capacity relative to transition scenario 2.1.a is accounted for by an approximately 69 GW increase (to 112 GW) in photovoltaic electricity generation. Generation capacity will have to be increased to just under 250 GW by 2050 (see Figure 4-14) in order to satisfy total electricity demand in that year. Inasmuch as the allowable wind energy expansion in transition scenario 2.1.a (509 TWh/a in 2050) has been reached, the remaining electricity will have to be produced via additional photovoltaic and geothermal capacity amounting to 70 and 120 TWh/a respectively.

Like scenario 2.1.a, scenario 2.1.b allows for continuous transition to new renewable electricity generation structures without any discontinuities in supply structures or the need for extremely high expansion rates. This scenario also necessitates an expansion of installed capacity chiefly by expanding compressed air energy storage in Germany and pump storage in Norway.

## 4.3 Transmission and storage capacity expansion

### 4.3.1 Why expansion?

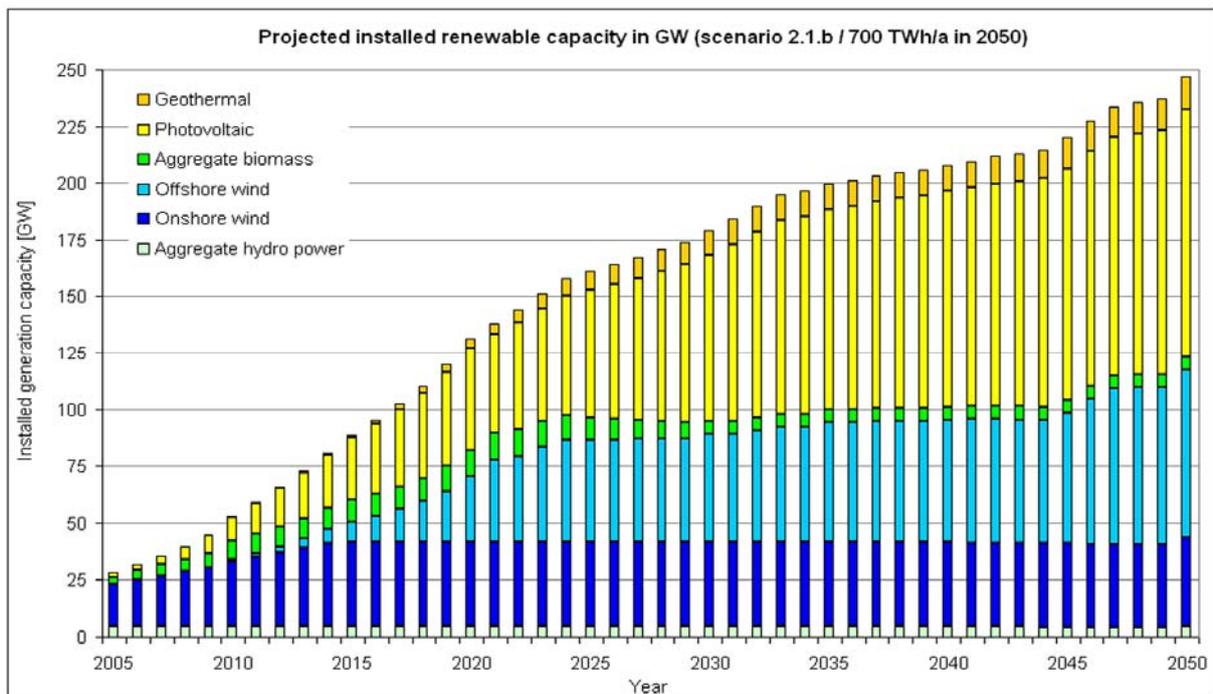
Substantial insolation and wind velocity variation can result in major fluctuations in local electricity generation for wind and solar power installations. Inasmuch as electricity generation must meet demand at all times in order to achieve a reliable electricity supply and grid stability, the so called residual load resulting from this intermittency must be covered. In cases where electricity generation from renewables exceeds demand, production can be reduced or the virtually cost-neutral surplus thus generated can be stored for later use. The following technologies are currently available for balancing intermittency:

- Energy storage
- Wide area transmission network
- Dispatchable power stations
- Demand side management (DSM)

These options could be combined in various ways to balance electricity generation and demand. The combinations that would deliver the most cost effective electricity under any given set of conditions can be determined via technical and economic simulations using models such as the German Aerospace Center's REMix model (DLR 2010a) or the Czisch model (Czisch 2009).

Figure 4-13

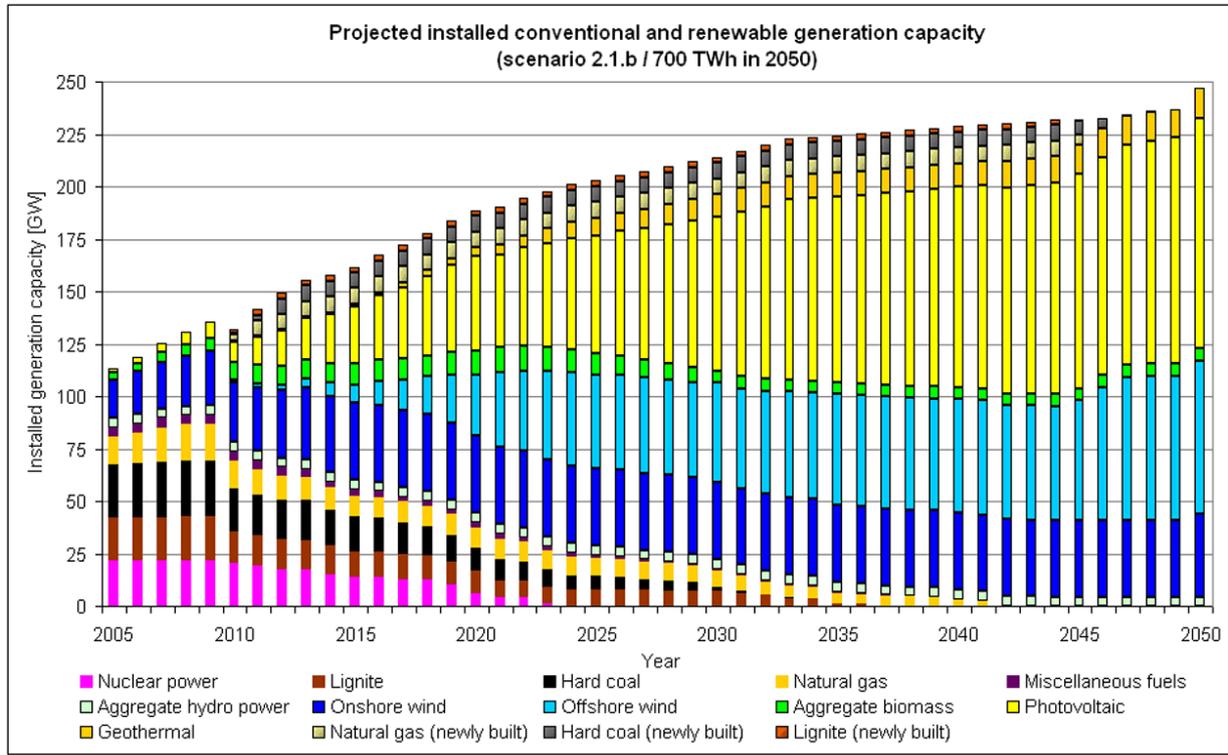
#### Projected renewable electricity generation capacity in GW (scenario 2.1.b/700 TWh in 2050)



Source: SRU 2010

Figure 4-14

**Projected aggregate electricity generation capacity  
(scenario 2.1.b/700 TWh in 2050)**



Source: SRU 2010, based on UBA 2009a; BDEW 2008a

The putative scope of storage and grid expansion described in the following is based on the simulations carried out by the DLR using the aforementioned models. The balancing options using dispatchable power plants and system performance in the German power plant fleet are discussed in chapter 4.4. We assumed that load dispatching will mainly be used for ancillary services in view of the relatively minor and difficult to develop capacity involved, i.e. maximum potential for energy intensive industries in Germany amounting to approximately 2.9 GW (Grimm 2007, p. 16). However inasmuch as ancillary services and technical grid stability exceed the scope of the present report they will not be discussed further.

### 4.3.2 Storage systems

Inasmuch as electricity can only be used immediately being generated if it is transmitted by power lines, it can only be stored after being converted to another form of energy. This property of electricity has prompted the development of many technologies that are compatible with various applications depending on the characteristics of the storage system involved. The key technical characteristics that are used to assess energy storage system are as follows: storage capacity and performance; efficiency; storage loss; power density; power gradient; and life cycle. The extent to which overall potential can be developed, as well as storage costs, are also relevant in this regard.

The forms of use of electricity grid storage systems include second reserves (which is one of the aforementioned system services), uninterruptible power supplies, and daily, weekly and annual equalisation solutions. In keeping with the present report's focus on energy storage in connection with the expansion of renewable energy with a view to achieving a wholly renewable electricity supply in Germany and Europe, the following technologies that allow for large scale electricity storage for daily, weekly and annual equalisation purposes are particularly relevant here (Leonhard et al. 2008, p. 21):

- Storage of potential energy via pump storage systems
- Storage of mechanical energy via compressed air energy storage systems
- Storage of chemical energy via hydrogen, hydrogen compounds and the like
- Storage of electrochemical energy using batteries

### Storage technologies

Pump storage systems are hydro power plants that are designed for both generator and pump operation. In cases where electricity supply exceeds demand, surplus electricity can be used to pump water from a lower basin to a higher basin. During peak load periods or the like, the power plant can then convert the stored energy into electricity via a generator and feed the electricity into the grid.

Germany currently has approximately 7 GW of pump storage system capacity and approximately 0.04 TWh of storage capacity (Leonhard et al. 2008, p. 21; Oertel 2008, p. 35) whose efficiency ranges from 70-80 percent (Neupert et al. 2009, p. 133).

In light of the topographical criteria that must be met (few high mountains in the area concerned) for pump storage systems and the large scale environmental interventions entailed by their realisation, in our view there is little additional potential available for this technology in Germany.

In the rest of Europe, most of this potential is found in Scandinavia and in the Alpine regions. Norway alone has hydro reservoir systems with storage capacity of up to 84 TWh (Nord Pool ASA 2010a), many of which could be converted to pump storage systems by installing the necessary riser pipes and additional pumps. Moreover, Sweden has hydroelectric storage capacity amounting to nearly 34 TWh (Nord Pool ASA 2010b).

The technical and economic parameters that formed the basis for the suppositions in the pump storage system scenarios discussed here are listed in Table 4-2.

Compressed air energy storage (CAES) plants are gas turbine power plants which, with the aid of electrical compressors, use surplus electrical energy to compress ambient air with a view to storing it in salt caverns or aquifers. This air can then be fed into a gas turbine during peak load periods in such a way that electricity is generated. Thus in conventional gas turbines such stored compressed

air obviates and replaces the compressor phase that would otherwise consume up to two thirds of the energy used in the power plant (Crotagino 2003, p. 4).

Unlike pump storage, CAES entails the use of additional fuel since the compressors dissipate heat into the environment and the cooled stored compressed air must be heated to several hundred degrees Celsius before being used to generate electricity. This reduces the efficiency of CAES systems to less than 55 percent (Crotagino 2003, p. 4).

This efficiency is currently optimised using advanced adiabatic compressed air energy storage (AA-CAES) systems, which temporarily store compression heat in heat accumulators so that it can be used to reheat the compressed air prior to use. This process uses no additional fuel and increases the efficiency of CAES systems to approximately 70 percent (Neupert et al. 2009, p. 129).

No AA-CAES systems are currently in use in Germany. The only CAES gas turbine power plant in operation in Germany is E.ON's Huntorf peak load power plant, which has been in operation since 1978 and has storage volume amounting to 300,000 cubic meters and 321 MW of capacity. This storage volume equates to approximately 0.642 GWh under the technical conditions that prevail at the plant. Hence the available compressed air energy storage capacity in Germany is negligible compared to the terawatt hours of capacity that are needed. Total storage potential via the many salt mines that are available, particularly in Northern Germany, is estimated to be as high as 3.5 TWh (Ehlers 2005, p. 4). However, this estimate was realised within the framework of a University of Flensburg diploma thesis and should thus be regarded as a preliminary assessment only. Scientifically sound results in this domain will necessitate further investigations.

The technical and economic parameters that formed the basis for AA-CAES suppositions in the scenarios discussed here are listed in Table 4-3.

Another storage technology is provided by electrolysis, that can be used to convert surplus electrical energy to hydrogen, which after being compressed is stored in conventional gas reservoirs in caverns or aquifers. However, thanks to the higher energy density of hydrogen, approximately 60 times more energy can be stored in the same space than in CAES storage systems (Leonhard et al. 2008, p. 25). Gas turbines, gas engines, or fuel cells can be used to convert the hydrogen back to electricity. The efficiency of the entire storage process entailing electrolysis, compression and fuel cell conversion is currently around 44 percent (DLR 2010a).

The technical and economic parameters that formed the basis for the suppositions in the scenarios discussed here involving hydrogen storage and electricity recovery using fuel cells are listed in Table 4-4.

Table 4-2

**Technical and economic parameters used for pump storage systems**

	unit	2010	2020	2030	2040	2050
<b>technical parameters</b>						
roundtrip efficiency		0.8	0.8	0.8	0.8	0.8
losses per hour	1/h	0	0	0	0	0
storage capacity in relation to power block size	kWh/kW	8	8	8	8	8
availability factor	-	0.98	0.98	0.98	0.98	0.98
<b>economic parameters</b>						
investment costs converter	€/kW	1600	1600	1600	1600	1600
fixed operation costs converter (percentage of original investment)	-	0.01	0.01	0.01	0.01	0.01
fixed operation costs converter (absolute)	€/kW	16	16	16	16	16
life-time converter	a	20	20	20	20	20
investment costs storage	€/kW	0	0	0	0	0
fixed operation costs storage (absolute)	€/kWh	0.1	0.1	0.1	0.1	0.1
life-time storage	a	60	60	60	60	60
variable operation costs	€/kWh	0.000	0.000	0.000	0.000	0.000

Source: DLR 2010a

Table 4-3

**Technical and economic parameters used for AA-CAES systems**

	unit	2010	2020	2030	2040	2050
<b>technical parameters</b>						
roundtrip efficiency		0.7	0.78	0.78	0.8	0.8
losses of pressure and heat per hour	1/h	0.002	0.002	0.002	0.002	0.002
availability factor	-	0.95	0.95	0.95	0.95	0.95
<b>economic parameters</b>						
investment costs converter	€/kW	310	300	300	290	280
fixed operation costs converter (percentage of original investment)	-	0.02	0.01	0.01	0.01	0.01
fixed operation costs converter (absolute)	€/kW	6.2	3	3	2.9	2.8
life-time converter	a	25	25	25	25	25
investment costs cavern/container	€/kWh	50	50	50	50	50
investment costs cavern/container, growing share of containers	€/kWh	50	50	140	230	275
fixed operation costs cavern (percentage of original investment)	-	0.02	0.01	0.01	0.01	0.01
fixed operation costs cavern (absolute)	€/kWh	1	0.5	0.5	0.5	0.5
life-time cavern	a	40	40	40	40	40
variable operation costs	€/kWh	0.000	0.000	0.000	0.000	0.000

Source: DLR 2010a

Table 4-4

**Technical and economic parameters used for hydrogen storage**

	unit	2010	2020	2030	2040	2050
<b>technical parameters</b>						
roundtrip efficiency		0.44	0.46	0.47	0.48	0.49
losses per hour	1/h	0.002	0.002	0.002	0.002	0.002
storage capacity in relation to power block size	kWh/kW	200	200	200	200	200
availability factor	-	0.95	0.95	0.95	0.95	0.95
<b>economic parameters</b>						
investment costs converter	€/kW	1500	1500	1500	1500	1500
fixed operation costs converter (percentage of original investment)	-	0.02	0.01	0.01	0.01	0.01
fixed operation costs converter (absolute)	€/kW	30	15	15	15	15
life-time converter	a	5	5	5	5	5
investment costs cavern	€/kWh	50	50	50	50	50
fixed operation costs storage (percentage of original investment)	-	0.02	0.01	0.01	0.01	0.01
fixed operation costs storage (absolute)	€/kWh	1	0.5	0.5	0.5	0.5
life-time storage	a	20	20	20	20	20
variable operation costs	€/kWh	0.000	0.000	0.000	0.000	0.000

Source: DLR 2010a

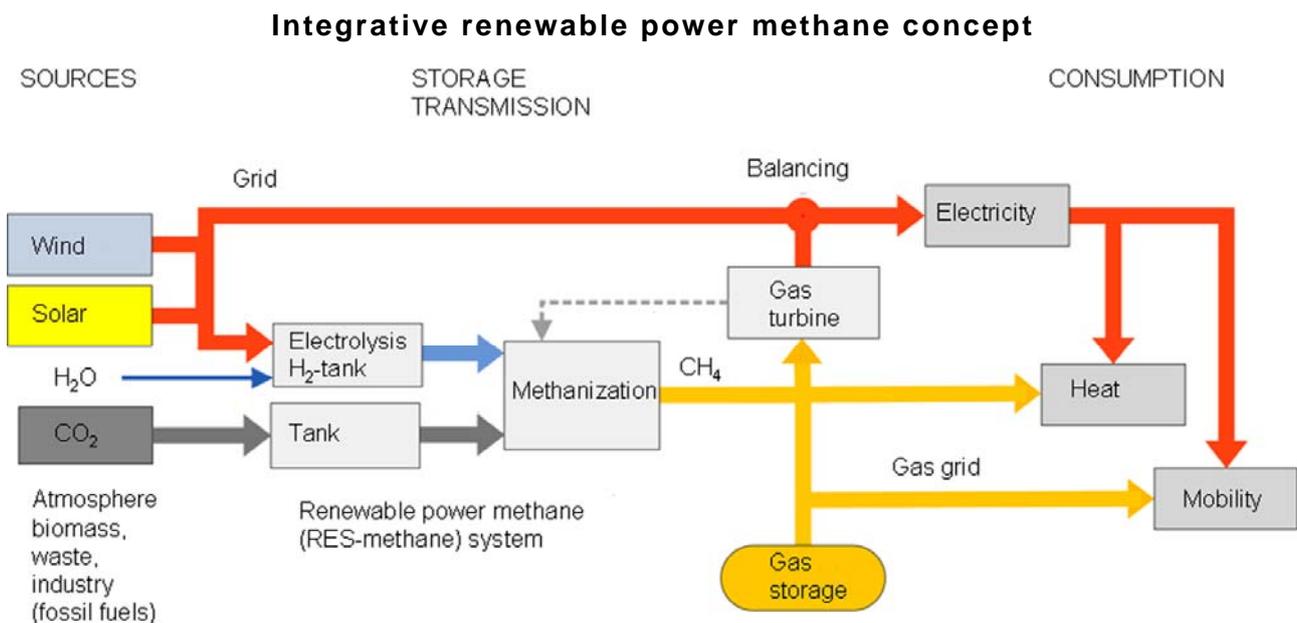
Despite the low efficiency of the process chain as a whole, this technology holds out promise for the storage of renewable energy in view of the fact that considerable storage capacity potential is available in Germany, and hydrogen produced via renewables can be used in the transport, heat and industrial sectors.

If this kind of multi-sectoral system approach is given more weight, the renewable power methane (RPM) concept (Sterner 2009) (see Figure 4-15) could provide a promising alternative or supplement to hydrogen storage. This concept, which was developed by Fraunhofer IWES (Fraunhofer-Institut für Windenergie und Energiesystemtechnik), is based on hydrogen methanisation, a technology that produces hydrogen using renewable electricity.

Although the efficiency of the RPM concept up to the methane storage phase is around 60 percent and is only around 36 percent for the electricity yielded by the process chain as a whole, this concept offers key advantages by virtue of its being applicable in a range of sectors and the fact that methane energy density exceeds that of hydrogen by a magnitude of five. Tremendous capacity potential could be tapped by intermeshing the electricity and natural gas grids and the attendant heating, transport and industrial infrastructures, which are already available, in contrast to the situation in the hydrogen sector.

In view of the fact that aggregate accumulator potential for long term energy storage and the requisite large storage capacity is lower than that of pump, hydrogen or compressed air storage technologies, this capacity was excluded from the scenario simulations discussed in the present report. Accumulators will be used in the coming years chiefly for network applications in the system services sector.

Figure 4-15



Source: Sterner und Schmid 2009

The role of storage systems in the scenarios discussed in this report

In the following, we discuss the role played by energy storage in the scenario simulations and which forms of storage were taken into consideration for the present study. This discussion mainly revolves around scenario group 2 (renewable electricity in the German-Danish-Norwegian energy supply network) and describes in detail the measures necessary for system integration of Scandinavian pump storage capacity. In our view, in all likelihood Germany would need to partner with Norway and other Scandinavian states, which would be a robust strategy even if a relatively large scale European energy supply network is to be established over the long term. For purposes of comparison, the role of energy storage in scenario groups 1 (German self sufficiency) and 3 (Europe-North Africa network) will be discussed briefly.

Scenario 1.a, which is intended as a hypothetical reference scenario (full German self sufficiency with annual demand amounting to 500 TWh), necessarily calls for extensive use of German energy storage potential in 2050, at which time a total of roughly 50 TWh of electricity would be stored as compressed air, and after allowing for energy loss approximately 34 TWh of this amount would be fed back into the grid. Over a 12 month period, approximately 1.2 TWh of energy would be stored in pump storage systems and approximately 1 TWh would be fed back into the grid. The energy difference between storage and output is based on conversion and storage loss, and thus cannot be fed back into the system.

Of Germany's estimated compressed air energy storage capacity amounting to 3.5 TWh (Ehlers 2005), up to 1.4 TWh (the difference between minimum and maximum storage levels) is used in scenario 1.a, whereby the amount stored over the course of a year (except for a few weeks) fluctuates by only 0.8 TWh, which means that effecting the relevant optimisation could potentially reduce the amount of aggregate storage capacity needed. The maximum pump storage capacity used amounting to less than 0.05 TWh is only slightly higher than the capacity that is already available in Germany today. This finding is reflective of our simulation supposition to the effect that German pump storage system capacity would not need to be expanded.

Despite the intensified use of compressed air energy storage in scenario 1.a, installed renewable electricity capacity amounting to 230 GW would have to be retained so as to ensure that demand can be reliably satisfied. However, this translates into a surplus of renewable (gratis) energy that cannot be used in Germany amounting to 53 TWh. This represents 10 percent of total German demand, assuming this figure is 500 TWh. Inasmuch as this surplus production would mainly occur during periods of high wind, it can be avoided by reducing wind power generation. However, this would increase mean electricity generation costs and prices.

Scenario 2.1.a foregoes the self sufficiency restriction, positing that Germany could exchange up to 15 percent of its annual output with Denmark and Norway. This considerably reduces the use of compressed air energy storage capacity in Germany, whereby aggregate annual storage declines from 50 to 5.7 TWh, while the amount of electricity fed into the grid declines from 34 to 4.3 TWh. In

this scenario, the lion's share of the requisite storage would be covered by less cost intensive pump storage systems in Norway, thus reducing the installed generation capacity needed in Germany from 230 GW in scenario 1.a to 163 GW and reducing the annual energy surplus from 53 to 0.8 TWh. Even the limited cooperation entailed by the German-Danish-Norwegian network would roll back Germany's electrical energy costs to a greater extent than would be the case in the German self sufficiency scenario. Under the conditions defined for scenario 2.1.a, which disallows net electricity import, Denmark would be an electricity transit state for all practical purposes, whereby Germany's electricity interchange would revolve around Norwegian storage capacity.

In order for German electricity interchange with Norway to be technically and economically feasible, the following three phase procedure would have to be implemented:

- Phase 1: Use of Norwegian electricity demand for load reduction purposes
- Phase 2: In addition, use of available Norwegian pump storage capacity
- Phase 3: Further conversion of hydro reservoir into pump storage systems in tandem with turbine capacity expansion

In phase 1, surplus German renewable electricity output could be used to cover part of Norway's electricity demand and thus replace hydro power plant operation. The consequent dormant water volumes could be used later to export electricity to Germany. The long term minimum load that would be available for this arrangement in the Norwegian supply zone is at least 7 GW, a figure that was not undercut between 2000 and 2010 (Statistics Norway 2010b). Norway is a suitable load reduction "facility" mainly by virtue of the fact that an average of more than 95 percent of Norwegian electricity output comes from storage hydroelectric power stations (Statistics Norway 2010a), which can be reduced at almost no additional cost. Moreover, in contrast to wind power, the used energy remains available as water. As this phase would require no additional investment except for transmission capacity expansion, it could begin immediately insofar as German renewable electricity generation peaks exceed domestic demand and the requisite transmission capacity has been installed.

Germany can currently interchange approximately 1.5 GW of capacity with Norway, via Denmark. Apart from this, the Nordlink and NorGer German-Norwegian transmission lines, which are slated to go into operation in 2018 and 2015 respectively, will each provide 1.4 GW of capacity (Fagerholm et al. 2010, p. 61). In order for the 7 GW of load reduction to be fully used, transmission capacity amounting to approximately 2.7 GW above and beyond the foregoing capacity would need to be installed between Norway and Germany.

Like phase 1, phase 2 would necessitate no additional investment apart from transmission capacity expansion, since only the available Norwegian pump storage capacity would be used. However, the available pump storage capacity would limit the scope of the load reduction to approximately 1 GW (NVE 2010). This load reduction option would be used whenever surplus renewable electricity generation in Germany exceeds the load reduction represented by Norwegian electricity demand

(i.e. phase 1). The rationale for this restriction is that pumping and generation loss would translate into higher storage costs for the output replaced in phase 1.

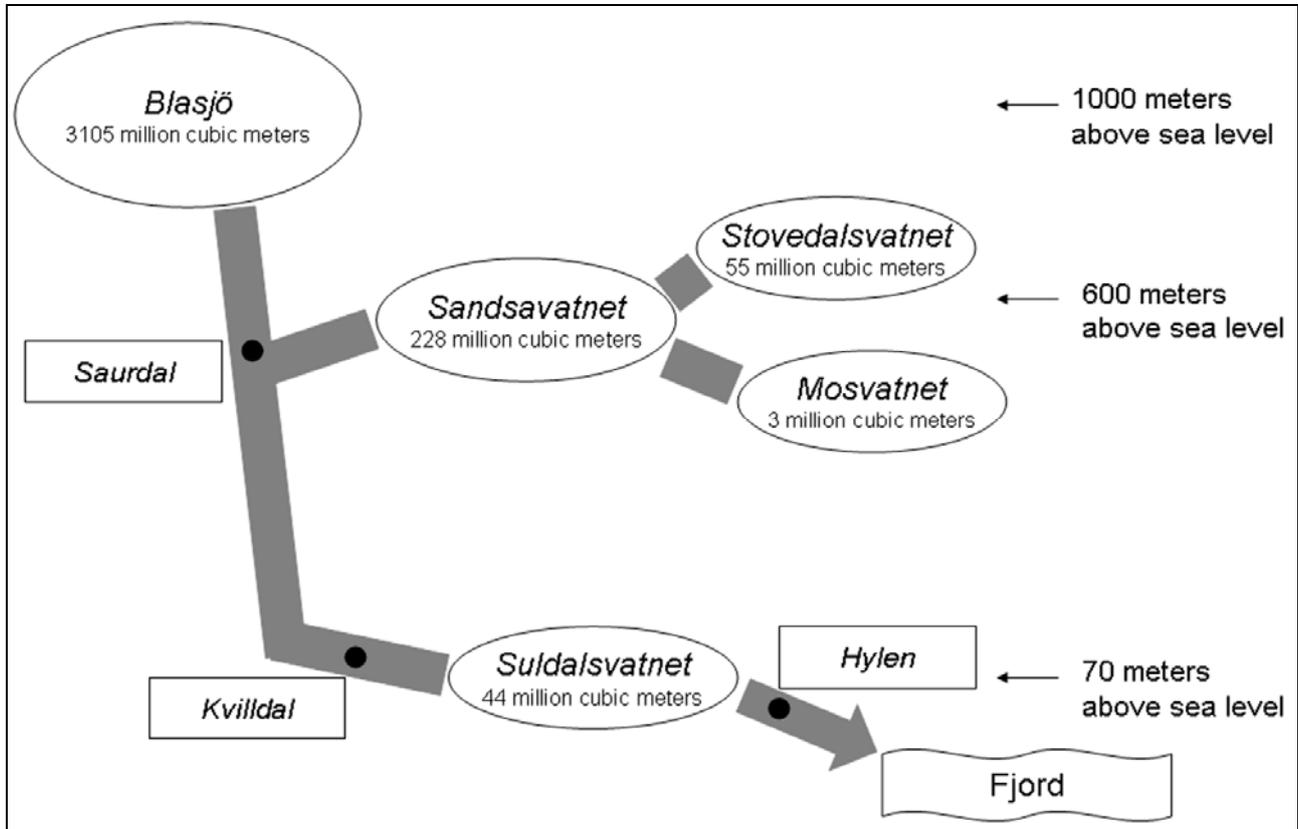
If these first two phases involving use and storage of Germany's surplus production fail to achieve the desired results, in phase 3 it would be possible to incrementally use Norwegian pump storage potential by converting storage hydroelectric power stations into pump storage systems. Most of Norway's approximately 370 storage hydroelectric power stations comprise a multi-lake systems whose various lakes are oftentimes interconnected by underground tunnels and pressure shafts. As Figure 4-16 shows, such systems – as in the example in the diagram, which actually comprises a series of additional lakes and power plants – are cascades of various lakes and power plants that can be converted to pump storage systems at a relatively low cost.

Our initial research shows that the height of drop and volume capacity of the Tonstad and Kvilldal storage hydroelectric power station lower lakes alone offer theoretical pump storage potential amounting to some 12 TWh (based on one circulation cycle of the storage content). However, inasmuch as Norway's hydro power system comprises a vast number of storage hydroelectric power stations that have lower lakes, it is safe to assume that a substantial portion of the available storage hydroelectric power station capacity amounting to 84.3 TWh (Nord Pool ASA 2010a) can be converted to pump storage capacity. In view of this supposition, scenario 2.1.a calls for maximum demand amounting to 22 TWh (maximum energy input or output).

To obtain the approximately 50 GW input and output capacity required for scenario 2.1.a, the turbine capacity of Norwegian power plants (currently 22 GW) would have to be expanded, apart from stepping up pumping capacity. This would necessitate the construction of additional inflow tunnels, pressure shafts, pumps and turbines whose realisation would necessitate long term planning and sufficiently long lead times. According to our calculations, these expansion projects could be completed more rapidly than the counterpart North Sea transmission line build-out or installation of high voltage line capacity from the German North Sea coast to German centres of electricity consumption. These relatively short lead and planning phases are mainly attributable to the fact that no new storage lakes would have to be created and that most of the construction work would take place underground (excavating pump/turbine tunnels and caverns).

Figure 4-16

**Schematic drawing of a characteristic Norwegian storage hydroelectric power station complex (Ulla-Førre power plants)**



Source: SRU 2010; based on Statkraft (undated)

We projected the curve of the requisite storage capacity by elaborating a possible capacity development roadmap using the prognosticated scope of renewable electricity generation expansion laid out in chapter 4.2, in conjunction with German electricity load that will have to be handled. Figure 4-17 shows the wind or photovoltaic energy induced capacity peaks exceeding the minimum and maximum German grid loads in our simulation, amounting to 35 and 81 GW respectively. The consequent surplus capacity is thus indicative of the scope of the need to expand storage capacity and cross-border transmission capacity. However, Figure 4-17 also overstates the demand that could be met reasonably from an economic standpoint, by virtue of the fact that this graph takes account of all surplus capacity, even if it only occurs for one hour each year. But of course such rare load peaks do not allow for the economically requisite capacity use of storage systems and transmission lines. Hence it is safe to assume that the capacity needed during the transitional period will fall far short of the capacity shown in Figure 4-17. However the projected storage and transmission capacities for 2050 are not unduly optimistic by virtue of having been derived from technically and economically optimised simulations. Inasmuch as scenario 2.1.a allows Germany to interchange electricity only with Denmark and Norway, the entirety of the 42 GW of Germany's projected surplus capacity in the 2050 scenario would be passed to Denmark

and Norway, where it would be used to satisfy electricity demand and/or stored in pump storage systems.

As Figure 4-17 shows, the scope of load reduction options and available pump storage system capacity in Norway entailed by the first and second expansion phases amounting to 8 GW would soon (between 2014 and 2020) be insufficient to absorb Germany's surplus capacity. The transition scenario 2.1.a simulation of the requisite storage capacity for the proposed wind energy expansion (based on projected demand for 2050) showed that more than 8 GW of Norwegian storage capacity would be needed as from 2017; this figure would roughly double by 2020 and by 2025 would rise by an additional 10 GW. This also holds true for transmission capacity expansion, where the shortfall would be even larger. The available and envisaged transmission capacity between Germany and Norway is currently only slightly above 4 GW, of which only about 1.5 GW actually exists. Larger scale expansion of renewable electricity generation in Germany (which the government has also called for) would necessitate the following, even if the expansion rate is lower than defined in our scenarios: connecting of wind energy capacity to German demand centres (see below); and optimally expeditious expansion of (a) transmission capacity between Germany and Scandinavian storage hydroelectric power station facilities; and (b) conversion of Scandinavian storage hydroelectric power station capacity to pump storage system capacity.

As scenario 2.1.a simulations showed, Norway could potentially be the key driver of successful German expansion of renewable electricity capacity by virtue of (a) Norway's large storage hydroelectric power station capacity (84 TWh), which is based on hydropower use derived from storage lake cascades; and (b) the fact that transmission lines to intermesh this capacity with German North Sea wind farms would be relatively easy to install as these lines would not pass through densely populated areas. Moreover Sweden could assume an analogous role and supplement Norwegian capacity by virtue of Sweden's (a) storage hydroelectric power station grid similarity to that of Norway; and (b) approximately 34 TWh of storage hydroelectric power station capacity. On the other hand, Austria and Switzerland could not play this role in view of (a) their far lower storage capacity amounting to an aggregate less than 30 TWh; (b) the absence of lower lakes in many cases; and (c) the fact that their capacity is already used by a numerous other states.

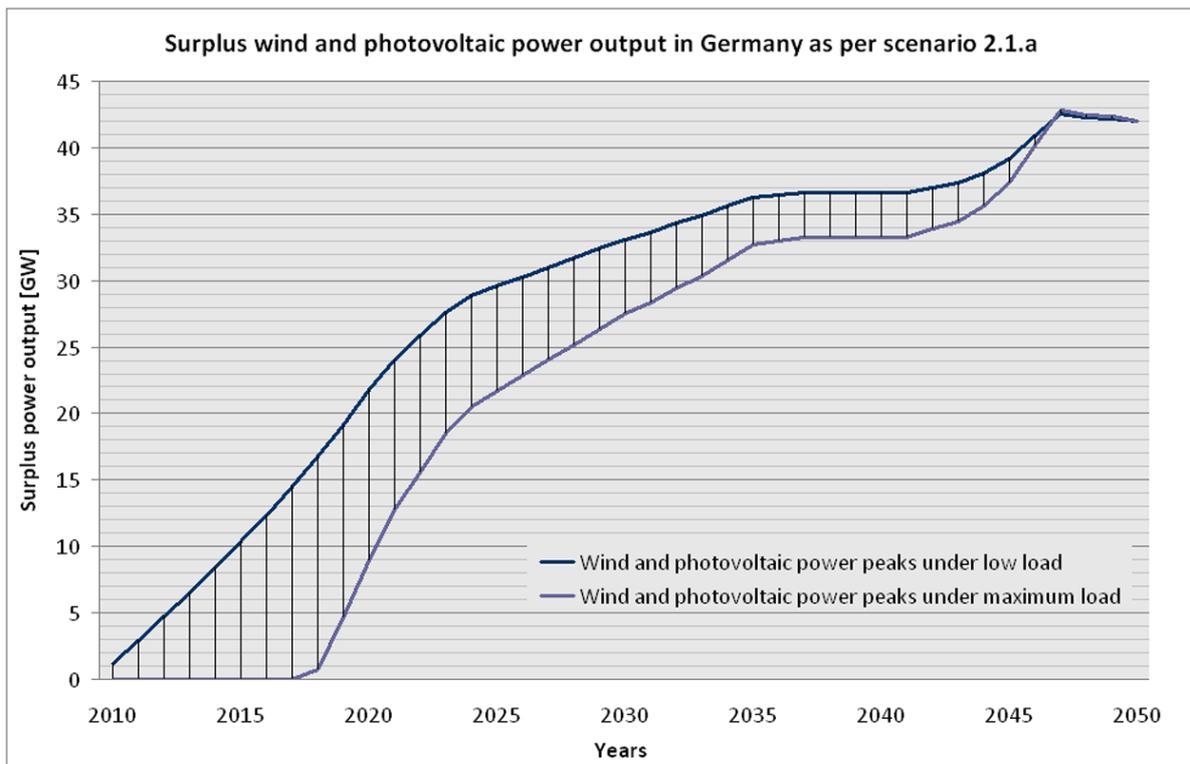
In view of the projected lead times, expansion of Norwegian pump storage capacity and of transmission capacity between Germany and Norway should get underway as soon as possible. Indeed, our simulations show that such projects should have long since taken centre stage in the German energy policy debate.

Assuming that Norwegian hydro power plays a central role in compensating for fluctuations in German renewable electricity generation, the question arises as to whether Norwegian electricity generation and storage capacity will be sufficient not only overall, but also at all times throughout the year.

The starting point for our assessment of this issue was the cumulative Norwegian reservoir fill level in 2008, plus the minimum and maximum reservoir fill levels between 1990 and 2007 (see Figure 4-18). If the requisite storage input and output from scenarios 2.1. and 2.2 is added to the mean Norwegian storage fill level for 2008 as per Figure 4-18, it emerges that additional storage capacity use would result in neither undercutting nor exceedance of (respectively) the aforementioned minimum and maximum fill levels; the latter are in fact (as Figure 4-18 shows) equalised over the course of the year. Moreover, in spring the aggregate filling level lies within the range of the annual fluctuations that occur in any case. Over the summer, Norway's substantial storage hydroelectric power station capacity is used via additional German demand, whereby fall and winter reservoir fill level is even higher than the prior year by virtue of additional storage input, which in turn reduces net draw-down in the following spring. All told (including natural inflow into storage lakes), reservoir fill levels tend upwards, further improving the reliability of Norway's electricity supply, which is currently assured via the import of Danish energy from coal fired power plants during periods of low annual water inflow. This analysis shows that the often expressed concern that Norwegian reservoir capacity is too low to compensate for shortfalls in German renewable electricity generation is unfounded. In point of fact, Norwegian hydro power would dovetail extremely well with German renewable electricity generation.

Figure 4-17

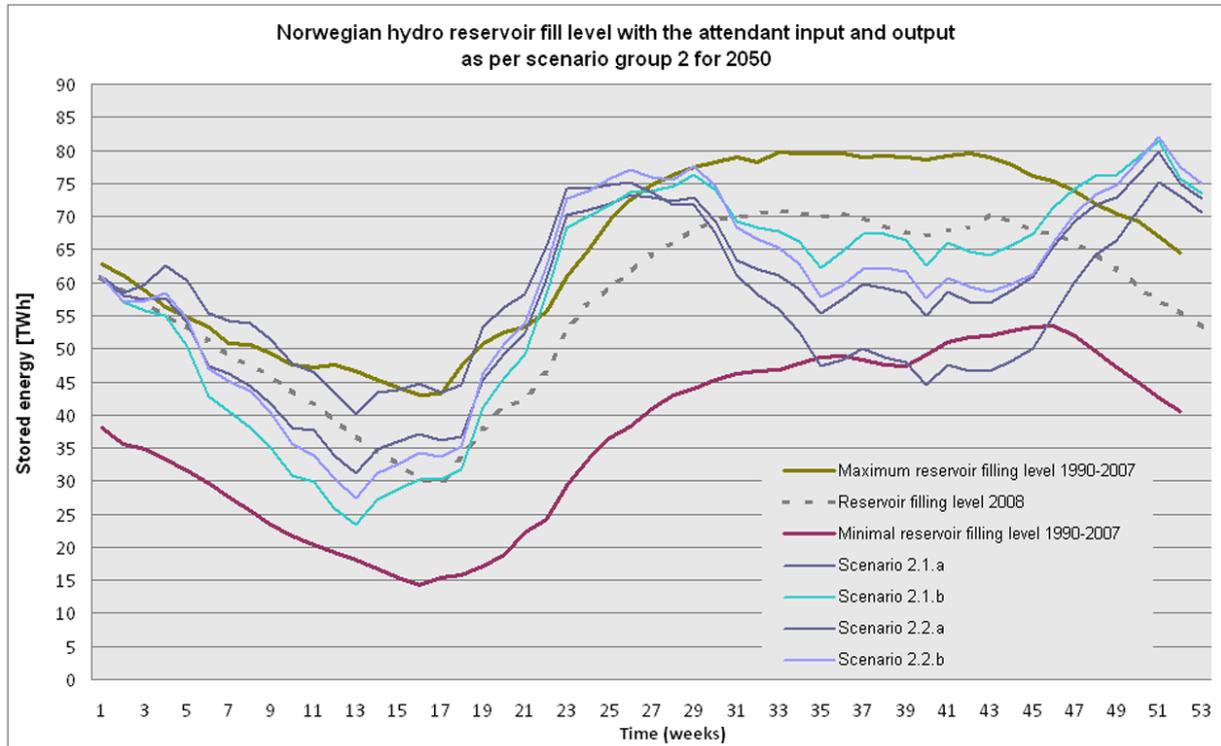
### Surplus wind and photovoltaic capacity in Germany as per scenario 2.1.a



Source: SRU 2010

Figure 4-18

**Norwegian reservoir fill level with the attendant input and output, as per scenario group 2 for 2050**



Source: SRU 2010, based on Nord Pool ASA 2010a

Admittedly, scenario group 2 involving a German-Danish-Norwegian network is an idealised case; for if Norwegian and Swedish storage hydroelectric power station capacity offers substantial potential for pump storage system capacity expansion, it stands to reason that other European states that greatly expand their renewable electricity use would also want to take advantage of this potential. Scenario 3.a., which analyses an analogous situation for the Europe-North Africa network, shows that Norway converting its storage capacity to pump storage capacity in such a case would exhaust this capacity, but would create sufficient aggregate storage capacity. It is also relevant in this context that a considerable portion of Swedish storage capacity exhibits similar structures to those of Norwegian hydro power. Factoring in Sweden's capacity would increase the potential from the 84 TWh offered by Norway to approximately 118 TWh. Moreover, other Europe-North Africa network states such as France, Austria, Switzerland, Italy and Spain also have considerable storage hydroelectric power station capacity; it would have to be determined, to what extent this capacity could potentially be converted to additional pump storage capacity. Hence, inasmuch as the real-world situation is far more favorable than that indicated by the DLR simulations in scenario 3.a, it stands to reason that there would be no storage capacity shortfall if the requisite capacity conversions are carried out.

### 4.3.3 Electricity grids

#### Wide area electricity networks and their balancing function

A study we commissioned in 2009 (Czisch 2009) clearly shows that a higher capacity trans-European network would constitute a far less cost intensive but also far more politically ambitious option in terms of achieving a wholly renewable electricity supply.

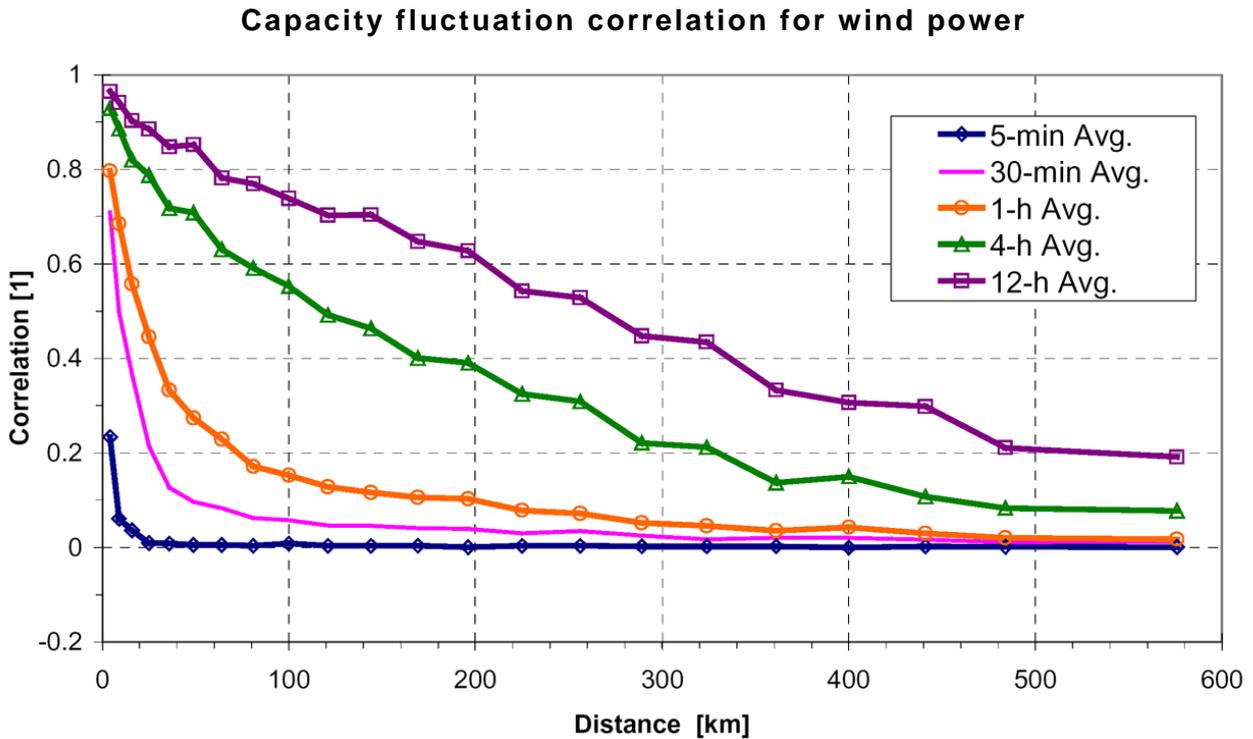
Compensation for volatile electricity generation in a large-scale energy network would be based on the principle of diversification, whereby the key criterion for volatility mitigation would be energy output correlation over time with a view to using minor or negative correlations in the network's generation portfolio to offset capacity fluctuations in the second and minute ranges, as well as energy output fluctuations at the seasonal level. Inasmuch as the availability of renewable energy, notably wind and solar power, depends on the weather, energy generation can only be statistically correlated using the distances of networked power stations from each other and combinations of various renewable energy sources. In practice, this would entail incorporating a maximum number of power stations with a range of weather correlations into a network extending over the largest possible geographical area.

The time curves and equalisation effects as determined by the relevant geographical distances will now be described using wind energy as an example.

Wind energy fluctuations that last only a matter of seconds (occasioned by wind gusts or the like) could be offset within individual large wind farms, whereas fluctuations lasting a matter of minutes would have to be offset over a catchment area diameter of approximately 10 kilometres. This distance would be 40 km for 30 minute fluctuations, 100 km for fluctuations lasting one hour or more, upwards of 1,000 kilometres for day long fluctuations and approximately 2,000 kilometres for month-long fluctuations; whereby for the larger of these distances, the nature of the location would have a major impact on the actual correlation. Seasonal energy fluctuations can only be offset via locations in different climate zones, e.g. by intermeshing power stations in Europe and North Africa. However, in order for such a network structure to work, it would have to include the southern areas of North Africa, which are particularly windy during the warm season.

The statistical background of the correlation of capacity fluctuations as determined by the distances and timelines of the relevant fluctuations is shown in Figures 4-19 and 4-20. In this context, the weaker the correlation, the sooner the capacity offered by various wind turbines is equalised.

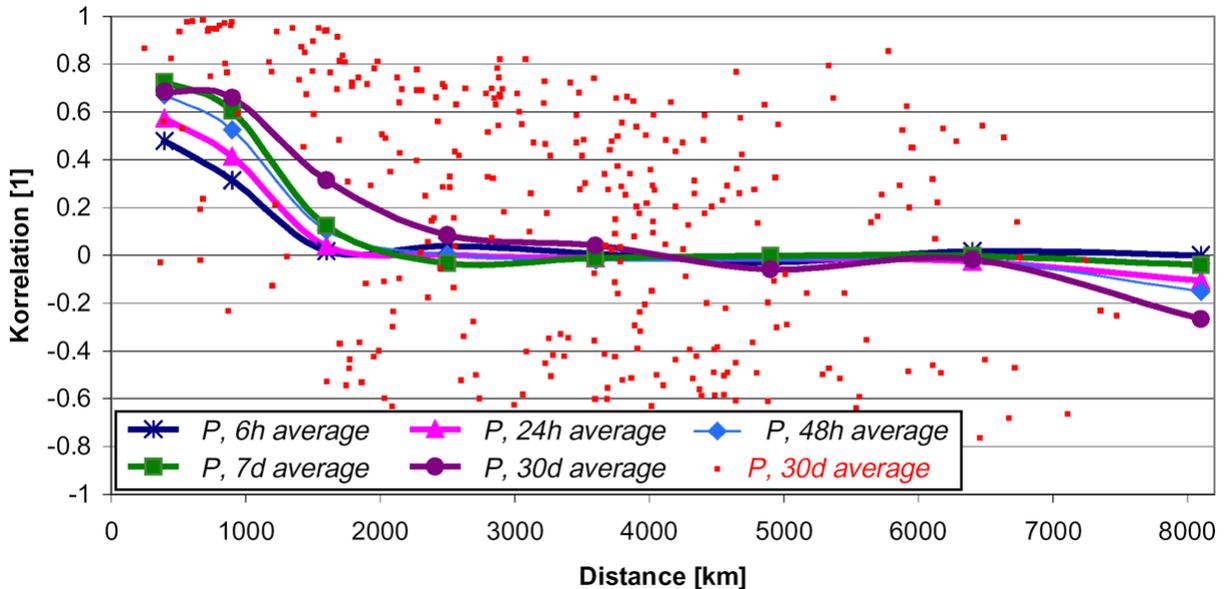
Figure 4-19



Source: Czisch 2009

Figure 4-20

### Capacity fluctuation correlation for wind power for distances ranging up to 8,000 kilometres



Source: Czisch 2009

Offshore wind power is likely to be Germany's main source of renewable electricity in the coming years from a technical and economic standpoint. In virtually all of our renewable electricity scenarios for the year 2050, offshore wind farms account for nearly 320 of Germany's aggregate 509/700 TWh demand, with the main generation capacity located at a considerable distance from

the electricity demand centres in western and southern Germany. In addition, a large proportion of Germany's onshore wind energy capacity is located in the northern coastal region (56-90 TWh/a). In view of the fact that according to transition scenario 2.1.a, both of these energy sources are poised for substantially increased electricity generation in the coming decade, large scale transmission capacity expansion between Germany's North Sea coastal region and the electricity demand centres in western, central and southern Germany is urgently needed. According to scenario 2.1.a, this increase would take the following form: from approximately 40 TWh in 2009 to 100 TWh in 2015, 180 TWh in 2020 and 260 TWh in 2025. At the same time, maximum offshore wind farm generation capacity is slated to increase from 8 GW in 2015 to 27 GW in 2020, 44 GW in 2025, 49 GW in 2030, and more than 80 GW in 2050. In order for this potential wind energy capacity to be of use to our national energy supply, we will need to step up the pace of expansion of our energy grid. But unfortunately, none of the current plans and government studies (DENA 2010) go far enough in terms of their timelines and the scope of wind energy capacity expansion, with the result that the importance of grid expansion aimed at allowing renewable electricity to be supplied to German electricity consumption centres has been woefully underestimated.

In our view, the energy policy debate in Germany has abysmally failed to recognise the central importance of establishing a network structure involving Scandinavian pump storage potential and entailing the conversion of Swedish storage hydroelectric power stations to pump storage systems.

Assuming that our policymakers do not call for German energy self sufficiency, we can only achieve cost effective renewable electricity generation by engaging in electricity interchange with other states via cross-border grid expansion, even if such a partnership comprises only a handful of countries as per scenario group 2. In such a network, viable electricity transmission capacity must be available no later than at the point where we are unable to use all of our own renewable electricity and the first energy interchange expansion phase with Norway for example (as per scenario 2.1.a) becomes necessary. The scenario 2.1.a timeline for load-dependent surplus wind and photovoltaic electricity generation (see Figure 4-17) shows that based on the renewable electricity expansion suppositions in chapter 4.2, Germany's need for a cross-border electricity interchange is set to expand exponentially in the foreseeable future. For example, the scenario 2.1.a development roadmap indicates that already in 2020 we will need 16 GW transmission capacity for transmitting energy to Norway.

In view of the enormous transmission capacity that we will presumably be needing in the near future, expanding the scope of cross-border electricity transmission to Norway or elsewhere would be a wise move from an ecological standpoint, but also economically feasible; for the rapid rate of expansion of Germany's wind farm fleet will ensure that the capacity of every single new transmission line we build will be fully used before very long. The aggregate 2.8 GW of capacity of the Nordlink and NorGer high voltage transmission lines that are currently in the pipeline would increase overall line capacity only to slightly more than 4 GW. Thus, by 2020 we will need upwards

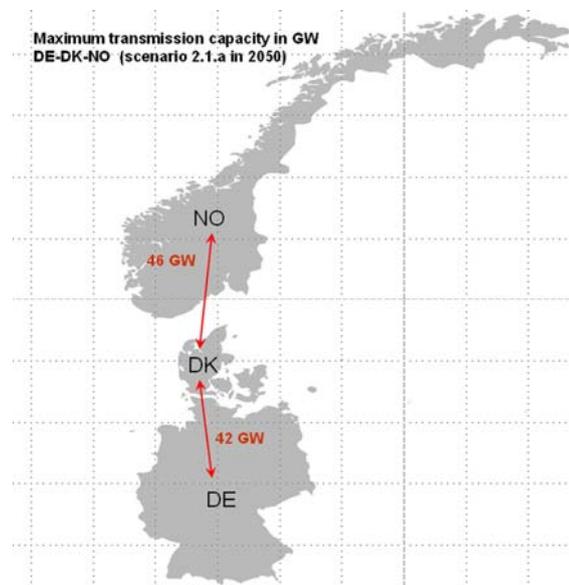
of 10 GW of transmission capacity above and beyond this 4 GW in order to interchange electricity with Norway.

Hopefully, a sea cable can be realised in far less than the up to ten years of lead time normally required in Germany for electricity grid expansion planning, authorisation and implementation (Kurth 2010, p. 39). If planning and expansion of these international transmission lines are not begun immediately, the missing transmission capacity and the consequent non-accessible Norwegian storage capacity in conjunction with expansion of the German transmission grid will constitute a second bottleneck in terms of the rapid expansion of Germany's renewable electricity capacity, which is both necessary and desirable from a climate protection standpoint.

Up to 42 GW of transmission capacity will be needed between Germany and Norway by 2050 as per scenario 2.1.a, with German demand amounting to 509 TWh/a; and up to 62 GW will be needed in scenario 2.2.b with 700 TWh/a of demand (see Table 3-6). Figure 4-21 shows the transmission capacity that will be needed in 2050 for electricity transmission with a wholly renewable electricity supply in the German-Danish-Norwegian network.

Figure 4-21

**Maximum transmission line capacity  
for the German-Danish-Norwegian inter-regional network in 2050**



Source: SRU 2010, based on DLR 2010b

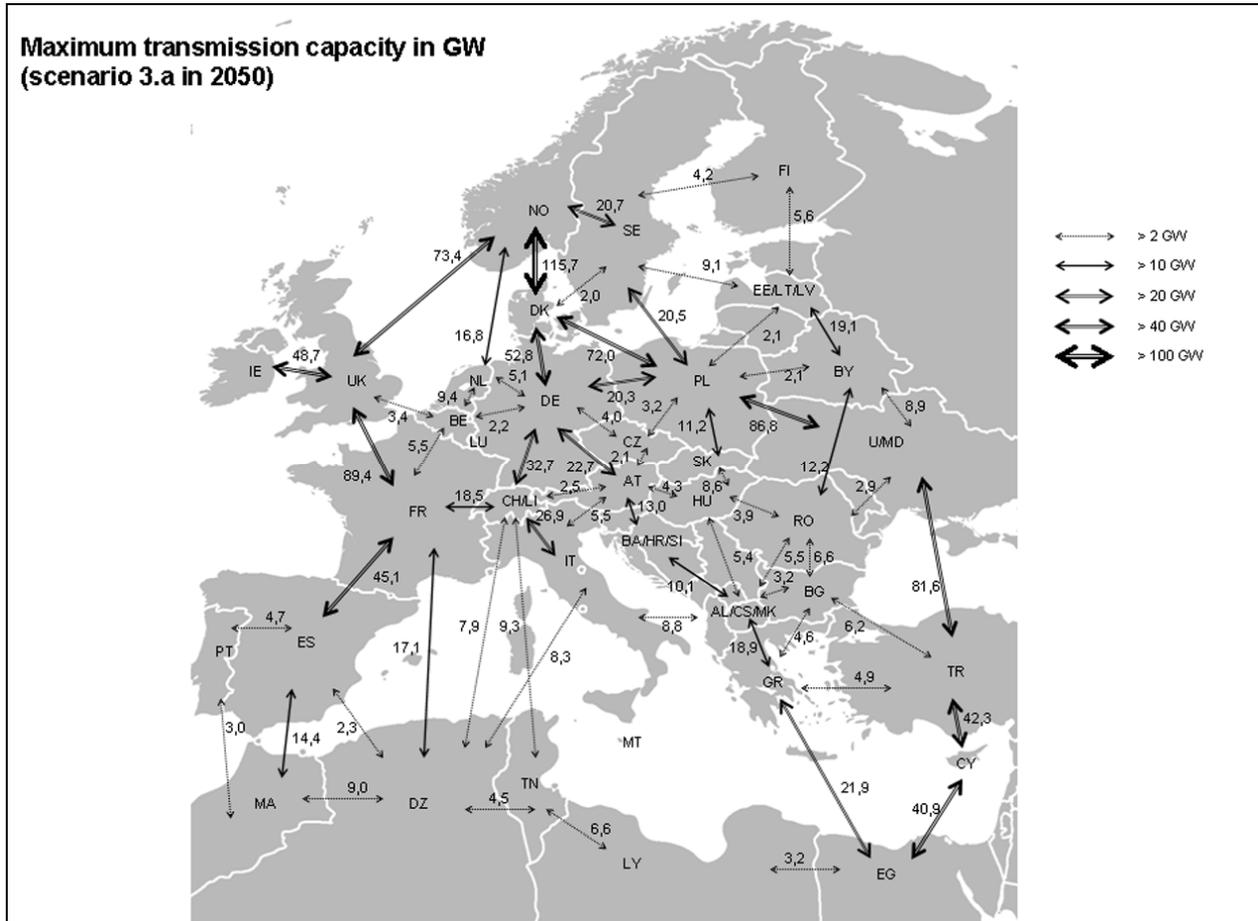
As scenario 3.a shows for the Europe-North Africa network, the kind of transmission lines needed for the relatively small scale German-Danish-Norwegian counterpart in all likelihood will prove to be economically viable even in far more extensive expansion scenarios. Even in the Europe-North Africa region energy interchange allowed for by scenario 3.a, the lion's share of Germany's surplus renewable electricity would be interchanged with Norway in the context of a technical and economic system optimisation.

The 2050 scenario 3.a transmission capacity simulation for the Europe-North Africa region with German demand of 509 TWh/a is shown in Figure 4-22, which indicates that the lion's share of Germany's electricity interchange would be realised to Norway via Denmark, as well as to Switzerland, Austria and Poland. The requisite line capacity between Germany and Denmark would increase from 47.1 to 52.8 GW and between Germany and Norway from 50 to 115.7 GW relative to scenario 2.2.a, which is analogous to scenario 3.a. The transmission capacity that would be needed for the German-Danish-Norwegian regional network would also be necessary for wider ranging European electricity interchange, and in all probability would exhibit better capacity use and would thus be more cost effective.

In view of the fact that establishment of a Europe-North Africa wide area high-capacity network (such as an HVDC overlay grid) would undoubtedly face myriad political and legal hurdles, an expansion strategy based on a smaller scale cooperation involving fewer states that already have the requisite political stability and energy technology would be far more likely to succeed, at least at first. Once such a moderate sized inter-regional network was established, other states could accede to it over time, with a view to building an a far-flung system. For Germany, this incremental approach would initially entail installing transmission lines between Germany and Norway in the guise of point to point connections via sea cables or indirect links via onshore cables passing through Denmark. The onshore cable solution would probably provoke far greater opposition if it did not entail direct advantages for Denmark. However, inasmuch as Denmark is set to increasingly use Norwegian storage capacity for fully tapping its wind power potential, joint transmission lines could be installed for a portion of the transmission capacity in such a way as to allow for input and draw-down in Denmark. In a subsequent expansion phase, point to point lines could be installed linking Germany with Switzerland and Austria, providing these two countries are able to convert some of their storage hydroelectric power stations to pump storage systems. However, such an approach would probably meet with far greater obstacles than would be the case in Norway, as in such cases it is often necessary to create additional upper or lower storage lakes. Whether a Europe-North Africa overlay grid ever comes to fruition will mainly hinge on which countries with which generation and storage potential will join a smaller scale system.

Figure 4-22

### Maximum transmission capacity for the Europe-North Africa region in 2050



Source: SRU 2010, based on DLR 2010b

According to a study we commissioned in 2010 (Brakelmann and Erlich 2010), the technologies and attendant costs of the various elements of the grid expansion differ greatly from each other as follows:

- Onshore power transmission lines for distances ranging from 400 to 500 kilometres are currently realizable in Germany via standard three-phase current 50 Hz technology at voltages ranging from 380 to 500 kV using underground VPE cabling (plastic cables with cross-linked polyethylene). The advantage of underground cabling is that it would allow for trouble free installation and approval of the new north-south and north-west transmission lines needed in Germany.
- Individual non-networked onshore electricity transmission lines for distances ranging from 400-2,000 kilometres can be realised using high voltage direct current technology (e.g., HVDC Classic) for up to 500 kV, via overhead lines (insofar as possible) and if not via ground cables. If the requisite technological advances are made, 800 kV high voltage direct current (HVDC) lines with 800 kV low-pressure oil cables laid in concrete channels and steel pipes could be used.

- In view of the development uncertainties entailed by high voltage direct current (HVDC) cables and circuit breakers, the report recommends that the wholly realistic goal be pursued of creating a 16.7 Hz overlay grid in Europe. To this end, 500 kV voltage capability would be rolled out, for which VPE cable or the three-phase grid technology either already exists or could be developed at a relatively low cost compared to the technological challenges that would be entailed by high voltage direct current (HVDC) technology. This approach would also reduce the ratio between line length resistance and frequency, which would represent a threefold reduction relative to today's 50 Hz frequency.

The report recommends that the following transmission technologies be used for ocean cables (Brakelmann and Erlich 2010, p. 9):

- For German wind farms that are up to 120 kilometres offshore: conventional 50 Hz three-phase current technology, if necessary in bipolar mode.
- For German wind farms that are more than 120 kilometres offshore, the report states that high voltage direct current voltage source converter (HVDC-VSC) technology is the only possible solution at present, and according to Brakelmann and Erlich 6.7 Hz three-phase current technology is highly advantageous for such solutions, possibly in combination with bipolar cable connections. This would allow for direct input via wind turbine converters, which would translate into considerable cost savings on offshore converter stations for HVDC transmission. This solution could be rendered more advantageous still through the use of 16.6 Hz onshore grids.

The report recommends that German offshore wind farms be linked to Norwegian pump storage systems via HVDC ocean cables with the highest possible voltage, which could likewise be supplied via a 16.7 HZ offshore grid.

Inasmuch as transmission grid expansion normally involves the realisation of point to point connections that are separated from existing high voltage transmission grids via voltage level, frequency, or transmission modality (direct current), it would be altogether possible to install the requisite lines progressively over time via a range of technologies. In our view, such an approach would allow for installation of the initial lines without the need for prior European consensus concerning the technology that is to be used, even if the long term goal is to establish an inter-regional network encompassing all EU and North African states.

That being said, the requisite expansion of grid and storage capacity will undoubtedly be the greatest stumbling block to expanding the scope of renewable electricity use in Germany and Europe that is necessary and desirable from a climate protection standpoint. At the same time, all of the simulations and calculations we have carried out in this regard clearly indicate that no such stumbling blocks would arise in connection with either usable potential for or the availability of the requisite technologies in renewable electricity generation scenarios.

## 4.4 Future role of base load power plants

Steadily expanding use of renewable electricity with a view to achieving a wholly renewable electricity supply will not only result in the gradual replacement of conventional power plant capacity and to grid and storage capacity expansion, but will also have a considerable impact on the possible future role played by base load power plants in a new electricity supply system. In view of the fact that to date the discourse on the future of Germany's electricity supply has conveyed the impression that we cannot achieve a reliable electricity supply without base load power plants, in the following we will discuss the role of such power plants in a changing electricity supply system.

### 4.4.1 The current electricity supply system

Today, daytime and nocturnal electricity demand is satisfied using variable output base, medium and peak load power plants. A base load power plant normally means a facility that generates electricity for anywhere from 7,000 to 8,760 hours a year; the figure for medium load facilities ranges from 2,000 to 7,000 hours and for peak load facilities is less than 2,000 hours (Fraunhofer IWES and BEE 2009, p. 32). The correlation between these differences is shown in Figure 4-23 via a stylised daily electricity demand curve.

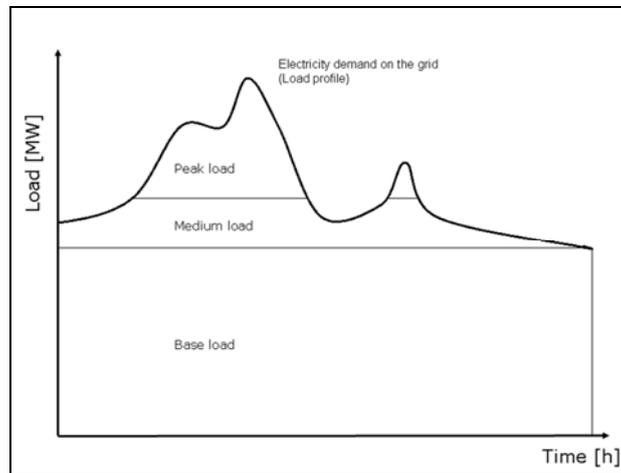
In this context, a so called dispatch determination is made at 15 minute intervals as to which of the available variable output power plants should be used to ensure that electricity demand can be satisfied at all times. Such decisions are mainly based on the variable costs of the available power plants, which are ranked in ascending order of their costs (referred to as a merit order).

In this process, power plant capacity is held in reserve in the event of demand and frequency fluctuations lasting minutes or seconds. This reserve is known as primary, secondary and tertiary reserve and the attendant capacity is referred to as controlling power range.

Base load electricity is normally generated by large nuclear and coal fired power plants, which despite their higher investment costs relative to other types of power plants, use relatively inexpensive fuel and thus exhibit low variable costs (Nicolosi 2010, p. 2). Such power plants therefore have higher merit order rankings than power plants with relatively high variable operating costs such as gas power plants, whose fuel costs tend to be elevated.

Figure 4-23

**Schematic graphic of how daily electricity demand  
is met in the current electricity system**



Source: SRU 2010

#### 4.4.2 Substantial proportion of renewable electricity generation in the system

Inasmuch as, unlike fossil fuel or nuclear energy plants, wind and photovoltaic energy require no fuel and thus exhibit virtually no variable operating costs, these forms of energy are always used to satisfy electricity demand before electricity generated by variable cost and output power plants is dispatched.

However, in the presence of a high proportion of virtually non-variable wind and solar electricity most of which is fed into the grid, radically different dispatch decisions are made for variable output power plants. In such cases, the primary goal is no longer to service grid demand via variable output power stations, but rather – and solely – to offset the difference between severely and possibly rapidly fluctuating renewable electricity generation (notably from wind power) on one side, and demand resulting from the dispatch of electricity from variable-output power stations on the other. This dynamic is illustrated schematically in Figure 4-24.

In a scenario involving a difference between electricity demand and intermittent input, variable output energy is in demand in the presence of a capacity shortfall (residual load) and electricity storage is in demand in the presence of surplus capacity. Residual load can only be provisioned via variable output power stations, which means that the scope of this load at any given moment is determined by (a) electricity demand; and (b) the amount of intermittent renewable energy (mainly wind power but also photovoltaic) that is fed into the grid.

According to transition scenario 2.1.a, by 2020 installed wind and photovoltaic energy capacity in Germany will amount to approximately 67 and 30 GW respectively, for an aggregate approximately 97 GW whose electricity production cannot be precisely forecast since wind and sunshine availability fluctuates greatly over time.

### 4.4.3 Requirements for Germany's future electricity system

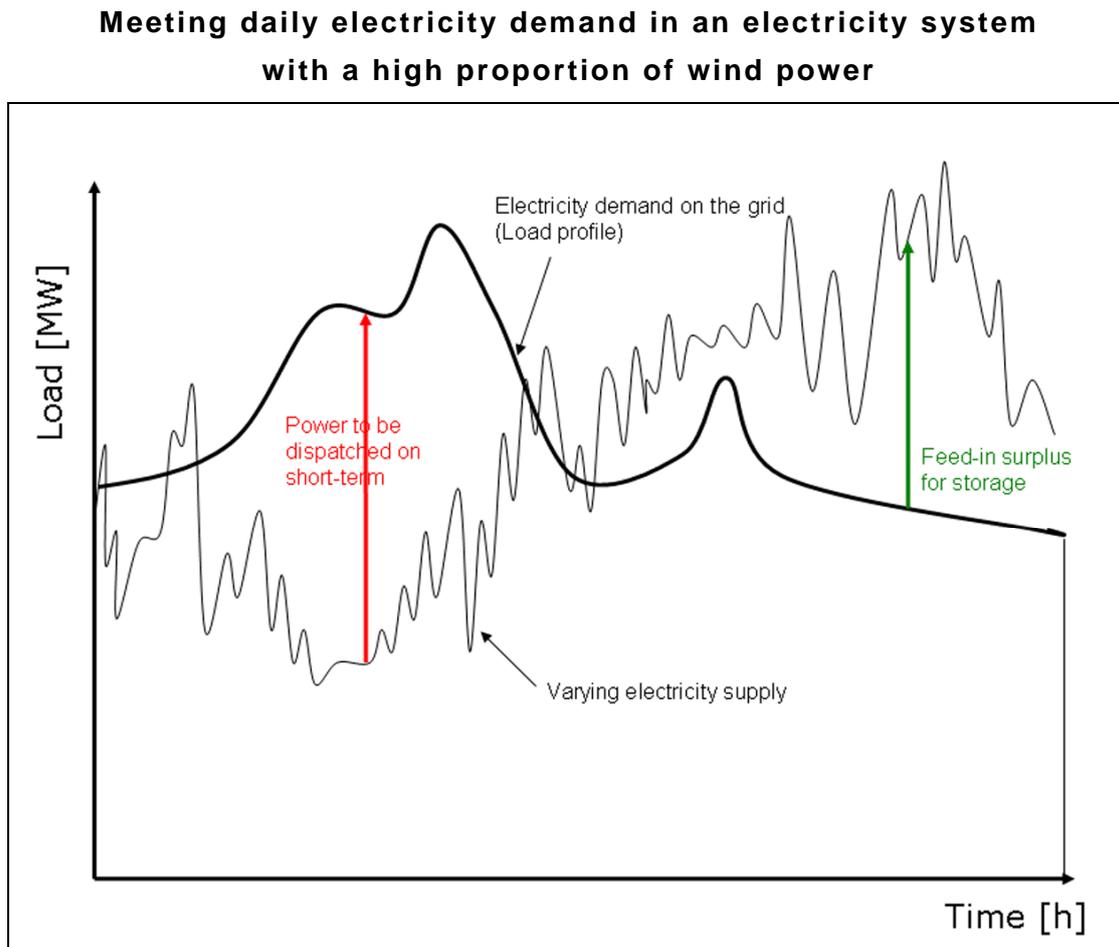
In order for us to greatly expand the use of renewable energy we will need to adapt our electricity supply system to new conditions. To integrate into such a system a high proportion of renewable electricity whose output varies (as is the case with wind and solar energy), it will be necessary to do the following: dispatch conventional electricity more flexibly; expand the capacity of electricity storage systems; establish variable-output renewable electricity systems; and institute effective electricity demand management. The expansion of renewable electricity energy should go hand in hand with increased uses of the technical and economic potential for a flexible electricity generation system (Nicolosi 2010).

Congruent with the foregoing, based on a simulation of Germany's electricity supply system in 2020 and a Bundesverband Erneuerbare Energien (BEE) projection of the scope of renewable electricity expansion, Fraunhofer Institut für Windenergie und Energiesystemtechnik (IWES) concluded that in light of more frequent and sharper capacity changes necessitated by intermittent grid input from renewable energy sources, by 2020 the need for medium and peak load electricity will rise and "classic base load" electricity will become obsolete (Fraunhofer IWES and BEE 2009, p. 37).

A simulation of the structure of our transition scenario 2.1.a for 2020 in light of the system's residual load illustrated in Figure 4-25 prompted Sterner et al. (2010) to conclude that base load coverage by conventional power plants will have gone out of existence by 2020.

The fact, however, that base load provision and the prerequisite flexibility of conventional power plants will be obviated has been given short shrift in the German debate concerning the future evolution of our electricity generation system in the coming years.

Figure 4-24



Source: SRU 2010

Up until now, most continuous operation of Germany's nuclear power plants and lignite fired power plants has been realised at nominal capacity, and few plants are operated in load following mode (Hundt et al. 2009, p. iii). Various views are expressed in the literature concerning the capacity of these facilities to handle the ever rising need for operation in load following mode. According to the study of University of Stuttgart's Institut für Energiewirtschaft und Rationelle Energieanwendung (Department of energy management and rational energy use), (Hundt et al. 2009, p. 28), capacity modification rates ranging from 3.8 percent to 5.2 percent per minute (based on nominal capacity) are achievable in normal operating mode in a facility preserving fashion. Another study (Grimm 2007, p. 9) indicates a capacity gradient ranging from 5-10 percent per minute for nuclear power plants under partial load. However, elevated wind power input over a lengthy period may entail base load power plant downtime. According to Hundt et al. (2009, p. 26), it is safe to assume that a nuclear power plant operating under a partial load can be reduced to 50 percent of its nominal capacity. But in the presence of less than a 50 percent load, nuclear power plants must be shut down completely. One author's analysis of historical data in this regard shows that in the past it has not been possible to shut down more than 54 percent of the capacity of base load power plants (chiefly nuclear power plants and lignite fired power plants) (Nicolosi 2010, p. 15). According

to data from the coal industry organisation Bundesverband Braunkohle (DEBRIV 2010), 75 percent of the nominal load of newer hard-coal power plants can be down regulated.

However, the fact remains that frequent and sharp capacity changes in nuclear and coal fired power plants entail at least three untoward effects, one being increased specific electricity production costs secondary to reduced efficiency under partial load, the second being that frequent capacity changes provoke material fatigue, notably in power plant components that are subject to high pressure or temperatures in electricity generation circuits and the third – a consequence of the first two – being a shorter service life (Nicolosi 2010, p. 2). In addition, a major expansion of renewable electricity capacity would entail a complete shutdown of conventional power plants from time to time. Such shutdowns are subject to minimum additional downtime to reduce thermal stress (Grimm 2007, p. 45 ff.), thus further reducing the facility's potential number of annual full load hours. An evolving electricity generation system will increasingly impose requirements on conventional thermal base load power plants in terms of required load following operation, as well as increasingly frequent shutdowns; such facilities are not suited for such operating modalities from either a technical or economic standpoint.

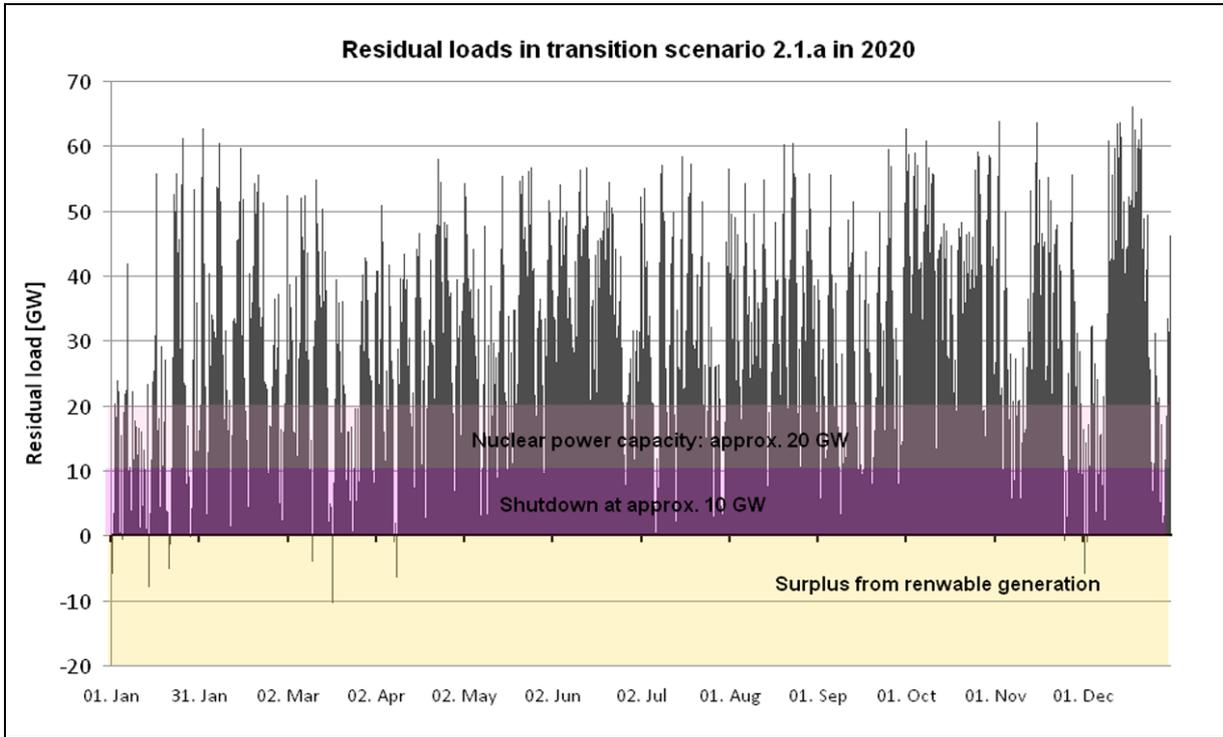
It was for this reason that a study commissioned by E.ON found that “unambiguous (idealised) allocation of load ranges to specific types of power plants” is set to become “increasingly blurred” in the coming years (Hundt et al. 2009, p. 22).

Rising input fluctuation will eliminate the demand for base load power plants (see Figure 4-25), whereby any residual demand of this type should be met, for technical and economic reasons, by power plants that are designed for operation under medium or peak loads.

According to an SRU-commissioned simulation of the year 2020 using our transition scenario 2.1.a and comparing the 2007 and 2020 annual electricity demand curves (Sterner et al. 2010), the requisite capacity of power plants whose annual full load hours exceed 8,000 will decrease from 43.9 GW in 2007 to approximately 10 GW in 2020 (see Figure 4-26). It should be noted, however, that this scenario allows a substantial portion of the peak load attributed to gas power plants to be serviced via existing storage capacity comprising approximately 16 GW of pump storage capacity in Norway, and 7 GW of pump storage hydroelectric power capacity and initial compressed air energy storage capacity in Germany (Sterner et al. 2010). But it should also be noted that these technologies are not included in Sterner's model (Sterner et al. 2010) and thus the necessary capacities are allocated to gas power plants. If the necessary storage systems are not incorporated into the German grid in a timely fashion, additional gas power plants will have to be built to fill this gap.

Figure 4-25

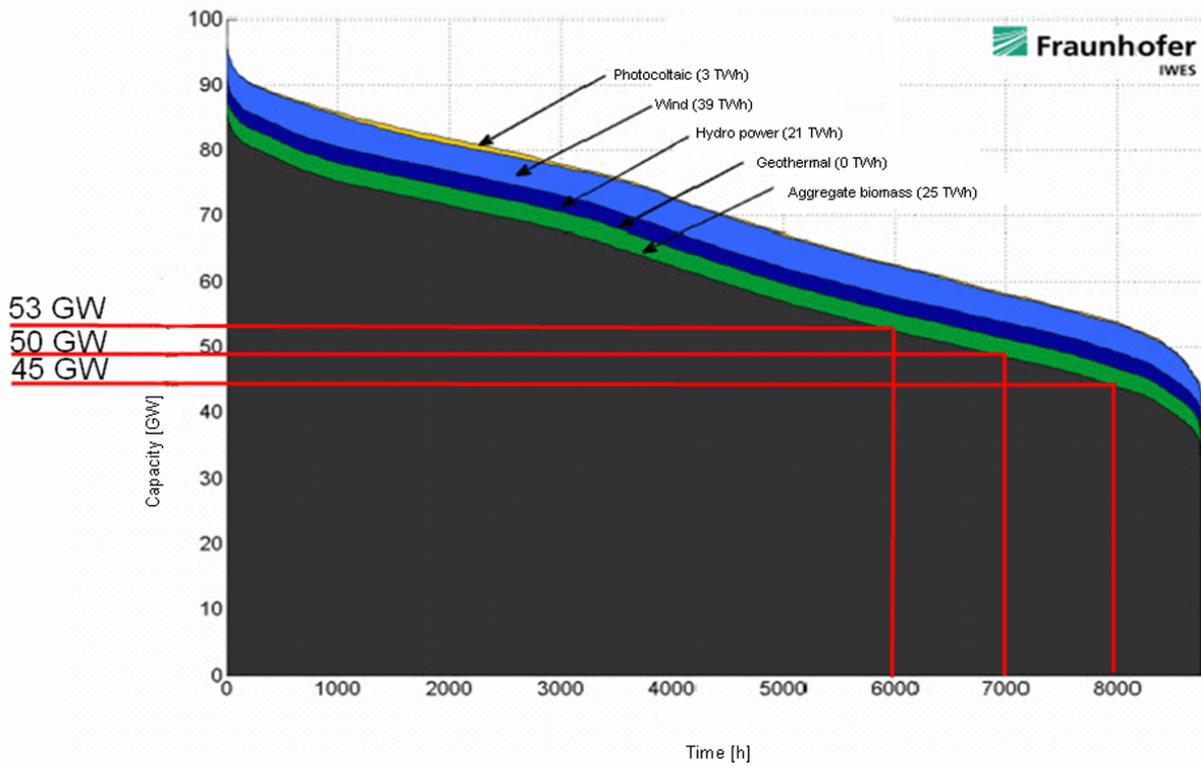
**Residual loads in transition scenario 2.1.a in 2020**



Source: Sterner et al. 2010

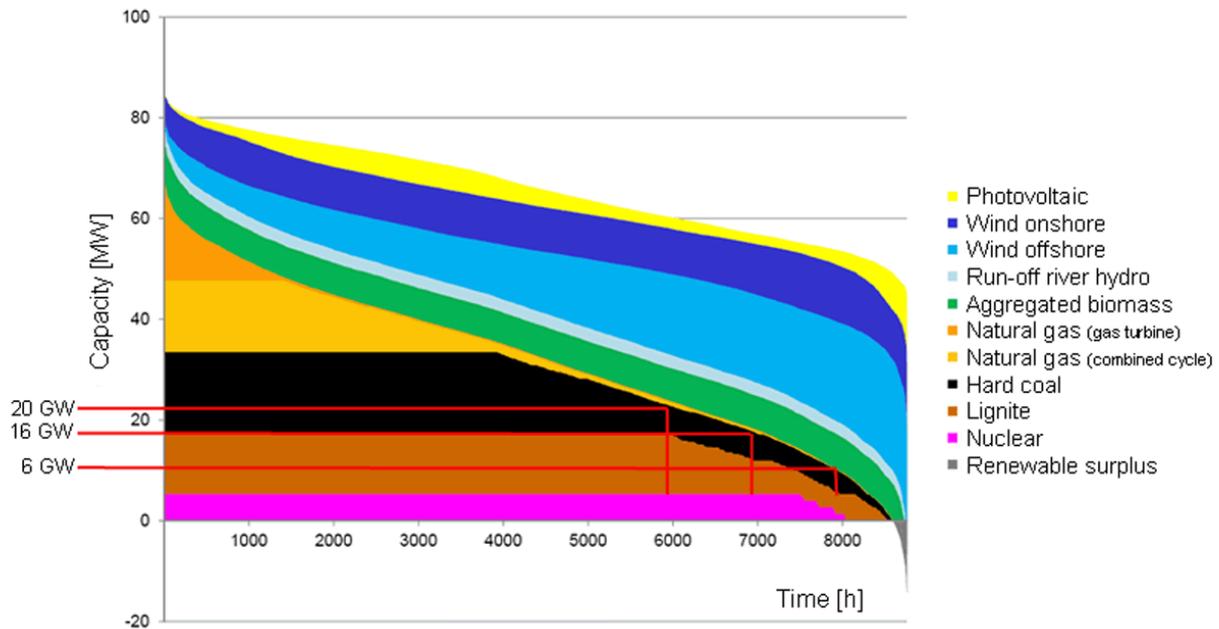
Figure 4-26

**Annual German electricity generation in 2007**



Source: Fraunhofer IWES and BEE 2009

## Annual German electricity generation in 2020



Source: Sterner et al. 2010

Figure 4-26 shows the annual hourly load curve for capacity demand over the cumulative number of hours entailed by this demand, whereby residual load is indicated by the black area, and the colors above the black represent renewable energy.

Extending nuclear power plant service life – an option some have advocated (see CDU et al. 2009) – would unnecessarily exacerbate the aforementioned problems, for nuclear power plants lack the flexibility that will be needed in the energy system of tomorrow. Moreover, construction of new base load coal fired power plants would not be a useful addition to our electricity system, nor would the attendant investments yield the anticipated returns for investors since the number of operating hours posited by the plans for such facilities cannot possibly be reached.

Hence in our view, we are faced with a choice between the following two radically different roadmaps for our electricity system:

- A massive expansion of renewable energy sources, a program that would have to be combined with power plants that can be started up rapidly (i.e. gas power plants), electricity storage systems, and a large scale grid expansion.
- A power plant system expansion program based on base load power plants (coal fired power plants with carbon capture and storage (CCS) systems and/or nuclear power plants), to the exclusion of large scale expansion of wind and solar electricity generation capacity, since a higher proportion of such energy cannot be viably combined with a base load oriented power generation system using coal and nuclear power.

In our view, the inherent antithesis between power plants that are based technically and economically on a base load paradigm on one side, and strongly fluctuating renewable energy sources on the other means that (a) proposals to extend nuclear power plant service life and the envisaged major capacity increase by building new coal fired power plants; and (b) a strategy of transitioning to a wholly renewable electricity supply are mutually exclusive.

## **4.5 Costs associated with the renewable energy development roadmap**

Our projected cost curve for the development of renewable electricity is based on the renewable energy simulations and projections described in chapter 4.2, whereby transition scenario 2.1.a was used as a specimen cost scenario in this regard. Our suppositions concerning the timeline for specific electricity generation costs were (a) based on a German government “Reference Scenario A” (Nitsch 2008); and (b) scaled in the REMix-model scenario (2.1.a), whereby the REMix model’s 2050 cost projections are derived from those of Nitsch.

Fluctuations in renewable electricity generation costs as posited in our simulations (see Figure 4-27) will be chiefly attributable to factors such as improved efficiency, cost reduction potential resulting from economies of scale, and the assumed capital interest rates, all of which are subject to uncertainty in view of the four decade period that comes into play here. As noted, the cost decrease potential posited for our simulations is in the range of various projections in the literature. For wind power, our backward projection of the relevant costs was based solely on German installed capacity in scenario 2.1.a entailing learning rates amounting to 11.5 percent and 18.6 percent for onshore and offshore wind power respectively (see Table 4-5). Neij’s most recent study yielded learning rates, by 2050, ranging from 18-22 percent for wind power, 15-22 percent for photovoltaic power and 0-10 percent for biomass energy (Neij 2008, p. 2,209). Hence our posited wind power learning rates resulting from our backward projections should be regarded as being extremely conservative, as should the 2.2 percent learning rate for biomass energy use that was posited using this same procedure. The backward projection for the posited photovoltaic power learning rate yielded a value of 26 percent, which is marginally higher than the upper limit of the range quantified by Neij (Neij 2008, p. 2,209). Hence this figure should be regarded as being highly optimistic. The posited photovoltaic power cost curve is likewise somewhat optimistic, particularly for the post-2035 period, as an analogously large scale expansion of photovoltaic energy use would have to occur globally in order for German installed photovoltaic capacity to achieve the highly ambitious goal of electricity generation costs amounting to considerably less than 15 euro-cents per kWh. Were it to emerge that the posited value of 8.9 euro-cents per kWh was unduly optimistic and that a cost reduction to only 15 euro-cents per kWh was achievable by 2050, the mean electricity production costs in scenario 2.1.a would rise from 7 to 7.56 euro-cents per kWh. In scenario 2.2.a, which allows for net electricity import, electricity generation costs would remain at 6.5 euro-cents per kWh since photovoltaic energy is not used in this scenario.

Table 4-5

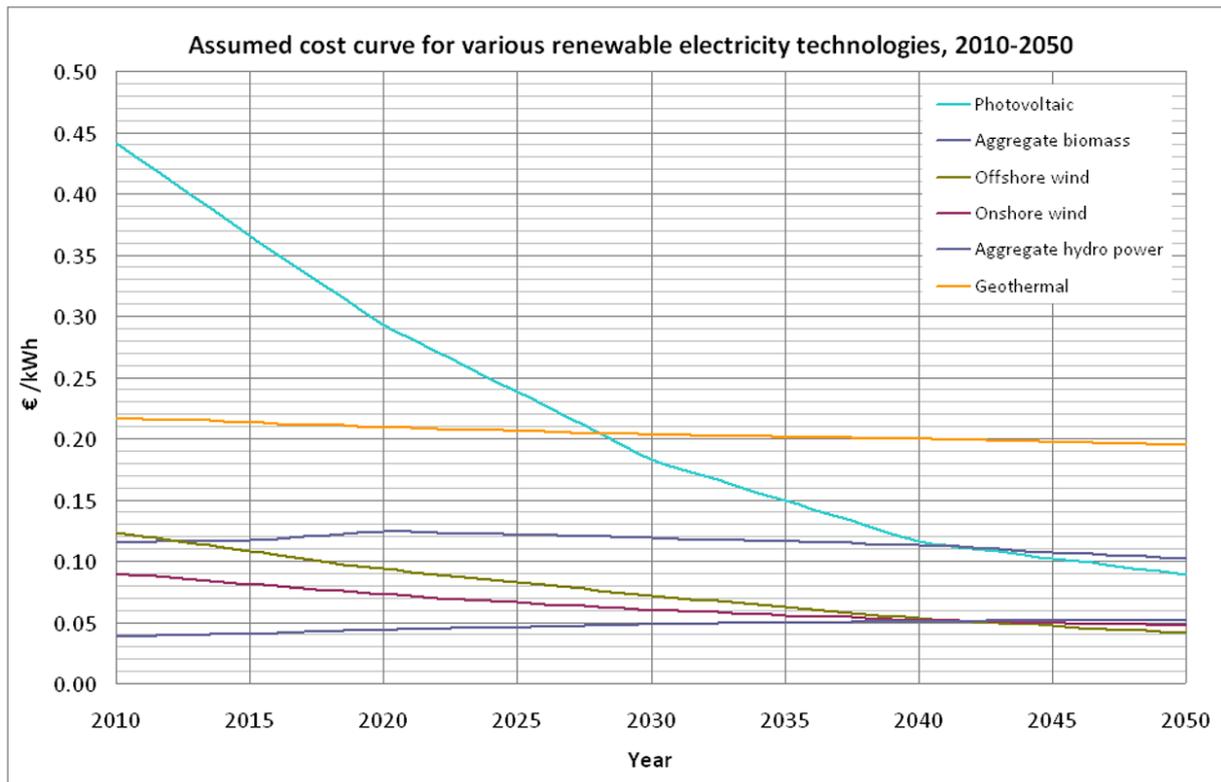
**Posited learning rates (percentage reduction in electricity production costs accompanied by a doubling of production) relative to the rates indicated by Neij (2008)**

	Our posited learning rates	Learning rates posited by Neij (2008)
Onshore wind farms	11.5%	18 – 22%
Offshore wind farms	18.6%	18 – 22%
Photovoltaic energy	25.9%	15 – 25%
Biomass energy	2.2%	0-10% (technical learning rate)

Source: SRU 2010, based on Neij 2008

Figure 4-27

**Posited cost curve for various renewable electricity technologies, 2010-2050**



Source: SRU 2010, based on Nitsch 2008

Our posited biomass cost curve presupposes moderately decreasing capital investment costs for biomass technology, but at the same time posits that the price of energy crops and forestry fuels will evolve similarly to conventional fuel prices.

Our suppositions concerning the cost reduction potential for geothermal electricity should be regarded as relatively conservative, since the figures that are currently under discussion presuppose far greater cost reductions.

Figure 4-27 shows the posited specific cost curves we used in our scenarios for the various renewables, whereby all scenario simulations presuppose a 6 percent public sector interest rate on capital investments, to the exclusion of any higher private sector rates.

The cost of conventional electricity generation in the coming years will be mainly determined by energy prices, as well as by the environmental protection costs entailed by carbon certificates, the evolution of whose prices is highly uncertain and will be strongly affected by climate protection policy goals in the coming years, as well as by the size of the markets for these certificates. As for fossil fuel prices, in view of the four decade period under consideration here they are subject to far greater uncertainty than renewable electricity costs, which are mainly governed by technological factors. Various studies have shown that extending emission trading to all countries of the world could potentially reduce the price of emission rights by a factor of five relative to the price that will result from trading that is limited to OECD member states (IPCC 2001, p. 537). Our simulations were predicated on the price curves for (a) fossil fuels (price delivered to power plants) and (b) emission rights posited by Reference Scenario A of BMU (Nitsch 2008).

Table 4-6

**Projected fossil fuel and carbon emission right prices within the framework of a very significant price increase (as per curve "A" below)**

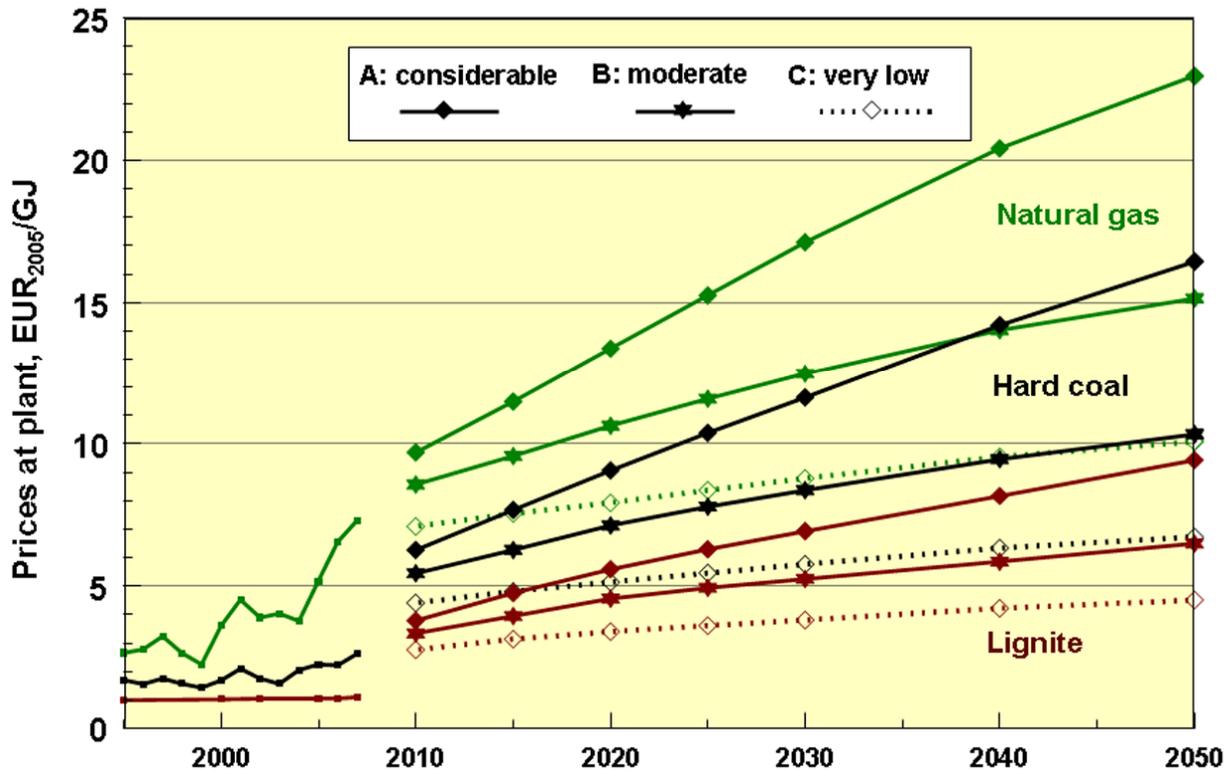
Brennstoffpreise frei Kraftwerke; reale Preise, (Preisbasis 2005) <span style="color: red;">mit CO2 - Aufschlag</span>											
	2000	2005	2006	2007	2010	2015	2020	2025	2030	2040	2050
<b>Preisfad A: DEUTLICH</b>											
CO2-Aufschlag; EUR/t					<b>24,0</b>	<b>32,0</b>	<b>38,0</b>	<b>45,0</b>	<b>50,0</b>	<b>60,0</b>	<b>70,0</b>
Erdgas											
ct/kWh th	1,30	<b>1,86</b>	2,36	2,64	3,49	4,14	4,82	5,49	6,16	7,35	8,27
EUR/GJ	3,61	<b>5,17</b>	6,56	7,34	9,70	11,51	13,40	15,26	17,12	20,43	22,99
Anteil CO2-Aufschl. (%)					15,9	18,6	19,6	19,9	19,6	19,7	20,7
Steinkohle											
EUR/t	49,5	<b>66,1</b>	65,1	77,1	183,8	225,1	265,9	304,6	341,3	416,4	481,8
ct/kWh th	0,61	<b>0,81</b>	0,80	0,95	2,26	2,76	3,26	3,74	4,19	5,11	5,91
EUR/GJ	1,69	<b>2,26</b>	2,22	2,63	6,27	7,68	9,07	10,39	11,64	14,21	16,44
Anteil CO2-Aufschl. (%)					54,3	62,2	65,5	66,3	65,4	63,6	64,4
Braunkohle											
ct/kWh th	0,37	<b>0,38</b>	0,38	0,40	1,36	1,71	2,01	2,27	2,49	2,94	3,40
EUR/GJ	1,02	<b>1,06</b>	1,06	1,11	3,78	4,75	5,59	6,31	6,92	8,17	9,45
Anteil CO2-Aufschl. (%)					240	298	347	383	408	444	476

Source: Nitsch 2008, p. 108

Figure 4-28

**Comparison of the three price scenarios posited by the BMU Leitstudie,  
including carbon emission surcharges**

- including CO<sub>2</sub> surcharge -



Source: Nitsch 2008, p. 107

This price scenario would indubitably entail substantial fossil fuel price increases by 2050 relative to Reference Scenario B involving moderate price increases; the aforementioned study presupposes that the very low price Reference Scenario C will not occur (see Figure 4-28).

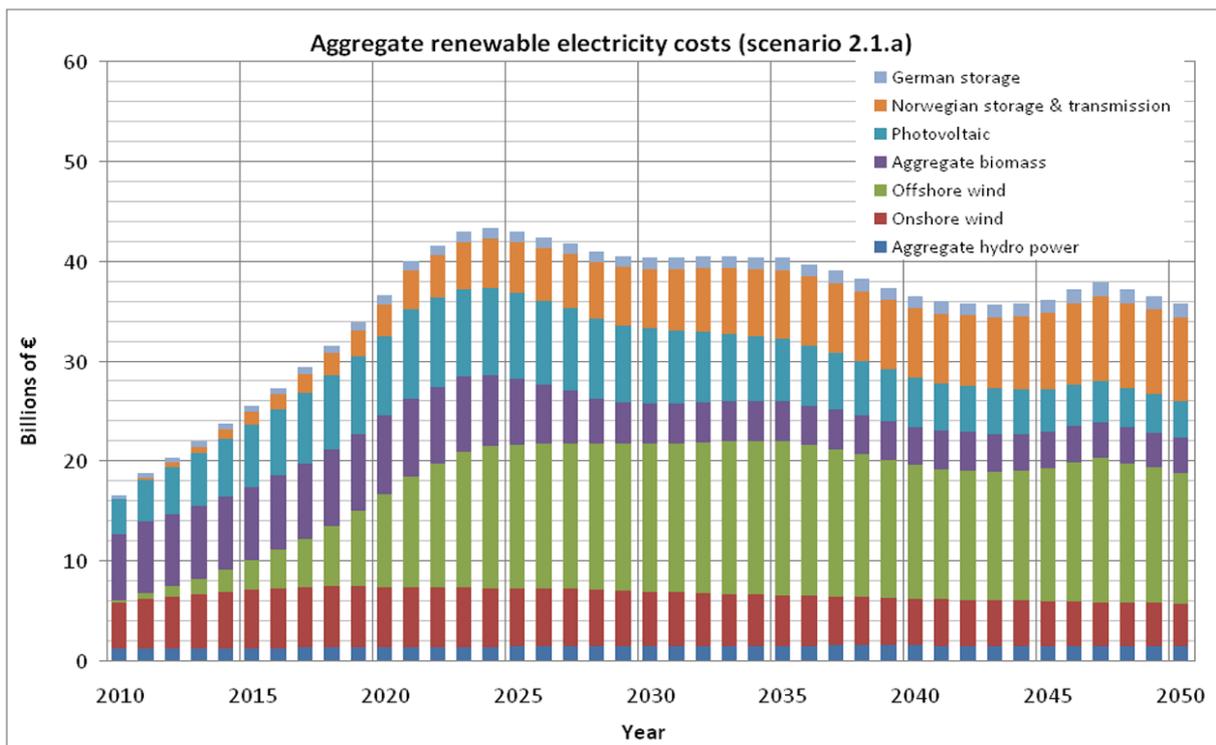
We computed aggregate annual renewable electricity costs on the basis of posited annual renewable electricity capacity expansion, in conjunction with electricity production as determined by specific costs. Figure 4-29 shows these costs broken down by renewable resource, storage costs in Germany, and the cost of transmitting electricity to and from Norway and storing it there. This graphic shows that the aggregate costs of renewable electricity generation will rise steeply from 2010-2024, an evolution attributable to (a) a substantial increase in the share of overall electricity generation accounted for by renewables; and above all by (b) the expansion of offshore wind energy capacity, which is still relatively cost intensive in this initial phase. However, despite the steady expansion of renewable electricity, having peaked at approximately 43 billion euros in 2024 aggregate costs will decrease steadily to approximately 36 billion euros by 2050 on account of technology induced cost degeneration (learning curve). Moreover, unlike the aggregate costs of renewable electricity generation, projected cross-border electricity transmission and storage costs will rise steadily.

Geothermal energy was excluded from scenario 2.1.a on account of its low potential and the elevated posited costs in 2050.

Figure 4-30 shows the mean specific renewable electricity generation costs from scenario 2.1.a, including the cost of storage use and installing transmission lines between Germany and Norway. For purposes of comparison, this cost curve is shown here alongside that for electricity generation using fossil and nuclear fuel, the latter in accordance with price scenario A in the *BMU Leitstudie 2008*. The specific cost calculations were based on the aggregate cost curves as determined by annual electricity generation for each of the various renewables.

Figure 4-29

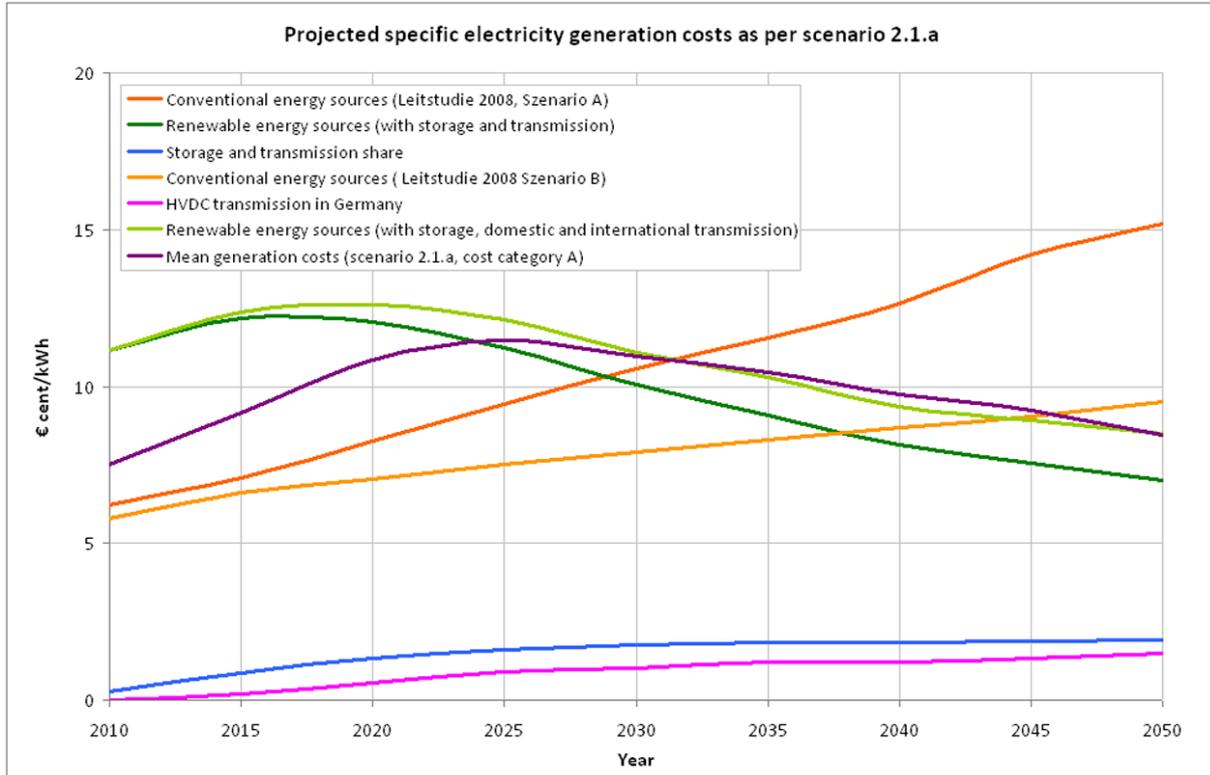
**Aggregate renewable electricity cost as per scenario 2.1.a**



Source: SRU 2010, based on Reference Scenario from Nitsch 2008; DLR 2010a

Figure 4-30

**Specific electricity generation costs as per scenario 2.1.a**



Source: SRU 2010, based on Scenario A from Nitsch 2008; DLR 2010a

Figure 4-30 shows that, following an initial rise, mean specific renewable electricity generation costs (green curve) decrease steadily as from 2017 owing to technological developments and their not being affected by the increasing scarcity of fossil fuels, reaching approximately 12 euro-cents per kWh by 2010 and approximately 7 euro-cents per kWh by 2050. Whereas cross-border and German storage costs will account for only 3 percent of specific electricity generation costs in 2010, this figure will rise to 27 percent by 2050, when the cost will be approximately 2 euro-cents per kWh. The latter figure includes the use of 42 GW of Norwegian storage capacity and more than 18 GW of German compressed air energy storage capacity that can be summoned very quickly. Norwegian pump storage system capacity equates to re-import of just under 123 TWh/a of electricity that would be stored in Norway until needed. It was also posited here that transmission and storage loss in Norway and Denmark will be offset by the purchase of renewable electricity in Norway and will be paid for accordingly.

The costs of grid expansion within Germany were excluded from our computations of mean conventional and renewable electricity generation costs. Assuming expansion entailing 3,000-4,000 kilometres of high voltage direct current (HVDC) transmission lines between northern, southern and western Germany with 30 to 45 GW of transmission capacity allowing for the transmission of 350-500 TWh/a (aggregate 2050 wind turbine generation in scenario 2.1.a amounts to approximately 408 TWh/a), additional costs (including the consequent grid loss) would amount to approximately 1-2 euro-cents per kWh, according to our rough estimates. Aggregate mean renewable electricity generation costs, including storage costs and the cost of domestic and international grid expansion would then amount to approximately 8-9 euro-cents per kWh. Figure 4-31, which shows the electricity generation cost curves, including the cost of domestic electricity transmission (light green curve) based on a posited 2050 cost of 1.5 euro-cents per kWh, presupposes that high-voltage direct current transmission (HVDC) line expansion within Germany will be on a par with that of wind power.

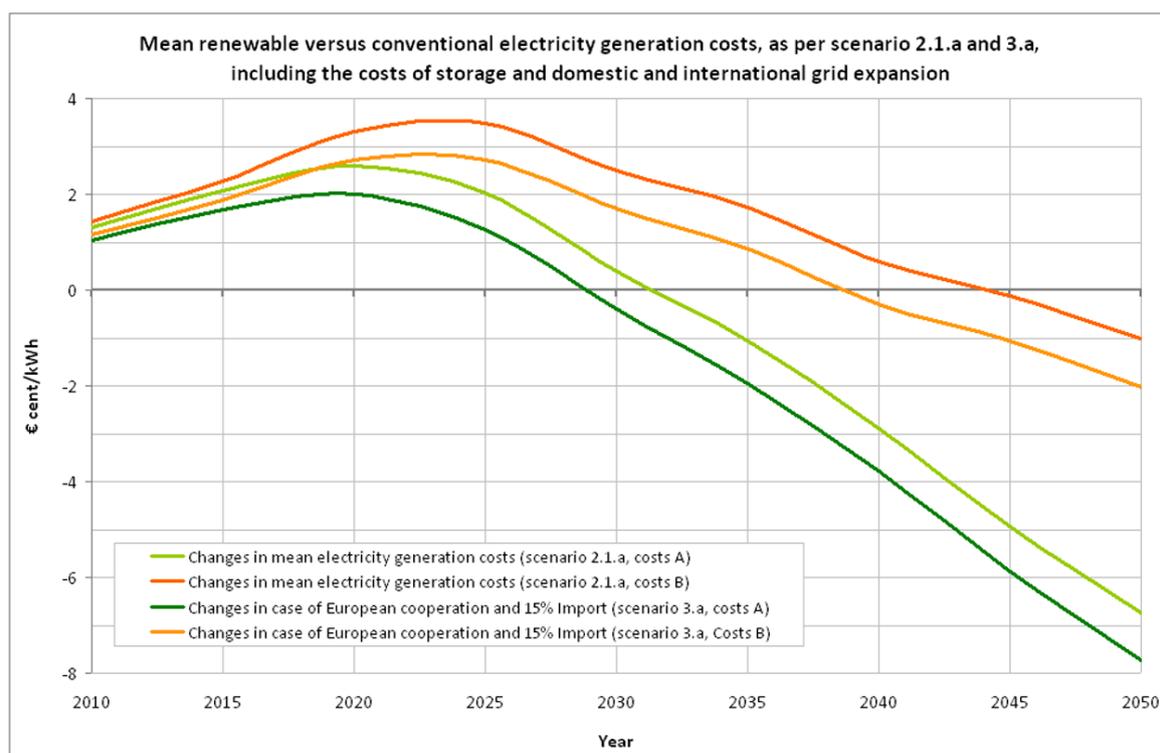
However, the additional costs arising from accelerated expansion of renewable electricity use will not increase mean electricity prices as much as the aggregate cost difference between renewable and conventional electricity generation (respectively, as per the dark green and red or orange curves in Figure 4-30) and are instead solely factored in with the portion of mean electricity generation costs accounted for by renewables. Figure 4-31 shows this initial increase and subsequent decrease in mean electricity generation costs (only the cost changes are shown to the exclusion of aggregate costs) relative to the costs of generating conventional electricity in scenario 2.1.a, against the backdrop of a substantial increase in the costs of conventional energy resources (light green curve) and a moderate increase in these costs (red curve). Allowing for net imports would decrease the costs of renewable electricity by 0.5 euro-cents per kWh in 2050, and institution of an inter-regional Europe-North Africa network would lower these costs by an additional 0.5 euro-cents per kWh. The

orange and dark green curves in Figure 4-31 show the impact of a 1 euro-cent per kWh decrease in renewable electricity costs on mean electricity generation costs. This projection presupposes that these cost reductions will be realizable continuously from 2010 to 2050.

A comparison of average electricity generation costs with costs of conventional generation as in Figure 4-31 shows that at some point between 2029 and 2044 (depending on the development of prices of conventional energy sources) the cost of renewable electricity may become lower than that of conventional electricity.

Figure 4-31

**Mean renewable versus conventional electricity generation costs, as per scenarios 2.1.a and 3.a, including the costs of storage and domestic and international grid expansion**



Source: SRU 2010, based on Scenario A from Nitsch 2008; DLR 2010a

In any case, in the long term renewable electricity in Germany will result in lower electricity prices than would be the case if our current electricity supply structures are retained. Moreover, conversion to a wholly renewable electricity supply would ensure a reliable and climate friendly electricity supply for up to thousands of years.

The down side of such a conversion, however, is that electricity costs would need to be 2-3.5 euro-cents per kWh higher for the next few decades in order to finance the timely transition to a wholly renewable electricity supply that is indispensable for successful climate protection. Although such cost increases would peak in Germany at between € 10 and 15 billion around 2020, costs would decline to a far lower level thereafter, and beginning in 2030 costs savings ranging up to € 40 billion per year would be achievable.

This additional expense to promote climate protection strikes us as a highly worthwhile investment in our country's future, in view of the fact that we would be completely solving the global warming problem in a domain that currently accounts for some 35 percent of our greenhouse gas emissions.

## **5 EU energy and climate policy against the backdrop of current energy policy conflicts and opportunities**

### **5.1 Introduction: The rise of renewables**

Over the past two decades renewables have emerged as a cornerstone of energy policy, thanks to pioneering efforts in this sector as well as subsidies that have become a permanent fixture in the firmament of German and international climate policy to the point where 62 percent of all new electricity generation capacities in the EU are now derived from renewables. New undertakings such as the offshore wind farms in the North Sea, the Desertec project, and the Mediterranean solar project are emblematic of the new economic and political importance of renewables – an energy source that is poised to become a widely accepted core technology for migrating the energy system toward climate neutral electricity generation and that has engendered new strategic partnerships between members of the industrial and political communities.

In this section we discuss the rise of renewables in terms of the relevant policy issues, with the aim of shedding light on the obstacles and opportunities entailed by transformation of the electricity sector, based on an analysis of the relevant policy environment up until the present day. In so doing, we discuss how obstacles have been overcome and breakthroughs realised for renewables in recent times, and outline the changing circumstances, the arguments for and against renewables, and the stakeholders that have come into play over the past two decades or so. This discussion is partly based on the advocacy coalition approach, which takes account of informal relationships between stakeholders, as well as their positions, values, and potential political clout (Sabatier 1993; 1999; Sabatier and Jenkins-Smith 1993).

As is the case in many areas of policymaking, the interplay between German and EU policymaking is key to understanding the history of energy policy. The foundations for sustainable energy use have been and are being laid in numerous spheres of action. On closer examination, it emerges that renewable-energy policymaking at the EU and German levels has unfolded for the most part in tandem over the years and that these two levels are interwoven.

Hence, this section provides the analytic basis for the more programmatically oriented chapter 6, insofar as the challenges of restructuring the electricity system are concerned. The translation has a focus on the EU policy analysis, the original version of the report also contains a national policy analysis.

## 5.2 EU renewable-energy policy

### 5.2.1 Phase 1 (up to 2001): initial directives overshadowed by the internal energy market program

The initial phase of European renewable-energy policy, which extends from the early research and technology program to an initial subsidy strategy debate in 1996 and 1997 to adoption of the first directive in 2001, was strongly influenced by the objectives and requirements of the internal energy market, as well as the European Commission's opposition to instituting feed-in tariffs for electricity from renewables.

The Europeanisation of EU energy policy was largely the result of other policies such as those concerning competition (whose main aim since the mid 1980s has been to establish a non-discriminatory internal energy market) and the ensuing environmental and climate policies. Although energy issues arose in the early days of the European integration process, on founding of the European Coal and Steel Community (ECSC) and Europe's atomic community agency Euratom, European energy policy led a shadowy existence for decades, mainly by dint of its endemic toothlessness resulting from the widely differing vested interests of the member states. Indeed, energy policy and particularly energy *source* policy have generated more intense controversy among the member states than practically any other policy arena. To this day, for reasons related to industrial, economic, and social policy, as well as because of their divergent geographical attributes, the member states use differing energy sources, as well as differing approaches to energy sector regulation (Müller-Kraenner 2007, p. 120 f; Kraack et al. 2001, p. 97; Geden and Fischer 2008; Badura 2003; Pointvogl 2009).

The EU's internal energy market orientation has also been a driving force in terms of the European Commission's renewable energy funding choices, and the Commission's actions concerning member state subsidies for renewables (Lauber 2007; Jacobsson et al. 2009; Hirschl 2008; Nilsson et al. 2009; Jordan et al. 2010a). The European Commission has tended to take a very dim view of Germany's feed-in tariffs as initially instituted by the *Stromeinspeisungsgesetz* (Electricity Feed Act) and subsequently (in 2000) by the Renewable Energy Act (EEG). In the Commission's view member states applying differing feed-in tariffs undermines the goal of a non-discriminatory internal energy market and raises suspicions that competition-distorting subsidies are being provided. The Commission proposed that a "market based approach" be adopted instead, by which is chiefly meant a renewable energy quota system that would encourage market actors to seek the least expensive renewables portfolio with a view to implementing renewable electricity development policies (Fouquet and Johansson 2008; Lafferty and Ruud 2008, p. 5).

The European Commission's preference for such a system is enunciated most clearly in a document titled "*Energy for the Future: Renewable Sources of Energy. White Paper for a*

*Community Strategy and Action Plan*” (European Commission 1997; 1996) – which, however, also lays down stringent conditions to introduce feed-in tariffs nationally aimed at ensuring that such tariffs have a minimal distorting effect on the internal market. This in turn means that renewable feed-in tariffs would have to meet specific market oriented criteria, for which the metrics are external benefits of renewables and the cost of substituted energy sources.

The European Commission’s initial drafts, issued in October 1998 after these two strategy documents, concerning a directive on renewables subsidies presupposed that member state subsidy programs would be harmonised via a quota model in order to avoid undermining the goal of achieving an internal energy market. The majority of the members of the Council of Ministers, as well as energy industry players, supported this measure at first, whereby the member states that were in favour of a quota model formed a majority on the Council. This approach was also endorsed by EURELECTRIC (the self-described “association of the electricity industry in Europe”), which has been particularly critical of the German feed-in tariff framework (Hirschl 2008, p. 328).

However, when a new administration took power in Germany in 1998, the balance of power concerning feed-in tariffs began to shift. On the initiative of the then-German EU presidency, which was pursuing new priorities that had been set by the new governing coalition, and following a Council of Ministers orientation debate during the first half of 1999, the European Commission withdrew its initial proposal. After the Santer Commission resigned in 1999, the European Commission’s position concerning subsidy instruments began shifting, which contributed to a more permissive take on the matter on the Commission’s part. In its draft directive of December 2000, the Commission indicated that it was currently not possible to determine with certainty whether one support instrument was superior to another in terms of the internal energy market. However, this issue was tabled for future consideration (Hirschl 2008, p. 347 ff; Lauber 2007, p. 21).

The coalition of European actors that came out in favour of German-style feed-in tariffs had relatively little clout during the 1990s, and even the then relatively new European renewable-energy alliances had differing takes on these tariffs. The European Wind Energy Association (EWEA) was far more in favour of a quota system than the counterpart German organisation known as Bundesverband Windenergie (Hirschl 2008, p. 336), which was instrumental in founding the European Renewable Energy Federation. The European parliament also displayed openness at an early stage to solutions other than the quota system. In large measure thanks to extensive efforts on the part of (a) a nonpartisan advocacy group of European parliamentarians known as the European Forum for Renewable Energy Sources (EUFORES); and (b) a European solar energy lobbying group known as Eurosolar, in the 1998 Linkrohr report the European Parliament stated that the member states should be free to choose their own feed-in tariff instruments (Lauber 2007, p. 12), while the Roth report from

that same year even came out in favour of pan-European feed-in tariff regulations (Hirschl 2008, p. 344).

Eventually, the issue as to which support instrument was most suitable was decided in court. Having received numerous complaints from power companies, the European Commission told Germany that its feed-in tariff law (StromEinspG) might not be compatible with the provisions of the Treaty on subsidies and recommended that the German law be amended. The complaint filed by the power company PreussenElektra concerning the German feed-in tariffs law ended up before the European Court of Justice, with the European Commission becoming a party to the suit. In 2001 the Court ruled that the statutory obligation to purchase electricity fed into the grid at a minimum price did not constitute a state subsidy under EU law by virtue of the fact that merely a prorated charge was involved (EuGH, Urteil v. 13. März 2001, Rs. C-379/98, NVwZ 2001, p. 665 ff). In the context of this controversy, the European Commission termed Germany's feed-in tariff model "superannuated," with a view to preventing other states from adopting it (Lauber 2007, p. 17).

The aforementioned European Court of Justice ruling on feed-in tariffs, which is considered to be a watershed moment for EU renewable-energy policy (Lauber 2007, p. 18; Hirschl 2008), marked the end of an era where a national renewable-energy subsidy framework – which in the decades following its adoption had turned out to be a highly successful system that was emulated worldwide – had been called into question, and the beginning of an era of greater European Commission openness to a range of feed-in tariff systems. The ruling also established the legal certainty needed for further member-state renewable energy development (Bechberger 2007).

During the controversy concerning German renewable-energy subsidy policies, the groundwork was laid for adoption of an initial directive concerning renewable-energy support. They were justified as a way to protect the environment and at the same time ensure security of supply via the energy source diversification allowed for by renewables (Hirschl 2008, p. 337), but in the early stages were subject to little in the way of regulation compared to what was called for by the dominant European-market discourse. This was clearly exemplified by the debate concerning the scope of European renewable energy development goals and the extent to which they were binding (Jordan et al. 2010a, p. 112).

The European Commission's 1996 *"Energy for the Future: Renewable Sources of Energy. White Paper for a Community Strategy and Action Plan"* launched the debate concerning renewables expansion goals in the EU, and eventually led to adoption of the Renewable Energy Directive (2001/77/EC). Up until this point, the debate concerning renewables expansion goals had fluctuated between an overarching and a sector specific approach as well as indicative and legally binding goals. Already in 1996, the European Parliament adopted a resolution to the effect that by 2010 member states should increase the share of their respective national energy supplies to 15 percent across all sectors (Hirschl 2008,

p. 331). In the following year, the European Commission (European Commission 1997) recommended a goal of 12 percent of primary energy generation for renewables, likewise by 2010 – although this goal remained a mere statement of intention for a time.

Particularly in view of the priorities of the three electricity sector “pioneer” states (Germany, Spain and Denmark), the European Commission’s proposed directive of May 2000 (European Commission 2000) shifted to a goal of increased use of renewables in the electricity sector, whereby the renewable energies that came into play and that were meant to meet 22.1 percent of energy demand by 2010 were as follows: wind, solar, geothermal, wave and tide, hydro power, biomass, landfill gas, sludge gas and biogas. But unfortunately, because the European Commission’s original plan of setting mandatory targets was rejected by the member states, the directive (2001/77/EC) promulgating the 22.1 percent target was of an indicative nature only, i.e. it did not define mandatory objectives under European law that would be subject to legal sanctions if not met (Lafferty and Ruud 2008; Hirschl 2008).

All things considered, this initial phase was marred by a controversy that engendered considerable uncertainty concerning, and jeopardised the adoption of, member state renewable-energy support, which were at first subordinate to the objectives aimed at implementing a European market; and as noted the renewable-energy coalition had little clout at the EU level. This uncertainty concerning the admissibility under EU regulations of renewable-energy subsidies via feed-in tariffs was resolved by a European Court of Justice ruling. The intense debate concerning the relevant goals that unfolded during this period laid the groundwork for an initial albeit relatively toothless directive that called for combining electricity sector related expansion goals with far reaching member state subsidy programs.

### **5.2.2 The 2009 Renewable Energy Directive: a breakthrough via an integrated approach involving technology, energy and climate policy**

The directive on the use of renewable resources (2009/28/EC) that was adopted in December 2008 as part of a comprehensive climate and energy policy package substantially strengthened the European legal framework for renewable energy sources and greatly expanded the implementation framework for such sources. The directive sets energy, environmental and industrial policy objectives, particularly in terms of security of supply, climate protection, and industrial infrastructure renewal (Lafferty and Ruud 2008, p. 4 f; Jordan et al. 2010a).

The industrial policy dimension of a European climate policy is a key factor in view of the sharp rise in European energy prices between 2005 and mid 2008. In particular, the synergy effects of the competitiveness oriented Lisbon Agenda on one hand and European climate policy on the other was widely regarded as a starting point for a so called third industrial revolution (on the interplay between climate protection and competitiveness see Jänicke

2008; SRU 2005; Piebalgs 2009). Already at the beginning of the decade, the industrial policy model that was jointly developed by the International Energy Agency (IEA) and the European Commission had a major influence on the Commission. According to this model, greater market penetration of renewable energies speeds up innovation, which in turn speeds up market diffusion (Lafferty and Ruud 2008, p. 14). As the importance of technological and industrial policy for renewable energies dawned on the European Commission, they also realised the importance of subsidy policies for achieving the EU's renewable energy objectives. As a result, the Commission realised that expansion of renewable energies would make a contribution to achieving the objectives of the EU sustainability strategy, the Göteborg strategy, and the Lisbon Treaty's competitiveness strategy (Lafferty and Ruud 2008, p. 16).

Likewise of importance here is the growing job policy dimension of the renewable energy sector, which is now estimated to account for 0.6 percent of Europe's aggregate output (Ragwitz et al. 2009) and according to the European Commission will employ 600,000 persons by 2020 (European Commission 2010b, p. 13).

The unexpectedly sharp rise in energy prices since 2005 has also lent the issue of security of supply greater importance in Brussels (Geden and Fischer 2008; European Commission 2006, 2008; Jordan and Rayner 2010, p. 71). In its communication concerning a sustainable, competitive and secure energy supply (European Commission 2006), as well as the initial strategy issued shortly thereafter titled *An Energy Policy for Europe* (European Commission 2007b), the European Commission promulgated a strategic triad comprising climate protection, competitiveness, and security of supply (Geden and Fischer 2008, p. 40).

Congruent with these developments, the frameworks for implementation of renewable energies, particularly against the backdrop of the European Commission's intensified climate agenda, have improved. In 2007 and 2008, global warming was the central focus of the research, political and media communities, and ultimately led to adoption of an ambitious climate and energy package by the European Parliament and Council in December 2008. This Europeanisation of climate and energy policy is mainly attributable to the convergence of member state awareness of global warming on one hand and the vested interests of highly influential actors on the other (Sauter and Grashof 2007; Oberthür and Roche Kelly 2008; Geden and Fischer 2008; Schreurs and Tiberghien 2007; Schreurs 2009; Jordan et al. 2010b), which took the following forms, among others: unusually large numbers of severe weather events; more scientifically sound estimates of the risks associated with global warming, as was clearly stated in the fourth status report of the Intergovernmental Panel on Climate Change (IPCC); the economic turn taken by the climate debate as a result of the Stern Report (Stern 2007), which found that global warming will entail extremely high economic costs if climate protection measures are not taken. Added to what had now become a far stronger scientific consensus was the muscular leadership displayed by Great

Britain, Germany and France, which addressed the issue of global warming in a series of EU and G8 presidencies from 2005 to 2008. The European Commission jumped on the climate policy bandwagon as well by profiling the EU as an actor in international negotiations on global warming (Oberthür and Roche Kelly 2008; Schreurs and Tiberghien 2010) and by folding energy policy more robustly into EU integration strategies (Sauter and Grashof 2007).

All told, these various factors laid the groundwork for a new climate policy consensus that promoted climate and energy policy Europeanisation in 2007 and 2008 and which – in view of the scope of the decisions that were reached in this regard – also culminated extraordinarily quickly in adoption of the EU renewable energy directive in December 2008. It has often been stated in the literature that such a convergence of interests and problem perceptions is pivotal for any move towards deeper EU integration (Schäfer 2005).

One of the main effects of this overall Europeanisation of climate and energy policy was to strengthen the legal framework for renewable energies. The Renewable Energy Directive of 2009 resulted in the setting of far more extensive – and above all mandatory – renewable energy expansion goals.

In its implementation reports to date (European Commission 2009b being the most recent one), the European Commission has indicated that most member states have failed to sufficiently achieve the mandatory targets. In 2006, renewables accounted for only 15.7 percent of the electricity used in the EU – which, relative to the progress in this domain as at 2010, equates to fulfilment of around 35.2 percent of the mandatory target. Germany and Hungary were the only two member states that had reached their specific targets by 2010, at which time 21 member states were not even halfway there (European Commission 2009b).

Hence the amended directive that was proposed in 2008 aimed to make such goals mandatory. Already at the spring 2007 summit, the goal of expanding renewable energy use by 20 percent across all sectors in the run-up to 2020 was widely endorsed by the member states (Council of the European Union 2007). The European Energy Directive was incorporated into the European climate and energy package in December 2008 after less than a year of deliberations on the part of EU institutions. The member states' contribution to achieving the aforementioned 20 percent goal was determined using the EU clean air and climate protection policy input distribution model, which has been implemented successfully and differentiates the various member states according to their historical baseline situation and future development potential. The directive calls for the increase in member state use of renewable energies to be based partly on a fixed growth level for all member states, and partly on per capita income (see Table 5-1). The renewable energy expansion goals were incorporated into and made mandatory in the amended 2009 directive, which also calls for the European Commission to closely monitor the various phases so as to ensure prompt compliance with these objectives (Ringel and Bitsch 2009, p. 807; Lehnert and Vollprecht 2009, p. 310). Despite differences between the member states' individual objectives and the

fact that they are free to choose the relevant implementation instruments, the 2009 directive set the stage for de facto convergence of member state renewable energy subsidy policies (Jordan et al. 2010a, p. 115).

Another noteworthy recent development is that all regulations governing the electricity and transport sectors have been integrated into the Renewable Energy Directive of 2009. Although the directive governs all energy sectors – i.e. electricity, heating, cooling, and transport – it does not set binding European regulations for the various uses that come into play, except for the transport sector. Although this had originally been called for by the European Parliament (May 2007), the compromise that was ultimately reached only calls for an indirect mechanism for the implementation of sector specific objectives. Article 4 of the directive requires each member state to adopt a national renewable energy action plan that sets “national targets for the share of energy from renewable sources consumed in transport, electricity and heating and cooling in 2020.” The directive also requires the member states to “work towards an indicative trajectory tracing a path towards the achievement of their final mandatory targets” and to regularly review and modify this trajectory. This will also ultimately add up – via national action plans – the European targets for the various sectors. Thus for example Germany’s draft national action plan “forecasts” a 38.6 share of energy from renewable sources, which far exceeds the current policy target (Bundesregierung 2010). As at September 2010, at least eight additional member states had announced plans to increase their share of energy from renewable sources to a level far exceeding that of Germany (ENDS Europe, p. 17) (see Table 5-1). According to a number of projections, implementation of the Renewable Energy Directive will result in at least a one third increase in the share of energy from renewable sources in Europe by 2020 (Coenraads et al. 2008, p. 45; Bloem et al. 2010, p. 5), at which point renewable energies would be a key component of the energy mix in the EU. And indeed, the share of new power station capacity from renewable sources was 62 percent already in 2008 and 2009 (Bloem et al. 2010, p. 4) – a growth rate which, if it continues, will result in a 45 to 50 percent of share of energy from renewable sources in 2020 (Bloem et al. 2010, p. 6).

Table 5-1

**Breakdown by member state and electricity sector of the goal  
of a 20 percent share of energy from renewable sources**

Member state	Share of energy from renewable sources			
	Primary energy consumption		Electricity demand	
	2005	2020	2010	2020
Austria	23.3%	34%	69.3	70.6
Belgium	2.2%	13%	–	–
Bulgaria	9.4%	16%	10.6	20.6
Cyprus	2.9%	13%	4.3	16
Czech Republic	6.1%	13%	7.4	14.3
Denmark	17%	30%	34.3	51.9
Estonia	18%	25%		
Finland	28.5%	38%	26	33
France	10.3%	23%	15.5	27
Germany	5.8%	18%	17.4	38.6
Greece	6.9%	18%	13.3	39.8
Hungary	4.3%	13%		
Ireland	3.1%	16%	20.4	42.5
Italy	5.2%	17%	18.7	26.4
Latvia	32.6%	40%		
Lithuania	15%	23%	8	21
Luxembourg	0.9%	11%	4	11.8
Malta	0%	10%	0.6	13.8
The Netherlands	2.4%	14%	8.6	37
Poland	7.2%	15%	6.2	19.4
Portugal	20.5%	31%	41.4	55.3
Romania	17.8%	24%		
Slovakia	6.7%	14%	19.1	24
Slovenia	16%	25%	32.4	39.3
Spain	8.7%	20%	28.8	40
Sweden	39.8%	49%	54.9	62.9
Great Britain	1.3%	15%	9	31

Source: Directive 2009/28/EC, Annex I; ENDS Europe 2010, p. 17

The transition from an internal-market orientation to one where harmonised climate, technology and job policies predominate resulted in growing support for and decreasing opposition to feed-in tariffs, which are a more effective subsidy instrument for renewable energies (Bechberger and Reiche 2007; Fouquet and Johansson 2008). The European Commission recently abandoned its view that a more internal market oriented quota system

is the better option (Jones 2010, p. 94 ff). As at 2007, 19 of the 27 member states had adopted feed-in tariffs as a central renewable energy subsidy instrument (Agentur für Erneuerbare Energien 2010, p. 18), whose application spread with unprecedented speed between 2002 and 2005 (Bechberger and Reiche 2007, p. 34). Since then, Great Britain, which had for many years favoured the quota system, decided to institute feed-in tariffs for offshore wind turbines (DECC 2010).

But on passage of the amended 2008 directive, a controversy nonetheless erupted concerning support instruments. Although the European Commission had opted for a unified European support instrument, in January 2008 the Commission nonetheless proposed implementation of a system of tradable guarantees of origin, a move supported by EURELECTRIC (the self-described “association of the electricity industry in Europe”) (Lamprecht 2009; ten Berge and Cross 2010, p. 145; EFET 2007; EURELECTRIC 2008). The aim of allowing guarantees of origin to be traded was to promote successful fulfilment of renewable energy targets by enabling member states with high renewable energy expansion costs to purchase guarantees of origin in cost efficient states. However, this guarantee of origin trading system encountered virulent opposition from countries with feed-in tariffs such as Germany and Spain, since this system would have enabled vendors of inexpensive electricity from such countries to sell their electricity abroad at prices higher than those obtained via feed-in tariffs. As a result, feed-in tariff states would have been forced to resort to relatively high cost renewable energies to meet their national renewable energy expansion objectives (Lehnert and Vollprecht 2009; Schöpe 2010; Lauber and Schenner 2009; Nilsson et al. 2009; Fouquet and Johansson 2008). Thus the incompatibility between feed-in tariffs and guarantees of origin provoked virulent and ultimately successful opposition on the part of some member states, as well as the European Parliament. Hence the directive that was ultimately adopted in December 2008 merely calls for bilateral and multilateral cooperation with a view to preventing national subsidy systems from creeping in. Article 6 of the directive states that member states “may agree on and may make arrangements for the statistical transfer of a specified amount of energy from renewable sources from one Member State to another Member State” insofar as such transfers do “not affect the achievement of the national target of the Member State making the transfer.” The directive furthermore allows for the importation of “physical” renewable energies from third states (which would pave the way for importing energy from North Africa), although this does not apply to “virtual” imports in the guise of investments in renewable energy sources in third states (Schöpe 2010). Hence Directive 2009/28/EC to all intents and purpose institutionalises the compromise that was reached for the previous Directive 2001/77/EC, to the effect that Brussels will not interfere with national sovereignty when it comes to legislating renewable energy support schemes.

Adoption and implementation of the Renewable Energy Directive inevitably induced spill-over effects in terms of market deregulation and infrastructure policy (Jones 2010; Hellner 2010). Of supreme importance in this context is the competition-policy stipulation in Article 16(c) of

the Renewable Energy Directive to the effect that “Member States shall also provide for either priority access or guaranteed access to the grid-system of electricity produced from renewable energy sources.”

The Internal Electricity Market Directive (2009/72/EC), which was adopted at the same time as the Renewable Energy Directive, likewise contains a number of rules that apply to renewable energy, including stipulations that aim to protect the interests of “new entrants” in connection with grid planning and installation approval; whereby the following provisions are relevant for renewable energies:

- Article 3 states that “Member States may introduce the implementation of long-term planning” with a view to achieving renewable energy development goals.
- Article 7(2) stipulates, among other things, that authorisations to build new generation capacity must take account of the Renewable Energy Directive’s objectives.
- Article 22(4) states as follows: (a) “The regulatory authority shall consult all actual or potential system users on the ten-year network development plan in an open and transparent manner. (b) Persons or undertakings claiming to be potential system users may be required to substantiate such claims.” and (c) The regulatory authority is to “publish the result of the consultation process, in particular possible needs for investments.”

Grid development requirements arising from renewable energy capacity expansion is also taken into account by the pilot project for a ten year plan envisaged by the 42-member European Network of Transmission System Operators for Electricity (ENTSO-E). This plan calls for nearly half of the envisaged 42,000 kilometres of new transmission lines to be used to meet renewable energy capacity expansion needs (ENTSO-E 2010, p. 15), and for the same to be done for the 6,900 kilometres of high-voltage direct current transmission (HVDC) lines that are included in the ENTSO-E plan (concerning the role of high-voltage direct current transmission (HVDC) lines).

Industrial, energy and climate policy considerations have prompted the EU to greatly strengthen the legal framework for renewable energies, to which end a development path has been defined that calls, on the one hand, for renewable sources to supply more than one third of Europe’s electricity in 2020, thus making renewables one of the pillars of the electricity supply in the EU, and for institution of the infrastructure and other policy measures needed to achieve this aim on the other. Although the various member states’ obligations to expand renewable energy capacity differ from each other depending on each state’s baseline situation and potential, these obligations will nonetheless lead to a convergence of the economic frameworks necessary for renewable energies and stabilisation of national subsidy policies.

### **5.2.3 The outlook for 2050: renewable energies as a key decarbonisation technology**

EU policy initiatives since 2009 have been increasingly focusing on the run-up to 2050. In its preparatory communication to the Copenhagen Conference, the European Commission emphasised that the repeatedly endorsed 2 degrees Celsius objective will necessitate an 80 to 95 percent reduction of industrial states' greenhouse gas emissions by 2050 – as well as, ultimately, complete decarbonisation (European Commission 2009c, p. 4). In the guidelines for the European Commission currently in office (and whose tenure expires in 2014), the European Commission president José Manuel Barroso underscored that decarbonizing the electricity and transport sectors is a strategic objective (Barroso 2009). This concept was endorsed by the communication to the March 2010 summit of the European Council concerning the Europe 2020 strategy. This document speaks in terms of a “vision” of structural and technological change that must be implemented by 2050 in order to achieve a low carbon economy (European Commission 2010b, p. 14). In this same vein, the European Commission's 2010 work agenda calls for elaboration of a roadmap for the run-up to 2050 (European Commission 2010a, p. 8), and also emphasises the supreme importance of expanding the European electricity grid.

This envisaged long term decarbonisation is prompted by both climate and technology policy considerations (Kübler 2010) – although the title alone of the European Commission's November 2007 communication *A European strategic energy technology plan (SET Plan) - Towards a low carbon future* already set the tone in this regard, and in so doing enumerated the key low carbon technologies ranging from carbon capture and storage (CCS) to solar and wind energy to nuclear fusion. The SET Plan also underscores the need for a dedicated renewable energy transmission grid (European Commission 2007a) comprising high voltage lines that would be overlaid on the existing grid. The Plan is based on energy source-specific technology platforms that would accommodate the research and investment activities of the relevant public and private sector actors and would enable the European research framework program to focus on the designated key technologies. Further details concerning this approach, which would subsidise various low carbon technologies both separately and together, can be found in a European Commission communication from October 2009 (European Commission 2009a).

The aim of expanding low carbon energy source capacity is to support the development of nuclear fusion, carbon capture and storage (CCS) and renewable energies. Both the financial assistance for technologies under the European economic recovery program pursuant to *Regulation (EC) No 663/2009 establishing a programme to aid economic recovery by granting Community financial assistance to projects in the field of energy*, as well as the envisaged use of emissions trading auction proceeds, clearly exemplify the European

Commission's technology-neutral approach, which promotes successful implementation of existing financial assistance and research instruments.

The EU's key role in defining Community energy policy is set to expand, particularly in connection with expansion of the trans-European electricity grid, an undertaking that has already gained widespread support, largely due to the fact that it serves the vital interests of all competing energy sources. While (a) load balancing via integration of distant intermittent energy source; (b) use of pump storage system capacity; and (c) interconnecting electricity generation installations that are far distant from each other (no. 232; Czisch 2009) are of primary importance for renewable energy capacity expansion, for operators of conventional power plants a larger and more efficient European electricity grid would establish conditions conducive to electricity sales in a market characterised by a growing share of intermittent energy sources, while new opportunities for the export of nuclear power might also open up (Pellion 2008; ECF et al. 2010). Such a trans-European grid would also mitigate conflicts between the intermittent and conventional electricity generation systems; in addition it is also of major policy importance to the European Commission and other supranational actors since this grid, unlike just about any other energy policy measure, underscores the importance of setting energy policy in Brussels and is absolutely essential if the internal European market is to function efficiently.

Hence the European Commission's decarbonisation agenda is technology-neutral in that in the Commission's view coal CCS, nuclear power, nuclear fusion, and renewable energies should receive equal treatment when it comes to technology policies, and all of these technologies have a role to play – which awaits further fleshing out – in the energy mix of tomorrow. Hence the medium term impact on renewable energies cannot be foretold with certainty, and will ultimately be determined by how the other relevant frameworks unfold. The European Commission's views on this matter were not slated for issuance until after the present report went to press.

Were the European Commission to follow the decarbonisation recommendations of the major power companies, the resulting technology neutral European market instruments such as emissions trading and abolishing separate national subsidy programs would level off the share of renewables at only around 40 percent in 2030, while nuclear energy, as well as coal CCS would continue as Europe's main sources of electricity (EURELECTRIC 2010; ECF et al. 2010). This view is also shared by the European Commission (European Commission 2010c, p. 14). But this would mean that the energy supply in the EU would fail the sustainability criteria discussed in chapter 2.

However, another possible scenario in this regard is that renewable energies will benefit from the European Commission's aim of achieving a low carbon economy by 2050. For it would seem that, in light of factors such as public opposition to nuclear power and the implementation problems entailed by carbon capture and storage (CCS), decarbonisation

cannot be readily achieved without additional substantial renewable energy capacity growth after 2020. However, once the share of energy from renewable sources has reached a certain threshold, problems may arise in terms of the interoperability of load based and wind/solar energy at the European level; and setting infrastructure policy milestones. This in turn could eventually lead to a situation where both member state and EU actors might regard pursuit of a technology-neutral and solely market driven decarbonisation strategy as an illusory goal (chapter 8; Matthes 2009).

Likewise a key factor in pending fundamental decisions at both the EU and member state levels is a series of emerging alliances that include large and financially powerful corporations – particularly in the technology, logistics, finance as well as think-tank sectors – and that far exceed the scope of the current coalition of renewable energy manufacturers associations and environmental groups. The efforts of these new coalitions centre around two types of activities. First, proving, by means of scenarios, that a largely or wholly renewable electricity supply is achievable in terms of potential capacity and can also be economically competitive. Secondly, various industrial consortiums have been formed that are looking into the possibility of investing heavily in electricity generation and the attendant grids in the North Sea or Mediterranean regions . Such efforts are helping to make the network of energy policy actors considerably more pluralistic at the European level.

The European Climate Foundation (ECF) – a relative newcomer among these actors, and one that falls into the category of neither an environmental group nor a manufacturers association – uses its considerable financial clout to carry out projects of its own and to support campaigns, citizen referendums, environmental groups, and the climate protection research activities of various organisations. The ECF's *Roadmap 2050: A practical guide to a prosperous, low-carbon Europe*, which was issued in April 2010 and caused a considerable stir, shows that there is little difference between the cost of a low carbon energy mix comprising nuclear power and carbon capture and storage (CCS) technology on one hand, and a largely renewable electricity supply on the other. The EREC – the self described “voice of the renewable energy industry” – is likewise using the upcoming debate concerning a European energy strategy in the run-up to 2050 to persuade the European Commission that abundant and cost efficient renewable energy potential is available (EREC 2010). These various scenarios and studies also constitute a response to a scenario advocated by EURELECTRIC (the self-described “association of the electricity industry in Europe”), which is attempting to persuade the European Commission of the wisdom of a balanced energy mix comprising renewable energies, nuclear power, and coal CCS (EURELECTRIC 2010; Lamprecht 2009). Although the effect of these various lobbies will ultimately have on the European Commission's energy policy decisions remains to be seen, this much is clear: the strategic agenda-setting capacities of a substantially expanded coalition of advocates of a more robust expansion of renewable energy capacity in the context of the European Commission's decarbonisation agenda have greatly increased, to the point where the option

of a largely renewable electricity supply in the EU is now being given serious consideration, and its viability has been demonstrated via a number of large studies.

That said, the EU still has a long way to go before a consensus on renewable energies is reached. Support for nuclear energy on the part of the European Commission and numerous EU member states including France, Great Britain, Germany and Finland for nuclear energy continues unabated, as does support for coal CCS on the part of Poland, Great Britain, Germany and Spain, among other states. This strong support for non-sustainable technologies, along with extensive technology subsidies, grid expansion, and a resurgence of the internal-market agenda could prevent further dynamic growth of renewable energies. The reality is that the EU is far more likely to opt for a strategy involving only a limited share of energy from renewable sources in an energy mixing involving substantial conventional energies, rather than making a clear decision in favour of a wholly renewable electricity supply.

This evolution will make it all the more important that EU policy decisions concerning a wholly renewable electricity supply keep all development options open and allow for incremental dynamic progress. Hence it is crucial that work continues on the developments that have come on the scene in recent decades, and that these advances be institutionalised from 2020 onward. To this end, it is essential that the envisaged grid infrastructure package promote (a) the needs of renewable energies; (b) an even-handed approach to the potentially conflicting goals of the European internal market and national subsidy policies; (c) the debate concerning the compatibility of intermittent and conventional energy sources. Such issues have yet to be explored in terms of the period after 2020.

### **5.3 Conclusions for Multilevel Policy Making on Renewable Electricity**

The past three decades have seen a sea change in EU and German policies in the realm of renewable energies that has also wrought a major change in the relevant legislative frameworks during this period. If renewable energies were primarily the province of a handful of pioneering SMEs, maverick energy experts, and the environmental movement in the 1980s, they have since proven their commercial viability and are widely accepted in both Germany and Europe. Moreover, their contribution to German and European technological leadership and security of supply is beyond dispute.

EU and member state environmental and energy policies have also become increasingly interwoven. Whereas at the outset the debate revolved around whether and how renewable expansion could be promoted via research and development path policy, the Renewable Energy Directive has made renewable energy capacity expansion a permanent fixture in both the EU and member state policy firmament in the run-up to 2020. Indeed renewable electricity capacity expansion objectives that have been set by Germany, which is an

international model when it comes to funding renewable energy development, are ambitious. German renewable energy sector growth has been mainly driven by national funding instruments, particularly the Renewable Energy Act (EEG) (for more detail: see chapter 8). The EU has set key environmental and climate policy frameworks via the Renewable Energy Directive as well as European emissions trading, while The Internal Electricity Market and Trans-European network (TEN-E) guidelines have been particularly relevant in terms of economic competitiveness.

All things considered, EU policy and legislative processes over the past three decades in these areas have indisputably established an advantageous and trend-stabilizing climate for member state renewable energy subsidy policies – whose medium term implementation is nonetheless jeopardised, particularly by EU competition policy objectives. Such policies have been successfully upheld in Germany thanks to the European Court of Justice's ruling against the complaint concerning Germany's feed-in tariffs (StromEinsG) and to the German government's successful efforts to fight off attempts to weaken Renewable Energy Act (EEG) funding instruments via the EU-wide guarantee of origin trading system.

In both Germany and the EU, the future status of renewable energies as a supplement to or replacement for other relatively climate neutral energy technologies such as nuclear energy and coal CCS remains a matter of controversy.

## **6 Elements of the transition to a wholly renewable electricity supply**

### **6.1 Basic considerations**

German and European energy supply systems – of which the electricity supply system is a core element – are currently non-sustainable. Transitioning to a wholly renewable electricity supply would greatly increase the ability of both Germany and the EU to bring greenhouse gas emissions down to the requisite levels. Although important steps toward this goal have been taken in both Germany and the EU, the lion's share of electricity still comes from conventional energy sources.

Inasmuch as energy systems are highly path dependent, the energy investments we make today will determine the shape of the energy industry for a long time to come. If we continue making climate-unfriendly investments in existing fossil fuel energy sources, it will become next to impossible for Germany to reach its long term climate policy goal of reducing greenhouse gas emissions by 80 to 95 in the run-up to 2050.

Among the key findings of the present study is that renewable energies would be sustainable, would meet German electricity demand in 2050, would provide electricity at competitive prices, and would allow for optimal security of supply since (a) renewable electricity would be less expensive than a conventional low carbon energy mix; (b) an all renewables electricity system would allow for precise load balancing of electricity generation and demand at all times; and (c) renewable electricity capacity would far exceed electricity demand, even after allowing for land use competition scenarios and above all the relevant nature conservation concerns.

However, it's not enough to merely prove the technical feasibility of an all renewables electricity system, for the federal government also needs to play a leading role in steering energy infrastructure investments in a climate friendly direction. A radical change such as transitioning to a wholly renewable electricity supply will necessitate strong political leadership, visionary policies, and political will.

In order to accomplish this, it will be necessary to translate the economic and ecological attributes of system change into political action and send the right policy signals at the right time.

In order for Germany to migrate to an all renewables electricity system, it will be necessary for the following to occur:

- We will need to continuously grow renewable energy production, grid (including high voltage grids) and storage capacity.
- The lifetime of written-down or climate-unfriendly production capacity must not be extended.

- No new power stations should be built that undermine the goal of decarbonisation and that are not conducive to variable load balancing from an economic and technical standpoint.
- All of the above needs to go hand in hand with energy efficiency policies that aim to maximally reduce energy demand and with it the aggregate economic cost of supplying renewable energies.

The politics of such a transformation will need to display the following dimensions, which are discussed in the subsequent chapters:

- All parties across the political spectrum must support the goal of transitioning to a wholly renewable electricity supply – at least in the long run. As this goal could be reached by 2050, it should be a fully integrated and clearly enunciated component of not only the federal government's sustainability strategy, but also government programs and party platforms. The government's current energy master plan calls for an 80 percent share of energy from renewables in 2050 (BMW and BMU 2010). Sustaining this kind of radical transformation across numerous legislative sessions will necessitate broad support among the electorate and a nonpartisan consensus, and will require politicians from all parties to put their shoulder to the wheel.
- Important infrastructure investment planning and decisions must be realised at the highest policy levels, in consultation with all other actors, and hard decisions will have to be made even if they arouse political opposition for a time. Hence it will be necessary to develop policies that steer us toward an all renewables electricity system and at the same time mitigate the social and economic impact of such policies on actors that lose out as a result of the envisaged changes.
- Inasmuch as our climate policies are inextricably bound up with EU energy and climate policies, the transition to an all renewables electricity system needs to be realised in a fashion that takes account of these multi-level climate policy interconnections. In other words, even if the federal government sets the stage for the desired transformation of our energy system, the relevant European frameworks must be not only taken into account but also optimised, and multi-faceted regional and municipal initiatives should be undertaken and strengthened.
- Market forces will not be sufficient to bring about an all renewables electricity system, which will instead necessitate the use of a broad range of strategic instruments. In view of the limitations of the current EU emissions trading framework, the extent of possible additional regulatory measures aimed at promoting the transition to renewable energies will need to be implemented. For while emissions trading is an essential climate protection instrument, it cannot hope to single-handedly achieve the same level of efficiency when it comes to meeting the requirements for effective climate protection, which include

expansion of renewable energy generation capacities, phasing out climate-unfriendly power plants, and banning the construction of new power plants that do not lend themselves to variable load balancing. This cannot be achieved through emissions trading alone, which will therefore need to be supported at a minimum by (a) other funding instruments that promote renewable energy capacity expansion; (b) planning instruments and incentives that promote intensified grid expansion and that foster public acceptance of such measures; and (c) policies that forestall the realisation of counterproductive investments.

In short, the need to establish a coherent instrument mix and to efficiently synchronise and coordinate the relevant capacity expansion and reduction processes will also give rise to new government responsibilities for orientation, investment and outcome certainty. Establishment of an all renewables electricity system should go hand in hand with an open, transparent, and pluralistic debate that people from all societal groups are afforded the opportunity to participate in; for this is the crucial factor when it comes to getting the general public to accept an all renewables electricity system and let go of the current system. This debate will also play a pivotal role in showing politicians which constellations of instruments have what it takes to bring about a wholly renewable electricity supply in a manner that is acceptable to the general public, ecologically sustainable, and economically viable.

## **6.2 Evolution of EU energy policy**

### **6.2.1 Allocation of Brussels and member state energy policy competence under the Lisbon Treaty**

If EU energy policies – which up until now have chiefly been an outgrowth of European environmental and internal market policies – are poised to take on a life of their own thanks to the Lisbon Treaty, there is no denying the fact that energy and environmental policies are inextricably bound up with each other, particularly when it comes to climate protection. This situation raises a number of issues concerning horizontal competency overlaps and the attendant issue of vertical competency delimitation in terms of the leeway allowed Member States to set their own energy policies. What this mainly boils down to is where Brussels' sphere of responsibility leaves off and where Germany's starts.

#### **6.2.1.1 Spheres of responsibility outside the framework of new energy competencies**

The previous treaty contained no provisions concerning regulatory authority over the energy sector, whereby the right to take measures in this regard was based on environmental competence (ex Article 175 of the Treaty establishing the European Union), authority over internal market harmonisation (ex Article 95 of the Treaty on European Union), and authority over trans-European electricity grids (ex Article 156 of the Treaty on European Union). These

spheres of authority were for the most part carried over to and retained their original meaning in the Treaty on the Functioning of the European Union (TFEU).<sup>2</sup>

#### Tenets of the subsidiarity principle pursuant to Article 5 of the Treaty on European Union

Whenever the EU exercises authority over a particular matter, the EU's overarching statutory competence principle known as the subsidiarity principle (pursuant to Article 5 of the Treaty on European Union (ex Article 5 of the Treaty establishing the European Union)) must be taken into account. This Article lays out the fundamental principles for all actions taken by the EU and is thus the lynchpin of all decisions concerning the exercise of EU authority. The principles of limited individual authority (paragraphs 1 and 2), subsidiarity (paragraph 3), and proportionality (paragraph 4) in Article 5 of the Treaty on European Union constitute a legal code for all exercise of authority by the EU. It therefore follows that the EU only has authority to act insofar as such authority has been formally vested in the EU, the matter at hand involves a cross-border problem that can best be resolved by the EU, and the measures taken leave the member states as much leeway as possible (Calliess 1999, p. 65 ff. and p. 240 ff).

Insofar as one of the rare cases that falls solely within the EU's authority does not come into play (see Articles 2 and 3 of the TFEU), the member states also retain authority for any matter that falls within the purview of the EU, until such time as the EU exercises its authority by enacting a concrete measure (this is referred to as the prohibitive effect).

Environmental policy authority pursuant to Article 192(1) and (2) of the TFEU  
Article 192(1) of the TFEU lays out the spheres of authority for EU actions that aim to realise the goals of its Article 191. The Lisbon Treaty defines "promoting measures at international level to deal with regional or worldwide environmental problems, and in particular combating climate change" as the goal of Community environmental policy, pursuant to Article 191(4)(indent 4) of the TFEU, and contains all other environmental policy provisions of the Lisbon Treaty.

In principle, environmental policy measures normally require a majority vote of the European Council, and are also subject to a European Parliament co-decision procedure. However, in derogation of this practice and on policy related grounds, Article 192(2) of the TFEU enumerates a series of specific types of actions that are of particular importance to the member states and that are therefore subject to "the Council acting unanimously in accordance with a special legislative procedure." Article 192(2) of the TFEU is relevant for energy in the following two respects.

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<sup>2</sup> Translator's note: In the interest of brevity, this treaty is referred to in the remainder of this document by its standard acronym, TFEU, or as "the Treaty."

First, pursuant to Article 192(2)(a) policy instruments that take the form of tax incentives (i.e. “provisions primarily of a fiscal nature”) are subject to a unanimous vote of the Council. In line with the narrow interpretation of the concept of “derogation” that prevails in the literature, such instruments here refer solely to taxes in the narrow sense of the term; and thus all other fees, charges and the like such as eco-fees in the guise of special fees and user charges fall within the scope of paragraph 1 and are thus not subject to the unanimous vote rule (Kahl in: Streinz/Burgi 2003, Art. 175 no. 18). The word “primarily” means that the environmental measures must have a taxation focus; and thus for example the tax deductions for low emission motor vehicles do not fall within the scope of paragraph 2. Against this backdrop, some authors have incorrectly claimed that the greenhouse gas emissions trading directive should have been adopted by a unanimous vote since issuance of the certificates for a fee constitutes a fee regulation within the meaning of paragraph 2(a) (Kirschhof and Kemmler 2003, p. 217). However, a unanimous vote was required on a proposed 1992 directive concerning a tax on carbon dioxide emissions and energy harmonisation.

Secondly, pursuant to Article 192(2)(c) of the TFEU, “measures significantly affecting a Member State's choice between different energy sources and the general structure of its energy supply” are subject to a unanimous vote and to an ensuing member state veto. “Significantly” here means that the unanimous vote requirement only applies to final measures that affect the general structure of a member state's energy supply (Kahl in: Streinz/Burgi 2003, Art. 175 no. 28 f). Hence there was considerable opposition to the envisaged directive concerning government subsidies for renewable energies, as this was regarded as a significant interference in the member states' energy supplies.

Although this wording of Article 192(2) of the TFEU lays down special procedural requirements for energy related environmental measures, it implicitly states that as a rule such measures fall within the scope of Article 192 of the TFEU. Hence this provision forms the basis for EU authority to adopt environmental policy measures, even in cases where such measures infringe on member states' freedom of action (Epiney 2005, p. 60; Pernice 1993, p. 110).

Authority over approximation of laws pursuant to Article 114(1) of the TFEU  
Numerous energy policy measures, particularly those concerning establishment of the European internal electricity market (in this connection, the European Parliament recently spoke in terms of full “ownership unbundling,” i.e. the separation of power companies' generation assets from their transmission networks in the electricity market), were based on the general harmonisation authority pursuant to Article 95 of the Treaty establishing the European Union (now Article 114 of the TFEU) (Calliess 2008), which stipulates that the relevant proposed legislation must relate to the establishment and functioning of the internal market. This criterion is deemed to be met insofar as a particular measure aims to eliminate

either obstacles to basic freedom of action or discernible distortions of competition (Kahl in: Calliess/Ruffert 2007, Art. 95 no. 14).

Trans-European grid authority conferred by Article 172(1) of the TFEU

Brussels' authority in the sphere of renewable energies takes on outstanding importance when it comes to trans-European electricity grids. For example, equal amounts of solar energy and hydro power cannot be generated in all member states owing to differences in climatic and topographical conditions. This in turn means that solar energy needs to be generated in southern Europe or North Africa, while hydro power mainly comes from Scandinavian and Alpine countries. But in order for this electricity to reach high demand regions, an efficient grid structure is necessary; and this is where the energy and environmental policy significance of Article 172 of the TFEU comes in.

The EU's competence concerning the trans-European network (TEN-E) is derived from Articles 170 and 171 of the TFEU, which expands on the application domain of Article 172, which confers the requisite authority; whereby in this context the term "trans-European" indicates that the networks that are to be established or expanded exhibit a specific cross-border attribute and that, by extension, infrastructure projects of solely local or regional nature are not the EU's responsibility. Nonetheless, the concept of a trans-European network (TEN) also includes infrastructure projects that solely relate to the specific interests of individual member states (Koenig and Scholz 2003, p. 223 f; Bogs 2002, p. 49 f).

Article 170 of the TFEU contains a complete list of TEN goals that the EU is authorised to pursue ("promotion"). Contrary to the previous practice whereby member states planned and constructed their networks in accordance with national standards, under the TFEU "action by the Union shall aim at promoting the interconnection and interoperability of national networks" – which means that what were once border or peripheral regions are now focal points of the internal market by virtue of not only geographic and economic factors, but also oftentimes owing to national defence or military infrastructure elements. Hence the Treaty also stipulates that the Union (a) "shall take account in particular of the need to link island, landlocked and peripheral regions with the central regions of the Union;" and (b) harmonise the member states' diverse technical standards. The goal here is to establish the interoperable trans-European network called for by Article 170 ff of the Treaty, with a view to enabling the networks of neighbouring states to interconnect, thus filling any gaps resulting from network construction or expansion and efficiently interconnecting autonomous national networks in the interest of the functionality of the system as a whole.

Article 171 of the TFEU enumerates the following measures and other actions that the EU is authorised "to achieve the objectives referred to in Article 170": establishing guidelines; ensuring network interoperability; and providing financial support for projects of common interest. The fact that this constitutes a complete list is signalled in the German version of the

treaty, by the absence of the term in particular” (Schäfer in: Streinz/Burgi 2003, Art. 154 of the Treaty establishing the European Union no. 2).

While the EU may or may not provide financial support in its discretion, it is obligated to establish guidelines and ensure network interoperability, although there is no ranking relationship between these latter two types of actions. Hence guidelines can also be established in cases where no interoperability measures have been promulgated (EuGH, Slg. 1996, I-1689, Rz. 26 – Parlament/Rat).

Viewed in this light, such EU guidelines are legally binding frameworks that the member states are required to implement. Article 4(3) of the Treaty on European Union stipulates that the member states are to “refrain from any measure which could jeopardise the attainment of the Union's objectives.” (Schäfer in: Streinz/Burgi 2003, Art. 155 of the Treaty establishing the European Union no. 5). The trans-European network guidelines were initially laid down in Decision No. 1254/96/EC amending Decision No. 1741/1999/EC. In addition, Decision No. 96/391/EC lays down a series of actions aimed at improving the conditions for expansion of the trans-European network in the energy domain. The list of categories defined in this decision and the ensuing Decision No. 1229/2003/EC concerning priority projects of common interest that are worthy of support was expanded by Article 8 of Decision No. 1364/2006/EC concerning projects of European interest, which are to be given (a) “appropriate priority” when “selected under the budget for the trans-European networks”; and (b) “particular attention” when “selected under other Community co-financing funds.”

These objectives and priorities are to be supported by harmonised procedural principles aimed at their effective implementation. To this end Article 8 of Directive 680/2007/EC lays down “general rules for the granting of Community support” that are to be fleshed out by the European Commission via its annual and multi-annual work programs (European Commission 2008a, p. 33).

In its Green paper: toward a secure, sustainable and competitive European energy network (European Commission 2008d), the European Commission calls for far reaching expansion of support (including support) for the trans-European network, in its capacity as a key factor for the achievement of EU climate protection objectives.

### **6.2.1.2 New areas of EU authority over energy policy under the Lisbon Treaty**

After the Lisbon Treaty came into force on 1 December 2009, the EU's authority over energy policy discussed above was expanded via a specific energy policy competence pursuant to Article 194 of the TFEU, wherein authority to implement the energy policy objectives in Article 194(1) is granted by Article 194(2)(1). Article 194(2)(2) contains derogations concerning the relevant application domain, while Article 194(3) calls for a special legislative procedure for energy taxes.

### **6.2.1.2.1 EU energy policy objectives, particularly those laid down in Article 194(1)(c) of the TFEU**

The four energy policy goals laid down in Article 194(1) of the TFEU are as follows: (a) ensure the functioning of the energy market; (b) ensure security of energy supply in the Union; (c) promote energy efficiency and energy saving and the development of new and renewable forms of energy; and (d) promote the interconnection of energy networks.

These objectives are subject to the following three guiding principles: EU energy policy is to be carried out (a) “in a spirit of solidarity between the Member States; (b) “in the context of the establishment and functioning of the internal market; and (c) “with regard for the need to preserve and improve the environment.” These vague objectives are essentially the same as those laid down previously by the EU on the basis of its prior “statute law”. The objective laid down in Article 194(1)(c) of the TFEU (“promote energy efficiency and energy saving and the development of new and renewable forms of energy”) is particularly relevant for energy and environmental policy. However, the extent of the environmental policy authority granted by Article 192(2) of the TFEU (ex Article 175(2) of the Treaty establishing the European Union) is unclear – particularly as to whether all renewable energy matters are now to be governed by Article 194. Most authors who have addressed this matter (albeit in a somewhat cursory manner) have concluded that Article 194 is a *lex specialis* (Britz 2009; Vedder/Heintschel von Heinegg 2007, Art. III-256 Rn. 3; Heemeyer 2004, p. 228 f; Trüe 2004, p. 786 f). Although this would theoretically meet the goal – pursuant to the EU’s new sphere of authority – of folding the EU’s current energy policy competence into a new energy regulation (draft of the Treaty Establishing a Constitution for Europe: Dok CONV 727/03, Annex VII, p. 110), there are also persuasive arguments against such a reading of the provision, namely the following:

First, Article 194 speaks in terms of promoting not renewable energies but rather the development of such energies – by which, it is safe to assume, only technological development could possibly be meant (Kahl 2009, p. 60). Likewise inconsistent with a blanket *lex specialis* reading of the provision is the stipulation that the EU’s authority to act is “[w]ithout prejudice to the application of other provisions of the Treaties.” Paragraph 2(2) supports this concept as well in that it limits the EU’s energy competence to situations involving a measure’s “choice between different energy sources and the general structure of its energy supply,” albeit “without prejudice to Article 192(2)(c)” of the TFEU. But this non-prejudice clause only makes sense if Article 192 of the Treaty applies in all cases in conjunction with Article 194.

Hence the EU’s newfound authority over energy policy solely empowers it to promote the technological development of renewable energies, whereby any economically or ecologically motivated support henceforth is governed by environmental regulations.

### 6.2.1.2.2 Authority granted by Article 194(2) of the TFEU

Article 194(2)(1) empowers the EU to “establish the measures necessary to achieve the objectives in paragraph 1” – an extremely vague formulation, which, coupled with other EU authority, makes its energy policy jurisdiction seem all encompassing at first glance, while mandating a far reaching limitation on this authority to the effect that such policy measures “shall not affect a Member State's right to determine the conditions for exploiting its energy resources, its choice between different energy sources and the general structure of its energy supply, without prejudice to Article 192(2)(c).” Although this limitation is similar to the aforementioned environmental policy provision pursuant to Article 192(2)(c) of the Treaty, it goes considerably farther for the following three reasons:

1. The requirements laid down in Article 192(2) need not be met cumulatively (“or”), whereby, unlike in Article 194 (“and”) they can be met alternatively.
2. There is no requirement that the measures must have a “significant” effect on the areas subject to a derogation. Article 192(2)(2) of the TFEU should be interpreted narrowly as a derogation (on Art. 175(2) of the Treaty see Calliess in: Calliess/Ruffert 2007, Art. 175 no. 21; Jahns-Böhm in: Schwarze 2009, Art. 175 no. 12), which thus does not apply across the board irrespective of the intensity of the measure in question (Ehricke and Hackländer 2008, p. 599). It then follows that a measure can be deemed to affect a member state's energy supply solely in cases where, for example, it relates solely to energy supply related details such as technical matters (Neveling 2004, p. 343). Nonetheless, in the absence of an expressly defined significance threshold, the derogation clause grants the member states considerable sovereignty vis-à-vis Community energy policy.
3. Unlike the procedure stipulated by Article 192(2)(c) of the Treaty, its Article 19(2)(2) lays down a genuine restriction on EU energy policy authority, for the formulation “without prejudice to Article 192(2)(c)” should by no means be regarded as a mere procedural-law allusion to the unanimous Council vote provision of paragraph 3. Unlike the environmental policy measures governed by Article 192(2)(c) of the Treaty, energy policy measures with no environmental implications and that could potentially infringe on member states' sovereign right to adopt such measures are not subject to the unanimous Council vote provision of paragraph 3, since in fact the Council has no authority in such matters (Ehricke and Hackländer 2008, p. 599). This concept is supported by two factors. First, paragraph 3 calls for a unanimous Council vote on energy tax measures only – *and* “without prejudice to paragraph 2” (Ehricke and Hackländer 2008). Secondly, such a reading runs counter to the process that gave rise to the provision (draft of the Treaty Establishing a Constitution for Europe: Dok CONV 725/03, p. 91; Calliess 2010).

### **6.2.1.2.3 The unanimous Council vote provision of Article 194(3) of the TFEU**

The derogation in Article 194(2) substantially limits the EU's jurisdiction over Community energy policy, which is further limited by the procedural rule laid down in paragraph 3, which – in keeping with Article 192(2)(a) of the TFEU (ex Article 175 2(a) of the Treaty establishing the European Union) and the tax derogation provisions in other treaties – requires a unanimous Council vote “after consulting the European Parliament” in matters that are “primarily of a fiscal nature.” The necessarily narrow reading of this restriction notwithstanding, it shows that the member states still regard energy law as a highly sensitive issue when it comes to their national sovereignty.

### **6.2.1.2.4 Interplay between Article 194 of the TFEU and other areas of EU jurisdiction**

The relationship between Article 194 of the Treaty and the EU's environmental policy authority was discussed above. Other issues regarding the scope of EU authority in this domain are raised by Articles 114, 122, and 222 of the TFEU.

#### Interplay between Article 194 and Article 114 (concerning approximation of laws)

Relative to Article 114 of the TFEU (ex Article 95 of the Treaty establishing the European Union), Article 194 is a *lex specialis* (Kahl 2009, p. 46; Rodi in: Vedder/Heintschel von Heinegg 2007, Art. III-256 No. 3). This reading is supported by the wording of Article 194, whose paragraph 1(a) expressly mentions the energy market, and, historically speaking, by the convention presidium's intention of aggregating energy policy authority (draft of the Treaty Establishing a Constitution for Europe: Dok CONV 727/03, Annex VII, p. 110). Hence the controversy over the admissibility of future oriented approximation of laws is superfluous, by dint of the fact that pursuant to Article 194 of the TFEU it is admissible beyond the shadow of a doubt (Neveling 2004, p. 43; Kahl 2009, p. 51).

#### Interplay between Article 194 and EU authority over the trans-European network pursuant to Article 172

It is unclear whether Article 194 of the TFEU (ex Article 156 of the Treaty establishing the European Union) is a priority regulation in its capacity as a more specific regulation (a view endorsed by Todi in: Vedder/Heintschel von Heinegg 2007, Art. III-256 No. 3; 3; Trüe 2004, p. 786; Kahl 2009, p. 60). Although the contention that Article 172 is a more specific provision than Article 194 of the TFEU would appear to be plausible at first glance, it is negated by the fact that Articles 170, 171 and 172 of the TFEU relate to all member state networks and access thereto, while Article 194 solely governs energy networks. Hence, in view of the lesser statutory scope and application domain of Article 194, it is in fact the more

specific provision. However, the application domain of Article 194 still remains to be determined, since Article 172 remains fully applicable in tandem with Article 194.

The issue here is whether the EU's new authority over support for energy network interconnection measures also includes jurisdiction over support for the trans-European network and interoperability of the various member states' energy networks pursuant to Article 170(2) of the TFEU. This would appear to be the case since interconnection is by definition the umbrella term in this context, i.e. interoperability is a subset of and is subsumed by interconnection. Interoperability refers to the technical ability of two systems to interact with each other, a process that chiefly involves common or at a minimum non-mutually exclusive standards. "Interoperability of national networks" refers to the preconditions for trouble-free interconnection of national networks and the components thereof, particularly when it comes to establishment of a trans-national network (Erdmenger in: von der Groeben/Schwarze 2003, Art. 155 No. 19).

The purpose of such a network is to compensate for the technical incompatibility of individual national networks (e.g. line voltage differences) by harmonizing the relevant technical standards or developing purpose-built technical equipment. In the latter case, it is crucial to ensure from the outset that the relevant technical standards are compatible with each other. Interoperability likewise encompasses the organisational realm, which means that harmonisation measures should also lay the groundwork for economically optimal networks that deliver the best possible security of operation. To this end, both statutory regulations and the applicable EU and industry-organisation standards should be adhered to (Calliess/Ruffert 2007, Art. 154 no. 19).

Interconnection (in a technical system) has a broader meaning, on the other hand, in that it refers to the interconnection of physical network structures by establishing the relevant standards and installing the relevant equipment at the interconnector and transfer points. However, in economic terms interconnection refers to a scenario where technically and logically interconnected networks are also used. Hence the term interconnection covers a broad range of scenarios, in that in a general sense it refers to market-actor access to a network used in common by all such actors. For electricity networks it refers to interconnection of the electricity networks of various states. Hence interconnection is used as a catch-all term – for example in a European Commission communication titled "Recent progress with building the internal electricity market" (European Commission 2000, p. 7), which states as follows: "[A]greement has been reached to analyse existing bottlenecks in terms of interconnectors between systems."

Hence the EU's authority to "promote the interconnection of energy networks" pursuant to Article 194(1)(d) of the TFEU goes beyond the scope of that provided by current legislation, since this authority is limited by Article 172 of the Treaty in the following ways:

(1) Pursuant to Article 171(1)(indent 1) of the Treaty, the EU has the authority to enact mandatory guidelines – which however are solely intended to coordinate the relevant measures (Härtel 2006 § 13 No. 13; Trüe 2002, p. 109);

(2) The authority granted by Article 171(1)(indent 2) of the Treaty is limited solely to measures that “may prove necessary to ensure the interoperability of the networks,” i.e. existing networks only; and

(3) Pursuant to Article 171(1)(indent 3), the EU is only allowed to “support projects of common interest supported by Member States” (Voet van Vormizee in: Schwarze 2009, Art. 155 No. 9). In contrast, Article 194 of the Treaty empowers the EU to undertake interconnection projects of its own; it also applies to projects that solely have a bearing on the interests of individual member states. Although the EU can require member states to carry out such projects, it cannot stipulate attendant implementation methods (e.g. specific power line routes) by virtue of the fact that the EU lacks the authority to plan such implementation (Article 5(2) of the Treaty on European Union) and of the subsidiarity principle as well (Article 5(3) of the Treaty on European Union). And thus authority over such matters is left to the member states.

Hence the question arises as to the actual scope of the application domain under Article 172 of the Treaty, since the trans-European network provisions of Article 170(1) of the Treaty still apply to energy policy. It is possible that Article 172 empowers the EU to enact basic general regulations across multiple domains, while Article 194 allows for the adoption of regulations that apply specifically to energy networks. It would also probably be necessary to interconnect with other third state networks (pursuant to Article 172), owing to the fact that, unlike Article 194, Article 171(3) states that “The Union may decide to cooperate with third countries to promote projects of mutual interest and to ensure the interoperability of networks.”

#### Interplay between Article 194 and the solidarity clause of Article 222 of the TFEU

The scope of the solidarity mechanisms called for by Article 222 of the Treaty may be difficult to delineate in cases where solidarity obligations entail mutual support measures. Article 194 is more specific than the solidarity clause of Article 222, whereby Declaration No. 37 of the intergovernmental conference concerning Article 222 is inapplicable. This document allows the member states to determine how they will fulfil their solidarity obligations, while it nonetheless empowers the EU to determine how such obligations are to be fulfilled in the energy realm.

### **6.2.1.3 Foreign policy concerning energy**

According to European Court of Justice rulings concerning the European Agreement concerning the work of crews of vehicles engaged in international road transport (AETR), which were affirmed by Article 216 of the Lisbon Treaty, the EU has express authority to conduct foreign relations as well as implicit authority to enter into treaties that co-exist with EU authority over internal matters (European Court of Justice, Slg. 1971, 263, No. 15/16). Hence the EU has authority over all foreign relation matters, including as regards the intra-Community aspects of such matters. This means that EU member states are prohibited from entering into any third-state treaty whose provisions deviate from those of an EU treaty, insofar as the EU has assumed its internal responsibility to enact regulations for the matter in question.

Of particular significance in this context is Article 191(1)(d) of the TFEU, which since the signing of the Treaty Establishing a Constitution for Europe has called for measures that exceed the scope of the existing “promotion of measures at international level to deal with regional or worldwide environmental problems” and that aim to fight global warming in a manner that promotes the achievement of Community environmental goals. In case of uncertainty, this provision also allows for the conclusion of EU energy and environmental policy treaties based on a number of legal principles.

### **6.2.1.4 Scope of the EU’s new energy policy competence under Article 194 of the TFEU**

Opinions in the literature vary concerning the EU’s new energy policy authority granted by Article 194 of the TFEU. Concerns have been expressed in some quarters that this new authority will prompt the EU to adopt additional regulations, since the vaguely worded objectives of Article 194 appear to grant the EU blanket authority over all energy policy matters (Jaspers 2003, p. 211; Classen 2003, p. 351; Götz 2004, p. 46). However, most authors feel that the change will merely result in amalgamation of the EU’s current authority, which will not greatly exceed that which it currently exercises (Blanke 2004, p. 232; Görlitz 2004, p. 381; Rodi in: Vedder/Heintschel von Heinegg 2007, Art. III-256 No. 1; Kahl 2009, p. 51).

From a historical standpoint, the latter view is supported by the convention presidium’s commentary to the effect that the EU’s new authority over energy policy concerns “the nature of the measures that have been implemented thus far” (draft of the EU Constitutional Treaty: Dok CONV 727/03, Annex VII, p. 110). As noted above, the coming into force of Article 194 of the TFEU following adoption of the Lisbon Treaty merely expanded the EU’s policymaking authority over the interconnection of energy networks. Hence Article 194 grants the EU no genuinely new authority for such interconnection, but instead merely expands the scope of its existing authority.

In view of the fact that, as we have seen, Article 194 of the TFEU does not endow the EU with all-encompassing new authority, its significance is largely political in nature – apart, that is, from the greater legal certainty and clarity created by the measure (Kahl 2009, p. 51 f; Neveling 2004, p. 342). But it should nonetheless be borne in mind that Article 194 vests virtually all power over energy policy in only two governmental bodies: the European Council's Transport, Telecommunication and Energy Council (TTE) and the Committee on Industry, Research and Energy (ITRE) of the European Parliament. Thus from now on EU energy policy will issue forth from “a single source” (Kahl 2009, p. 51) in a manner that will allow for coherent harmonisation of policy goals and measures.

### **6.2.1.5 Exercise of energy policy authority by the EU**

The manner in which the EU exercises its energy policy authority is governed by the stipulations of the EU energy regulations that are discussed above, as well as the general provisions concerning the exercise of power pursuant to the Lisbon Treaty (Article 5 of the Treaty on European Union).

#### Meaning of the energy policy solidarity clause under EU law

Article 194 of the TFEU stipulates that EU energy policy objectives are to be pursued “in a spirit of solidarity between the Member States.” This clause is a statutory innovation under EU law, since it makes jurisdiction over energy policy subject to the overarching principle of solidarity among the member states. Under EU law, application of this clause is to be governed by the general EU solidarity principle.

By adopting a solidarity clause concerning energy policy competence, the member states have sent a clear signal that they regard energy as a sector involving their common interests; in other words, the member states have realised that when it comes to energy, they're all in the same boat. This solidarity principle gives rise to the two types of binding solidarity obligations referred to in Articles 194 and 222. First, the member states are enjoined from taking any action in the name of national interest that would interfere with achievement of energy policy goals of common interest – although this applies only to areas that fall within the scope of EU energy policy authority. And secondly member states may be obligated to provide assistance to one or more states that are facing an energy policy emergency, particularly in connection with security of supply (European Commission 2007, pp. 4 and 12; Ehrlicke and Hackländer 2008, p. 595). This latter aspect of the solidarity principle represents a mindset shift from one where security of supply, once regarded as a national matter, is now seen as a policy concern for the EU as a whole. The solidarity principle enables a member state that is facing an energy supply shortage – occasioned by domestic policy conflicts or the like – to obtain the assistance of another member state. At the same time, it sets the stage for application of the EU's general subsidiarity principle, which is a precondition for joint action that the EU is required to demonstrate it has undertaken. The energy policy

solidarity clause acts as a corrective to the subsidiarity principle by presupposing that the objectives of energy policy measures cannot be adequately governed at the national level alone and can be governed more efficiently in Brussels. Hence in effect the solidarity clause shifts the burden of proof to the sphere of a collective procedure.

At first glance, the energy policy solidarity clause has no direct implications for energy and environmental law, since the clause's main focus is security of supply. But measures in this sphere can also have an impact on environmental policy, one example of this being the EU European Commission's *Energy Security and Solidarity Action Plan* (2008), which contains measures aimed at promoting development of the combined heat and power (CHP) sector.

#### Stipulations of Article 11 of the TFEU

The Treaty's Article 11 – the likes of which are not to be found in any member state statute – stipulates that “Environmental protection requirements must be integrated into the definition and implementation of the Union policies and activities, in particular with a view to promoting sustainable development,” whose requirements stem from the EU environmental policy objectives and principles laid down in Article 191(1) and (2) of the Treaty. Thus this clause means that all measures that are governed by Article 194 of the Treaty must be realised in a sustainable and environmentally compatible manner.

#### **6.2.1.6 Remaining sovereign rights of the member states**

The entirety of the EU's energy and environmental policy competence is governed by principle of shared competences pursuant to Article 4(2)(i) of the TFEU, whereby the member states “exercise their competence to the extent that the Union has not exercised its competence” (Article 2(2) of the TFEU) – in which case the member states are free to exercise their own policymaking competence, subject to the principle of loyal cooperation with the EU.

#### Unilateral Action by member states

Like ex Article 176 of the Treaty establishing the European Union, Article 193 of the TFEU allows individual member states to introduce more stringent environmental protection measures under Article 191 of the TFEU. Article 194 of the Treaty contains no such provision in the energy policy realm, and thus not for energy law either. This lack is regarded in some quarters as a structural shortcoming that works to the detriment of environmental protection in the EU particularly in the realm of energy efficiency measures and technical development of renewable energies (Britz 2009, p. 86; Kahl 2009, p. 61). Financial aid for the furtherance of renewable energies falls within the scope of environmental rather than energy competence, as has always been the case.

It has been suggested, in light of the non-prejudice clause of Article 194(2) of the Treaty, that Article 193 be applied *mutatis mutandis* to energy and environmental law (Britz 2009, p. 86)

– a dubious proposition, as it would set the stage for an unintended statutory loophole. Such a reading of the non-prejudice clause would also be inadvisable in light of the uniqueness of energy and environmental law, whose limited aims and measures necessitate special “reconciliation” provisions between EU and national policy measures. The delicate balance of the European energy and environmental policy triad could be upended by national “go it alone” measures (see Gundel 2008, p. 468 for a critical view of market differentiation resulting from such measures). The lack of a clause allowing for the adoption of more stringent protective measures can thus be viewed as the embodiment of the target and measure limits imposed by energy and environmental law.

#### Restrictions imposed by Article 345 of the TFEU (ex Article 295 EGV)

The Treaty’s Article 345, which is generally regarded as a provision that imposes limitations on competence (Kingreen in: Calliess/Ruffert 2007, Art. 295 EGV No. 5), stipulates that “The Treaties shall in no way prejudice the rules in Member States governing the system of property ownership” – which has led some to conclude, for example, that the EU is prohibited from adopting property related measures.

However, Article 345 of the Treaty was originally promulgated in order to assuage member state fears that EU laws would result in privatisation and/or nationalisation. According to its counterpart in German law – the official commentary on ex Article 222 of the Treaty establishing the European Economic Community – Article 345 is meant to forestall any EU measure that aims to nationalise a privately owned company or vice versa (Deutscher Bundestag 1957, Annex C, p. 154). Hence it follows from a historical reading of Article 345 that it aims to ensure that the EU remains neutral when it comes to basic issues concerning national economies; and thus the current prevailing view refers to the wording of Article 345, which concerns not property rights but rather property ownership (Calliess 2008, p. 27 ff) – which basically means decisions concerning nationalisation and privatisation.

#### **6.2.1.7 Conclusions**

In the following, we recap the insights gained from the discussion above concerning energy policy competence sharing between the EU and member states in light of our recommended goal of achieving a wholly renewable electricity supply by 2050, as well as our proposed measures in this regard.

Article 194(1) of the TFEU grants the EU competence as regards the following energy policy goals: (a) ensure the functioning of the energy market; (b) ensure security of energy supply in the Union; (c) promote energy efficiency and energy saving and the development of new and renewable forms of energy; and (d) promote the interconnection of energy networks.

In so doing, however, in terms of all of these areas except energy network interconnection, Article 194(1) of the Treaty solely allows for amalgamation of these competences to the

exclusion of any major expansion thereof in terms of energy policy, particularly those aspects of it that relate to environmental policy.

In terms of renewable energies, we feel that Article 194(1) expands the scope of EU energy competence solely in respect to promoting technological development, and thus all remaining aspects of renewable energies still fall within the environmental competence laid down in the Treaty's Articles 192(1) and (2) – which are therefore also governed by the “more stringent protective measures” clause of the Treaty's Article 193, thus leaving the member states leeway to institute measures as they see fit, despite EU legislation.

#### Expansion of electricity generation capacity

In view of the above, thanks to the EU's environmental competence pursuant to Article 192(1) and (2) of the TFEU the EU is entitled to set requirements for the member states concerning the aspects of renewable electricity expansion capacity that are relevant for the present report, but to the exclusion of the relatively minor and specialised sphere of promoting technological development. EU measures pursuant to Article 192(2)(c) of the TFEU reach their statutory procedural limit insofar as they significantly affect “a Member State's choice between different energy sources and the general structure of its energy supply,” whereby such measures must be adopted by a unanimous vote of the European Council. This is the key change wrought by the EU's new energy policy competence under Article 194(2)(2) – which, unlike the Treaty's purely procedural provisions in Article 192(2)(c), constitutes a genuine competence delineation. Consequently, the EU has no authority over non-environmental energy policy measures that fall within the competence of the member states; and thus environmental policy measures pursuant to the Treaty's Article 192(2)(c) can be subjected to a unanimous vote by the European Council.

However, it is no easy matter to determine exactly which types of measures are governed by Article 192(2)(c) of the Treaty, particularly when it comes to the share of energy from renewable sources that are mandated for the various member states. But any decision that institutes a durable all renewables electricity supply would in any case necessitate a unanimous vote. Under the provisions of Article 193 of the Treaty, the member states are entitled to exceed the share of energy from renewable sources stipulated by the EU.

#### Electricity transmission network expansion

The EU's authority over the electricity transmission network expansion necessary for a wholly renewable electricity supply is expanded by Article 194 of the Treaty, particularly in terms of the interconnection of energy networks, whose expansion is one of the lynchpins of the internal European electricity market. The EU's competence for the promotion of grid interconnection is farther reaching than the trans-European network competence accorded by Article 172 of the TFEU (ex Article 156 of the Treaty establishing the European Union). As a result, the EU's network interconnection financing competence is limited to coordination

measures for existing networks or to financing ongoing network projects that are already being subsidised by one or more member states. Hence, save for cross-border network interconnections, the EU is prohibited from imposing on the member states any measure involving transmission network expansion exceeding the scope of that which is in the pipeline in the member states at any given time. However, this restriction also has an upside – namely that the EU can use guidelines as an instrument to coordinate and finance measures aimed at expansion of cross-border networks, and can thus further the cause of expanding such networks to the requisite degree. As a result of this situation, network expansion is mainly the legal responsibility of private transmission system operators. Carrying out such planning at the European level is not mandatory, but instead mainly allows for coordination and consultation, and in some cases information related revision, of member state transmission network plans from a European perspective. Bolstering EU policies with a view to promoting network expansion will need to mainly focus on successfully interconnecting the various national networks – a goal that will, however, open up considerable member state leeway.

#### Energy efficiency optimisation

Article 194(1)(c) of the TFEU endows the EU with far reaching (albeit not new) authority over promoting energy efficiency and saving energy. The extent to which Article 194 of the TFEU empowers the member states to adopt more stringent energy efficiency policies than those mandated by the EU is open to question. In our view, however, the member states are not entitled to adopt “more stringent protective measures” in this regard within the meaning of Article 193 of the TFEU.

The statutory grounds for energy efficiency provisions, measures and programs have traditionally been Article 175(1) (now Article 192 of the TFEU) or Article 95 (now Article 192 of the TFEU), both of which empower the member states to introduce “more stringent protective measures.” However, the member states are not empowered to do so under Article 194 of the TFEU, which lays down the EU’s new competence for energy efficiency.

This problem can only be resolved by either applying the more stringent protective measures clause of Article 193 of the TFEU (ex Article 176 of the Treaty establishing the European Union) in accordance with Article 194 (Britz 2009) or incorporating such a clause into future energy efficiency legislation. Such an application of Article 193 would probably be inadmissible, since the existence of a statutory loophole for an area in which the EU intends to find a definitive solution cannot be presumed. Hence EU energy efficiency regulations that are based on Article 194 of the TFEU should expressly empower the member states to enact more stringent protective measures. One example of such a regulation in the realm of energy efficiency is the Energy end-use efficiency and energy services Directive (2006/32/EC), which expressly empowers the member states to set a higher national energy saving objective than that laid down in the Directive’s 13th recital.

## 6.2.2 Advancing the EU energy policy framework

The EU has pivotal competences for a number of frameworks that relate to the expansion of renewable energies, to which end the EU has adopted the following interrelated policies and strategies in particular:

- EU climate protection policies in conjunction with mandatory objectives for greenhouse gas reduction; and a broad range of implementation instruments in this regard, notably emissions trading.
- EU energy policies, in particular those involving to some extent competing objectives as regards an internal European electricity market and expansion of renewable energy capacity.
- EU infrastructure policy, via the trans-European network.
- European energy research (not discussed in detail in this report).

In all four of these areas, relevant developments and discussions are occurring that improve the chances of successful implementation of renewable energy policies in the various member states. Hence it is of crucial national-interest importance that these EU fields of endeavor unfold in a manner that promotes and institutionalises national strategies aimed at an all renewable electricity supply. Achievement of ambitious national objectives will be greatly eased if the dynamic expansion path mandated by the Renewable Energy Directive (2009/28/EC) continues to unfold in the post-2020 period. In addition, such an expansion via a coordinated approach between the various member states would be less cost intensive than if each individual member state expands its own renewables (ECF et al. 2010a; Czisch 2009; SRU 2010a). Our analysis of the situation clearly shows that the EU has robustly set the stage for renewable energy expansion; whereby in light of this analysis there is good reason to believe that an EU framework conducive to development of renewable energies will be in place for the period after 2020 as well. This framework needs strengthening. We will now discuss the various aspects of this evolution.

### 6.2.2.1 Refinement of EU climate protection objectives

The EU climate package of December 2008 – which calls for a triple target of 20 percent reduction of greenhouse gas emissions with a 30 percent contingent option; a 20 percent share of energy from renewable sources; and 20 percent greater energy efficiency relative to the current trend – could potentially pave the way for a transition to a climate neutral and largely or wholly renewable electricity supply. This package, whose elements include a reform of the EU emissions trading system and an amended directive concerning the furtherance of renewable energies, also constitutes a breakthrough after the prior long, drawn out process of EU integration of in energy policy, since the package grants the EU considerably greater climate policy authority than that wielded by the member states (Olivier

et al. 2008; Geden and Fischer 2008; Schreurs et al. 2009; Jordan et al. 2010b). This breakthrough from climate policymaking practices of the past was based on a relatively broad consensus in the EU concerning the importance of European climate policymaking in the realms of security, economic, and industrial policy.

However, this consensus has been greatly weakened by the economic crisis and the failure of the UN climate summit in Copenhagen – a phenomenon graphically demonstrated by the fact that the EU has as yet been unable to reach an agreement concerning a unilateral 30 percent greenhouse gas emissions reduction by 2020. This goal, whose advisability is demonstrated by European Commission and other analyses (European Commission 2010b), is also seen as a way to revitalise international energy policy (WBGU 2010) but no longer commands a majority within the European Commission or among the member states – a fact demonstrated by this headline from *Ends Daily* of 10 June 2010: “30% CO<sub>2</sub> reduction goal put on the back burner.”

This aside, the only possible benchmark for medium term EU climate protection policy comprises the often-stated position of the European Council in this regard (Council of the European Union 2009) and the roadmap to 2050 in the European Commission Commission’s work program (European Commission 2010a, p. 8), both of which place an 80 to 95 percent greenhouse gas reduction by 2050 on the EU’s policy agenda. In the view of the European Commission, only a minute proportion of these reductions can be achieved through implementation of flexible mechanisms outside the EU (European Commission 2010b, p. 6). The Climate, Mobility/Traffic, and Energy General Directorates of the European Commission are in the process of elaborating strategies, scenarios, and consultation documents aimed at further decarbonisation of the European Economic Area.

Only a roadmap for the run-up to 2050 will enable Europe to achieve the greenhouse gas reductions necessary to adhere to the 2 degrees Celsius goal (SRU 2008), and is thus an indispensable yardstick for the climate protection policies of industrialised states. From the perspective of the EU’s envisaged unilateral greenhouse gas reduction goal, such a roadmap is also a coherent and sensible instrument that is essential in order to establish guideposts for technological development and above all avoid technological lock-in effects whose reversal would exact a high economic cost if binding international climate policies came into force aimed at bringing about the requisite reductions (see the detailed discussion of emissions trading in chapter 8; Holm-Müller and Weber 2010; SRU 2009; UNRUH 2000).

Hence this overarching objective should be anchored more firmly in EU policy and ideally should be compulsory. The goal of decarbonisation has yet to be incorporated into the official strategy documents used by all European bodies. The European Council, the EU 2020 Strategy, the 7th Environmental Action Programme, the amended EU sustainability strategy, the revised European emissions trading system, binding obligations in connection with international climate protection negotiations, and the G20 process are suitable instruments

that would give more teeth to the EU's overarching climate protection goal of cutting greenhouse gas emissions by 80 to 95 percent in the run-up to 2050.

The 80–85 percent greenhouse gas reduction goal should be refined by defining greenhouse gas reduction goals for individual sectors. A single overarching goal for all sectors would be unrealistic, since the greenhouse gas avoidance options and the attendant costs vary greatly from one sector to another. The cause of achieving the requisite sectoral differentiation would not be served by an across the board 95 percent reduction goal, but rather by its 80 percent counterpart, which, however, would probably not go far enough. In the electricity sector, even the more modest 80 percent goal would make it necessary to aim for full decarbonisation, to which this sector readily lends itself in any case (ECF et al. 2010b; Jones 2010; Edenhofer et al. 2009, p. 7; Öko-Institut and Prognos AG 2009).

### **6.2.2.2 Roadmap 2030: additional expansion objective for renewable energies**

A policy feedback approach to renewable energy expansion in the EU

Any number of paths could be taken to the sectoral climate protection goals discussed above – one such path being a massive pan-European expansion of renewable energies beyond the mandated 2020 goal, with the aim of achieving a wholly renewable electricity supply. Most member state action plans for implementation of the Renewable Energy Directive call for a very significant renewable energy expansion – an evolution that would result in an EU electricity supply that is more than one third renewable in 2020. Achieving this will necessitate substantial growth in the renewable energy sector in all member states, as well as the establishment of robust incentives for renewable energy development (Rathmann et al. 2009), grid expansion and other complementary measures. It is also likely that coalitions of economic and political actors will rise to greater prominence in all member states. And thus, spurred by EU climate-friendly economic objectives, we are likely to see an altogether more favourable framework for renewable energy expansion in the post-2020 period.

On the other hand, if the share of energy from renewable sources in the EU is limited to 40 percent – as posited by some scenarios, particularly those involving leading power companies – a massive expansion of nuclear power on the order of 200 GW and coal CCS amounting to some 120 GW would be unavoidable (ECF et al. 2010b, pp. 9 and 50; EURELECTRIC 2010, p. 61 ff). The question as to whether such scenarios stand a chance politically in the EU will be answered by the strategy papers that the European Commission will be issuing in 2011.

That said, we need to bear in mind that the EU's competence when it comes to exercising a direct influence over member state energy source choices is limited, which means that any measures in this regard must stem from the EU's environmental competence pursuant to

Article 192(2) of the TFEU, and must be adopted by unanimous consent of all 27 member states for measures that have a major impact on national energy source policy. Hence any EU effort to fix the putative 2050 energy mix in stone would be premature at this point from both an institutional and political standpoint, regardless of whether a wholly renewable electricity supply (as we advocate for Germany) or a mix of nuclear, fossil and renewable energy is involved.

The relatively few actors that have come out in favour of a wholly renewable electricity supply are mainly found in environmental groups, the renewable energy industry and think tanks – plus the European Parliament, particularly in the parliamentary coalition known as the European Forum for Renewable Energy Sources (EUFORES) (EREC 2010; PwC et al. 2010; May 2010). Only states such as Germany, Denmark, Spain and Portugal that are in the vanguard of the renewable energy movement are likely to push more strongly for a wholly renewable electricity supply; and the only member state that has thus far recognised the need to establish a widely renewables electricity supply over the long term is Germany (BMW and BMU 2010). States such as Austria, Sweden and Lithuania with largely conventional renewable energy sources may also jump on the renewable electricity bandwagon, albeit with only measured enthusiasm – as is evidenced by the relatively slow pace of “new” renewable energy expansion in some of these states (European Commission 2009). However, we are unlikely to see support emerging for a *wholly* renewable electricity supply any time soon in the majority of member states. Take France for example. Although the French have decided to ramp up the share of energy from renewable sources in their economy from its current level of 15.5 percent to 27 percent by 2020 (see Table 5-1), the nuclear industry is still the major player in the French energy policy arena (Koopman 2008; Mez et al. 2009; Pellion 2008). Another example is Great Britain, whose energy policy calls for a major off shore wind farm development program in conjunction with the construction of nuclear power plants and investments in carbon capture and storage (CCS) technology (DECC 2009; HM Government 2009; Helm 2008). And as for most of the Central and Eastern Europe states, their electricity is mainly derived from large centralised nuclear power and/or coal power plants, and renewable energy development is still in its infancy (Barbu 2007). In addition, the major power companies will in all likelihood fiercely oppose efforts to establish a wholly or largely renewable electricity supply (EURELECTRIC 2010; Lamprecht 2009).

Against this backdrop, the European Commission's current advocacy of an energy mix comprising carbon capture and storage (CCS), nuclear power and renewable energies is perfectly understandable. This tendency toward technology neutrality on the part of an EU body that is often referred to as the “guardians of the treaties” – but that is nonetheless keeping the decarbonisation option open for the member states – is also unavoidable at present, in view of the EU Treaty's restrictions on the EU's energy source policy competence. In short, the EU is very unlikely to take a system decision in favour of

renewables based electricity in the short run. And in any case, a European Commission decision to pursue such a policy would be premature, even if the Commission were able to prove that a largely renewable electricity supply is economically and technically feasible and could thus keep this option open in the discourse on the subject.

Instead, the European Commission should pursue the policy feedback paradigm, which has been applied in areas such as agricultural policy (Pierson 1993; Jordan et al. 2010c, p. 45 f) and which holds that for the most part new policies need to be instituted incrementally over a lengthy period, but also need bolstering every step along the way. This strategy engenders a new policy path that grows stronger with the passing years and whose initially inadequate institutional innovations and measures prompt calls for more extensive reform – thus creating a more robust underpinning for the path per se. The policy of incremental self-obligation (Eichener 2000), as the policy feedback paradigm is also called, has enabled the EU to institute reforms despite their initial unpopularity. The Renewable Energy Directives of 2001 and 2009 are commensurate with this approach, which allows for self-driven policy innovation.

#### A roadmap for renewable energy in 2030

Against this backdrop, we need a medium term European roadmap for the expansion of renewable energies in the run-up to 2030 and thereafter, particularly in terms of German and EU infrastructure development (EEAC 2009; ECF et al. 2010a, pp. 9 and 28). According to Article 24(9) of Directive 2009/28/EC, the European Commission is planning to issue a renewable energy development roadmap for the post-2020 period as late as 2018, which would not allow sufficient lead time to establish conditions conducive to planning certainty, particularly for network and storage capacity expansion for the post-2020 period. Hence the discussion concerning development objectives should get underway long before 2018. For example, key preliminary decisions could already be taken in 2010 and 2011 within the context of the debate concerning a strategy for achieving decarbonised electricity generation by 2050, and could be placed on the spring 2011 summit agenda.

In order to establish international high-voltage direct current transmission (HVDC) networks or strategic regional networks in the North Sea, it is essential that clearly defined goals and guideposts be laid out concerning renewable energy capacity development, since otherwise the investment risks for such projects will be unduly high. Timely establishment of the requisite transmission grids is a key factor in terms of renewable energy capacity development (ECF et al. 2010b, pp. 16 and 58). Grid planning based solely on scenarios – the approach by recommended European academies of science, among other actors (EASAC 2009; Wagner 2009) – will not get the job done in terms of establishing the requisite investment certainty.

A prime example of the importance of timely grid planning is the pilot project for a ten year plan (2010–2020) devised by the European Network of Transmission System Operators for Electricity (ENTSO-E) (ENTSO-E 2010, p. 9 ff), according to which transmission system operators need to undertake investment planning for the 2010–2020 period for more than 42,000 kilometres of transmission lines, half of which will be necessitated by renewable energy capacity expansion. But according to ENTSO-E's own calculations, the scope of the grid build-out will need to be even greater than this, since the national action plans for renewable energies, which had not been submitted as at June 2010, cannot be taken into account until the next ten year plan is issued in 2012. Against this backdrop, ENTSO-E also advocates that grid development objectives be set for a more extended period (ENTSO-E 2010, p. 17).

Development objectives are essential for the electricity sector in view of the pivotal importance of transmission networks for load balancing. The groundwork for the requisite planning of such networks can only be laid if sectoral development objectives are set – which, as called for by the Renewable Energy Directive, could also be added to and be one of the outcomes of national action plans. Inasmuch as the share of European energy from renewables may well reach 35 percent in 2020, a share on the order of 50–70 percent in 2030 would appear to be well within reach (European Commission DG TREN 2006; EEAC 2009; EREC 2010).

### **6.2.2.3 Subsidiarity and support instruments**

The Renewable Energy Directive of 2009 – whose adoption was fraught with conflict from start to finish – represents a conscious decision on the part of the EU to leave renewable energy support policy to the member states or to cooperative arrangements between groups of member states (Schöpe 2010; Jones 2010). This solution was preceded by a basic conflict over which support instruments are appropriate. Although a harmonised European quota trading system for renewable based electricity can be more easily coupled with the Internal Market, national feed-in tariffs have by and large proven to be the more efficient and robust instrument thus far. The debate on this issue is still ongoing, however. The electricity and hydro power industry association known as Bundesverband der Energie- und Wasserwirtschaft (BDEW), as well as a number of large power companies, are still pushing for a harmonised European quota system of the type described in a 2010 study that was conducted for one such organisation by Cologne University's Department of Energy Studies (EWI) (Fürsch et al. 2010; for EURELECTRIC's position see ten Berge and Cross 2010). But there have also been calls in recent years for a European approach along the lines of Germany's Renewable Energy Act (EEG) or other feed-in tariff instruments (Czisch and Schmid 2007; Sensfuss et al. 2007) – an approach likewise advocated by EU Energy Commissioner Guenther Oettinger ("Oettinger presses for European green electricity subsidies," Euractiv, 6 August 2010).

Moreover, this camp holds that (a) such an approach would be a better fit with the internal European electricity market, since divergent national feed-in tariff systems could inhibit or distort cross-border electricity trading (Fürsch et al. 2010; Sensfuss et al. 2007); and (b) a large scale network would also open up relatively cost efficient load balancing options and would greatly reduce storage capacity investment costs (ECF et al. 2010a; ECF et al. 2010b; Czisch 2009).

But it is also felt in some quarters that current EU directive arrangements concerning bilateral and multilateral cooperation should remain in force in lieu of striving for European harmonisation (Schöpe 2010; Fouquet and Johansson 2008). The main argument against a harmonised quota system is the evidence that comparable national systems have enjoyed only limited success (Fouquet 2010; Fouquet and Johansson 2008; Jacobsson et al. 2009; Lauber 2007; Lafferty and Ruud 2008). A problem with harmonised European feed-in tariffs is that (a) if they are unduly high they may engender considerable windfall profits in states with conditions more conducive to electricity generation; or (b) basing the tariffs on the lower costs in regions with better electricity generation conditions could result in a concentration of installations in regions that display such conditions (Sensfuss et al. 2007, p. 54); and (c) thus would fail to incentivise the requisite investments in other regions. This in turn could provoke a conflict between EU designating optimised installation sites on one hand, and possible ambitious expansion plans in individual member states on the other.

Regionally balanced renewable energy development that also takes account of cost differences is also realizable under the current regulation framework based on European objectives and national support instruments, in cases where the development objectives in regions with more favourable site conditions are more ambitious than those in regions with less favourable conditions. Applying such an approach would mean, for example, that Germany would place more emphasis on wind energy development, while Spain would focus more on photovoltaics.

The differences in the renewable energy development phases of the various member states also need to be taken into account, and the attendant support instruments will need to be adapted to the conditions in each state.

A total of 21 member states have instituted feed-in tariffs as a central or partial instrument of their energy mix, although the exact modalities of these instruments differ greatly from one state to another (Rathmann et al. 2009). Any attempt at harmonizing these systems would inevitably engender high costs and serious conflicts, as partial modification of well established long term investment frameworks would also be involved, whereby switching from member state to EU level policy would set in motion a period of investment uncertainty that would temporarily put the brakes on renewable energy growth. Moreover, the resulting compromise, apart from the extensive negotiations it would undoubtedly entail, would probably result in a support system that is relatively impervious to policy innovation. This

same problem of barely resolvable conflicts between the various national subsidy systems and a harmonised European support framework would arise under a harmonised quota system, as it would necessarily replace national feed-in tariffs with flexible quota market prices.

Hence EU subsidy frameworks for renewable energy should take honor of the subsidiarity principle and should enable EU member states sufficient leeway for action that is also compatible with Community principles (Scharpf 1999). And in point of fact, a workable compromise for the foreseeable future in this regard was put in place by the Renewable Energy Directive of 2009.

The Directive does two main things.

1. It lays down differentiated national contributions to the EU's 20 percent share of renewables goal, based on the extremely heterogeneous baseline electricity generation conditions and potential exhibited by the various member states – a condition that will persist until at least the end of this decade. However, since all member states are required to implement support measures for their renewable energy development goals, the directive stipulates that the gap between the support costs in the various member states is to be kept within reasonable bounds. Against this backdrop, the aforementioned roadmap for 2030 is also indispensable, as it will – at least indirectly and despite any unavoidable cost differences – to some extent balance out the development, promote support cost harmonisation, and thus institute a modicum of convergence among the various member state financing instruments (Jordan et al. 2010a, p. 115).

2. Under the Directive, the member states retain the right to optimise their support instruments and adapt these instruments to the specific renewable energy development phase the state happens to be in – an approach which, it would seem, makes good sense, particularly in terms of allowing for learning curve-driven optimisation of support instruments. The Renewable Energy Directive also stipulates that member states may agree on and make arrangements for the statistical transfer of a specified amount of energy from renewable sources from a state that has exceeded its development objectives to one that has not (Article 6), for joint projects between member states (Article 7) or for joint support schemes (Article 11) (Schöpe 2010). Competition resulting from electricity price differences can be avoided in particular via regional cooperation between neighbouring member states.

Once an extensive trans-European network has been established – an event unlikely to occur before the 2020s – it will be necessary to consider further medium term Europeanisation of support instruments in an electricity market where renewables may well be the dominant force by this time.

#### 6.2.2.4 Development of the trans-European network

Key to the expansion of renewable energies in the EU is development of a high capacity trans-European network, or supergrid (see scenario 3.a; Czisch 2009; Battaglini 2008), which would be overlaid on the existing grids and interconnectors (which would also need to be optimised) and would be chiefly composed of high-voltage direct current transmission (HVDC) lines, even if other technologies would be viable options. In order to establish this supergrid, it would be essential to expand North Sea grids, and in particular to also be able to leverage Norwegian and Swedish pump storage system potential (Woyte et al. 2008; EEA 2009; Lilliestam 2007). According to the *Green paper towards a secure, sustainable and competitive European Energy Network* (European Commission 2008d; 2008b), an offshore wind farm grid and an energy ring in the Mediterranean region are both crucially important projects for successful expansion of renewable energies.

In order to establish policies for a European infrastructure, or for the more limited trans-regional counterparts, we will need to find answers to the following key questions:

- Are the existing network-like and predominantly private sector cooperative arrangements sufficient; or do EU grid development policies need to be bolstered?
- In view of the growing share of wind and solar power being fed into the grid, do the current bottom-up grid planning processes get the job done, or are more robust and strategic planning goal and scenario based planning processes needed?
- To what extent can market driven grid expansion be stimulated? To what extent is public financing or at least risk mitigation measures necessary for such expansion?

#### Grid development players in the EU

Grid planning and development activities fall within the province of transmission system operators, which can be either private sector or public sector enterprises and for which the organisational structures, duties (most of which involve coordination activities) and oversight at the EU level are governed by the internal electricity market directive and by Directive 2009/72/EC (implemented in Germany as the *Stromhandelszugangsverordnung* (StromhandelZVO)).

The 42 transmission system operators that in December 2008 founded the European Network of Transmission System Operators for Electricity (ENTSO-E) are required under EU law to submit, at two year intervals, revised ten year Community grid development plans. These plans are not legally binding and indicate, among other things, scenarios and forecasts concerning the adequacy of electricity generation as well as areas where investments are needed (Article 8(10) of the *StromhandelZVO* law). As such plans take their cue from national ten year plans, they constitute the main national plan coordination instrument.

Organisations such as Nordel (Organisation for the Nordic Transmission System Operators) – one of the ENTSO-E entities in charge of developing a cross-border regional grid investment plan – act as an intermediary instrument in this regard (Article 12 of the StromhandelZVO law), while the Agency for the Cooperation of Energy Regulators (ACER) provides advice and carries out oversight activities (Directive 713/2009/EC; law titled *ACER Verordnung*). A network agency that arose from informal cooperation between national regulatory authorities, ACER and the latter's governing board, is composed of political appointees (named by the European Commission, the member states, and the European Parliament) and oversees the activities of key regulatory decision makers, provides support and coordination for national regulatory authority measures aimed at implementing the objectives of the internal electricity market, has far reaching competence in areas such as access modalities for cross-border infrastructures, as well as work safety pursuant to Article 8 of the relevant regulation (*ACER Verordnung*) reviews ENTSO-E ten year plans, and draws up a statement of position containing any changes deemed necessary in such plans (Article 8(11) of StromhandelZVO). These statements of position are not legally binding, and ACER has no say in or veto over their content. Although during the negotiating process concerning the internal European electricity market Directive it proved impossible to give ACER greater say in these matters (Hancher and de Hauteclocque 2010), the European Commission has called for strengthening of ACER's competence in connection with the integrated energy market (European Commission 2010d), and thus ACER's competence in this domain could potentially expand over time. In this regard, the StromhandelZVO empowers the national regulatory authority to jointly delegate decision making rights to ACER, which in some cases (such as incentives rules for interconnectors) is entitled to draw up proposed decisions for the European Commission. Hence ACER may assume a more important role going forward, particularly if the European Commission begins relying on ACER recommendations (Hancher and Hauteclocque 2010, p. 6).

The EU's trans-European network (TEN-E) policies also constitute a key albeit weak grid development policy instrument, whereby the TEN-E guidelines, which the European Council and Parliament adopted at the proposal of the European Commission, comprise the main statutory European infrastructure policy instrument. First adopted in 1996, the guidelines, which were amended in 2003 and again in 2006 (most recently via Decision No 1364/2006/EC), mainly serve the following purposes: formulate objectives (Article 3) and selection criteria for Community measures in the field of trans-European energy networks (Article 4); identify corridors of European interest (Article 6), priority projects (Article 7), "ensure the interoperability of electricity networks" (Article 4(2)); and adapt and develop networks "to facilitate the integration and connection of renewable energy production" (Article 4(2a)). The TEN-E guidelines are essentially a coordination and financing instrument for cross-border linkages, although they offer only very limited financial contributions to projects of common interest. According to Articles 6 and 9 of the guidelines, when it comes to projects

of common interest it is incumbent upon the member states to facilitate and expedite their realisation (including the attendant approval procedures), to coordinate such projects, to submit completion schedules in their regard, and to report any delays in such completion. In this regard the TEN-E guidelines mirror current EU competences as laid down in Articles 170 to 172 of the TFEU (ex Articles 154 to 156 EGV), whose scope is limited to improved and trouble-free coordination of cross-border planning processes. Although extended competences for promoting “the interconnection of energy networks” pursuant to Article 194 of the TFEU theoretically enable the EU to impose more stringent electricity grid development obligations on the member states, it remains to be seen exactly how the EU will use this new authority. A new EU instrument for security of supply and infrastructure is currently under consideration (European Commission 2008d, p. 13), with a communication in this regard due for release in December 2010.

In reality, the EU has relatively little control to steer grid development, which, as it is mainly driven by the regulatory framework and the financial interests of transmission system operators, unfolds in a decentralised manner as a bottom-up process; and thus only its coordination is under EU control. Hence grid needs planning at the EU level reflects the incentive shortcomings and planning deficits for national grid regulation and planning systems. In view of the considerable investment risks and planning uncertainty entailed by the renewable energy development sector, such a decentralised market structure is unlikely to prompt private investors to plough large amounts of money into the development of high-voltage direct current transmission (HVDC) grids.

As there are various ways to strengthen the hand of European actors in the electricity grid development arena, expanding ACER’s competence would appear to be the best option (in conjunction with a comitology procedure), including when it comes to folding scenarios into a high capacity transmission network plan (ECF et al. 2010a, p. 29). To this end, key grid development needs should be laid down as soon as possible in amended TEN-E guidelines – although the success of this undertaking will be largely contingent on modifying the upstream needs analysis process.

#### Needs analysis and project selection

Electricity grid planning in Europe is mainly a needs analysis, project identification and bottom-up process involving information interchange and cross-border interconnection planning on the part of neighbouring states (EASAC 2009, p. 5) which, in this process, mainly rely on network development plans devised by transmission system operators (see StromhandelZVO 2009; UCTE 2009); whereby such plans ultimately form the basis for updated TEN-E recommendations. The remaining responsibilities are met via market mechanisms, which means that “the construction and maintenance of energy infrastructure should be subject to market principles” and that “Community financial aid for construction and maintenance should therefore remain highly exceptional, and such exceptions should be

duly justified” (Recital 4, Decision No 1364/2006/EC); whereby exceptions include in particular high-voltage direct current transmission (HVDC) lines (see Article 17 of StromhandelZVO). Projects are to be selected only insofar as a cost-benefit analysis indicates that they display “potential economic viability” (Article 5, Decision No 1364/2006/EC).

By dint of this bottom-up planning process alone, it has been shown that the current TEN-E guidelines are sorely lacking when it comes to the development of grids for renewable energies, one example of this being that the 2006 guidelines do not contain a single mention of a high-voltage direct current transmission (HVDC) project of European interest (Holznagel and Schumacher 2009, pp. 168 and 170). According to a European Climate Foundation estimate, grid development between 2004 and 2009, which resulted in an aggregate European capacity increase of 12.6 GW, was considerably below the necessary development rate (ECF et al. 2010a, p. 28).

Nonetheless the TEN-E guidelines, as well as UCTE (Union for the Coordination of Transmission of Electricity, the precursor of ENTSO-E) plans, contain grid development projects that clearly undermine Community objectives, one example being transmission lines linking Tunisia and Sicily that put a coal fired power station on line that was built mainly for the Italian market (UCTE 2009, p. 42) (project 4.2.4 in Decision No 1364/2006/EC), with a view to avoiding the carbon certificate costs that would have been incurred had a new power plant been built in the emissions trading zone.

The European Academies Science Advisory Council (EASAC) – which has correctly pointed out that the current grid development planning process is highly unsatisfactory, particularly for the requisite renewable energy expansion process (EASAC 2009, p. 5) – has recommended that the bottom-up planning process be paired with a scenario based strategic planning process. Using this approach, EASAC says, more accurate estimates of network development needs and the robustness of specific future scenarios could be obtained based on various future scenarios. EASAC signals in this regard the exemplary practice of NORDEL (Organisation for the Nordic Transmission System Operators), whose Grid Master Plan 2008 is based on three different scenarios – namely business as usual, climate protection and integration, and national focus – that allows for determination of both internal and external grid development needs (NORDEL 2008). In the same vein, the European Climate Foundation (ECF) *Roadmap 2050* calls for the grid development planning process to encompass a far longer period than is currently the case with a view to harmonizing in the medium term presumed renewable energy capacity development and grid development needs (ECF et al. 2010a, p. 29). ENTSO-E has also indicated that in the absence of clearly defined long term climate protection and renewable energy capacity development goals, the organisation’s members will simply be unable to elaborate electricity grid planning scenarios (ENTSO-E 2010, p. 45). A far stronger and more target oriented planning paradigm is

needed in order for the EU to send robust signals that will promote grid development for renewable energies. The cause of strengthening planning certainty and greatly reducing investment risk would be served if the scenarios awaiting elaboration could be largely based on mandatory development targets for renewable energies. Such an approach would also call for the use of scenario design backcasting methods, which appear to be more suitable for target oriented planning than conventional trend and policy scenarios.

Although amending the TEN-E guidelines (Holznagel and Schumacher 2009, p. 170) is a step in the right direction, it would not do enough to reduce the influence of the major market players on grid planning outcomes; nor is this problem likely to be resolved by the infrastructure initiative that the European Commission is planning to issue in December 2010. Hence it is essential that the European Commission or a subsidiary body acquire the wherewithal to carry out an independent grid development needs analysis for 2020 and 2030 in light of the policy goal of expanding renewable energies, and that this analysis be harmonised with transmission system operator plans. Inasmuch as transitioning to a wholly or largely renewable electricity supply is a primarily policy driven undertaking, in keeping with EU Treaty tenets the EU's governing bodies need to acquire the competence to also evaluate market driven plans and to amend them in the light of the EU's renewable development policies.

### Financing

EU subsidies cover only a minute proportion of the cost of electricity grid development for priority projects as well as possibly risky large scale projects such as those involving high-voltage direct current transmission (HVDC) lines; whereby such financing is particularly meager for preliminary studies and for undertakings involving common structural policy. The €22 million annual trans-European network (TEN-E) budget for 2007 to 2013 can only be described as Lilliputian. European Investment Bank (EIB) loans amounting to €1,135 million annually for 2007 to 2009 are more generous, however, as is cohesion-policy financial support of €223 million a year. There was also at one time a European economic stimulus program grant of nearly €4 billion that was partly used for grid infrastructures (proprietary calculations, derived from European Commission 2010c). Despite the European Commission's view that grid infrastructure investments are mainly incumbent upon private sector network operators (i.e. investment decisions should be primarily market driven), the Commission nonetheless recognises the need for such investments to be supplemented by public funding for non-commercial objectives in projects such as underground cables for environmental reasons, and the incorporation of renewable energies into the electricity grid (European Commission 2008d, p. 12). In the same vein, the European Parliament and Council have underlined the importance of robustly promoting investments in large scale infrastructures, particularly in view of the exceptionally high risk profile entailed by such investments (Recital 23 StromhandelZVO). It is for this reason that the said regulation

exempts investors who are willing to invest in high-voltage direct current transmission (HVDC) lines from the differentiation requirements of the internal electricity market directive, subject to review by the agency. However, it is doubtful whether such a derogation – whose aim of course is to promote renewable energy capacity expansion investments by large investors – will be a sufficient incentive (Holznagel and Schumacher 2009). In the view of the European Commission, far more comprehensive public financing instruments and risk mitigation measures will be needed to promote grid expansion, particularly in the renewable energy sphere.

In the interest of establishing a high voltage overlay network, we recommend that public contracts be awarded, for point to point connections, to the bidder that offers the requisite investments in conjunction with the lowest grid charges over a 20 year period. This contract award procedure could also be used for cross-border connections between member states, whereby measures that facilitate cooperation between member states for the award such contracts would be particularly useful. It should also be determined whether set EU procedures containing a number of standardised elements aimed at expediting joint tenders for key cross-border connection contracts would also be useful and could help to expedite the process.

#### **6.2.2.5 In conclusion: EU renewable energy support policy going forward**

EU renewable energy support policy needs to develop within the framework of the competence structures discussed in Section 6.2.1, the key policy areas that come into play here being climate protection, meeting renewable energy development goals, and adapting the trans-European network in a timely manner to a higher proportion of renewables.

It is essential that renewable energy capacity expansion and the expansion of incentive and subsidy programs are keyed to statutory medium term EU climate objectives whose touchstone should be the position taken by the European Council in October 2009 and the forthcoming European Commission's Decarbonisation Roadmap 2050, according to which greenhouse gas reductions of 80 to 95 percent in 2050 compared to 1990 levels are on the EU policy agenda. This is the only reduction target that is consistent with the global reduction of greenhouse gases needed to achieve the 2 degrees Celsius objective. In order to implement the reduction path necessary for this objective and at the same time avoid investment missteps in the run-up to 2020, a minimum 30 percent reduction target will be necessary for 2020.

The Renewable Energy Directive of 2009 will go a long way toward keeping renewable energy capacity expansion on track for the remainder of this decade and achieving partial convergence of renewable-energy support schemes; this policy should be extended beyond 2020. A European roadmap that lays down a framework for renewable-energy expansion up

to 2030 should be developed, particularly in terms of national and European infrastructure development beyond 2030. Moreover, EU support schemes for renewable energy should take account of the subsidiarity principle and should enable EU member states sufficient leeway, but in a manner that is compatible with Community principles. The Renewable Energy Directive sets a goal of a 35 percent share of energy from renewable sources in 2020, while allowing for differences in the various member states' contribution to achievement of this goal; in addition, the Directive allows, and indeed encourages the member states to enter into cooperative regional arrangements that could potentially resolve problems associated with cross-border electricity trading and joint infrastructure projects. The German government should make all-out efforts to forge such alliances.

Member state grid expansion should be accompanied by intensified needs planning at the EU level. Despite the indisputably key European dimension of grid expansion in general and the development of high-voltage direct current transmission (HVDC) grids or equally high capacity technologies in particular, EU policy instruments in this domain are relatively toothless. Grid expansion is chiefly market driven and for the most part is realised by merging national ten year plans, which are inadequate for Germany and other member states since they mainly mirror the incentive effects of national market regulations and the interests of the various grid operators rather than the need to transition to a wholly or largely renewable electricity supply over the long run. And while this approach to grid expansion planning may suffice for incremental development of the electricity supply, it can never hope to bring about the requisite long term target oriented transformation. On the other hand, continued renewable energy capacity expansion will make it indispensable to strengthen the policymaking hand of all supranational European players – namely the European Commission, the European Parliament, and the recently established European Agency for the Cooperation of Energy Regulators.

In this regard, member state grid expansion programs should be strengthened via improved coordination, notably as regards cross-border expansion needs for renewables and high capacity long distance connections, whereby such efforts should focus on the following in particular:

- More tightly intermeshed coordination of renewable energy expansion and grid planning measures for post 2020 period.
- The European Commission or its subordinate authorities should conduct dedicated needs analyses, based on information from transmission network operators, concerning expansion and optimisation of the trans-European grid, with a view to achieving efficient quality assurance for EU energy policy objectives.
- Cross-border cooperation for public contracts and notably for new cross-border high capacity long distance connections should be intensified.

- The groundwork should be laid for regional cooperation among grid operators notably in the North Sea and Mediterranean.
- Government subsidies for renewable energies should be beefed up.
- 

## **6.3 Bilateral and multilateral cooperation**

Regional alliances are a key step toward an integrated European energy market. Establishing bilateral and multinational networks of electricity market players with dovetailing interests is simpler than an EU-wide approach. Such networks form an integral part in the process chain of electricity market Europeanisation as they can be used in a modular fashion and are amenable to incremental expansion. In addition, strengthened intermeshing of national electricity markets serves the cause of (a) harmonizing market regulations and grid standards across the EU; (b) establishing a calculable and level playing field for electricity transmission and trading; and (c) striking a balance between supply and demand in the various electricity markets (Geden and Dröge 2010, p. 19; Oettinger 2010, p. 4).

### **6.3.1 Towards interconnected electricity markets**

In view of the advantage of establishing an energy supply network comprising Germany and Scandinavia as a first step toward electricity market interconnection (see scenarios 2.1.a and 2.1.b), grid development in the North Sea is of prior importance as it would pave the way for the use of offshore wind energy and Scandinavian pump storage capacity, which in turn are key to achieving a highly renewables based electricity supply (European Commission 2008b).

The TEN-E guidelines and the Renewable Energy Directive in particular have established a de facto planning framework that paves the way for regional grid interconnection alliances. The TEN-E guidelines call for coordination of projects “declared to be of European interest” involving the interconnection of member state electricity grids, whereby the European Commission is to designate a European coordinator for any such project that encounters significant delays or implementation difficulties (Article 10 of Decision No 1364/2006/EC). Apart from this, there is also a planning framework resulting from the issuance of ten year European electricity grid development plans by the European Network of Transmission System Operators for Electricity (ENTSO-E) that builds on previous efforts to establish regional grids in the North Sea and Baltic region, as well as in the Mediterranean (ENTSO-E 2010, p. 69 ff). Interconnecting offshore wind farms in the North Sea, as well as integrating them into the onshore electricity grid, is an important component of this plan. The EU will need to set clear targets in order to attract investors in such networks.

This planning framework will also allow Germany to forge a grid interconnection alliance with Norway, which while not an EU member state is a member of the European Economic Area

and a participant in the internal market program, which seeks the removal of all remaining restrictions to the free movement of persons, capital, goods, and services.

The various forms of bilateral and multilateral alliances that have been established to date at various levels are an exemplary spur to electricity grid integration and show that numerous state and non-state players have already taken the initiative to establish cross-border electricity grids.

#### Forms of inter-state alliances

One example of such an alliance is the North Seas Countries' Offshore Grid Initiative, which was established by the North Sea Declaration (EWEA 2009) and has the following aims: (a) interconnect offshore wind farms in the North Sea and integrate them into the onshore electricity grid with a view to rendering current flow more persistent and minimizing the attendant costs; (b) promote information interchange concerning the offshore development objectives and policies of the participating states; (c) coordinate efforts to develop the relevant electricity infrastructure; and (d) establish a harmonious policy and regulatory framework for international wind farm development plans in the North Sea. The signatories to the North Sea Declaration are representatives of governments and transmission system operators from nine EU member states (Belgium, Denmark, France, Germany, Ireland, Luxembourg, The Netherlands, Sweden and the UK), as well as Norway ("Norway joins cooperation on energy grid in the North Sea," Ministry of Petroleum and Energy, December 2010 press release dated 2 February 2010). Although a clearly structured organisational roadmap for the next steps has yet to be established, discussions in this regard are being conducted under the aegis of the EU coordinator and in the context of the Pentalateral Energy Forum (de Jong and van Schaik 2009, p. 7).

This cooperative arrangement between the North Sea states was the brainchild of the Pentalateral Energy Forum, a policy driven regional alliance between France, Germany and the Benelux states, whose principle strength lies in the fact that it is given political credit and prioritises policymaking by enabling ministries, regulatory authorities, and private companies to engage in direct collaboration and in so doing settle energy policy issues involving the various players in an efficient and un-bureaucratic manner. The Forum also seeks to promote load balancing-based interconnection of regional electricity markets with a view to energy security optimisation. On Germany's initiative, all of the Forum's participating public and private sector players have signed a Memorandum of Understanding that specifies the implementation of specific regional projects.

Apart from cross-border European electricity markets, various players are seeking ways to integrate the massive solar energy potential of the Mediterranean and North African regions into Europe's electricity sector (see scenario group 3). Although such efforts for the Mediterranean are still in their infancy they are making good progress, as is evidenced by (a)

the bilateral agreements that were concluded between the European Commission and Morocco, Jordan, and Egypt in July 2007, December 2007 and December 2008 respectively (European Commission 2008c); (b) the bilateral negotiations that began in 2010 between the European Commission and Armenia, Georgia and Azerbaijan with the aim of bolstering energy cooperation in the Black Sea region (Oettinger 2010); and (c) current efforts on the part of Algeria, Morocco and Tunisia to establish a North African electricity market that would be integrated into the European market (European Commission press release of 20 June 2010).

The Mediterranean Solar Plan was developed in the context of the Barcelona process via the Euro-Med Energy Partnership and is a step toward integrated energy markets. The Union for the Mediterranean – a coalition of heads of state of Mediterranean EU and non-EU member states, as well as the European Commission – aims to broaden the integration and optimisation of energy security (EU Council Presidency 2008), whereby the organisation's overarching mission is to interconnect the electricity transmission systems of the various coastal Mediterranean states (EPIA 2008). To this end, the organisation seeks, by the end of this decade, to expand renewable energy capacity in the Mediterranean region by 20 GW via 3–4 GW of wind, 5–6 GW of solar power, and 10–12 GW of photovoltaic installations.

#### Private sector cooperation projects

The importance of grid expansion is also underscored by large private sector initiatives. Although *bilateral* cooperation between non-state players has long been common for electricity trading, load balancing, coordination of transmission line construction projects, and system reliability, the *multilateral* alliances discussed below for electricity generation and grid capacity development are based on a more comprehensive approach and could thus set the stage for European integration of renewable electricity. The lessons learned from such undertakings could be funneled into the process of expanding the scope of electricity development cooperation going forward.

An undertaking that could potentially bolster efforts to integrate Scandinavian electricity sector into the EU is the already largely interconnected and deregulated electricity sectors of Norway and Sweden, and to a lesser extent of Sweden and Denmark. The grid operators of these states joined forces more than four decades ago in a regional alliance of Scandinavian grid operators known as NORDEL, with a view to coordinating their activities. As regional alliances with an extensive track record, initiatives such as NORDEL – which has pioneered efforts to implement a renewable energy-oriented strategy for electricity grid development and use – play a pivotal role in efforts aimed at multilateral electricity market integration.

In July 2009 NORDEL and five other alliances of transmission system operators established the European Network of Transmission System Operators for Electricity (ENTSO-E), whose mission is to coordinate grid operators planning processes and allow for management of the

trans-European network on the basis of ten year plans containing infrastructure investment recommendations (ENTSO-E 2010; Weinhold 2010, p. 60). Hence far reaching planning competence for the European grid is already available via ENTSO-E.

Another exemplary cooperative project is the envisaged international offshore wind farm known as Kriegers Flak II, which will be located in the western Baltic and which since 2005 has been under the aegis of the Vattenfall power company. This 1,600 MW project, which could likewise serve as a model for similar undertakings in EU territorial waters, will be located in an area where the territorial waters of Denmark, Germany and Sweden converge and will be spread across the economic zones of Denmark, Germany and Sweden. Although a joint offshore grid for these three states would be far less cost intensive than separate interconnections, such a grid faces a series of problems that need to be resolved: (a) it encompasses states with differing energy market systems and synchronous zones; (b) it will need to deploy interoperable offshore systems; and (c) it will entail a heretofore unprecedented type and level of international cooperation (Vattenfall Europe Transmission et al. 2009).

Established in 2009, the Renewables Grid Initiative promotes the development of production and high voltage grid capacity aimed at full integration of both centralised and decentralised renewables via cooperation between the World Wide Fund For Nature (WWF) and Germanwatch on one hand, and the prominent grid operators 50Hertz, Elia, National Grid, RTE, Swissgrid and TenneT on the other, for a project involving massively expanding the integration of renewables into the European electricity grid (Battaglini et al. 2009).

Growing private sector interest in the development of interconnections is also exemplified by Friends of the Supergrid, an alliance of companies and organisations whose main aim is to promote the development of the North Sea grid. The founding companies, which include Hochtief, Areva, Mainstream and Siemens, own elements of supergrid technology and would thus be able to deploy this technology both onshore and offshore (Weinhold 2010, p. 59).

Established in October 2009, the Desertec ("clean power from deserts") project, which has close ties to the Mediterranean Solar Plan and has attracted substantial media attention, is under the aegis of the Desertec Foundation, an international network of companies and researchers that is run by the insurance company Munich Re and which, in collaboration with the Club of Rome (via the Trans-Mediterranean Renewable Energy Cooperation, or TREC) has developed a plan for extremely large scale development of solar energy installations in the North African desert (de Jong and van Schaik 2009, p. 8) that would supply solar power to North Africa and the Near East and bolster Europe's renewable energy capacities (DLR 2005). Solar power from the North African desert would be carried to Europe via low-loss high-voltage direct current transmission (HVDC) lines that would help to reduce European carbon emissions without the use of nuclear energy (European Commission 2008e; Battaglini et al. 2008). Desertec's long term goal is to meet a substantial share of electricity

demand in the Mideast and North Africa, and 15 percent of European electricity demand. The German government has voiced support for the project, and is making efforts to persuade the EU to cooperate. In addition, German companies that could potentially provide technologies needed for the project have expressed great interest in it.

All of these various initiatives underscore the importance, from a business and economic incentive standpoint, of the billions of euros that will be invested in grid development in the coming years. There is a certain amount of overlap between the players behind these various initiatives (e.g. technology companies such as Siemens and ABB; the grid operators Tennet-T and Vattenfall-Netz; banks; and renewable energy producers). Although Desertec II, now 17 members strong, counts as one of the largest alliances in this domain, it will probably take the longest to get off the ground – assuming it does. The most substantive initiative appears to be the 12 to 14 billion euros in investments in the North Sea grid that the ten members of Friends of the Supergrid will be making over the coming five years.

### **6.3.2 Optimisation of cross-border cooperation**

These various cross-border grid interconnection initiatives are essentially bottom-up undertakings that can not only be used as components of a future trans-European network, but will also serve as beacons on the hill for European electricity supply integration. The partners in such cooperative undertakings will benefit from the availability of balancing power and access to cross-border electricity markets. Such undertakings also foster dialogue between the relevant public and private sector players; they demonstrate, via initial implementation measures, that integrated electricity grids are achievable, and they may promote harmonisation of the relevant statutory, economic, and technical frameworks of the participating states, which would in turn streamline cross-border electricity and grid services trading and strengthen energy security through increased load balancing options.

Cooperative development efforts for an offshore North Sea grid hold out particular promise in terms of laying the groundwork, by the end of this decade, for renewable electricity importing and exporting. In addition, the efforts undertaken by the Union for the Mediterranean to eliminate obstacles to electricity trading and establish innovative trading systems and to harmonise the electricity trading and feed-in tariff frameworks in the EU, Middle East and North Africa will help to promote strengthened electricity market integration and create incentives for investments in renewable electricity installations (EU Ratspräsidentschaft 2008, Holznapel and Schumacher 2009, p. 166).

The North Sea grid alliance should be greatly expanded in view of its pivotal strategic role (a) in our scenarios; (b) for offshore wind farm development; and (c) in particular for leveraging the considerable pump storage system capacity that is available. It was not until the energy master plan of September 2010 that the German government officially acknowledged the importance of German-Scandinavian cooperation initiatives (BMW and BMU 2010, p. 22).

The energy scenarios that form the basis for the government's energy master plan give offshore wind farms, North Sea grid development, and use of Norway's pump storage system woefully short shrift (Schlesinger et al. 2010, p. 39 f). The activities of German private sector investors also appear to be quite inadequate in this domain.

Hence the frameworks for cross-border cooperation should be improved with the goal of rendering the relevant systems interoperable, which is mission critical in an electricity infrastructure comprising a high proportion of renewable energies (Czisch 2009). Establishment of the infrastructure needed to implement cross-border grids in the Mediterranean and Europe is a task that raises regulatory, economic and political issues that simply cannot be resolved at the national level.

In view of the German Advisory Council on the Environment, implementation of the following optimisation measures is a matter of some urgency:

#### Coordination of grid optimisation, strengthening and expansion efforts

In order to expeditiously implement a robust trans-European network for cross-border load balancing (EASAC 2009), a master concept whose clearly defined stipulations establish the requisite planning certainty for investors is needed, together with coordination by member state bodies that are endowed with the requisite competences. Strategic planning, general coordination of European grid development, and integration of existing bilateral and multilateral initiatives should be realised at the EU level – particularly when it comes to the development of high-voltage direct current transmission (HVDC) lines as an overlay grid vis-à-vis existing grids and interconnectors – and should be coordinated and implemented for Europe as a whole (Czisch 2009; Battaglini et al. 2008; European Commission 2008d; also see: scenario group 3).

Although interconnection initiatives stem in part from the private sector – which signals a growing awareness in this sector of the potential profitability of electricity market integration – past experience with energy infrastructure engineering has shown that private sector players oftentimes pursue their own interests, which may not necessarily overlap with the public interest. It often takes tremendous effort to interconnect energy markets, a move normally opposed by the major market players and other actors that wield considerable political and economic clout and have a strong vested interest in preserving their competitive advantage in national markets (Geden and Dröge 2010, p. 18). Hence the government should play a central and controlling role in cross-border electricity grid development efforts.

Although a first step has been taken toward coordination of electricity and gas network development via the designation of four honorary EU coordinators, the German Advisory Council on the Environment nonetheless recommends that in addition to these coordinators, integrated regional network development planning be instituted, particularly for offshore wind farm integration, with a view to ramping up the share of energy from renewable sources as

expeditiously as possible. A centralised policy entity that focuses on the big picture of electricity supply development should be established as an umbrella organisation for integrated grid and installation planning in the North Sea basin and should lay the groundwork for transparent joint public tenders for North Sea grid development. Coordination solely by the North Sea states will simply not get the job done in this regard.

In addition, the following policy measures should be implemented with a view to coordinating, streamlining and managing multilateral cooperative arrangements:

- Concrete international offshore wind farm development plans should be devised and implemented, if necessary via bilateral and multilateral alliances.
- Concrete strategic development plans for cross-border high voltage transmission lines should be developed and implemented.
- Equable, transparent and harmonised rules concerning cost allocation for grid interconnectors and strengthening, as well as for cross-border tariffs should be elaborated.
- Internationally compatible technical standards for the metering and transmission technologies used by transmission system operators should be established.
- Congestion management should be realised via clearly formulated regulations concerning storage capacities, available electricity capacities, and grid security standards.

#### Optimisation of joint cross-border projects via a master concept

Suitable frameworks are needed for cross-border projects, particularly those involving offshore wind farms, as well as for cross border trading of renewables, and for grid stabilisation. Such frameworks should be established not by standardizing support schemes, but rather through international harmonisation and coordination of such schemes and the attendant development strategies (Brodersen and Nabe 2009, p. 67).

Efforts should also be made to prevent regional markets from creating new obstacles to the expansion of cross border electricity trading throughout Europe, or projects from being implemented that deviate from the mandated EU objectives. In the same vein, while bilateral and multilateral agreements allow for relatively expeditious interconnection of individual electricity markets, such arrangements are no substitute for master plans (Czisch 2009).

#### Sharing lessons learned

Measures should be taken to ensure that the players involved in various regional initiatives can learn from each others' successes and mistakes. To this end, advanced regional initiatives could set standards that enable future initiatives to use proven solutions that in turn would promote the uniformity of such projects. The process as a whole should be subject to an umbrella organisation that lays down targets, timelines and standards. For example, the

North Sea Countries' Offshore Grid Initiative could serve as a platform for information interchange and process coordination for North Sea installation and grid development. In addition, the lessons learned from interconnection projects will also highlight problems that need to be addressed at the higher echelons of such an organisation.

#### Avoidance of environmental damage

It is crucial that bilateral and multilateral energy sector alliances make serious efforts to avoid environmental damage (Grassmann 2009; del Papa 2009) by conducting thorough pre-implementation environmental impact studies. A thorough debate should be conducted concerning the ecological risks of interconnecting the European, Mediterranean and North African electricity grids, and the European Commission should commission environmental impact studies that form a sound basis for assessment of these risks.

## **6.4 Political requirements for transitioning to renewable electricity supply**

### **6.4.1 System related decisions and energy mix consensus**

Transitioning to a renewable electricity supply will necessitate broad support among the general public, the various political parties, and in the relevant business sectors. This support can only be garnered through a debate based on the relevant hard facts and that demonstrates the crucial economic and ecological importance of unequivocally opting for renewables.

Although the federal government's energy master plan of 28 September 2010 (BMW and BMU 2010) sets ambitious climate protection objectives and calls for renewable energy and electricity grid development, it also calls for a substantial (albeit not clearly expressed in terms of residual power generation) extension of nuclear power plant lifetimes,<sup>3</sup> a move that will, however, be a drag on the process of transitioning to a renewable energy supply (SRU 2010b). Another problem with the government's energy master plan is that it is not discernibly oriented toward marshalling a broad social consensus and extensively involving energy policy players across the entire political and social spectrum. Indeed, the envisaged lifetime extension for nuclear power plants is very likely to have a polarizing effect on public opinion – a phenomenon clearly evidenced by the controversy over the German Bundesrat's right to participate in the decision on extending the operational life span of nuclear power plants. This matter will probably have to be settled by the German Federal Constitutional Court.

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<sup>3</sup> Note: the text has been written prior to the Fukushima accident and the revision of German nuclear policy at end of 2011. It is still up-to-date, however, and it offers a more fundamental reasoning for that revision of nuclear policy.

Of supreme importance in this regard is a far reaching debate on the technical, scientific and statutory aspects as regards which mix of instruments will best promote institution of a wholly renewable electricity supply. In addition, ground rules need to be established that mitigate and provide compensation for any possible negative external effects of such a system.

One possible way to generate a debate that is well grounded and that promotes consensus building is the approach to establish a Parliamentary Study Commission, which, while inherently political in nature, is also based on the empirical facts and is involved in a process that promotes consensus by involving the relevant stakeholders. Thus the Parliamentary Study Commission *Vorsorge zum Schutz der Erdatmosphäre* (Protecting the Earth's Atmosphere) report, which was commissioned by the parliament, promulgates a robust framework for a cross party consensus on climate policy in Germany. However, the Parliamentary Study Commission *Nachhaltige Energieversorgung unter den Bedingungen der Globalisierung und der Liberalisierung* (A sustainable energy supply in the context of globalisation and liberalisation) report (the commission's final report was issued in 2002) failed to bridge the gap between the various energy policy factions. The federal government should instigate a process of similar quality involving stakeholder committees and public hearings concerning a sustainable energy supply. Establishment of a government commission charged with investigating the possibility of a wholly renewable electricity supply would undoubtedly attract broad international attention. Its conclusions and consensus building impact on the debate concerning the need to transition to a renewable electricity supply would also provide the government with support for key policy decisions.

In addition, the government should propose – jointly with the Scandinavian states if possible – establishment of an international panel whose brief would be to elaborate a strategy for renewable energy in Europe; for in the final analysis, support for renewables will need to be gained not just in Germany but in all EU member states.

As one of the world's leading industrial nations, Germany is well positioned to have a strong influence on European energy policy, in that the decisions made in Germany will set the tone for the European energy debate as a whole. Germany should continue to push hard in Brussels for continuous strengthening of the EU's renewable energy policies.

To this end, the goal of a wholly renewable electricity supply should be folded into high ranking government policy documents and be continually laid down in law by (a) optimizing the government's current energy master plan; (b) extending the Integrated Energy and Climate program (in German: Integriertes Energie- und Klimaprogramm, or IEKP); (c) effecting the necessary changes in the 2012 progress report on the sustainability strategy; (d) looking into other ways to enshrine the goal of a wholly renewable electricity supply in law. Setting such a goal – which hopefully will garner widespread support across all parties – will promote long term orientation certainty, which is an indispensable precondition for the fundamental changes that need to be made in energy and climate policy. Coherent political

strategies of the type discussed below will also improve the federal government's ability to stand up to the various powerful interest groups that oppose a wholly renewable electricity supply.

#### **6.4.2 Options and requirements for achieving a radical social consensus**

The concept of a radical mainstream

British sociologist Antony Giddens has pointed out that, thanks to what he terms a radical mainstream, it is altogether possible for a social consensus to be radical in nature (Giddens 2009, p. 113 ff), and that, by extension, when radical problems and challenges arise, it is possible to form a majority social consensus that supports extremely far reaching concepts and that exceeds the classic lowest common denominator. Some issues in democracy for the most part escape the usual partisan politics and factional disputes by virtue of a nonpartisan consensus having emerged to the effect that certain actions simply must be taken. Examples of this are found in the arena of economic policy (e.g. fighting inflation, capping nonwage labour costs), environmental policy and other policy realms. Giddens offers the example of the climate policy mainstream in Great Britain (Giddens 2009, p. 114). In Germany as well, pioneering climate policy has been based on nonpartisan, as well as broad public support. This fundamental consensus concerning the need for climate policy measures and ambitious climate protection targets exceeding those called for by international agreements has existed for some two decades now, ever since the establishment of the first German parliamentary commission on long-term climate protection (Parliamentary Study Commission) in October 1987 (Weidner 2007, p. 454 f; Hirschl 2008, p. 114 f; SRU 2005, p. 3 f). And despite varying government coalitions, goals sometimes not being met, and some international climate negotiation setbacks, the government's national climate protection goals have repeatedly been confirmed and dynamised. In September 2009, the newly elected coalition not only came out in favour of a unilateral greenhouse gas reduction target of 40 percent by 2020 (relative to the reference year 1990), but also underscored the need for additional greenhouse gas reductions of at least 80 percent by 2050 (CDU et al. 2009, p. 26). These far reaching cross-sector targets, which lie at the lower end of the emissions reduction range deemed necessary by scientists (SRU 2008), entail even farther-reaching objectives for individual sectors, and thus would presumably also involve massive energy consumption cutbacks across the board, particularly in the electricity sector (Jones 2010; Öko-Institut and Prognos AG 2009; Edenhofer et al. 2009, p. 7).

But it's one thing to set ambitious climate protection objectives, and quite another to implement the attendant policy measures, which normally involve a redistribution process where some players get a bigger piece of the socioeconomic pie than others (Lowi 1972; Dose 2006). Implementation of a renewable electricity supply would ultimately result in a

substantial cutback of conventional electricity generation technologies (SRU 2010a, p. 85), and a broad political consensus has yet to be reached concerning the energy mix we should be aiming for over the long run. In Germany, the role that nuclear energy, coal, and renewables should play in our energy mix has been a hotly debated and often polarizing issue for decades (Hirschl 2008; Reiche and Bechberger 2006; Jänicke et al. 2000, p. 32 f).

### Building a broad consensus for renewables

If the principles espoused by our political parties are to be believed, there is already broad support across all parties for development and continued funding of renewable energies. Both the government and opposition have called for establishment of a wholly renewable electricity supply, with the coalition agreement speaking, in terms of transitioning to a “renewable era” (CDU et al. 2009, p. 27) and demoting nuclear power and coal to the status of mere “bridging technologies” – in public communication, at any rate (CDU et al. 2009, p. 30). In other words, this symbolic policy gesture (for that is what it is) holds that these conventional power technologies are no longer held to be irreplaceable pillars of our future energy supply, but are instead technologies that will enable us to transition to a wholly renewable electricity supply. Such gestures have often been faulted for an action instead of words stance that seeks to delude the public (Hansjürgens and Lübbe-Wolf 2000; Edelman 1971). But symbols in the political process invariably create expectations that voters expect politicians to live up to at some point; and this phenomenon can also have an impact on policy measures (von Prittwitz 2000). Thus for example the concept of “bridging technology” has also been used in political discourse to defend positions that are premised on a limited service-life extension for nuclear power plants (Röttgen 2010) or no extension at all. However, the government’s energy master plan (BMW and BMU 2010) construes the concept of bridging technology to mean that the lifetimes of nuclear power plants will be substantially extended (SRU 2010b).

The political consensus to the effect that renewables should be our preeminent source of energy is promoted by the following factors:

- Thanks to substantial renewable energy growth over the past decade, the importance of renewables for the economy and innovation, and thus as a force that creates jobs, has grown considerably (Oschmann 2010; Ragwitz et al. 2009).
- Where at one time renewable energy market growth affected a mere handful of pioneering companies, it now encompasses an ever growing field of players whose activities used to be confined to the conventional electricity generation value creation chain. The vested interests of these players is set to grow in complexity, while their opposition to renewable energy development will likely lessen.
- Despite regional problems and protests, public acceptance of renewables far exceeds that enjoyed by nuclear power and coal.

- The public is becoming increasingly leery of nuclear power and coal due to the fact that their risks and long run negative consequences are far greater and far more difficult to cope with than those of renewables.
- Renewables will allow for full decarbonisation of the economy, while still meeting key criteria such as promoting energy security, sustainability and cost efficiency.
- Unlike other energy sources – which are problematic mainly by virtue of (a) being dependent on finite resources; (b) the limited waste input capacity of the environment; and (c) their inherent risks – renewables are sustainable from a number of standpoints or can be used sustainably in various ways.

#### Why political and social support is essential for the transition to a wholly renewable electricity supply

The fact remains, however, that it cannot simply be presumed that the requisite political and social support for an all renewables electricity supply will emerge as a matter of course. The process of rolling back conventional energy is not a conflict-free process, even in the presence of generous transition support – the breakdown of the nuclear power consensus that had been negotiated in 2000 being only one example. The example of the steel industry shows that an industry severely impacted by globalisation can be scaled back in an orderly fashion and that the attendant untoward social effects can be mitigated (Binder et al. 2001). The dismantling of the German steel industry was politically acceptable by virtue of its having been set in motion by globalisation which is impossible to stop by lobbying, publicity or public protest. On the other hand, structural change brought about by environmental or climate factors requires politicians to spend far more effort explaining these matters. After all, the government always has the option to do nothing. This is one of the main reasons why most efforts to effect structural change driven by environmental and climate policy objectives that work to the detriment of major polluters have failed (Jänicke 2008, pp. 71 and 161).

There is no getting around the fact that transitioning to a wholly renewable electricity supply will mean shutting down conventional power plants that have outlived their useful economic life and need to be replaced. Although this process is to all intents and purposes part of the natural lifecycle of such power plants and can thus be carried out without eating up huge amounts of capital or provoking economic and social conflicts, there are nonetheless powerful economic and political players that have a strong vested interest in retaining the current business model and that will not readily get behind a large-scale transition to renewables. Moreover, we are likely to see (a) economic activity shifting from one region to another owing to phenomena such as the declining fortunes of coal mining regions that work to the benefit of wind and solar energy sites; and (b) the devaluation of existing technological infrastructures (Monstadt 2008), both of which are likely to provoke virulent opposition to renewables by the industries and regions affected (SRU 2004, p. 115).

In its 2004 Environmental Report (SRU 2004, p. 116) the German Advisory Council on the Environment called for institution of what was termed a transition management dialogue between government authorities and the coal and electricity industry for the purpose of offering regional stakeholders viable alternatives and finding ways to mitigate the effects of the social and economic change that would be wrought by the advent of a renewables based electricity system. The economic and political conditions for the construction of new coal fired power plants have worsened in the interim, without the government having instituted the aforementioned dialogue. The government needs to make it crystal clear that companies that persist in building such plants will be proceeding strictly at their own risk and cannot expect the government to bail them out if such installation prove to be unprofitable owing to changes in climate policy and stiffer competition from renewables (SRU 2008). In addition, those players that lose out as a result of the transition to renewables should be offered attractive options, such as compensating for electricity revenue losses by promoting growth in the relevant supply sectors. Industry specific policies could be instituted as an adjunct to such measures, and would need to be proactively communicated. In view of the fact that any climate policy-driven transformation process will draw upon vast stores of knowledge, transition management instruments should be implemented from the get-go with a view to enlisting the support of the scientific community and an optimally broad range of players for a transparent process that strives for binding agreements.

Foreign policy in the energy arena:

Germany's influence at the international level

In order for Germany to successfully pursue a strategy of transitioning to a renewable electricity supply, it will be necessary to be able to detect and avoid bottlenecks and missteps in a timely fashion as well as for all political actors and governmental echelons to move the transition process forward.

Inasmuch as Germany's status as a climate policy pioneer in the EU has traditionally garnered wide popular and cross party support, Germany could potentially have a major say in European energy policy going forward. To this end, Germany's EU representatives should get behind EU renewable energy policies as much as possible with a view to promoting establishment of an EU policy framework that sets the stage for the advent of a renewable electricity supply. The policy instruments in this regard should not be confined to support for renewable electricity, storage capacity, and grid infrastructures, but should also encompass a broad range of administrative echelons, social actors and technical and industry sectors. Against this backdrop, we will now discuss the role of local and regional players in the electricity system transformation process.

## **7 Energy efficiency strategies and instruments**

### **7.1 Challenges on the road to robust electricity efficiency policies**

The least cost intensive “bridging technology” available today transitioning to renewable electricity is scaling back electricity demand. As energy demand decreases, so do the internal and external costs of a wholly renewable electricity supply. In addition, the task of transitioning to renewables would be eased by energy saving measures, as this would allow more time for the expansion of renewable energy capacity and the attendant grid and storage capacity. Hence in order to transform our electricity system to renewable energies, it is essential that energy efficiency be improved.

Although the discussion below centres around energy efficiency in the electricity sector, in the interest of minimizing electricity demand it will also be necessary to optimise efficiency in the heat and transport sectors as electricity use there is likely to increase. Key to achieving this optimisation are energy renovation of existing buildings as well as measures aimed at transport demand reduction, modal shift, and traffic flow optimisation (Schlesinger et al. 2010; Klaus et al. 2010; SRU 2008).

Emissions trading can also help to improve energy efficiency, as it creates incentives for polluters to reduce emissions at the lowest possible cost. However, emissions trading as currently structured lacks the wherewithal to bring about the necessary structural change. The discussion below centres around specific demand-side energy efficiency instruments.

The electricity saving potential available to us today has yet to be leveraged to the requisite degree. In view of the multitudinous realms and actors that come into play, developing coherent strategies and the systematic application of appropriate instruments constitute a major challenge.

Electricity efficiency policies that aim to promote climate protection should fulfil the following two goals to an equal extent:

- Such policies should create smoothly functioning energy efficiency markets and should overcome current obstacles to energy efficiency.
- Such policies should ensure that technological improvements and other measures that are instituted bring about a reduction in overall electricity demand.

Implementation of such policies is fraught with difficulty on a number of fronts.

#### **Policy goals**

German and European energy efficiency policies have traditionally called for electricity demand reductions relative to a benchmark as defined by a reference scenario. The 2006 European Commission Energy Efficiency Action Plan called for a 20 percent energy demand

reduction by 2020 relative to the reference scenario (European Commission 2006), which would represent a decrease of around 12 percent relative to 2005 levels.

To this end, the Energy end-use efficiency and energy services directive (2006/32/EC) aims to promote improved energy end-use efficiency in the member states and increased energy efficiency competition in the context of deregulated energy markets. The directive obligates the member states to adopt an indicative (i.e. nonbinding) energy saving target of 9 percent (of the mean demand over the five years preceding adoption of the directive) within nine years following the effective date of the directive. However, this target figure is unrelated to overall energy demand. The member states are required to demonstrate that they have (or plan to) implement measures aimed at reducing energy demand to a level below that which would occur in the absence of such measures. Hence there is no guarantee that such energy saving measures will actually translate into a reduction in aggregate energy demand.

Germany's 2002 sustainability strategy calls for the doubling of energy efficiency and productivity by 2020 relative to 1990 levels (Bundesregierung 2002) in a manner that is commensurate with the European efficiency goal of reducing energy demand by 20 percent relative to the trend. Unlike the EU's 20 percent target, the government's energy master plan of 28 September 2010 lays down clearly defined energy saving objectives and the attendant absolute numerical values relative to a reference year (Bundesregierung 2010). The 20 and 50 percent reduction in primary energy use in 2020 and 2050 respectively (relative to 2008 levels) called for by the government's energy master plan would necessitate a 2.1 percent annual rise in energy productivity. The master plan calls for electricity demand reduction of 10 percent in 2020 and 25 percent in 2050, which means that net electricity demand would need to decline from 540 TWh in 2008 to 500 TWh in 2020 and 400 TWh in 2050.

The energy efficiency targets set by the EU and the individual member states thus far have been notable for their non-compulsory nature. Hence such targets only find their way into action plans or strategy papers, and even the 9 percent energy saving target is merely an indicative value. The European Commission is now considering the possibility of laying down binding energy efficiency targets in an energy efficiency action plan that is slated for issuance in early 2011 (European Commission General Directorate for Energy and Transport 2009).

### Obstacles to energy efficiency

The failure thus far to fully leverage the economic potential of energy efficiency improvements is attributable to various structural, economic, social and socio-psychological factors such as the following (SRU 2008):

- An information and motivation gap that afflicts end users, equipment manufacturers, architects and building contractors alike.

- The impact of the myriad disparate potentials for minor energy savings afforded by household appliances and the like, an arena where the relevant information is for the most part readily available to users, who nonetheless feel that the amount of effort involved is hardly worthwhile relative to the anticipated cost savings.
- The split-incentive- or user-investor-dilemma, describing a constellation whereby the investor in energy efficiency measures is not the beneficiary of the resulting savings.
- Inertia problems resulting from long reinvestment and maintenance cycles for energy consuming durables such as buildings and installations (Prognos AG and EWI 2007).
- High investment costs and uncertainty concerning amortisation periods.
- Financial limitations such as a lack of disposable income, combined with prioritisation of short term cost reductions (Kaschenz et al. 2007).
- Consumer and supplier risk aversion in technology markets (Barthel et al. 2006, p. 11).

#### Price signals, efficiency and rebound effects

In order for energy saving policies to work, it is crucial that the various interrelationships between efficiency improvement, energy prices, and energy demand be clearly differentiated from each other.

Energy prices and in particular electricity prices have only a minor effect on short-run energy demand, whereby various studies have shown that the price elasticity of electricity demand (a measure of how demand responds to price) varies from  $-0.1$  to  $-0.4$  (Hamenstädt 2009; OECD 2008; Branch 1993). Thus for example a ten percent electricity price increase will reduce electricity demand by anywhere from 1 to 4 percent, which means that short-run electricity costs are essentially fixed costs for a household (Hamenstädt 2008). The long-run price elasticity of household energy demand, which is greater since capital stock adjustments have time to take hold, is put at  $-0.7$  (OECD 2008, p. 102). Hence electricity price fluctuations have more of an impact on energy demand in the long-run than in the short-run.

In addition, a comparison of affluent OECD states showed that long-run electricity prices are a key economic determinant of electricity intensity (as expressed in kWh/US\$1,000) (Verbruggen et al. 2003). In other words, the higher the electricity price in a given country, the lower is its electricity intensity. This suggests that an economy's overall energy efficiency will respond to energy prices over the long run. In Germany, both electricity prices and the economy's electricity efficiency are relatively high.

However, electricity demand levels in Germany have shown that efficiency improvements of specific energy uses do not necessarily translate into reduced aggregate energy demand, since oftentimes the positive effects of electricity saving measures are offset by increased consumption of energy services; efficiency improvements can even promote increased overall energy consumption by virtue of the fact that lower specific costs of energy services

occasion increased demand (Alcott 2005; 2008; Sorrell 2007; Jackson 2009; Sanne 2000). In this context, the so called rebound effect refers to the share of energy saved at the technical level that is offset by increased demand for energy services (Sorrell 2007). There are in fact two types of rebound effect: direct and indirect. The former involves increased demand for an energy application whose efficiency has been improved, while in the latter, energy cost savings from the energy use becoming more efficient are spent on other forms of energy use. Rebound effects can occur within a range of timeframes. However, in the final analysis the key assessment factor for the long term climate effects of energy efficiency measures is the combination of direct and indirect rebound effects, whereby a 50 percent rebound effect would mean that only half of the potential energy savings for the energy application in question actually materialise in overall energy demand. If the rebound effect exceeds 100 percent, a backfire is deemed to have occurred, i.e. overall energy demand even increases.

Efficiency optimisation, energy demand increases, and economic growth have traditionally gone hand in hand, since technological progress allows for growth in both production and consumption. For example, energy efficiency in the product and service sectors in OECD states rose by around 30 percent from 1970 to 1991, while aggregate energy demand increased by around 20 percent during this period (Holm and Englund 2009). It seems that the aggregate long-run economic rebound effect oftentimes exceeds 50 percent and can even rise above 100 percent – which means that anywhere from 50 to 100 percent of the immediate energy savings from improved efficiency are offset by induced increases of the demand for energy services (Sorrell 2007; Barker et al. 2009).

In Germany, while household appliances (for example) are more efficient than they used to be, household electricity demand has risen by an average of just under 1 percent annually since 1990 (BMW 2010), presumably due to the increased use of electronic devices, the growth in per capita living space, and greater demand for modern conveniences. In this context, rebound effects reinforce the impact of rising real income. Efficiency standards for certain products such as TVs are unlikely to translate into absolute energy savings since TV sales and sizes are expected to increase going forward (Oehme et al. 2009).

## **7.2 Energy efficiency policies revisited: consumption caps in lieu of energy saving targets**

In view of this situation, we recommend that an absolute electricity demand target be set at the national level and that efforts be made to stabilise energy demand in the long run, considering the available energy savings potential and the anticipated rebound effects.

To this end, targets for aggregate energy demand should be set for ten years at a time. In keeping with the government's September 2010 master energy plan, efforts should be made to reduce net energy demand by 10 percent in 2020, to roughly 500 TWh. Subsequent

energy demand ten-year targets should then be adjusted in light of the available energy saving potential and the extent to which electric vehicles have come into use.

In our view, stabilizing electricity demand at 500 TWh is an achievable long-run goal as well. Efficiency improvements of the electrical devices and appliances themselves as well as more comprehensive approaches such as measures to increase buildings' entire space heating and hot water systems could reduce aggregate electricity demand for traditional electricity uses to far below 500 TWh over the long run (Schlesinger et al. 2010; Klaus et al. 2010; UBA 2009; Öko-Institut and Prognos AG 2009; Enquete-Kommission Nachhaltige Energieversorgung unter den Bedingungen der Globalisierung und Liberalisierung 2002). However, if, as is likely to occur, electric vehicles come into increasing use, savings realised in traditional uses would be offset by the consequent incremental rise in electricity demand for electric vehicles.

A national electricity demand target would rectify key failings of current energy efficiency policies, as such a target would be easier to convey and more readily verifiable than the energy saving and efficiency targets defined relative to reference scenarios; and it would promote greater planning certainty in the electricity sector.

### **7.3 Household electricity accounts**

#### Introduction

Our proposed household electricity account model would provide an innovative energy efficiency policy instrument that would impose an upper limit on total household electricity consumption, takes its cue from the basic concept of White Certificates, and expands it into a genuine cap and trade system. Unlike the existing White Certificates schemes, which are based on putative amounts of energy that is saved via specific projects, household electricity account certificates would set an absolute cap on the overall electricity supply. Inasmuch as the price elasticity of electricity demand is very low, particularly in the short run, a steering mechanism based on electricity prices such as an electricity tax ecobonus scheme (von Weizsäcker et al. 2010; ITEN et al. 2003) would not allow for expeditious adjustments. We are therefore in favour of a framework that would entail direct quantitative controls of energy use and would hold power companies responsible for the target achievement. This would effectively limit electricity demand and promote the leveraging of household energy savings options.

Under our household electricity account concept, certificates would be distributed to power companies according to their household customer fleet, whereby each company would be credited a lump sum amount of electricity per household that would be based on the aggregate electricity demand targets for the household sector.

This system would (a) allow for the requisite flexibility via electricity certificate trading between power companies; and (b) even out electricity consumption on the part of individual customers via price mechanisms. Electricity consumption of individual households would not be rationed, and thus the instrument would not limit the customers' freedom of choice (regarding individual electricity consumption) to any greater extent than prices now do.

There is tremendous potential when it comes to the efficiency of household electricity use, which currently accounts for around 30 percent (140 TWh) of total electricity end-use. The potential savings in terms of household electricity use is put at 24 to 40 TWh (Pehnt et al. 2009; Kascheinz et al. 2007). Altering household usage patterns could engender considerable savings above and beyond this of up to 30 TWh (Bürger 2009). Despite these energy saving opportunities, household electricity demand rose significantly between 1990 and 2008, and despite the economic crisis has declined far less than in other sectors (AGEB 2010).

In view of the enormous electricity saving potentials, it appears certain that judiciously implemented reductions in aggregate electricity demand could be achieved over the long run without infringing on modern comforts and conveniences, in a manner that would leverage untapped energy saving potentials by overcoming the barriers to energy efficiency discussed above.

Although emissions trading already limits carbon emissions from electricity generation, the positive impact of energy savings extends far beyond that of merely climate protection measures. All types of energy use, including renewables, unavoidably impact the eco-balance, although the spatial and temporal scope of such effects varies. Moreover the use of renewable energies entails the use of natural resources such as land, landscapes, and water and cannot be expanded ad infinitum; it further brings about a rise in aggregate system costs as consumption levels increase. Hence capping and reducing energy use helps to (a) curb its environmental impact; (b) promote security of supply; (c) reduce costs; and (d) thus bring us closer to reaching the strategic-triad objectives – namely climate protection, competitiveness, and security of supply (Geden and Fischer 2008, p. 40).

#### How household electricity accounts would work

Household electricity accounts would be held by power companies that service private households. These companies would be required by law to cap the aggregate amount of electricity that is provided to such households, whereby the aggregate electricity allocation would be based on a lump sum amount of electricity per household customer (i.e. the household electricity account per se) and the company's private-customer fleet.

In the interest of promoting additional energy savings, each power company's aggregate electricity allocation for any given year would need to engender scarcity in that the allocation would be lower than anticipated electricity demand in the absence of supplemental measures

and it would decrease each year. Ideally, the development path for aggregate private household demand will be consistent with the cross-sectoral target aggregate demand and should take account of any possible or anticipated demand reductions from other consumption sectors.

Each power company would receive its aggregate electricity allocation at the beginning of the year in the guise of certificates, which the companies could trade back and forth. At year's end, the certificates would need to cover the aggregate amount of electricity the company provided over the course of the year. Thus a power company would be free to encourage its customers to save energy and sell off spare certificates, or alternatively to forego energy saving measures and purchase additional certificates.

It would be up to the individual power companies to determine which energy saving measures they wish to encourage their household customers to adopt. For example, households that decide to opt for energy saving refrigerators or other appliances could be given a subsidy toward such a purchase. In addition, progressive sliding-scale electricity rates or a bonus/penalty system could be used as a carrot and stick mechanism for households. Pairing such measures with information and advice provisioning instruments would also be useful.

#### Anticipated effects

Unlike the current project-based white certificates systems, household electricity accounts would allow for control of private households' cumulative electricity consumption, and could thus make a direct and verifiable contribution to the implementation of a nationwide cap on electricity demand. A household electricity accounts scheme would not only create incentives for technical efficiency measures, but would also provide incentives for electricity saving through changes in consumer behaviour patterns.

Household electricity accounts would mitigate rebound effects within the household sector, and would make consumers more aware of the importance of aggregate electricity consumption. For example, a power company would presumably subsidise a customer's purchase of a more energy efficient refrigerator only insofar as the improved specific energy efficiency is not offset, in terms of absolute electricity consumption, by the appliance's potentially larger dimensions.

A household electricity accounts scheme will trigger new philosophies and strategies developed by power companies, since in order to optimise their competitiveness and profits, such companies will need to provide their customers with high quality electricity services. Thus what were once "mere" power companies will become providers of energy services (SRU 2008, p. 115). Power companies could still expand their household electricity activities by acquiring new customers, and this in turn would increase competition for such customers.

Our proposed household electricity account concept would also promote economic equity. On average, high income households use more electricity than low income households (see Table 7-1) (Statistisches Bundesamt 2005), thus account for a greater proportion of the environmental pollution attributable to electricity generation, and at the same time consume a higher proportion of the finite common-pool resources that are used for electricity generation. Inasmuch as electricity prices do not sufficiently reflect the scarcity value of these environmental resources, environmental policies that are based on the principal of equal per capita resource usage rights can promote social equity (Barnes 2006; Ekardt 2010). Our household electricity account concept is a step toward implementation of this principle.

Under this system, power companies would tend to prefer new customers with below average electricity consumption, since the difference between this consumption and the per household allocation – which the companies will have originally received as certificates – can then be sold to other power companies, whereas new customers with above average consumption will make it necessary for the companies to purchase additional certificates. Hence power companies would put more effort into acquiring low-consumption customers (many of whom are of course socioeconomically disadvantaged) by offering them lower electricity rates based on a progressive sliding scale. On the other hand, the higher electricity prices to which high consumption households would be subject would be an incentive to save electricity and use it more efficiently.

The incremental decrease in the amount of electricity allocated to household energy accounts would ensure that the aforementioned effects would occur gradually and would enable the relevant actors to carry out long-run planning in this regard.

Table 7-1

**Monthly household outlays for electricity,  
according to household income**

Household income (in euros)	Electricity outlays (in euros)
< 500	32.68
500–900	28.28
900–1,300	33.41
1,300–1,500	38.30
1,500–1,700	39.01
1,700–2,000	42.85
2,000–2,600	47.75
2,600–3,600	56.91
3,600–5,000	64.55
5,000–7,500	71.96
7,500–10,000	81.33
10,000–18,000	87.01
Source: Statistisches Bundesamt 2005	

Our proposed household electricity account system would open up new possibilities for the shaping of energy efficiency and energy saving policies. We recommend that this model be studied and refined, particularly from the standpoint of constitutional law – an aspect that exceeds the scope of the present report. In addition, the exact modalities and methods entailed by the household electricity account system need further study. For example, such an assessment would attempt to determine the impact of the system on various types of power companies such as large electricity suppliers or municipal power utilities that produce a high proportion of combined heat and power (CHP) electricity. Moreover, the possible mechanisms for initial electricity allocations need to be carefully investigated.

## 7.4 Conclusions

Successful implementation of energy efficiency and energy saving policy measures is indispensable for a sustainable and cost efficient energy supply, since the lower the aggregate electricity demand, the cheaper and simpler it will be to transition to a renewable electricity supply. But unfortunately there is still a yawning gap between available energy efficiency and energy saving potentials and the actual impact of efficiency measures that are put into effect. This particular policy realm is politically especially difficult due to (a) its

numerous barriers and market obstacles, (b) the risk of rebound effects, and (c) the murky actor structure that obtains in this realm.

Energy efficiency policies should first and foremost set clear and verifiable targets, and in our view should be based on a ten-year national energy demand target that is adjusted at the end of each period. In keeping with the government's September 2010 master energy plan, efforts should be made to reduce net electricity demand to 500 TWh in 2020. This goal should then be adjusted for the ensuing ten year periods in light of the projected energy saving potentials and developments in the electric vehicle sector.

In order to reach the national energy demand target, consistent efficiency policies are needed that employ a comprehensive mix of available management instruments, since merely disseminating information and consumer guidance will simply not get the job done. Stringently implemented, energy efficiency funding and white certificates can go a long way toward the establishment of national energy efficiency policies, whose success is largely determined by how sweeping they are, as well as the extent to which they call for (a) clear and ambitious energy saving targets, (b) transparent coordination processes with national efficiency policy targets, and (c) robust outcome monitoring. The federal government should push Brussels to lay down more ambitious and dynamised product standards by implementing a European Top Runner program and to dynamise the current eco-design directive requirements. For our part, we also favour the mandatory establishment of energy management systems in industrial companies, whereby such systems should be differentiated according to company size and the energy costs the company incurs.

Moreover, energy efficiency and energy saving instruments need to be developed such that they have the wherewithal to stabilise and durably reduce electricity demand. One example of such an instrument is our proposed household electricity account concept, which would impose an upper limit on aggregate household electricity sector consumption.

Under this scheme, power companies would be given certificates for specific amounts of electricity to be supplied based on the number of households they service. This system would (a) allow for the requisite flexibility via electricity certificate trading between power companies, (b) even out electricity consumption on the part of individual customers via price mechanisms, (c) make a direct and verifiable contribution to the implementation of a nationwide electricity demand target, (d) make energy efficiency a strategic business objective of power companies, and (e) create incentives for technical efficiency measures on one hand and saving electricity through changes in consumer behaviour patterns on the other. We recommend that this model be studied and refined in more detail, particularly from the standpoint of constitutional law – an aspect that exceeds the scope of the present report. The white certificate pilot projects proposed by the federal government's master energy plan could be used for such a study.

Our proposed household electricity account system as well as other instruments such as more stringent efficiency standards for household appliances dovetail with each other, whereby household electricity accounts would serve as a buffer against rebound effects and would allow for electricity consumption control at a super-ordinate level. Rapid advances in the field of appliance efficiency will reduce certificate costs, while household electricity accounts would support the market penetration of highly efficient appliances.

## **8 Policy Framework for Renewable Energy and Storage**

The transformation of the electricity sector towards a renewable based system depends upon an appropriate policy framework both to promote renewable energy, to establish necessary storage capacities and the grid development. The argument presented here is the following: (1) Emission Trading as stand alone will not deliver dynamically efficient results due to the specific economic characteristics of the electricity sector and of renewable energy sources. A complementary support mechanism for Renewable Energy is needed. (2) Beyond this fundamental argument, even the existing framework is not exploiting its full potential due to a number of design deficits. (3) On this basis the successes and shortcomings of the German Feed-in-Tariff System will be assessed in depth. (4) The analysis leads to recommendations for a reform, which sticks to the essential pillars of the system, while correcting some of the problems especially in relation to cost and environmental impact. (5) Finally recommendations on research and demonstration projects as well as on market incentives for the development of storage technologies are developed.

### **8.1 The Need for Policy Instruments in Addition to Emissions Trading in the Electricity Sector**

It is variously argued that in the long run, converting electricity generation to renewables is the least-cost option for decarbonising the electricity supply (see Czisch 2005; Nitsch 2008; Nitsch and Wenzel 2009). If so, then according to supporters of an emissions trading-only approach, once the right emissions targets are chosen, market forces will ensure that this option prevails. Other policy instruments then do more harm than good because the emissions cap prevents them from delivering additional reductions and they lead away from the least-cost abatement achieved by emissions trading. This standpoint has been adopted in Germany in particular by a number of prominent critics of the German and European policy instrument mix (Wissenschaftlicher Beirat beim Bundesministerium für Wirtschaft und Arbeit 2004; Sinn 2008; Donges et al. 2009; Monopolkommission 2009; RWI 2009; Sachverständigenrat zur Begutachtung der Gesamtwirtschaftlichen Entwicklung 2009).

The SRU aims to show in contrast that a largely renewables-based electricity supply would not prevail through emissions trading alone even if it was the least-cost option. In the short run, greenhouse gas emissions trading is naturally blind to externalities of other abatement options. This is why nuclear energy becomes relatively more attractive in a carbon emissions trading scheme and is reason enough to support intervention in such trading.

In the long run, there are further reasons to deploy other policy instruments in addition to the European Emissions Trading Scheme:

- The theoretical model in which emissions trading results in cost minimisation does not allow for learning curve effects and economies of scale in production.

- It does not account for lock-in effects as a result of initial incremental investment which cause investors to prefer continuous incremental improvement over necessary fundamental change. Furthermore, the theory also works on the assumption that profitable projects can obtain sufficient funding, which does not accord with reality.
- The electricity sector also has special characteristics relating to the grid dependency of electrical energy and the lack of options for storing electricity.

The following will return to these points in detail after outlining how emissions trading works as presented in most textbooks.

### **8.1.1 How emissions trading works in principle**

Emissions trading is a market-based instrument that aims to reduce greenhouse gas emissions at least cost. The European Emissions Trading Scheme is a cap and trade arrangement. The quantity of greenhouse gas emissions is first limited for the sectors involved in trading by setting a cap, and emission allowances (European Union Allowance Units, or EUAs) can then be freely traded among participants (for a critical appraisal of the European Emissions Trading Directive, see Endres and Ohl 2005). While the cap ensures that the environment policy goal is met, the trading part means it is met at least macroeconomic cost (for a detailed description of emissions trading, see for example (Baumol and Oates 1988; Michaelis 1996; Tietenberg 2006; Endres 2007); on the cost-efficiency of market-based instruments (Newell and Stavins 2003). The price of emission allowances is found by interaction between the marginal costs of abatement that determine demand and the state-imposed supply limit created by the emissions cap. Unlike under a carbon tax, the emissions cap is certain to be attained; all uncertainty is built into the price.

In the case of carbon emissions, the price of emission allowances causes companies to choose, for example, clean and efficient production methods whose current costs are higher than other methods that harm the climate. If the target is made more stringent, the price of emission allowances rises, leading to the choice of costlier abatement options. At very stringent emissions targets, it not only becomes profitable to invest in carbon-efficient power generation, but ultimately in renewables alone. This effect of emissions trading is referred to as market pull (Grubb 2005). It enhances the competitiveness of clean technologies relative to emission-intensive technologies. We do not dispute its existence.

Theoretically, emissions trading – because it equalises the marginal costs of all abatement options for all emitters – attains the abatement target at least cost. In ideal conditions it does this not only in the short term but also in the long term. It is this last aspect which we subject to critical appraisal in the case of fundamental innovation in the electricity sector.

### **8.1.2 Critical appraisal of central assumptions of emissions trading theory**

In order to substantiate the necessity for further instruments alongside the EU ETS, a closer look is taken at a number of critical assumptions on which the cost-minimising effect of emissions trading depends in theory. A fictitious situation is assumed in which the government relies on emissions trading as the sole instrument. This obviously does not reflect reality in Germany and most other European countries where renewable support schemes exist. The aim is to reveal shortcomings of a climate policy strategy that only builds on the EU ETS as stipulated by many critics of a policy mix. In the following, we differentiate between problems that arise from unrealistic assumptions underlying the theory of emissions trading and those that are characteristic for the electricity sector.

#### Learning and scale economies through market penetration

In the basic environmental economics model, economic instruments lead to selection of the option with the lowest marginal costs of abatement. If these costs are given exogenously, selection of an abatement option, for example as a result of emissions trading, does not affect the future attractiveness of other emission abatement options. If technical progress makes other abatement options more cost-effective at time  $t+1$ , this is unaffected by the option chosen at time  $t$ . Selection of the least-cost option at each point in time therefore also results in least cost over time.

There is however long-standing discussion, included in almost all textbooks, concerning the incentive effect of various policy instruments on technical progress. This relates to the recouping of R&D expenditure from savings obtained with various instruments of environmental economics. Endres (2007) goes a step further by showing in a least-cost analysis over two periods that on realistic information assumptions, emissions trading (but not only emissions trading) fails to induce the investment in technical progress needed to recoup emission abatement costs over both periods. On realistic information assumptions, however, no environmental policy instrument can be expected to produce optimum results.

Alongside the R&D spending incurred for all innovation, fundamentally new technologies also have a further disadvantage in that they lack market penetration at the start of the product life cycle. Learning and scale economies are significantly larger for such technologies than for incremental innovations, which often only require minor changes and in some cases can be incorporated very quickly into all output, allowing economies of scale after only a short pilot phase.

Requate and Bläsi distinguish between private learning effects and spill-over effects (see Bläsi and Requate 2010). They assume that private learning effects arising from a company's own production operations are already taken into account in its decision to produce. By this argument, a wind turbine manufacturer, for example, will market its wind

turbines at a price below cost in period 1 if it expects in period 2 to make good the first-period loss through learning and scale economies.

The situation is different if learning and scale economies at earlier production stages have spill-over effects, i.e. where companies learn by pioneers' mistakes. Such spill-over effects tend to cause market failure as early adopters create positive externalities in the form of cost-saving opportunities. As they are not rewarded for this, the outcome is underinvestment in new technology (see for example Arrow 1962; Jaffe et al. 2005; Bläsi and Requate 2010).

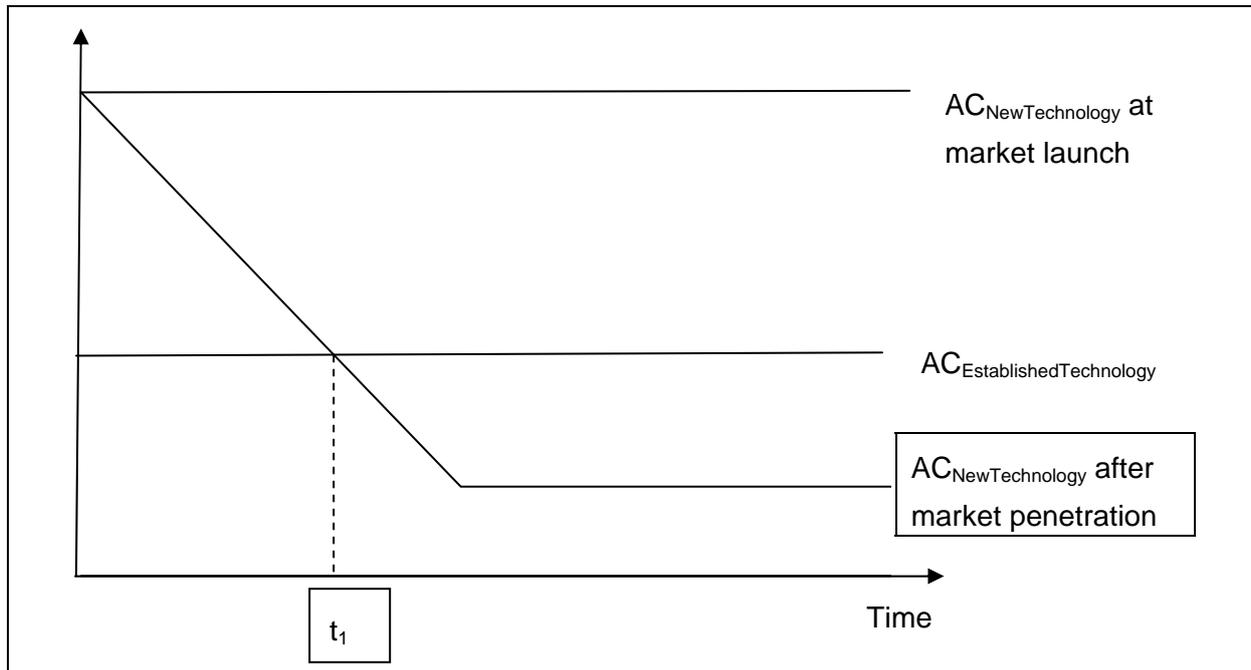
Emissions trading improves the chances of technologies that, not counting environmental impacts, cost more than established technologies. Because, however, the least-cost technology is always selected at any given time, fundamentally new abatement technologies, which can only become competitive with other already established abatement options through market penetration and the associated sector-level learning and scale economies, are not brought to maturity. This applies even if they are more cost-effective in the long term than incremental abatement options. Learning and scale economies only arise if a technology is used on a large scale (IEA 2000; Stern 2006).

This is simply illustrated in Figure 8-1: Assuming without loss of generality that the abatement costs per unit with the established technology stay constant over time and are lower than with the fundamentally new technology when it first comes on the market, then the new technology will not be selected by market participants and its costs will not change over time. If on the other hand the new technology achieves significant market penetration (e.g. due to incentives from other sources), its costs will drop below those of the conventional technology from time  $t_1$  onwards. Even if the additional costs at  $t_1$  are more than offset by later savings, emissions trading alone does not result in market launch (see also del Río González 2008; Fishedick and Samadi 2010).

To the extent that companies learn by others' experience, i.e. that spillover effects exist, this is not a problem of imperfect foresight, because the meeting of additional costs in period 1, something which is of joint benefit to all in the future, constitutes a typical prisoner's dilemma (Jaffe et al. 2005; Bläsi and Requate 2010). The same applies to scale economies at earlier production stages, which likewise arise for the sector as a whole, once again meaning that early adopters generate positive externalities for later investors.

Figure 8-1

### Marginal abatement costs with new technologies



Source: Holm-Müller and Weber 2010

While trading can thus deliver short-run, 'static' efficiency and so meet short-term targets at least cost, it cannot guarantee long-term, 'dynamic' cost-efficiency because it does not automatically ensure attainment of a long-run goal at least cost.

Del Rio Gonzáles (2008) also points out in this connection that early state promotion of new technologies resulting in early production learning and scale economies can prevent a steep rise in the price of emissions and of marginal abatement curves. Special promotion schemes for new technologies consequently have a further benefit in that they make the abatement cost curve more elastic, so target adjustment causes less upheaval, including with increasingly stringent targets. This is particularly important when emissions trading – as in the EU – is structured so that emission abatement targets are made increasingly stringent over time. With long-term targets in force, the marginal abatement costs of conventional technologies will at some point sharply increase. If at this point new technologies are still only just coming onto the market, they will then become competitive but will only be available at high introductory cost. Early state promotion of promising technologies can thus allow more stringent emissions targets to be met with less friction.

Möst and Fichtner (2010) attempt to quantify this effect and estimate that state promotion of renewables can mitigate the scarcity of emissions allowances and so reduce marginal abatement costs by up to 30 percent by 2030.

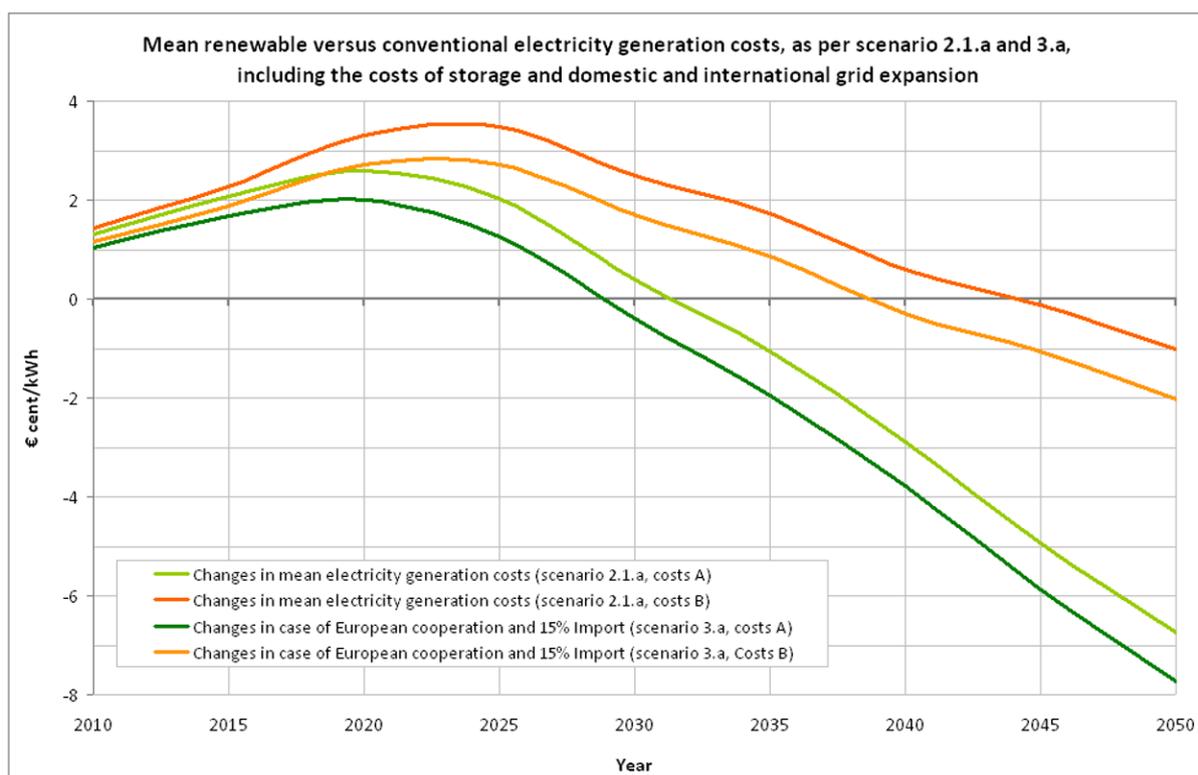
The unit energy cost reductions already seen for wind, solar and biogas, largely brought about by Germany's Renewable Energy Sources Act, likewise testify to large potential

savings through learning and scale economies. The largest cost reductions, for example, were obtained on photovoltaics. For wind turbines, the unit cost per kWh annual energy yield has halved since 1990.

It is reasonable to assume that the huge potential attained by these energy sources today could not have been secured without state promotion. Despite large cost savings in recent years, accumulating experience, technical progress and mass production are expected to continue delivering large cost reductions which, combined with the rising cost of fossil fuels, may make renewables not merely competitive, but even the least-cost energy source in the long run (on the scope for future cost reductions see e.g. Neij 2008). In this case, it makes sense at macro level to continue state promotion of promising technologies. If technologies do not come up to expectations, however, the state must also stop promoting them.

Figure 8-2

### Plausible development of costs for renewable and conventional energy sources



SRU/SG 2011-1/Abb. 8-2

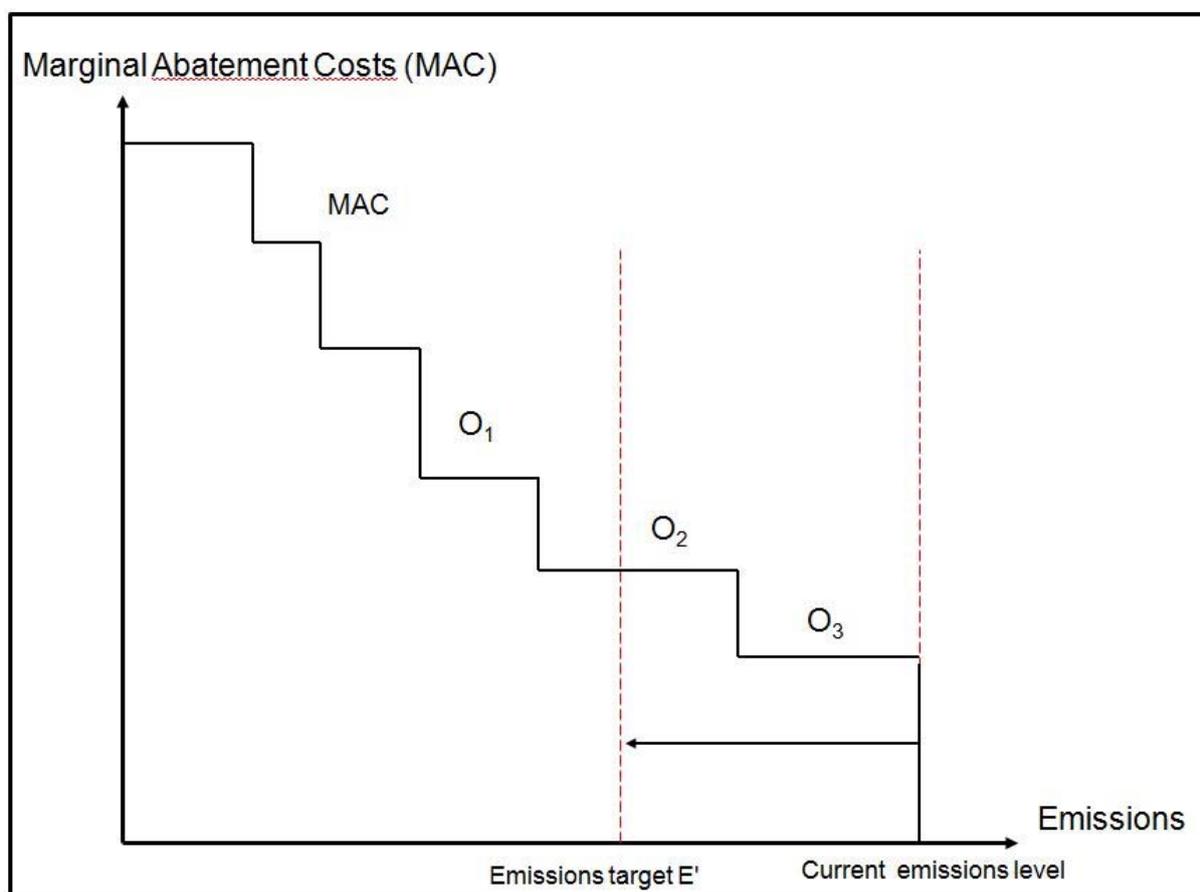
Given the great uncertainty about future cost trends, any policy to promote new technologies will tend to include some that prove uncompetitive in the long term. This makes determining how far state promotion of new technologies is allowed to deviate from the short-term cost minimisation goal a political decision. Without any state promotion, however, there is also a risk of missing out on long-term cost-efficient technologies, or at least of their adoption being wastefully delayed.

### Path dependencies in investment under uncertainty about future trends

For cost-minimising abatement under emissions trading, companies are assumed to rank their abatement options. Preference is given first to options that are most cost-efficient overall (i.e. over the whole of the applied time horizon) and allow a certain degree of abatement, then to slightly more expensive options that enable further emission reductions, then to the next more expensive set of options, and so on. In other words, all least-cost abatement options are used before turning to more expensive ones. Emissions target  $E'$  in Figure 8-3 can therefore be attained with options  $O_1$  and  $O_2$ . At a more stringent emissions target, option  $O_3$  would also come into play.

Figure 8-3

#### Options behind the marginal abatement cost curves



SRU/SG 2011-1/Abb. 8-3

In actual fact, the options are not mutually independent. Some costlier options based on entirely new technologies make previously used options obsolete. For example, technical improvements to raise generating efficiency (such as increasing steam pressures) cease to have any effect when a different system is used. If companies always plan for the long term and with perfect foresight, this is not a problem. In other words, if they know how the price of emission allowances will change in future periods, they will choose the combination of options that minimises their costs over the entire investment period, i.e. that maximises the

difference between the cost of emission allowances saved (under auctioning) and the (lower) capital and operating costs incurred. If their assessment correctly mirrors reality, then (except as regards the problem of learning and scale economies after market launch as mentioned above) the emissions target will be met in the way that is most cost-effective in the long term. If not and they have underestimated the trend in the price of allowances, however, they will incur unnecessary costs.

In reality, neither the state nor the private sector has perfect foresight, in emission abatement or in purely commercial investment, and 'unnecessary' costs of this kind are frequently incurred. On transition to a largely decarbonised electricity supply, however, these problems become especially pronounced and may justify the deployment of other policy instruments alongside emissions trading. This additional problem is due to factor specificity – the ease with which committed investment spending can be put to other uses (Williamson 1990, S.60). Investment expenditure in the energy industry is often highly factor-specific as it is mostly planned for a specific purpose and so constitutes a sunk cost once made.

Emissions allowances can be expected to rise in price as abatement targets are made increasingly stringent. If, however, companies mostly make their decisions based on current allowance prices (or significantly underestimate future prices), then while there will be investment to cut emissions, it will prove insufficient in the long term and will alter the relative attractiveness of other emission abatement options in favour of incremental investment. Once committed, investment spending – for example on an efficient coal-fired power station – is very factor-specific because it cannot be put to another purpose than first planned. If a coal-fired power station can no longer be used to generate electricity in Germany, it may be possible to sell off parts of the plant, but this will not be enough to recover the investment costs, which are therefore largely sunk costs.

To illustrate this problem, let us assume that construction by Company A of an ultra-efficient coal-fired power plant in place of an old lignite power plant was the optimum solution at an expected relatively low allowance price  $p_1$ . At a higher price  $p_2$ , the company would have picked another solution, such as several gas-fired power stations or possibly investment in a wind farm. If the price now unexpectedly rises to  $p_2$ , the investment costs of the power station become sunk costs. As such, they are not counted when comparing the cost of options for adapting to the new price. Instead, only the incremental cost of upgrading the power station – another highly factor-specific investment – will be compared with the cost of building gas-fired power stations or a wind farm. It goes without saying that such comparisons will tend to favour upgrading the coal-fired power station and keeping it in use, regardless of the fact that this would not have been the least-cost abatement strategy in a full-cost comparison based from the outset on the higher price  $p_2$ . The initial misjudgement thus perpetuates a macro-economically suboptimal abatement path.

The state does not have perfect information either, of course, but there is a key difference: Emissions trading operates based on targets set by the state that constitute the cap in the cap-and-trade system. If mistakes are made here, the misjudgement is reflected in emissions trading and so is not a criterion for or against operation of the trading scheme. Companies do not base their decisions on the relatively clear long-term emissions target, however, but on their estimate of the allowance price. In an emissions trading scheme, as we have seen, all uncertainty is built into the price. Private-sector decisions therefore have a far more uncertain and volatile basis than state decisions, which use the long-term emissions target.

This price uncertainty is compounded by the fact that carbon emissions closely track the performance of the economy, because the economic situation determines whether emissions targets can be attained for little effort or only at high marginal abatement cost. This is clearly shown by the global economic crisis that led Europe into recession in 2008. The slump in the economy and hence in electricity demand delivered an emissions cut at zero marginal cost. As a result, many emission abatement activities were no longer necessary for attainment of the current EU abatement target, and this in turn affected the price of emission allowances. A booming economy produces the reverse effect.

Added to this in the real world is uncertainty about the long-term credibility of policy targets. These two factors mean that any long-term forecasting of allowance prices is subject to considerable uncertainty. As shown above, inaccurate estimation – and in this connection especially underestimation – of the long-term trend in emission allowance prices in the emissions trading scheme very quickly causes deviation from the long-term least-cost solution path.

The problems are further exacerbated if the phenomenon of learning and scale economies is encountered in combination with the problem of factor-specific investment spending. It is then, as shown above, inefficient for companies even with perfect foresight to adopt new technologies until learning and scale economies have set in. If this point is reached later on in a full-cost comparison, however, the new technology is then still forced to compete at its full cost with the incremental cost of abatement using existing infrastructure, so established technology enjoys an incumbent's advantage that cannot be made good by emissions trading alone.

These two aspects cause the emissions trading scheme to favour incremental change over new technology, and additional policy instruments are still needed to attain long-term least-cost emission abatement.

#### Problems with the funding of emission abatement measures

In the basic model of emissions trading, no importance is attached to funding problems. It is assumed that finance is available for all investment that generates a suitable return. This does not reflect reality. Banks can charge higher interest in return for taking on greater credit

risk, but capital requirements alone require them to demand relatively large amounts of collateral when granting loans. A study by Chatham House in London concluded that policies need to allow for relevant criteria that are checked by banks when assessing project finance applications (Hamilton 2009). All applicable risks must be taken into account, including those resulting from state regulation and intervention and from limitations of existing infrastructure. Key policy features include clear objectives, long-term policy stability and precision in policy instrument design. Carbon revenues are not eligible as collateral, for example. Instead, according to the Chatham House study, financiers merely view such revenues as added 'extras' when assessing the bankability of renewables projects. This also explains why the largest wave of investment unleashed so far related to policies to promote renewables that generated stable revenue streams (Hamilton 2009).

That significant price uncertainty acts as a major barrier to investment is also shown by difficulties with a quota system (green certificates) launched to promote renewables in the UK. This system is principally no more than a mirror image of emissions trading, with energy utilities required to generate a specified proportion of their output from renewables. Significant price uncertainty regarding the certificates meant that necessary investment could not be financed by borrowing and ultimately that the use of renewables in the UK was obtained at higher cost than in Germany, even though the quota, like emissions trading, was meant to ensure target attainment at least cost (Dinica 2006; Carbon Trust 2007; Fouquet and Johansson 2008; Mendonça, Jacobs et al. 2010). This suggests that price volatility can severely impede long-term profitable investment, and reducing price uncertainty by supplementing emissions trading with other policy instruments can be key in achieving a cost-effective transition to renewables.

### **8.1.3 Special characteristics of the electricity market**

Alongside discrepancies between assumptions made in the basic model and real world conditions that apply generally for all sectors, the electricity sector also has certain special characteristics that make it necessary to supplement emissions trading with other policy instruments if cost-reducing investment in wind and solar energy is to have a chance. These include the grid dependency of electricity transmission, which limits the effectiveness of emissions trading in the sector, and volatility in wind and solar power output, which in conjunction with electricity market circumstances will continue to impede the financing of solar and wind power installations for at least some time to come.

#### **Lack of incentives for grid investment**

Renewables, and especially wind and solar power, can only be used on a large scale if security of supply is assured at all times. This requires new investment in the grid both at European level and nationally, first and foremost to create long-distance links between where power is generated and where it is needed. There will also be a need for regional investment

in power storage and further advancements in storage technology. Unlike the current coal-based electricity supply, solar and wind power is not generated close to today's centres of demand, which have grown around the use of fossil energy. The grid investment needed to use these energy sources creates inertia merely through network effects in the electricity system, and without other policy instruments in addition to emissions trading, this inertia presents at least a major impediment to cost-efficient transition.

If there is no extra state intervention to assure investment in the grid, then despite emissions trading, carbon abatement options requiring new grid infrastructure will either not be adopted at all or their adoption will be delayed. This is because such options incur added network costs from the very first unit, making them uncompetitive in the short run. Lacking grid infrastructure can thus be a major cause of failure to adopt cost-effective technologies. This provides another reason with regard to grid investment to deploy other policy instruments alongside emissions trading.

#### Electricity market pricing as an obstacle to wind and solar power

In addition to the grid problems, special characteristics of electricity markets – primarily on the supply side – pose a problem of another kind for electricity generation from strongly fluctuating energy sources such as wind and solar power. This problem results in wind and solar power installations not being built even if they are the least-cost option for attaining the emissions target. Unlike the problems just described, this is not just a market launch problem. In fact, it actually becomes worse if the electricity supply is entirely converted to renewables – at least until sufficient storage capacity becomes available.

There is sufficient incentive to build capital assets if the discounted future revenues are greater than the discounted costs. As Bode and Groscurth (Bode and Groscurth 2008) show, the problem in the case of wind and solar power is on the revenue side. The revenues equal the price on the wholesale electricity market at the time of sale multiplied by the quantity sold. The electricity price, on the other hand, is based on the marginal cost of generation.

For the sake of simplicity, we will initially restrict ourselves in the following line of argument to wind power, which by all estimates will be by far the most important renewable energy source in Northern Europe for the long term. The reasoning applies for all renewables, however, for which output varies sharply with weather conditions and which are available largely free of charge, and hence in particular for solar energy, which in all likelihood will be the predominant renewable energy source in Southern Europe and North Africa. We also assume to begin within our scenario that no significant storage capacity is available, as is the case today. To bring out the argument in all clarity, we also assume that apart from emissions trading there is no other policy instrument to promote renewables.

We will then see in a second scenario how the situation changes when substantial storage capacity becomes available. This is the scenario we consider to be most favourably

achievable in the medium term (see SRU 2010). In addition to building new storage capacity and making better use of existing capacity, it notably requires a concerted effort between Germany and, for example, Denmark and the rest of Scandinavia, something for which preliminary activities are already underway. Representatives of all EU North Sea states and Ireland have launched the North Sea Offshore Grid Initiative to build a power grid in the North Sea ensuring the connection of new offshore wind farms (EWEA (European Wind Energy Association) 2010).

#### Scenario 1: No storage

One of the tasks of a transmission system operator is to decide on the deployment of ('dispatch') available power stations at 15 minute intervals. Each time, power stations are dispatched in merit order (ascending order of variable cost) (Figure 8-4).

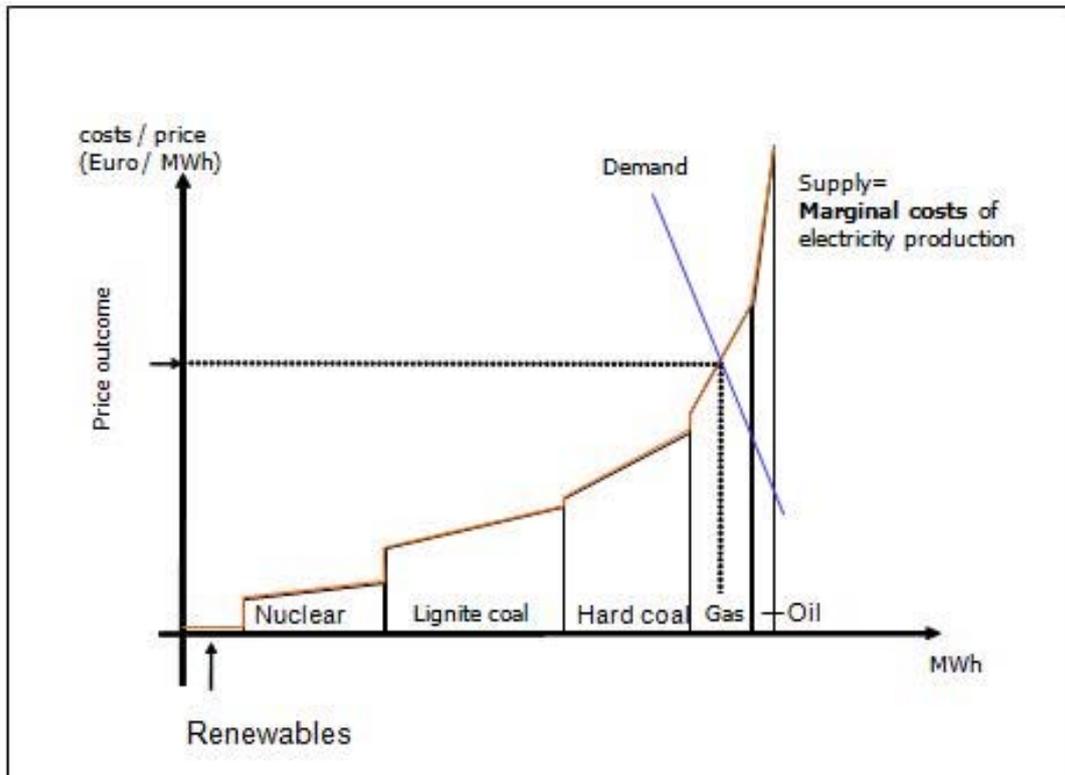
Wind energy, and especially offshore wind energy, has a high average overall cost due to the large initial investment, but marginal costs are very low and tend towards zero. This places it at far left in the merit order. Wind power is always used if available.

Conventional power stations, on the other hand, have a lower overall cost on average, but a significant proportion of this consists of fuel and carbon costs. The marginal costs of conventional power stations are therefore significantly higher than for wind power. Because of these higher marginal costs, such power stations are dispatched when insufficient power is available from hydro, wind and solar power.

In a situation where wind power makes up a small part of the total, all power generated by wind turbines will always be sold, sometimes at high and sometimes at low prices. Emissions trading in this situation improves the competitiveness of wind power, as it raises the marginal cost of conventional energy and hence the average price paid for electricity. If the wind power share increases, there will be times when the supply of renewables is enough to meet all demand. In this event, the electricity price drops to levels close to zero and emissions trading ceases to have any effect on the wholesale electricity market price.

Figure 8-4

### Electricity market pricing

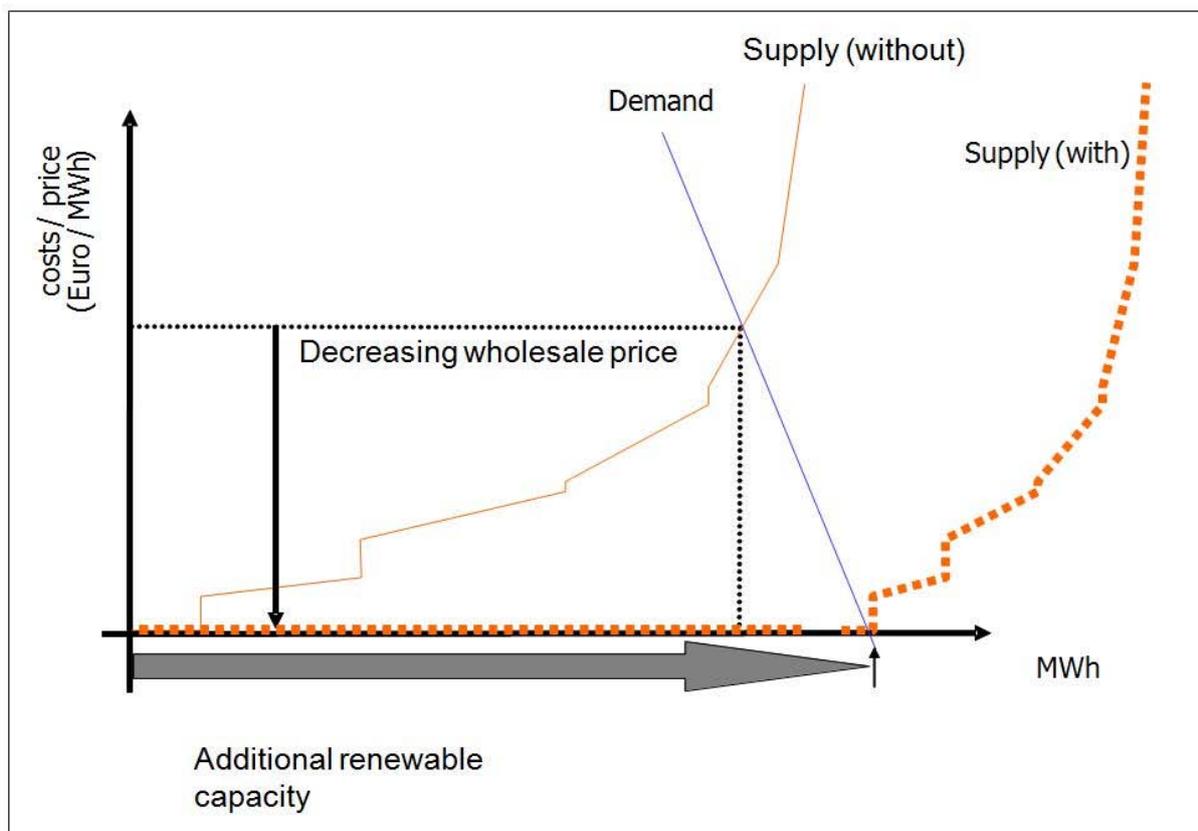


Source: Bode and Groscurth 2008

In a situation where the grid has a large share of strongly fluctuating renewables, ensuring ongoing security of supply at times of low wind power output calls for relatively large amounts of surplus capacity. Without further policy action and still under the assumption of zero storage, prices will only be positive when little wind blows in Northern Europe, and wind turbine operators will be unable to generate positive contribution margins. This would make wind power installations unable to cover their full cost despite being competitive with conventional power stations overall (surplus capacity included).

Figure 8-5

### Merit order with large supply of wind power



Source: Bode and Groscurth 2008

There are already signs of such a situation emerging today. Prices on German spot markets were even negative for a total of 71 hours between October 2008 and November 2008. This is because it is difficult to regulate the output of most conventional power stations, so such power stations keep on generating at times when it is more expensive for them to do so than their variable production cost but cheaper than shutting down. When strong winds produce surplus supply, operators of coal and nuclear power stations are willing to pay for electricity to be taken up or for another operator to stop generating, with the result that as well as their being times of very low prices, there can also be moments when prices are negative (for a more detailed analysis of such events see Nicolosi 2010).

This problem – failure to recover investment costs due to marginal cost pricing – is an even greater burden for wind turbines than, say, for coal-fired power stations. These are likewise unable to recover investment costs at marginal cost prices, but they also produce when market prices are high and can then generate a positive contribution margin. With wind energy, on the other hand, supply fluctuations heavily affect price. The more wind power enters the grid, the lower the price. This means that on transition to a system mostly reliant on renewables, there will be times when new and not fully depreciated base load power stations can no longer operate profitably because they too frequently earn zero or even

negative revenues, but also times when new wind farms go unbuilt because it is not possible to recover the capital outlay from electricity revenues.

The moment we cease to have just one fluctuating energy source in the form of wind power and broaden the perspective to include solar energy in a large, integrated grid – possibly one extending beyond European boundaries – then the problem of having to maintain surplus capacity shrinks because regional shortfalls can always be made good with energy from elsewhere. Once the necessary technology and infrastructure are in place, Europe and Africa will have several times more energy available than they can use. At the same time, however, the difficulty of financing capital investment is exacerbated. In this situation, almost all power stations operate in the falling average cost range and therefore make a loss at marginal cost prices. As their marginal costs all lie within a fairly narrow range near to zero, there is no longer any opportunity under free market conditions to recover investment costs from revenues. If this is the case, then the establishment and maintenance of this energy system requires incentives – not just during transition but on a long-term basis – that make it possible to refinance capital outlay.

When in a scenario such as this so much generating capacity is built that there is always potentially a surplus supply of electricity, then technically speaking there is no need for storage to provide demand for the surplus and the result is the situation just described. It is likely, however, that there will be a need for storage given the high cost of building systems such as offshore wind farms. Such a need will arise if it proves to be cheaper to build or maintain storage capacity than to build additional generating capacity, because storage capacity is filled with (almost) free electricity. It is therefore conceivable that despite virtually unlimited energy resources, the high cost of building generating capacity means an energy system is at its most cost-effective when not enough generating capacity is available to meet demand at all times, creating deployment opportunities for storage capacity. In principle, this is identical with the situation of a Northern European grid – the scenario we consider to be well within reach in the medium term and the easiest to gain acceptance for politically (see SRU 2010). This scenario chiefly relies on the use of wind power and storage.

#### Scenario 2: Use of storage

Without storage capacity, electricity is a non-storable good. Goods of this kind are prone to a relatively frequent absence of scarcity prices. While electricity cannot be stored directly, there are means of converting it into potential energy, for example in conjunction with hydropower. Water pumped into a reservoir using surplus electrical power can be released when needed to generate electricity again (pumped storage). Other options include compressing air stored in an underground cavern by an electric-powered compressor operating at weak load times. When energy demand is high at peak load times, the compressed air is released through a gas turbine, which because the compressor is no longer needed is able to deliver its full output to a connected generator (compressed air energy storage).

Although energy is lost with both methods, storage is economical both at micro and macro level as energy is lost at times when there is little or no scarcity, whereas more energy can be fed to the grid when scarcity is greater and the price of electricity correspondingly high. The use of storage not only defuses the problem of very low prices in a wind power-intensive system; it also reduces the need to maintain surplus capacity and so makes for a more cost-effective system overall.

It appears plausible in principle that such storage capacity will be profitable enough to be built on market incentives alone, and will then assure positive prices in the electricity sector on a long-term basis enabling the investment costs of wind and solar power installations to be refinanced. Problems persist, however, at least for a fairly long transition period: As described, both pumped and compressed air energy storage make use of certain natural phenomena. As such they are subject in all European countries to approval procedures. The natural conditions needed to build them are not found everywhere. In Europe, most of the locations suitable for compressed air energy storage are in northern Germany, while pumped storage requires large altitude differences of the kind found in Austria, Switzerland and Scandinavia. Even with approval, however, this storage capacity can only be used if linked with high-capacity transmission lines to the European grid, which brings us back to the problems addressed in section 4.1.

Also, storage capacity is only built when there is surplus energy available. Because of the price determination mentioned above, however, surplus energy is only produced when storage capacity is available. In either case, major changes to existing grid networks are required. Such major changes to an entire system cannot be delivered by the market alone, or to put it differently, market incentives alone would not bring about such changes even if they were desirable for the economy as a whole. The better coordinated the process of building and upgrading all necessary system components, the sooner market incentives such as emissions trading can take effect, but at least until then, other incentives are needed for the required capacity to be built in the first place. This can then trigger the building of storage capacity and so, in the long term, help create a stable electricity supply system in which supply and demand are well balanced over time. As this exposition has made clear, a major transition in electricity supply involves far-reaching systems choices that require state intervention above and beyond emissions trading.

#### **8.1.4 Summary: Requirements profile for policy instruments supplementing emissions trading in the electricity sector**

It is undisputed that emissions trading, by putting a price on carbon emissions, improves the profitability of various generation options not only in favour of conventional power stations that are less harmful to the climate, but also in favour of renewables. Emissions trading therefore remains a key instrument in our advocated policy instrument mix, because without it there would be a sharp rise in the cost of other policy instruments that we still consider

indispensable in promoting renewables. Positive incentives to boost efficiency would be lost, as would the clear maximum limit on emissions that is important among other things in the attainment of international goals.

Our aim in this article was more to show why, particularly in the electricity sector, the use of additional policy instruments remains important even when the emissions cap in the emissions trading scheme means that they do not achieve an overall emissions reduction in sectors required to trade allowances. We have therefore attempted to highlight key reasons why, under fundamental path changes such as decarbonisation of the power generating industry, emissions trading alone does not deliver least-cost emissions abatement for the economy as a whole. One of the main reasons relates to externalities that arise even with carbon abatement technologies. To this are added economies of scale and learning effects that only become available at market penetration levels not reached under emissions trading alone, and imperfect information, which combined with factor specificity in power station investment and collateral requirements for bank borrowing is a cause of path dependencies. These effects are all compounded by special characteristics of the electricity system comprising, firstly, network effects in a highly interconnected system that make it very hard to attain the necessary control of the system as a whole via the market and, secondly, specific problems with the refinancing of wind and solar power installations that likewise necessitate additional policy instruments.

From this diagnosis, we can identify what is required of the policy instruments that are needed in addition to emissions trading. One need is for funding instruments to promote options picked out as long-term low-cost alternatives to conventional power generation so that such options can attain scale economies and learning effects through market penetration. We will not discuss such funding instruments in detail here. Direct support for the manufacture of fundamentally new power generating systems as proposed by Bläsi and Requati (2010) could certainly be considered as an alternative to the feed-in tariffs for the electricity sector under Germany's current Renewable Energy Sources Act (see Requate and Bläsi 2010). Alongside the welfare effects referred to by Requate and Bläsi, however, it is also necessary to allow for the requirements imposed by banks in order to secure urgently needed liquidity. This applies at least as long as the private-sector banking system is expected to remain the main source of liquidity.

The problems of factor-specific investment under imperfect foresight also confer a de facto incumbent's advantage on existing power stations and underscore the need for specific state promotion of fundamental investment during transition. At least in the medium term until adequate storage capacity is in place, there is also a need for support so that investment in wind and solar installations can be refinanced. This should be provided along "as much state as necessary, as much market as possible" lines and could take a form such as auctioning subsidies for the supply of electricity similar to the approach used today for public transport.

The reduced investment incentive from emissions trading due to uncertain and in some cases strongly fluctuating emission allowance prices is not limited to renewables, but in principle affects all factor-specific investments involving long-term commitment. A floor on the allowance price might be considered as a way of mitigating this problem. This would continue to ensure that the maximum level of emissions is not exceeded but, if this target can (temporarily) be attained at low cost, would also permit (temporary) over-attainment of the target. It is important in this connection, however, to avoid turning emissions trading into a kind of tax by setting maximum *and* minimum prices, because this would endanger the unquestionably important property of emissions trading – that of providing a maximum limit that is easy to communicate and monitor.

More than is the case with other sectors, system characteristics of the electricity sector create a need for intervention by the state, which among other things must provide the conditions for coordinated investment in generating, transmission and storage infrastructure. While we definitely consider it important for this strong role for the state in restructuring the electricity supply to remain under critical public appraisal and be kept to a minimum, we consider that there is no alternative to it if decarbonisation of the electricity sector based on renewables is to be achieved.

## **8.2 An imperfect emissions trading system: Current design problems**

Apart from the aforementioned inherent limits even of an ideal emissions trading framework, the SRU feels that as currently configured the EU ETS displays a number of design flaws and undesirable trends which have been exacerbated by the global economic crisis of 2008 and 2009. If the current emissions trading system is to help pave the way for transitioning to a wholly renewable electricity supply, it will need to be overhauled. For only then can such a system constitute the backbone of the policy mix advocated in this report and pave the way to a sustainable wholly renewable electricity supply in tandem with other measures. In the following sections, we discuss the problems with the current emissions trading system, and then recommend far reaching reforms which would optimise the impact of the EU ETS.

### **8.2.1 Emission targets**

The effectiveness of emissions trading hinges first and foremost on the set emissions target. In the field of economics, emissions trading is considered to be a quantitative instrument in that it provides certainty concerning the emissions reduction target. Targets should be set in such a way that the economy remains on a development path that is consistent with the oft-advocated goal of limiting the mean global temperature rise to 2 degrees Celsius (European Council 2007; European Commission 2007; UNFCCC 2010; G8 2009; MEF 2009). Another

decisive factor for transitioning to a wholly renewable electricity supply is that emissions limits should display scarcity signals at an early stage so that industrial polluters feel encouraged to use more efficient and less polluting manufacturing methods. It is essential that the amount of allocated and auctioned emissions certificates is lower than projected emissions (Dekten et al. 2009). The more stringent the target – that is, the lower the amount of allocated and auctioned certificates relative to projected emissions – the more pressure companies will be under to lower their emissions.

The current EU emissions reduction targets are neither commensurate with a sustainable development path, nor are they stringent enough to prompt polluters to undertake far reaching measures. Moreover, this problem has been exacerbated by reduced production levels, especially of the processing and energy intensive industries, resulting from the global economic crisis.

Largely as a result of its weak price signal, emissions trading has also been unable to forestall the construction of new coal-fired power plants with an installed capacity of 11,508 MW, that are planned to go into operation over the next two to three years (DUH 2010). Only one of these plants (in Grevenbroich-Neurath) is to date envisioned to be CCS-ready. CCS retrofitting has been instructed in the Moorburg coal-fired power plant in Hamburg. Some of the remaining plants have reserved space for CCS-technology. The use in the other plants is uncertain as of now. Furthermore, an additional 12 coal-fired power plants with an installed capacity of 13,620 MW are planned. However, it is too soon to be determined how the nuclear power plant service life extensions called for by the government's energy strategy will affect the realisation of these projects. According to *Leitstudie 2008*, only a 9 GW expansion of coal-based power generation capacity is compatible with the 80 percent reduction target (Nitsch 2008). This figure would have to be lower for a more ambitious reduction goal.

Under the assumption that adequate carbon and capture storage technologies are not available in 2050, one of two things would happen: either such coal-fired power plants would become so called stranded investments, since emission certificate prices would have risen so drastically that the plants are no longer profitable; or it will simply be impossible to reach the mandated climate policy targets.

In addition, the impact of the existing emissions trading system on long term investments will be further weakened by an inadequate long term emissions reduction target fraught with political uncertainty. The target of reducing emissions by 21 percent in 2020 relative to 2005 levels is based on a linear emissions reduction factor of 1.75 percent, which is to remain in effect also after 2020. The new Emissions Trading Directive calls for the European Commission to review this factor in 2020 and for the European Council and Parliament to recommend a new factor at that time (if necessary) for the post 2020 period (Directive 2009/29/EC). If a 1.74 percent factor were to remain in force until 2050, this would equate to

an aggregate reduction of 73 percent relative to 2005 and 79 percent relative to the original reference year of 1990. According to the IPCC's calculations, the industrialised states will need to reduce their carbon emissions by 80 to 95 percent by 2050 relative to 1990. The emissions trading sector would fall just short of even the 80 percent target. This is particularly noteworthy in light of the fact that the emissions trading system promotes greenhouse gas reductions more that are relatively well accomplishable and more inexpensive than in sectors such as transport and agriculture. Thus the current reduction factor is inadequate.

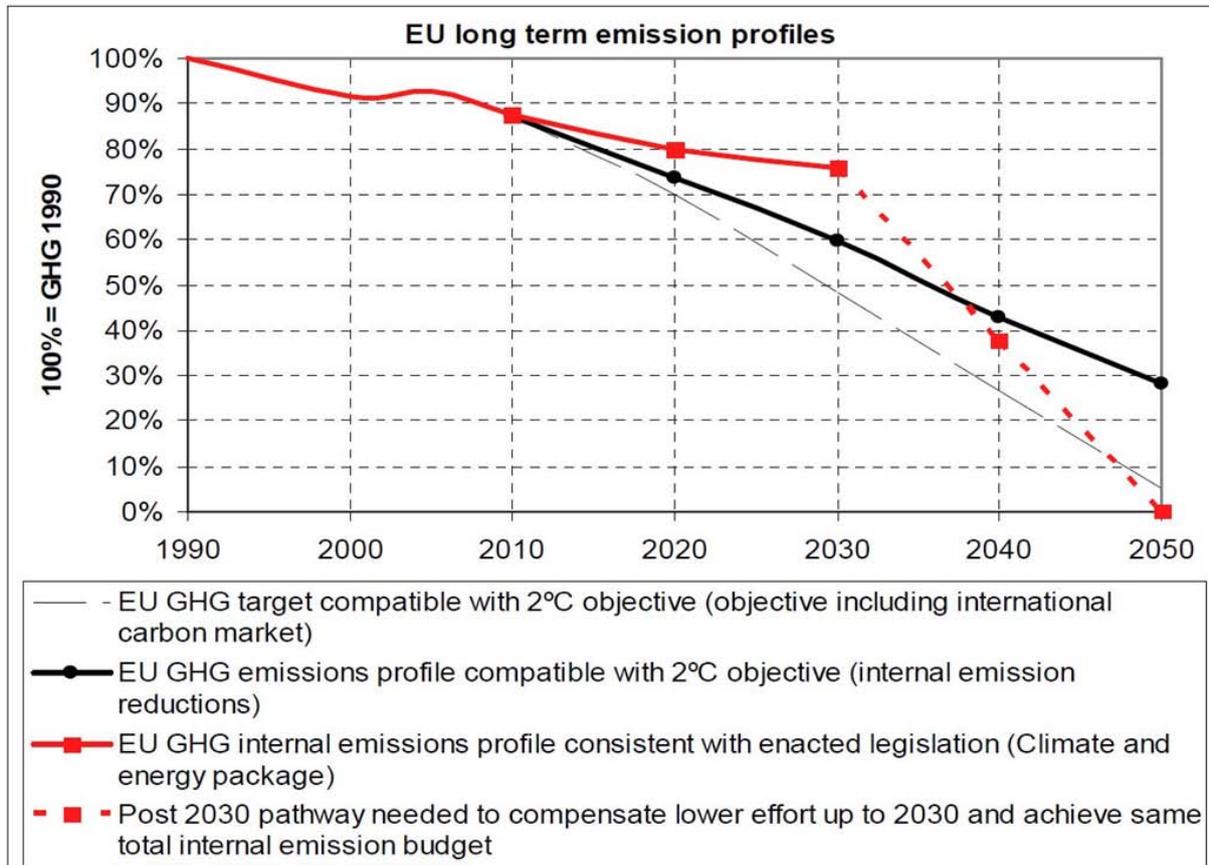
Another important factor here is that emissions trading reduction targets will be achieved not so much by virtue of reductions in the EU per se, but especially through the purchase of credits under the flexible mechanisms of the Kyoto Protocol. These enable industrialised states to promote cost efficient emissions reductions in developing and newly industrialised countries. At first glance this arrangement appears to make good economic sense, since it allows emissions to be reduced where doing so is least expensive. It could give rise to problems, however, if large newly industrialised countries commit themselves to emissions reductions but are deprived of the opportunity to implement such inexpensive emissions reductions measures themselves once they commit themselves to reductions.

Furthermore, shifting emission mitigation measures to other states in this fashion could result in a situation where, if emissions trading were a stand-alone emissions reduction instrument, Germany itself would be unable to transition to a renewable electricity supply. Consequently, this would require more stringent targets in the EU and a national commitment to longer term targets. This is the only way to assure companies that investments in climate friendly technologies will earn a robust ROI.

The European Commission has stated that the EU is increasingly moving away from a cost-efficient path to achieving the emissions reductions necessary for the 2 degrees Celsius goal (European Commission 2010b, p. 6). As Figure 8-6 shows, the discrepancy is widening between the current development path consistent with the EU climate and energy package (as adopted in 2008), and the Europe-wide avoidance path that the European Commission deems necessary (European Commission 2010a, p. 41). This path needs to be strengthened by means of international emissions mitigation measures so as to allow for achievement of a cumulative EU avoidance target that is compatible with the 2 degrees Celsius goal. Reaching the mandated emissions level in 2050 would necessitate considerable catching up by the EU in the post-2030 period; and this in turn would engender a somewhat steeper reduction path in tandem with higher aggregate costs.

Figure 8-6

### Shortfalls of the current EU emissions reduction targets



Source: European Commission 2010a, p. 41

A development path that moves from moderate to more stringent emission reduction targets is not compatible with our scenarios and the high renewable energy growth rates they project. For what is in fact needed in order to establish a renewable electricity supply are ambitious targets to be set right from the start. Studies have shown that an emissions reduction path that calls for ambitious targets engenders lower costs than a path where such reductions are implemented at a later stage (Stern 2007; IEA 2009a).

#### 8.2.2 Oversupply of emission certificates during the second trading period and its long-term effects

Apart from the scientific evidence that current emissions limits are inadequate, there are additional reasons for the limited scarcity in the current emissions trading framework. The main reason is the global economic crisis in tandem with (a) the unduly generous amount of emission certificates that are allocated to the industrial sector during the second trading period; (b) the oversupply of certificates in the New Entrants Reserve; and (c) the supply of cost efficient international emissions certificates under the Clean Development Mechanism. As a result of this oversupply, emission certificates currently sell for around €15, far below the €32 price projected in the European Commission's Impact Assessment (European

Commission 2008). The dangers of such a situation were clearly demonstrated during the first trading period, when the establishment of national allocation plans led to a race to the bottom involving substantial over-allocation of certificates in virtually all member states (Ellerman et al. 2007). This in turn prompted the EU to set more stringent emission limits for the second trading period. However, over-allocation could still not be prevented – primarily due to the economic crisis. According to the European Commission, the verified emissions from installations in the emissions trading sector in 2009 were 11.6 percent below 2008 levels (European Commission 2010b, p. 3). The emissions trading system displayed an ability to adapt rapidly to the changing economic circumstances. The SRU thinks – similarly to the European Commission – that further action is urgently needed in response to the economic downturn in order to guarantee that the emissions trading system functions over the long run as it was intended to (European Commission 2010b). For the third trading period, national allocation plans are replaced by an EU-wide emissions budget (Directive 2009/29/EC). This is a step in the right direction but an oversupply of permits in the second period can cause continued oversupply also in the third trading period. Due to the economic crisis, a significant proportion of emission certificates will go unused, which thanks to the possibility to bank certificates companies are permitted to transfer to the third trading period. A British NGO (see Table 8-1) predicted an emission certificates surplus amounting to 579 Mt. Even *excluding* certificates from international project activities and the New Entrants Reserve, scarcity in the market cannot be expected. The European Commission came to a similar conclusion, predicting that companies would be able to transfer anywhere from 5 to 8 percent (500 to 800 million) of the certificates from the 2008–2012 commitment period to the next trading period (European Commission 2010b, p. 4). While this transfer mechanism prevents emission certificates prices in the OTC market from plummeting (unlike what occurred at the end of the first trading period), their prices will be kept low over the long run unless policy intervention reduces the supply of certificates.

Table 8-1

**Projected emission certificates surplus, 2008–2010 (in Mt)**

	Actual figure, 2008	Actual figure, 2009	Estimate, 2010	Estimate, 2011	Estimate, 2012	Total
<b>Total emissions</b>	2,105	1,866	1,986	2,105	2,410	10,472
<b>Allocated emission certificates</b>	1,944	1,952	1,948	1,943	2,153	9,942
<b>Auctioned emission certificates</b>	44	66	66	66	66	307
<b>International emission certificates</b>	81	81	81	81	287	611
<b>Balance excluding new storage capacity</b>	-36	233	109	-15	96	387
<b>Certificates for new storage capacity</b>						192
<b>Overall balance</b>						<b>579</b>

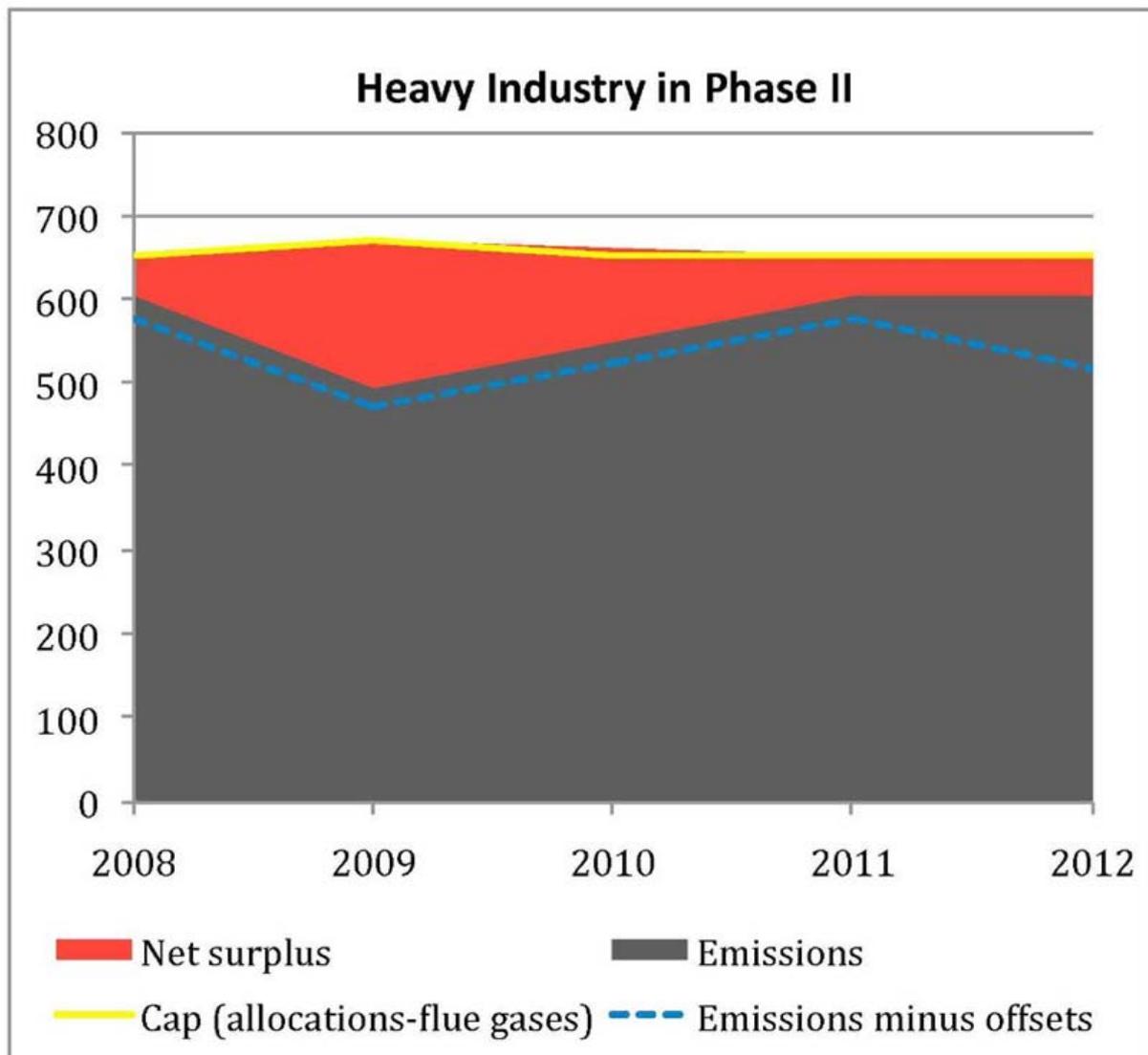
Source: Morris and Worthington 2010

This oversupply of emissions trading certificates is also attributable to an unduly high number of certificates having been allocated to industrial sector companies (Pearson and Worthington 2009; Morris and Worthington 2010). Despite the fact that the second trading period emission limits were set substantially lower than in the first period, solely the electricity

sector is required to realise emission reductions, whereas there is room for growth in the industrial sector. This problem is illustrated in Figure 8-7, which compares heavy-industry emissions with the certificates available in this sector. As the chart shows, certificates were over-allocated from the outset – a situation that was exacerbated by the production collapse in 2008 and 2009 brought about by the economic crisis. This certificate surplus in the industrial sector contrasts with the relative scarcity of certificates in the electricity sector, which reduces incentives for transitioning to a renewable electricity supply. The certificates surplus in the industrial sector drives prices down, thus enabling power companies to purchase the certificates they need cheaply and thus save themselves the expense of cost-intensive emissions abatement options at their own installations.

Figure 8-7

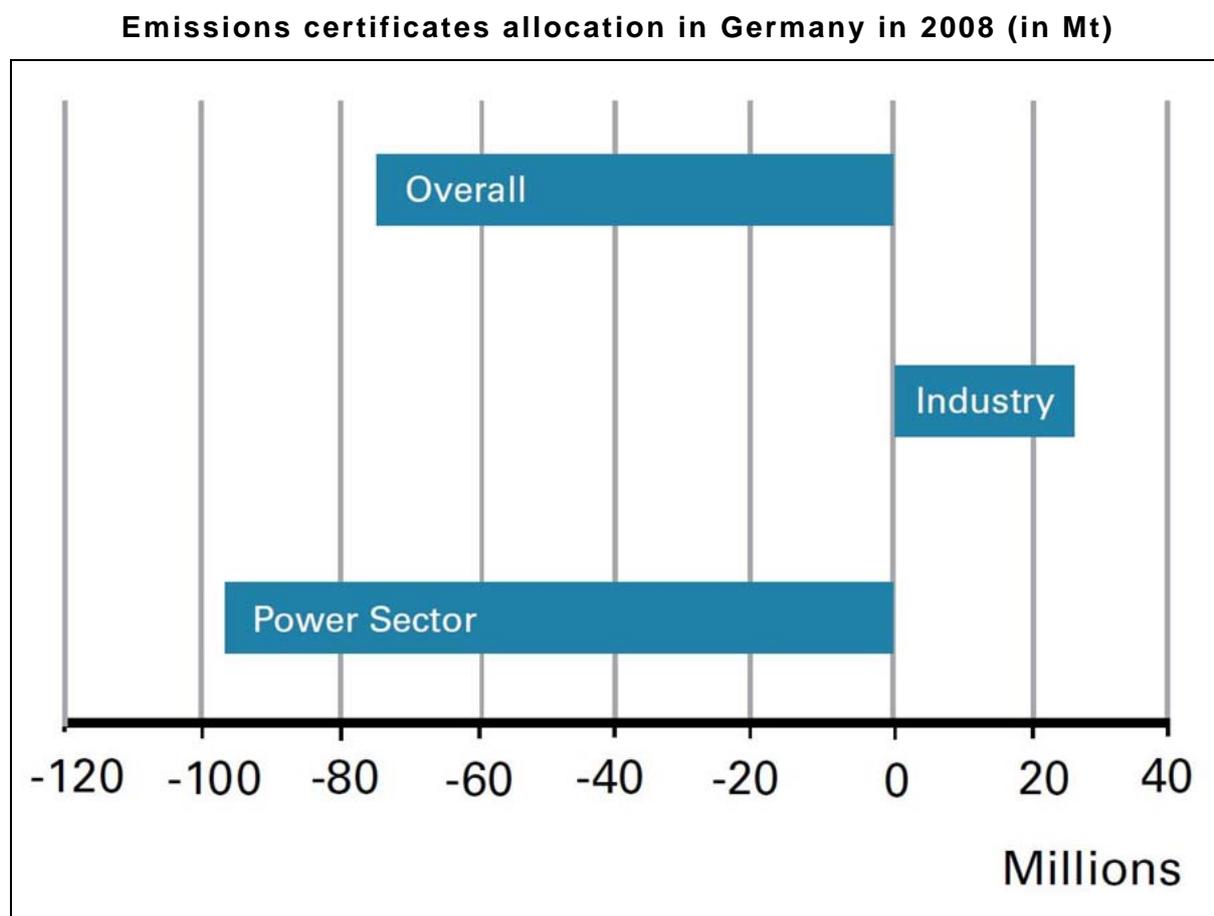
**Allocation of certificates and emissions in the heavy industry sector  
(in Mt)**



Source: Morris and Worthington 2010

This characteristic emission certificates allocation pattern in the EU is found in Germany as well (see Figure 8-8), and likewise has been exacerbated here by the production collapse resulting from the economic crisis (Morris and Worthington 2010, p. 55). Against this backdrop, it is small wonder that in a KfW/ZEW-CO<sub>2</sub>-Barometer survey concerning corporate investment strategies, 88 percent of the respondents indicated that CO<sub>2</sub> reductions are a mere ancillary effect of other measures they take or plan (Detken et al. 2009, p. 56), while only 6 percent stated that their measures are mainly prompted by the desire to reduce CO<sub>2</sub> emissions.

Figure 8-8



Source: Pearson and Worthington 2009, p. 19

Besides the economic crisis and unduly generous initial allocations, the emission certificates oversupply is also attributable to the New Entrants Reserve certificates surplus. This reserve is a pool of certificates comprising 5 percent of all available certificates that is set aside for new market participants. Certificates from installations that have been shut down are also added to this reserve. Apart from France and Ireland, which have decided to void their certificates on expiration of the trading period, most of the member states intend to auction or distribute them. This will result in an even greater surplus of certificates in 2012, which will in turn make it easy for polluters to meet their emission reduction obligations; or alternatively,

such companies can simply keep their certificates in reserve for the third trading period. Hence the problems engendered by over-allocation will be exacerbated still further.

### **8.2.3 Undesirable developments caused by international project activities**

Article 11a of the Emissions Trading Directive (Directive 2009/29/EC) “provides for the creation of certified emission reductions (CERs) from clean development mechanism (CDM) projects and emission reduction units (ERUs) from joint implementation (JI) projects and their use”. The flexible mechanisms of the Kyoto Protocol allow European companies to fulfil their emission reduction obligations through cost efficient emissions reduction measures in developing and newly industrialised countries, instead of realising such measures at their own installations, which is usually more cost intensive. The use of international emission certificates thus frees up European certificates so that European companies can reduce their emissions to a lesser extent than would otherwise be required. This approach appears to be sound at first glance in view of the fact that reaching climate policy targets does not hinge on emissions being reduced at any particular location. However, on closer scrutiny it emerges that this mechanism engenders undesirable developments that put the effectiveness of the emissions trading system at risk.

First of all, it should be borne in mind that doubt has often been cast on the climate performance of international project activities (Schneider 2007), including and in particular in connection with the emission avoidance additionality of numerous CDM projects (Michaelowa and Purohit 2007). Critics have argued that many projects in developing and newly industrialised countries would have been carried out even in the absence of external financing (Schneider 2007; WWF Deutschland 2008). In the final analysis, projects that are granted certificates but whose additionality is not ensured actually result in increased emissions.

At the same time, the transferability of international emission avoidance measures in the European emissions trading system translates into a lower level of emissions reductions in Europe and thus complicates the task of transitioning to a renewable electricity supply within the EU. The combination of lacking certificate scarcity and the purchase of CERs and ERUs provokes a certificate surplus and will undermine the incentives needed in the third trading period to move toward a renewable electricity supply if emissions limits are not reduced.

The relevant directive concerning the national allocation plans for the second trading period states as follows: “Member States may allow operators to use CERs and ERUs from project activities in the Community scheme up to a percentage of the allocation of allowances to each installation, to be specified by each Member State in its national allocation plan for that period” (Directive 2004/101/EC). A comparison of the NAPs reveals that German operators are entitled to a considerably greater use of international certificates (452.9 Mt) than

operators in other countries. The total allowed use of international certificates represents 22 percent of all emission certificates allocated in Germany (Lewis and Curien 2009). Thus German companies can fulfil virtually their entire emission reduction obligations by purchasing international certificates. Spain is the only large EU member state that permits the use of a similarly high proportion of CERs and ERUs in the second trading period (20.6 percent/160 Mt). The figures for France and Great Britain are far lower, i.e. 13.5 percent/89.1 Mt and 8 percent/92.3 Mt respectively.

But European companies have yet to take advantage of this far reaching option: in 2008 and 2009 only 81 Mt worth of CERs and ERUs were used (Morris and Worthington 2010, p. 19). The currently limited supply of certificates on the international market apparently has prevented a more extensive use. A total of 440 million CERs has been issued worldwide (UNEP Risoe Center 2010). However, even CER and ERU use to date will result in a surplus of certificates that can be banked for the third trading period. Moreover, the additional international certificates that are expected to be issued by 2013, in conjunction with the very high maximum use limit that has been set for the remainder of the second trading period, is likely to further exacerbate the certificate surplus problem. The fact that companies have good reason to fear that the EU will tighten international certificate use regulations at the beginning of the third trading period (see Directive 2009/29/EC) is likely to prompt them to purchase newly issued CERs and ERUs before 2013; and this will in turn increase the volume of available European emission certificates available during the third trading period. Hence the CDM and JI mechanisms are helping to maintain the energy system status quo in Europe.

#### **8.2.4 Summary and recommendations for reforms aimed at an effective emissions trading system**

Emissions trading in the EU suffers from a number of problems, the main one being that the oversupply of emissions certificates in the system is an obstacle to the achievement of EU emission reduction targets at a reasonable cost. This in turn blocks the emergence of genuine scarcity prices that would promote the economic viability of climate friendly and renewable energy sources. Additionally, the fact that companies are allowed to retain emission certificates for future use may mean that the third trading period, too, will fail to move the EU closer to a renewable electricity supply. Unduly timid emission limits and the persisting over-allocation of certificates to the industrial sector are responsible here. This situation is exacerbated by the economic crisis and an oversupply of additional certificates from the New Entrants Reserve (NER) and the flexible mechanisms under the Kyoto Protocol. In addition, the high proportion of certificates represented by CERs and ERUs prevents the EU from taking the steps necessary to transition to a renewable electricity supply.

The EU's primary climate policy instrument is emissions trading. Pricing CO<sub>2</sub> emissions tends to promote the profitability of climate friendly manufacturing methods. However, the system's timid targets and in some areas suboptimal arrangements have prevented it from reaching its full potential. The SRU therefore recommends that emissions trading be reformed via the measures described below.

#### Increase in the emissions reduction target for 2020 to at least 30 percent

Our analysis shows that neither the emission limit set by the European emissions trading system – nor the goal of reducing GHG emissions by 20 percent across all economic sectors relative to 1990 levels – goes far enough. These goals do not equate to the reductions deemed necessary to put the European economy on the path to sustainable development. The SRU therefore recommends that a policy calling for a unilateral emission reduction of at least 30 percent and a multilateral reduction of at least 40 percent relative to 2005 levels be adopted (SRU 2008, p. 105). To this end, the annual linear reduction factor of 1.74 percent should be upped to at least 2.5 percent for the third trading period, which would then equate to 30 percent emission reduction relative to 2005.

Thanks to the emissions reductions over the past two years the EU's energy and climate package are expected to only cost €48 billion annually in 2020, or 0.32 percent of GDP in that year, rather than the €70 billion that was originally projected in early 2008 (European Commission 2010b, p. 3). Costs will also be lower owing to the economic slowdown, higher oil prices, and the option to bank emission certificates. The additional cost resulting from raising the emissions target to 30 percent is put at €33 billion in 2020, or 0.2 percent of GDP. Thus the package would cost a total of €81 billion with the more stringent emission limits in place, which would be only €11 billion more until 2020 relative to the original estimate of €70 billion with the less stringent emission reduction target (European Commission 2010b, p. 9). Even if these calculations are based on the assumption that 50 percent of the additional emission reductions would be accounted for by certificates from international project activities – a proportion the SRU views as far too large – they still show that greenhouse gas emissions could be greatly reduced at relatively moderate cost.

#### An ambitious, long-range emission target for the emissions trading sector

The EU should orient its climate policy towards a long-term perspective compatible with the greenhouse gas reductions necessary to fulfil the 2 degrees Celsius target (see section 6.2.2.1). The emissions trading sector would play a pivotal role with its relatively cost effective avoidance options, as compared to other sectors. Even if the new Emissions Trading Directive that went into effect in 2009 provides for the current linear emission reduction factor to remain in force beyond 2020 and thus virtually sets a long range emission target for companies that are affected by emissions trading, projections for 2050 show that this target will not allow for fulfilment of the reduction obligations that have been

recommended by climate scientists. This in turn means that the emissions trading market will not display the scarcity signals that are needed over the long run, posing the risk that the attendant price signals will not translate into incentives for companies in the emissions trading system to reduce their greenhouse gas emissions. This could lead to investment decisions that against the backdrop of ambitious emission reduction targets can turn out to be economically unviable in the long term. In order to ensure that the EU emissions trading sector adheres to a cost efficient emission reduction path, the emissions trading system should be brought into line with the requisite long-range greenhouse gas reductions. Since emission reductions are more difficult to achieve in sectors such as agriculture, it will probably be possible to reach the recommended cross-sector emission reduction target of 80 to 95 percent by 2050 only in case the electricity sector is completely decarbonised. Hence the emission reduction target for the emissions trading sector should be as close as possible to 95 percent.

#### Measures aimed at reducing the certificate oversupply

The practice of allocating unduly high numbers of certificates to the industrial sector must be abandoned. In this context, the decision that free certificates will be distributed not on the basis of an installation's past emissions (i.e. the grandfathering principle), but rather in accordance with the best available technology in light of prior benchmarks is a step in the right direction and can, providing that such benchmarks are stringent, create scarcity in the emissions trading sector.

Although this move could potentially reduce over-allocation during the third trading period (2013–2020), there still may be a surplus of certificates during the second trading period (2008–2012) that could have a negative effect on the emissions trading system during phase 3. Moreover, companies still have the option to fulfil a large proportion of their emission reduction obligations via international certificates. The SRU therefore considers additional appropriate (short-term) interventions necessary, such as the following: The remaining certificates from the New Entrants Reserve should not, as now planned, be auctioned or allocated, but should instead be voided at the end of the second trading period (House of Commons Environmental Audit Committee 2010, p. 15; Pearson and Worthington 2009, p. 17). Ireland and France have already opted for this policy; and if Germany, as the EU's largest economy, followed suit, the German government could take a substantial number of the surplus certificates out of circulation. This would send a clear signal to the other member states.

#### Quantitative and qualitative caps on international certificates

In our view, action is urgently needed in connection with the use of international certificates from CDM and JI project activities, since the allowable volume of certificates for such activities during the second trading period has greatly contributed to the current oversupply.

Inasmuch as the amended Emissions Trading Directive continues to govern the use of such certificates for EU installation obligations to a limited degree only, this problem is likely to persist. It makes good economic sense to avoid emissions in settings where this provides the most cost effective option, i.e. by allowing a certain percentage of emission obligations to be fulfilled via ERU and CER credits. This practice, however, means that member states are in effect turning away from a path of long-run cost efficient emission reductions. Moreover, it reduces the extent to which poorer states would be able to fulfil abatement obligations under a possible post-Kyoto framework in a cost effective manner, since industrial states will have already exhausted their least expensive mitigation-options.

Moreover, in view of the dubious quality of credits from CDM and JI project activities, the supply of such credits should be limited by, for example, imposing more stringent qualitative criteria or by adopting a policy to the effect that over the longer term newly industrialised countries such as China and India should derive less benefit from these credits. Furthermore, less well off developing countries should profit from project activities to a greater extent than is currently the case (European Commission 2009b).

#### Hybridisation of emissions trading by setting a minimum price

The failings of the emissions trading system are mostly reflected in low certificate prices. There is also the possibility that unforeseen events such as the economic crisis of 2008 and 2009 may prevent scarcity prices and thus incentives for the desired measures from emerging. While it should be priority to prevent systemic failures of the emissions trading system – such as unduly timid emission targets or over-allocation of certificates to industrial concerns –, the possibility of setting a minimum price for certificates should also be considered. Such a move could mitigate unforeseen problems and guarantee investors the requisite investment certainty. There have been repeated calls for a minimum certificate price (Helm 2008; Wood and Jotzo 2010; Burtraw et al. 2009; Hepburn 2006; Grubb and Neuhoff 2006), which should be set in such a way as to at least guarantee that operators will switch from base load-oriented coal to more flexible natural gas.

A minimum certificate price would provide emissions trading with certain tax-like features without turning the mechanism into a tax or robbing it of its positive attributes. This hybridisation of emissions trading is increasingly regarded as the most viable way forward (Aldy et al. 2008; Ekins 2009; Nordhaus 2007). It is crucial that the most important attribute of emissions trading – namely adherence to a monitorable cap on certificate supply – is not undermined but provided with the advantages of a minimum incentive.

Instituting a minimum price during the third trading period's envisaged auctions would be a relatively simple matter (House of Commons Environmental Audit Committee 2010; Grubb 2004). In order to ensure that the minimum auction price is translated into a minimum price in the entire emissions trading sector, a sufficiently large number of certificates would have to

be available for auctioning. A fixed minimum price might take a relatively long time to emerge due to the EU's decision to roll out auctions outside the electricity sector very slowly (the number of free certificates will be reduced incrementally to 30 percent in the run-up to 2020, except for industries that are prone to carbon leakage). Hence, it should be further researched which amount of auctioned permits could enforce a minimum price. If necessary and desired, member states could also intervene directly in emissions trading by withholding emission certificates. However, this could lead to distortion of competition in the EU. Imposing more stringent emission targets at the EU level early on would therefore be a better solution.

## **8.3 Instruments for promoting cost effective use of renewable energies**

### **8.3.1 Critical assessment of the Renewable Energy Act (EEG)**

The purpose of the 2000 Renewable Energy Act (EEG) has been to pave the way for a sustainable development of the energy supply in the interest of promoting climate and environmental protection. It is intended to reduce the economic costs of the energy supply by accounting for the relevant long term external effects. Further aims are to preserve fossil energy resources and to promote the development of renewable electricity technologies. It aims at increasing the share of energy from renewables to 30 percent in 2020 and to continue this trend thereafter (Articles 1 and 2 of the Renewable Energy Act (EEG)).

Germany appears to be making good progress toward achievement of these goals (Oschmann 2010). The share of renewable electricity in Germany tripled between 1999 and 2009, from 5.4 percent to more than 16 percent (BMU 2010b, p. 20). However, fundamental criticism has been voiced about instrument redundancy because of the co-existence of the EEG and the emissions trading system (Sinn 2008; Monopolkommission 2009; Sachverständigenrat zur Begutachtung der Gesamtwirtschaftlichen Entwicklung 2009; Wissenschaftlicher Beirat beim Bundesministerium für Wirtschaft und Arbeit 2004; Donges et al. 2009; Frondel et al. 2009). In this context, questions have also been raised concerning the cost-benefit-ratio brought about by the Renewable Energy Act (EEG) (Monopolkommission 2009, no. 63; Frondel et al. 2009, p. 6). However, other studies have found the Renewable Energy Act (EEG) to be cost-effective (Wenzel 2009b; 2007; Breitschopf et al. 2010; Krewitt and Schlomann 2006).

The coexistence of emissions trading and efforts to promote renewable energy development will only translate into additional emission abatement if emission limits take account of the additional emission reductions resulting from such efforts (Kemfert and Diekmann 2009). That said, additional renewable energy support instruments are needed mainly because emissions trading alone will not pave the way for the transition to renewables even if it is more cost effective than emission abatement in conventional power plants (see chapter 8.1).

Against this backdrop, our critical assessment of the Renewable Energy Act (EEG) is confined to the following issue: To what extent has the EEG served the cause of transitioning to renewable energies? It will be discussed to what extent the EEG could realise cost reduction potentials. However, whether this occurred to the lowest possible costs is unverifiable. Nonetheless, the future EEG financing costs will be *the* pivotal factor for public acceptance of renewable energies. Therefore, this matter will be considered here.

The Renewable Energy Act (EEG) requires network operators connect renewable energy installations to their grids (Article 5(1)(sentence 1)). They have to give priority to grid access (Einspeisevorrang), transmission and distribution of electricity generated from those installations (Article 8(1)). They also have to pay a feed-in tariff at the statutory rates for 20 years, differentiated by technology and site (Articles 16 ff and 23 ff). These provisions guarantee installation operators good ROI while minimizing their risk. In addition, priority grid access ensures that established market players cannot place new entrants at a strategic disadvantage. Although the Renewable Energy Act (EEG) has been amended a number of times, its core attributes have remained unchanged (also see the sections below concerning the various technologies).

The aforementioned provisions of the Renewable Energy Act (EEG) have allowed for an unprecedented expansion of renewables in the electricity sector. As of 2009 Germany had the third highest installed capacity of renewable energies (excluding hydro power) after China and the U.S. (REN21 2010, p. 13). The Renewable Energy Act (EEG) has proven particularly successful in terms of promoting onshore wind energy, solar energy, and biomass, whose share of total electricity generation (see Table 8-2) and installed capacity (see Table 8-3) has risen rapidly since the 1990s. The net decrease in wind from 2008 to 2009, despite a gross increase in installed capacity amounting to 1,917 MW, was attributable to the unusually low winds during that period and does not represent a trend.

Table 8-2

**Wind, biomass and photovoltaic electricity generation in Germany,  
1990–2009**

	Wind power	Biomass*	Photovoltaic
	[GWh]	[GWh]	[GWh]
1990	71	222	1
1991	100	259	2
1992	275	297	3
1993	600	433	6
1994	909	570	8
1995	1,500	665	11
1996	2,032	759	16
1997	2,966	879	26
1998	4,489	1,642	32
1999	5,528	1,847	42
2000	7,550	2,893	64
2001	10,509	3,348	76
2002	15,786	4,089	162
2003	18,713	6,085	313
2004	25,509	7,960	556
2005	27,229	10,979	1,282
2006	30,710	14,840	2,220
2007	39,713	19,430	3,075
2008	40,574	22,872	4,420
2009	37,809	25,515	6,200

\*Solid, liquid and gaseous biomass, landfill gas and sludge gas; for 1990–1998, only electricity fed into the grids of general power companies is included.  
Source: BMU 2010b

Table 8-3

**Installed wind, biomass and PV electricity generation capacity  
in Germany, 1990–2009**

	Wind power	Biomass*	Photovoltaic
	[MW]	[MW]	[MW <sub>p</sub> ]
1990	55	85	1
1991	106	97	2
1992	174	105	3
1993	326	143	5
1994	618	178	6
1995	1,121	215	8
1996	1,546	253	11
1997	2,080	318	18
1998	2,871	432	23
1999	4,439	467	32
2000	6,104	579	76
2001	8,754	696	186
2002	11,994	826	296
2003	14,609	1,090	439
2004	16,629	1,444	1,074
2005	18,415	1,964	1,980
2006	20,622	2,619	2,812
2007	22,247	3,502	3,977
2008	23,897	3,973	5,994
2009	25,777	4,509	9,800

\*Solid, liquid and gaseous biomass, landfill gas and sludge gas  
Source: BMU 2010b

Until recently, Germany was “the photovoltaic market” (Chew 2010), a statement that likewise applies, albeit to a lesser extent, to the wind energy market (REN21 2005, p. 10, Figure 6). The rise in photovoltaic demand brought about by the Renewable Energy Act (EEG) in recent years has allowed for major economies of scale worldwide for PV installation manufacturing. This in turn has resulted in a decrease in the cost of PV electricity generation, even for the highest-priced installations, to 30 percent of the roughly 1.50 euros per kWh price in 1985. Hence it is also in large measure thanks to the Renewable Energy Act (EEG) that PV installations are now used worldwide and in ever increasing numbers.

Although Germany does not hold the same kind of leading position in the wind energy market as it does for photovoltaic power, it was at one time Europe’s second largest market in this sector, after Spain (REN21 2010, p. 17). Specific per kilowatt hour costs of onshore wind

energy have been halved since 1990, to 0.05–0.12 euros per kWh at the 5–6 m/s wind speeds that prevail in Germany at ten meters above ground in coastal areas, and 4–5 m/s at good inland locations (BMU 2009, p. 70).

Feed-in tariffs are an effective renewable energy support instrument, particularly for onshore wind power, photovoltaics, and biogas (IEA 2008, pp. 102, 117, and 123), and have been adopted in around 45 States (REN21 2010, p. 38 f., Table 2).

As the EEG is intended to induce learning curve effects, the amount of the feed-in tariffs are technology specific. For this reason more cost intensive technologies such as PV earn a higher tariff than cheaper technologies such as wind power. The feed-in tariffs guaranteed for twenty years have to be continuously adjusted to cost trends so as to avoid placing an undue financial burden on electricity customers and to ensure public acceptance of promoting renewable energies (Grösche and Schröder 2010). Hence these tariffs will decrease steadily per year by a percentage stipulated in Article 20(2) so as to ensure that they remain in step with real electricity generation cost decreases resulting from learning curve effects and economies of scale. However, the feed-in tariffs for PV energy, which displays the highest specific costs as well as the highest feed-in tariffs, have not been successfully adjusted in recent years. Owing to evident underestimation of PV module production cost savings, potential investor ROI has skyrocketed, causing a dramatic rise in installed PV capacity in Germany and a sharp increase in Renewable Energy Act (EEG) costs. However, this occurred without a comparable rise in the overall share of energy from renewable sources (Frondel et al. 2009).

Table 8-4 shows feed-in tariffs from 2001–2009 (excluding a deduction of the network charges saved). In 2009, feed-in tariffs amounting to €10.78 billion were paid. Overall feed-in tariffs expenses are expected to undergo another major increase in 2010 owing to the extremely large amount of PV capacity added during that year relative to previous years.

Table 8-4

**The steady rise of overall feed-in tariffs  
under the Renewable Energy Act (EEG)**

	2001	2002	2003	2004	2005	2006	2007	2008	2009
EEG-electricity (GWh)	18145,50	24969,85	28417,10	38511,20	43966,60	51545,20	67010,00	71147,90	75053,40
<b>Hydropower</b>									
Produced quantity of electricity (GWh)	6088,30	6579,28	5907,70	4616,10	4952,60	4923,90	5546,80	4981,50	4877,20
Percentage of total EEG-Mix (%)	33,60	26,30	20,80	12,00	11,30	9,60	8,30	7,00	6,50
EEG-support payments (Mio. Euro)		476,76	427,45	337,67	364,10	366,56	417,70	378,81	382,38
Percentage of total support payments (%)		21,42	16,42	9,35	8,09	6,31	5,30	4,20	3,55
<b>Landfill, sewage und mine gas</b>									
Produced quantity of electricity (GWh)			mit bei Wass	2588,60	3135,60	2789,20	2751,10	2208,20	2019,50
Percentage of total EEG-Mix (%)				6,70	7,10	5,40	4,10	3,10	2,70
EEG-support payments (Mio. Euro)				182,17	219,24	195,62	192,88	155,87	142,64
Percentage of total support payments (%)				5,04	4,87	3,37	2,45	1,73	1,32
<b>Biomass</b>									
Produced quantity of electricity (GWh)	1471,70	2441,95	3483,60	5241,00	7366,50	10901,60	15923,90	18947,00	22979,90
Percentage of total EEG-Mix (%)	8,10	9,80	12,30	13,60	16,80	21,10	23,80	26,60	30,60
EEG-support payments (Mio. Euro)		231,67	326,88	508,46	795,19	1337,37	2162,13	2698,74	3699,99
Percentage of total support payments (%)		10,41	12,55	14,08	17,68	23,02	27,44	29,93	34,32
<b>Geothermal power</b>									
Produced quantity of electricity (GWh)	0,00	0,00	0,00	0,20	0,20	0,40	0,40	17,60	18,80
Percentage of total EEG-Mix (%)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
EEG-support payments (Mio. Euro)		0,00	0,00	0,03	0,03	0,05	0,06	2,64	3,73
Percentage of total support payments (%)		0,00	0,00	0,00	0,00	0,00	0,00	0,03	0,03
<b>Onshore-Wind</b>									
Produced quantity of electricity (GWh)	10509,20	15786,19	18712,50	25508,80	27229,40	30709,90	39713,10	40573,70	38542,20
Percentage of total EEG-Mix (%)	57,90	63,20	65,80	66,30	61,90	59,60	59,30	57,00	51,40
EEG-support payments (Mio. Euro)		1435,34	1695,88	2300,48	2440,68	2733,77	3508,44	3561,04	3388,90
Percentage of total support payments (%)		64,50	65,13	63,70	54,26	47,05	44,53	39,50	31,44
<b>Offshore-Wind</b>									
Produced quantity of electricity (GWh)									37,50
Percentage of total EEG-Mix (%)									0,00
EEG-support payments (Mio. Euro)									5,62
Percentage of total support payments (%)									0,05
<b>Solar power</b>									
Produced quantity of electricity (GWh)	76,20	162,43	313,30	556,50	1282,30	2220,30	3074,70	4419,80	6578,30
Percentage of total EEG-Mix (%)	0,40	0,70	1,10	1,40	2,90	4,30	4,60	6,20	8,80
EEG-support payments (Mio. Euro)		81,71	153,67	282,65	679,11	1176,80	1597,48	2218,62	3156,52
Percentage of total support payments (%)		3,67	5,90	7,83	15,10	20,25	20,28	24,61	29,28
<b>EEG-total support payments (Mio. Euro)</b>	<b>1576,62</b>	<b>2225,48</b>	<b>2603,68</b>	<b>3611,46</b>	<b>4498,35</b>	<b>5810,17</b>	<b>7878,69</b>	<b>9015,72</b>	<b>10779,78</b>
Avoided electricity grid charges (Mio. Euro)				33,94	102,89	204,65	270,01	298,73	321,88
Support after deduction of avoided grid charges (Mio. Euro)				3577,52	4395,46	5605,52	7608,68	8998,59	10457,90
EEG-quota (%)	3,91	5,37	6,019	8,48	10,028	12,008	15,682	17,134	18,582
Average support (Cent/kWh)	8,69	8,91	9,161	9,29	9,995	10,875	11,36	12,253	13,945

Source: 50HERTZ Transmission et al. 2010a

The pivotal factor in the debate on costs of the EEG are not feed-in tariff expenses but rather the additional costs incurred by consumers. This is attributable to the fact that renewable electricity displays a market value in itself which needs to be deducted from the feed-in tariff expenses for purposes of an economic assessment. The decisive factor are the differential costs and the resulting EEG cost apportionment that is paid by the electric power companies and then passed on the electricity consumers. Differential costs result from the difference between total expenses for the EEG feed-in tariffs and the income generated through the sales on the spot market. The projection here is based on futures for relevant calendar years, whose price serve as a benchmark (Article 54 of the EEG) (Wenzel 2009a; Wenzel and Nitsch 2010). The EEG differential costs are then applied to all non-subsidised electricity customers by dividing the total differential costs by the end use that is subject to apportionments. This calculation yields the "EEG cost apportionment". Under the modified compensatory mechanism that came into force on January 1, 2010 (pursuant to the "Ordinance on the further development of the nationwide equalisation scheme compensation mechanism ("Verordnung zur Weiterentwicklung des bundesweiten Ausgleichsmechanismus im EEG"; AusglMechV)), EEG electricity is to be sold on electricity exchanges in a non-discriminatory and transparent fashion (Article 1(1) to 1(3) and Article 2(1) of AusglMechV)

(BMU 2010a). Electricity suppliers need only factor in the difference between the proceeds of EEG electricity sales accruing to transmission grid operators on the electricity exchanges, and the feed-in tariffs paid to renewable energy installation operators (Rostankowski 2010; Buchmüller and Schutenhaus 2009). This difference is now estimated as a lump sum advance apportionment for the coming year by 15 October of the current year. Electricity suppliers have to bear the EEG apportionment, which they are permitted to pass on to their customers (Article 3(1) and 3(8) of the AusglMechV in conjunction with Article 53 and 54 of the Renewable Energy Act (EEG)). Any overpayment or underpayment resulting from the estimation of the new apportionment is factored into the apportionment of the following year.

This new mechanism endows the system with greater transparency, since the EEG apportionment is no longer an unknown quantity, but is instead set on a nationwide basis – a procedure that is likely to intensify the debate concerning the acceptability of the apportionment.

Hence it should be noted that the price of electricity traded at any given time will be determined by the variable costs of the highest priced MWh that is still needed. The use of renewables will tend to drive down these costs since at certain times the use of renewables with very low variable costs (solar and wind energy in particular) obviates the need for the use of energy sources subject to high variable costs. This merit order effect as it is called substantially drives down prices on the electricity exchange. This can result in renewable energy use being advantageous to electricity customers if power companies pass on the lower spot prices to such customers in the form of lower electricity prices. However the merit order effect also tends to lower the achievable price for electricity from renewable at the energy exchange, thus increasing the EEG cost apportionment and attenuating the effect's economic benefits for end users. This in turn is reflected in an apportionment increase, which may be referred to by critics of the EEG as proof of its high costs.

Although EEG costs have on occasion been blamed for higher electricity costs (“Solarboom lässt Strompreise explodieren”, Solar sector growth driving electricity prices sky high,” *Spiegel Online*, March 19, 2010), they have in fact had little impact on end customer electricity prices. Only about one third of the 2010 increase in the EEG cost apportionment is attributable to increased support for renewable energy (particularly photovoltaics), while the remainder, and lion's share, resulted from the procedural change from the old, intransparent compensation mechanism to the AusglMechV on the one hand and, paradoxically, from the collapse of spot market electricity prices, which provoked an arithmetic increase in the difference between these prices and the EEG feed-in tariffs (BMU 2010a, p. 8 f). As the EEG cost apportionment accounted for only around 9 percent of the per kilowatt hour electricity rates paid by households and small businesses in 2010 (Wenzel and Nitsch 2010, p. 45), renewable energy expansion cannot possibly be the main driver of past electricity price increases (BMU 2010a). Hence these price increases are chiefly attributed to rising

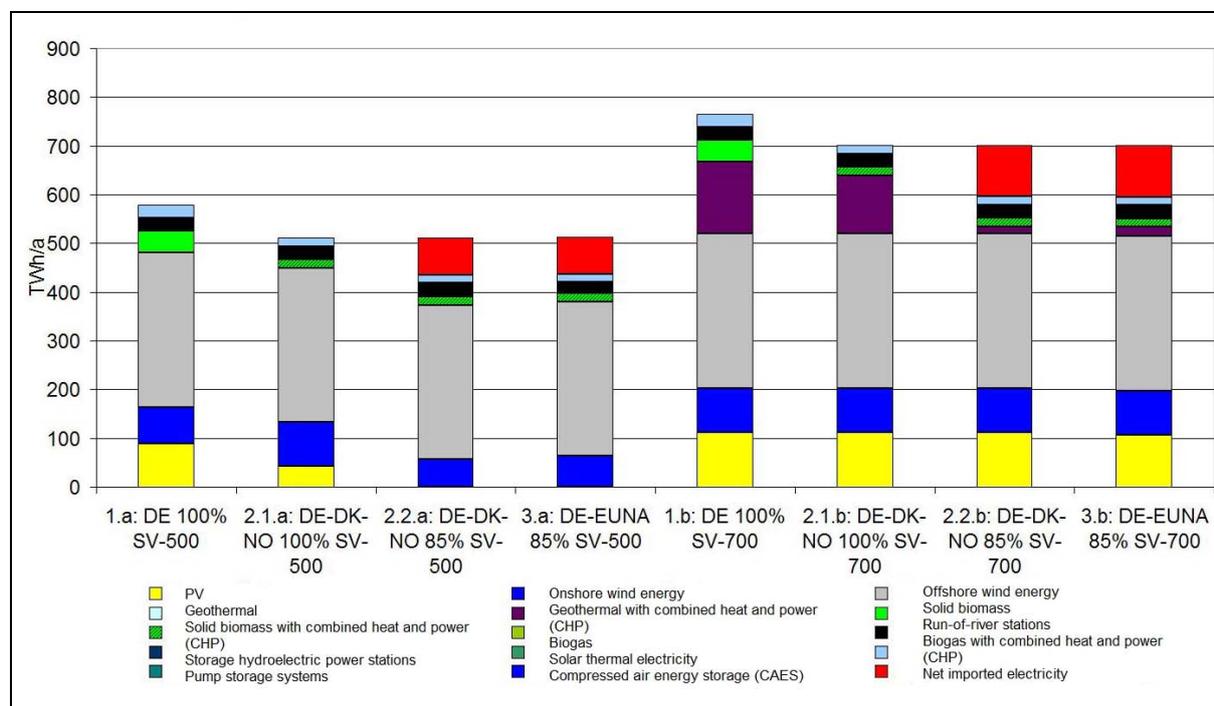
procurement costs of electricity producers, differing purchase dates on the electricity exchange, and differing grid charges (Hildegard Müller, chief executive of BDEW in Tagesspiegel, 30 November 2009). However, doubt has also been cast on the soundness of such claims (Harms 2010). The apportionment for 2011 is estimated to increase from 2.047 ct/kWh in 2010 to 3.530 ct/kWh, chiefly owing to extensive PV and biomass sector growth.

Consequently, the increased financial support for PV installations poses a problem. The larger the share of German energy from renewable sources and the larger the share EEG costs comprise of total consumer electricity prices, the more the policy (EEG) should be reformed to establish an optimally cost effective portfolio of renewables that will provide for full decarbonisation of the electricity supply.

The SRU scenarios are by no means intended as forecasts on whose basis decisions concerning specific technologies should be made. But these scenarios do provide insight into trends (based on current technological and scientific knowledge) that should not be neglected and that should be folded into climate policy instruments. Inasmuch as the SRU calculations clearly indicate that offshore wind energy will play the most prominent role in a cost optimised energy mix in all scenarios (see Figure 8-9), there is good reason for enhanced promotion of this technology today. However, a number of criteria need to met in order to minimise possible environmental damage. According to the SRU modelling results, other renewables are assumed to be developed only to a limited or, depending on the scenario, to varying degrees (see Figure 8-9). Hence, a more modest development path for them is the viable way forward. However, such a path should leave open an option for further expansion in the event such development becomes necessary (owing to technological advances or trends in the energy sector such as energy demand, which will be determined by factors such as the extent of electric vehicle use and the success of efficiency policies).

Figure 8-9

### Projected electricity generation and net electricity imports in Germany in 2050



SRU/SG 2011-1/Fig. 8-9

Minimising external costs is central to the further promotion of onshore wind energy and biomass and biogas electricity. Biomass must meet the challenge of providing system services (balancing power via load-following operation). As for biogas, it is one of the few renewable energies that can provide electricity on demand (see Section 8.4.3); but to do this, it will be necessary, among other things, to amend the Renewable Energy Act (EEG). In addition, in view of the balancing power and reserve capacities required for a wholly renewable electricity supply, currently still cost intensive storage technologies will need to be developed further. A discussion of support for geothermal energy and hydro power development has been foregone in the present report, since according to the scenario results, use of geothermal energy is at present negligible. It offers far greater potential in the heating sector. Hydro power, on the other hand, has already reached its capacity limits in Germany, which obviates the need to consider possibilities of promoting it still further.

### 8.3.2 Support for offshore wind energy

#### Introduction

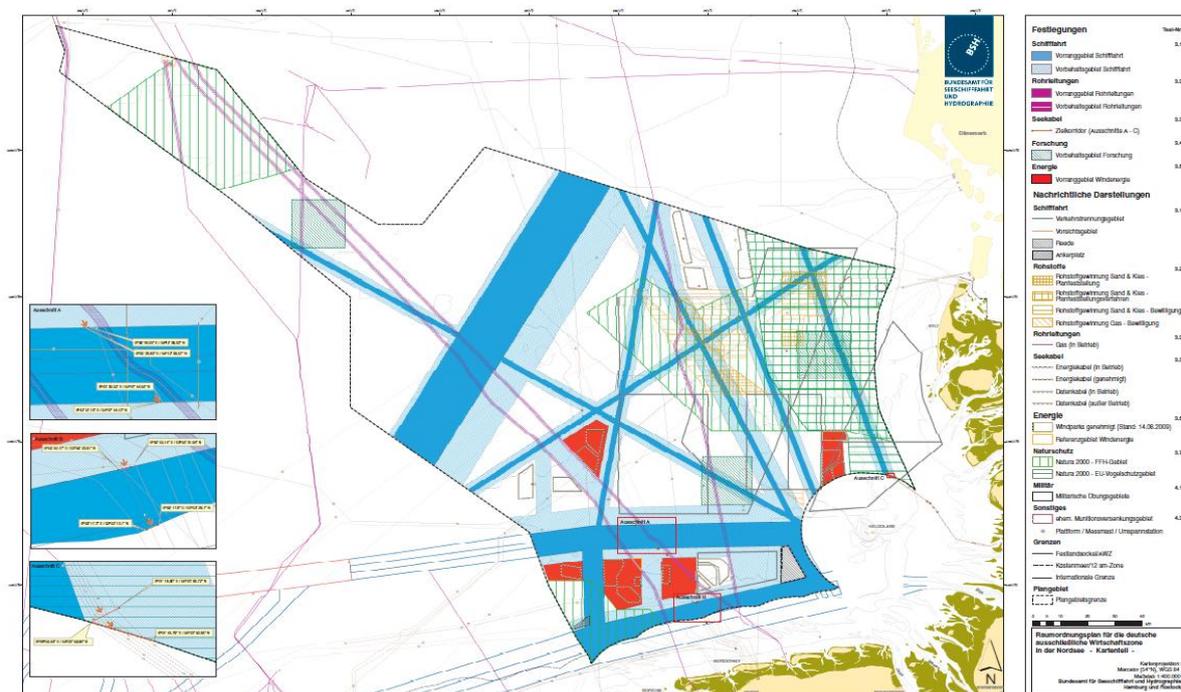
Offshore wind energy accounts for the largest share of electricity generation in all of the SRU scenarios. It offers substantially greater technical and economic potential than onshore wind power because offshore locations display higher wind speeds for a higher number of operating hours. In light of the lower specific costs of offshore versus onshore wind energy,

all of the SRU scenarios call for utilising of all allowable offshore wind energy potential. Expansion is unaffected by the scenario assumptions concerning electricity demand or cross-border electricity trading. Hence it can be safely assumed already today that an extensive development of offshore wind energy capacity will be needed. Wind energy will remain a cost effective option providing that the requisite network connections are realised, that the electricity grid is expanded, that negative effects on marine ecology are avoided and that competition for alternative land use does not arise.

The federal government formulated the goal that offshore wind energy capacity can reach 20 to 25 GW by 2025 or 2030, provided that profitability is achieved (BMU et al. 2002, p. 7). However, the SRU regards a more extensive expansion of wind power capacity to be possible and needed: assuming that it will be necessary to add around 70 GW of capacity by 2050, 25 to 30 GW will be needed by the end of the present decade. This target is achievable.

Figure 8-10

### Land use plan map for the exclusive German economic zone in the North Sea



Source: BSH 2010b

The offshore wind energy expansion called for by the SRU scenarios is compatible with the current regional planning for Germany's exclusive economic zone (EEZ) in the North Sea and Baltic Sea. The relevant regulations (Raumordnungsverordnungen (RVO)) designate three wind power use areas of priority in the North Sea ("Nördlich Borkum", "Östlich Austergrund", and "Südlich Amrumbank", see AWZ Nordsee-ROV) and two in the Baltic Sea ("Kriegers Flak" and "Westlich Adlergrund", see AWZ Ostsee-ROV), where other uses

are allowed only if they are compatible with wind energy (see Figure 8-10). The aforementioned spatial plans, in addition to previously approved offshore wind farms, will provide around 12 GW of capacity comprising more than 8 GW from the priority areas and around 4 GW from previously approved wind farms (BMVBS 2010). Wind farms can also be installed outside of these priority areas. Relevant permit applications have been submitted to the competent authorising body responsible for the EEZ (i.e. the Bundesamt für Seeschifffahrt und Hydrographie, BSH) (pursuant to the AWZ Nordsee-ROV and AWZ Ostsee-ROV regulations, Section 3.5.2 in both cases; also see Table 8-5)). Additional offshore wind farms outside the current areas of priority are being planned, and will be necessary if the government is to achieve its mandated targets. Figure 8-11 displays all uses and protected areas in the North Sea, including all offshore wind farms that are in operation, under construction, have been approved or are in the planning stages. In addition, an assessment as to whether additional areas of priority should be designated is envisaged for 2011 (BMVBS 2010). The purpose of this review is to ensure that the capacity planning process will be able to adapt to changing needs. However, prerequisite for future offshore wind energy expansion to go forward is that all environmental compatibility requirements will be met.

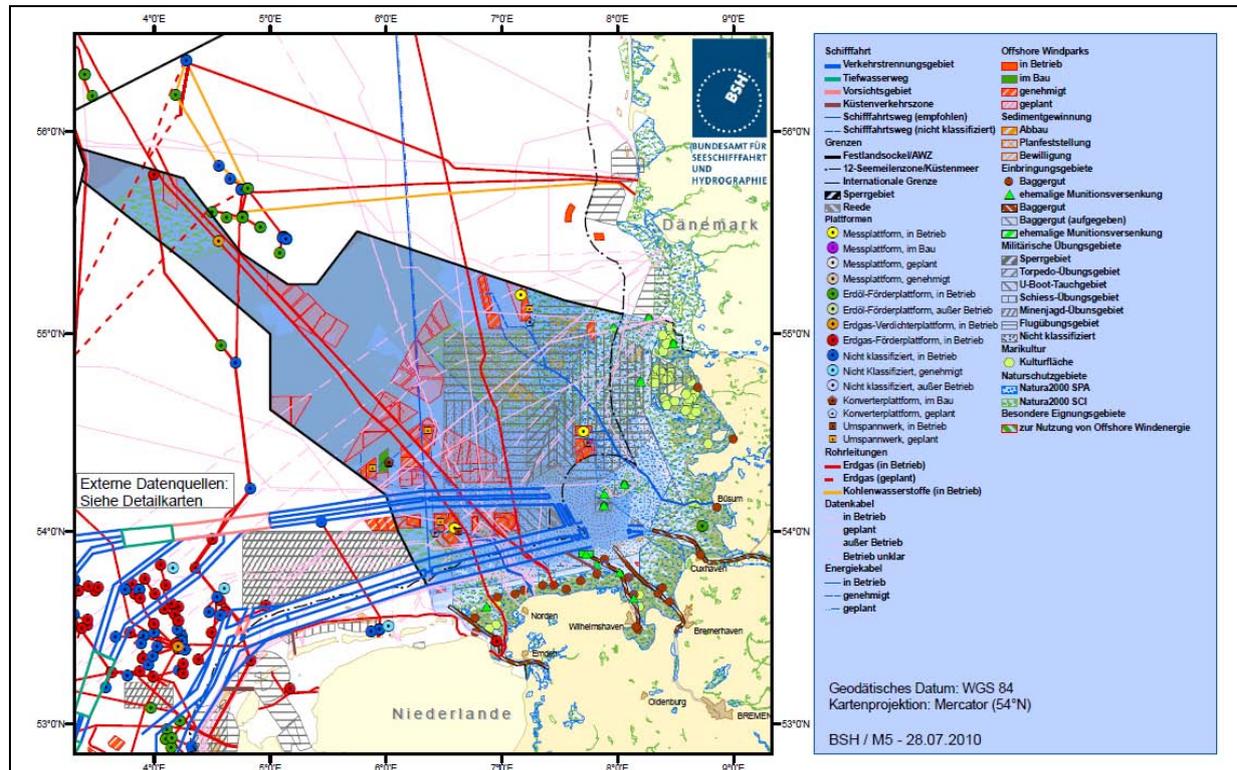
Table 8-5

**Planned offshore wind energy development  
in the North Sea and Baltic as at March 2010**

	Windpark fleet	Wind turbine fleet	Maximum MW capacity per wind turbine
<b>Approvals granted</b>			
EEZ	26	1.850	8,695 (4.7)
Coastal areas	3	44	171.6 (3.9)
<b>Pending approval procedures</b>			
AWZ	68	5.178	25,890 (5)
Coastal areas	-	-	-
<b>Total</b>			<b>34,757</b>
Source: Deutscher Bundestag 2010			

Figure 8-11

### Uses and protected areas in the North Sea



Source: BSH 2010a

### Wind energy development: key factors and issues

Typically, financing for offshore wind farms comes from large investors and/or consortiums; and thus parties that have applied for offshore wind farm approval include German power companies, consortiums of municipal utilities, investment funds, and foreign investors. In 2007, the mean specific investment costs for an offshore wind farm in the EEZ can amount to 2.5–3.5 million euros per MW of installed capacity (Stein and Gottschall 2010, p. 89). Included are the cost of the wind turbines and transformers, as well as the costs of installation, noise abatement measures, and wind turbine interconnection. However, decommissioning and dismantling costs are normally not included. For example, the total investment costs for an 80 wind turbine offshore wind farm with a mean capacity of 5 MW per turbine would range from 1–1.5 billion euros, a figure also confirmed by a financial investment group (Blackstone Group press release of 15 July 2008 titled *Blackstone Group Announces Partnership to Build and Manage 400 MW Offshore Wind Farm in Germany*). However, normally a wind farm has more than one investor, to which end the park is sold in tranches of, for example, 20 wind turbines (100 MW of capacity) to various investors, each of which invests a minimum of 250 million euros in the project. As these investments are subject to a high risk, they are normally within the reach solely of major investors with a high equity ratio. Moreover, offshore wind farms take far longer to build than onshore wind farms

or PV installations – periods of time which can only be bridged by well capitalised large corporations, or financial investors such as banks or pension funds.

Offshore wind farms need to be planned centrally so as to ensure that the development of the land will be as ecologically sound as possible. The requisite grid development and expansion activities can be rendered as efficiently as possible by interconnecting two or more wind farms via nodes. Germany and other states have only limited experience with the construction of offshore farms in deep waters as found in the North Sea (the construction of sites in the Wadden Sea is not allowed for nature protection). Owing to the long distance from offshore sites to the coast and the large water depths, only one offshore wind farm has gone on line in Germany to date. More favourable conditions in this regard have enabled Denmark and Great Britain to build about 600 MW and 1 GW of offshore wind farm capacity respectively (REN21 2010, p. 17).

In late 2009 Germany's first wind farm, Alpha Ventus, a pilot installation with 12 wind turbines at a depth of 30 meters 45 kilometres north of Borkum Island was put into operation by Deutsche Offshore Testfeld- und Infrastruktur GmbH & Co. KG, a subsidiary of EWE AG, E.ON Climate & Renewables GmbH and Vattenfall Europe New Energy GmbH. The installation, which was funded with financial support from the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), will afford wind farm manufacturers, operators and investors the opportunity to gain important experience with this new technology. Any problems that may arise in connection with the project should be regarded as part of the learning process (DOTI 2010). It is precisely such unforeseen technical difficulties that justify government support for these kind of projects.

#### Wind energy support under the Renewable Energy Act (EEG)

The amended Renewable Energy Act (EEG) of 2009 increased the feed-in tariff for offshore wind energy in order to measure up to the challenges of this technology more effectively (Article 31 EEG):

“(1) The tariff paid for electricity from offshore installations shall amount to 3.5 eurocents per kilowatt-hour (basic tariff).

(2) During the first twelve years after the commissioning of the installation the tariff shall amount to 13.0 eurocents per kilowatt-hour (initial tariff). For electricity from installations commissioned prior to 1 January 2016, the initial tariff paid in accordance with the first sentence above shall increase by 2.0 eurocents per kilowatt-hour. The period in accordance with the first and second sentences above in which the initial tariff is paid shall be extended in the case of electricity from installations located at least twelve nautical miles seawards and in a water depth of at least 20 metres by 0.5 months for each full nautical mile beyond 12 nautical miles and by 1.7 months for each additional full metre of water depth.”

The increase in the tariff constitutes a necessary adjustment to actual costs and should considerably improve the profitability of offshore wind farms. The feed-in tariffs that were in effect prior to 2009 failed to create conditions that were conducive to profitable wind farm operation (Stein and Gottschall 2010, p. 87 f). In particular, the requirement that German wind farms need to be at distance from the coast for ecological reasons necessitated technological development and entailed considerably higher costs than wind farms located closer to shore (Stein and Gottschall 2010, p. 88). These circumstances slowed the pace of wind farm development in Germany relative to other European countries, where offshore wind farms are already successfully utilised for power generation.

According to Article 31(2) of the EEG, the initial feed-in tariff period for wind farms that are located farther offshore and/or in deeper water is now extended: "The period ... in which the initial tariff is paid shall be extended in the case of electricity from installations located at least twelve nautical miles seawards and in a water depth of at least 20 metres by 0.5 months for each full nautical mile beyond 12 nautical miles and by 1.7 months for each additional full metre of water depth." On expiration of the initial tariff period, the basic tariff is reduced to 3.5 ct/kWh (below the 5.95 ct/kWh called for by the 2004 EEG), the aim being to prompt operators to market their electricity directly (Andor et al. 2010). The annual plant depreciation for offshore wind farms amounting to 5 percent will not take effect until 2015, whereas the 2004 law had called for a 2 percent depreciation as from 2008.

Table 8-6

**Offshore wind energy feed-in tariffs under the Renewable Energy Act  
(EEG)**

Commissioning date	Phase-1 tariff (first 12 years)	Bonus in first 12 years	Basic tariff for operating years 13 to 20
Prior to 2015	13 ct/kWh	2 ct/kWh	3.5 ct/kWh
Prior to 2016	12.35 ct/kWh	1.9 ct/kWh	3.33 ct/kWh
Prior to 2017	11.73 ct/kWh	-	3.16 ct/kWh
Prior to 2018	11.15 ct/kWh	-	3 ct/kWh
Source: Stein and Gottschall 2010, p. 89			

In addition to the feed-in tariff regulations, transmission system operators are also required to incur the grid connection costs up to the wind farm – for installations whose construction began prior to January 1, 2016 (Article 17(2a) of the Energy Industry Act (EnWG)) – and to establish the connection by the time the installation is ready for operation. This rule removes a major financial obstacle to offshore wind farm development (Stein and Gottschall 2010, p. 89), and the network connection requirement is a major step towards ensuring offshore wind energy cost efficiency. However, it will hamper the process of clustering grid connections more efficiently. In addition, Article 17(2a) has posed a coordination problem in

that offshore wind park investors have to prove to banks that transmission system operators (TSOs) are committed to establish the grid connection. The TSO on the other hand makes his assent contingent upon the banks' willingness to grant loans. Although the federal government and the Federal Network Agency (Bundesnetzagentur) take the view that this problem was resolved by the Agency's statement of position concerning Article 17(2a) (Bundesnetzagentur 2009; Deutscher Bundestag 2010, p. 2), it cannot really be said that network connection has been optimised in terms of wind farm clustering.

#### Optimizing support schemes: EEG plus government risk funds

The current EEG offers adequate support to investors on principle. Feed-in tariffs in conjunction with obligations to connect wind farms to the grids and to purchase their electricity produced (Articles 2(1) and Article 9 of the EEG) as well as the requirement that transmission system operators incur wind farm grid connection costs (Article 17(2a) of the Energy Industry Act, EnWG) ensure security for investors to a great extent. However, additionally the implementation of a government risk fund that would protect operators against unforeseen problems beyond their control should be considered. It would ensure that operators can continue paying off their loans in the event of operational breakdowns.

Although offshore wind energy technology is already available, it still needs to be further tested on the ground and optimised. The government funded pilot installation has provided important insights. However, further technological issues are not unlikely. This in turn makes offshore wind farm ROI a matter of uncertainty, and thus installation operators will be reluctant to invest in these installations. Above all banks are less willing to grant the requisite loans. Such financing problems could potentially result in projects being postponed or even cancelled, which would constitute a financial blow to the wind turbine industry and in the worst case could threaten smaller companies with bankruptcy. Furthermore, competition in the industry could suffer. Hence in order to ensure that offshore wind energy is developed comprehensively, the government should assume at least some of the attendant investment risk.

The increased EEG feed-in tariffs provided for until 2015 (see Table 8-5) compensate installation operators for minor risks during the start-up phase and make up for short-run financial problems by ramping up installation income during normal periods. This in turn provides wind farm operators with investment certainty while giving them an edge over potential competitors that decided not to invest until further experience has been acquired with offshore wind energy technology.

The proposed government risk fund, however, should protect operators against major operational breakdown risk beyond the operators' control such as recurring damages, unexpectedly high maintenance costs and grid breakdowns. This would in particular greatly reduce banks' loan risk exposure, since the fund would ensure that installation operators can

continue paying off their loans even in the event of serious operational breakdowns. Conversely, the risk fund would probably facilitate granting of loans and reduce bank risk premiums.

Reducing the risk entailed by offshore wind farm investments would facilitate a more rapid and ambitious wind power expansion. With increasing production capacity, the emphasis should then be on cost efficiency. It is crucial that feed-in tariffs are commensurate with investment and operating costs and are adapted in a timely manner to cost reductions resulting from technological advances. The SRU therefore recommends that tenders as described below will be introduced, following an initial learning phase up to 2015.

#### Public tendering for offshore wind energy projects

The cause of keeping offshore wind energy costs within reasonable bounds would be greatly furthered by the adoption of a public-tendering “fixed cost compensation” model. This is desirable for a number of reasons. Such a model would allow for more efficient management of wind energy expansion, and would thus ensure that the requisite large capacity expansion is in fact implemented. In addition, wind farm grid connections could be clustered according to the tendered areas. And thirdly, a proper and adequate design of public tendering would ensure the cost efficiency of offshore wind energy expansion, since, in the presence of sufficient competition, bidders would be prompted to disclose their projected costs; and thus, in turn, there would be no risk of over-funding.

This model would ensure that the bidder that offers the lowest operating costs is awarded the operating permit for the wind park. Public tendering in this way builds on the success of feed-in tariffs, while at the same time aiming at integrating more market-like structures into the Renewable Energy Act (EEG) to ensure cost optimised wind power capacity expansion.

Public tendering procedures for promoting renewables actually are no novelty. One example is the British government’s 1990 Non-fossil Fuel Obligation (NFFO), which set the purchase price of renewable electricity via a competitive bidding process (Sawin 2004). A similar support scheme has been used in France for some time (Laali and Benard 1999). But unfortunately, such public tendering has not resulted in fulfilment of the government’s mandated expansion targets owing to the lack of a mechanism to ensure the implementation of the projects that operators had applied for. Also, authorities tended to approve preliminary wind farm plans that stood little chance of realisation as closer scrutiny revealed later. This situation prompted the British government to abandon the NFFO model in favour of a system for tradable renewable energy quota (Menanteau et al. 2003; Mitchell et al. 2006; Schöpe 2010). France introduced feed-in tariffs based on the German model (Menanteau et al. 2003).

Public tendering procedures have often come in for criticism in the literature (Lehmann and Peter 2005). Aside from the volatile expansion and the low implementation rates for

contracted projects, it is criticised that operators postpone construction so as to take advantage of the possibility that production costs might decrease further by the time construction begins (Lehmann and Peter 2005). While this criticism was justified for these tenders, it was nonetheless based on the specific design attributes of these models and their attendant shortcomings. And it is not without reason that the governments of Great Britain, Denmark, Ireland and Brazil (among others) today again tend to use public tendering procedures. France also recently announced more than 15 billion euros worth of public contracts for the construction of at least 600 offshore wind turbines (*Eoliennes en mer: plus de 15 milliards d'euros d'investissements en vue*, Les Echos, August 2010).

In the following sections, the proposed public tendering procedure is discussed in greater detail. It folds in the positive attributes of other models while at the same time putting forward improvements aimed at avoiding the missteps of other states.

### The Non-fossil Fuel Obligation (NFFO)

The Non-fossil Fuel Obligation (NFFO), which was introduced in 1990 with the aim of promoting the development of nuclear and renewable energy in England and Wales, was replaced by new instruments 12 years later owing to the NFFO's poor results. The NFFO obligated public sector power companies to purchase the electricity generated by NFFO projects. NFFO contracts were awarded and the price of NFFO electricity was set via public tendering. This process was technology specific, i.e. a wind energy project was only up against other wind energy projects. Such contracts were awarded to the bidder that offered the lowest per kilowatt hour price. Regional power companies then paid NFFO power companies the contractual price, but were only required to pay the market prices for renewables. The resulting difference was compensated by the Fossil Fuel Levy, which was imposed on all electricity customers.

### Clearly defined expansion goals and plans are key

In order for wind farm zones to be tendered for auction, the government would have to establish conditions that are conducive to such a procedure, the most important being the promulgation of medium and long term renewable-energy expansion targets, as well as specific objectives for offshore wind power. To this end, the government should draw up an offshore wind energy expansion plan that will be consistent with the establishment of a wholly renewable electricity supply. Apart from providing operators with investment certainty, such a plan would also allow for early stage infrastructure planning for the attendant network expansion activities.

In order to devise such a plan, the government will need to determine the scope of the offshore wind energy capacity remaining in the North Sea and Baltic Sea regions and allocate this capacity to suitable areas. The areas in the EEZ designated in spatial plans for

competing uses such as marine ecology protection and shipping are excluded from consideration right from the start (BMVBS 2010).

One of the problems with past tendering procedures, the NFFO included, was that the successful bidders oftentimes failed to gain the requisite building approval (Mitchell 2000, p. 297; Sawin 2004). It was a balancing act for investors and operators to bid in *those* tenders where a low bid was possible and at the same time where the project also stood a good chance of being approved (Mitchell 2000, p. 297). However, this problem is very unlikely to arise in Germany, where the designation of priority areas for wind energy, as per the North Sea and Baltic Sea spatial plans, ensures that wind farms will not be subject to competing uses. Hence we recommend that in 2011 the government look into the possibility of designating additional priority areas for wind energy.

Moreover, on the basis of information currently available, the current wind farm approval procedure under the *Seeanlagenverordnung* (Offshore Installations Ordinance) – which differs from the procedure used in the past by states such as Great Britain and that oftentimes resulted in approval being denied – is unlikely to pose a major obstacle to approval of public wind farm projects (concerning the approval process see Dahlke 2002; Jarass et al. 2009, p. 119 f; Müller 2008). Normally only two years elapse between the time the project plans are submitted and the permit is granted (Deutscher Bundestag 2010, p. 5). Until 2010, the *Bundesamt für Seeschifffahrt und Hydrographie* (BSH) had granted permits for 26 wind farms in the EEZ with an aggregate 1,850 wind turbines (see Table 8-5), the first of which were issued 2001/2002. The BSH posed a fixed period on permits and made them contingent upon certain requirements (the construction of the installation must begin within three years following issuance of the permit). Since 2009, the BSH has made extension of these permits contingent upon the permit holder achieving certain milestones (e.g. the wind turbine foundations having been ordered) that will ensure that the wind farm is actually built and prevent operators from retaining sites as a reserve. Failure to comply with these milestones can result in revocation of the relevant permit (Deutscher Bundestag 2010, p. 3 f).

The actual approval procedure for envisaged wind farms should be carried out by the investors themselves; for it is they who plan the installation and its technical attributes. Otherwise the operators would have to be obliged to meet an unduly high number of requirements on technical matters. Another option would be to first award a public contract for the project development phase of an offshore wind farm, following which the construction and then the operating permit would be tendered. This procedure would render the associated risks more transparent, because the respective realisation phases are shorter, and could potentially enable more companies to bid on each of the contract tranches. For example, this might enable a greater number of smaller companies to bid on the project development phase, but it would likely be more difficult to obtain a large number of bidders for the project as a whole.

In addition, the tenders could contain stipulations aimed at ensuring that the project bidder that is awarded the contract will actually follow through on the project. For example, on award of the contract it could be stipulated that the operating permit will be automatically transferred to the company with the second best offer if the project does not progress strictly in accordance with the mandated milestones. The new contractor will not be required to compensate the original contractor for the latter's costs. And the original contractor will be required to pay a contractual penalty if the project is not duly implemented. Such stipulations would prevent companies from gaining control over wind farm sites solely with the aim of delaying wind energy expansion in order to further their own business interests in other sectors. Public contracts for offshore wind farms should also stipulate that at the end of the installation's lifetime it must be dismantled in such a way that a new wind farm can be built at the site. To this end, the condition of the installation's foundations and wind turbines should be examined. After that, a new tender can be issued for an installation at the same site, and the process can begin all over again.

#### Market-like mechanisms via auctioning

Public tenders for a zone that offers the relevant minimum capacity should require bidders to offer a per kilowatt hour tariff, via an auction. The lowest bidder is granted the right to install wind turbines and generate electricity in this zone. This tariff is paid for the 15 year minimum lifetime of an offshore wind farm (Gasch and Twele 2007, p. 535). It would be a fixed-cost compensation, thus termed because this subsidy enables offshore wind farm operators to recoup their investment costs. Once the 15 year installation lifetime mark has been passed, the tariffs of installations that are still operational should be reduced so as to enable the operator to utilise the full potential installation lifetime and at the same time turn a profit.

Unlike the EEG, the tendering procedure proposed here would guarantee (assuming the procedure is competitive) that fixed costs would be covered at lowest cost (Menanteau et al. 2003; Mitchell 2000; Mitchell and Connor 2004). Tariff auctioning would generate competition between bidders and would assure that companies offer the lowest bid of which they expect that it would recoup their investment costs. Even if the bidders are only major players, in all likelihood there would still be a sufficient number of them.

That said, the proposed tendering procedure for offshore wind farms might entail the risk that bidders underestimate project costs, only to find out after being awarded the project that their proffered tariff is too low to finance the project. In the field of economics, this phenomenon is termed the winner's curse (Thaler 1988), whereby the winner of a common value auction will overpay due to not having enough information. "Overpaying" in this case means offering an unduly low tariff. This has occurred before in connection with the awarding of oil drilling concessions or auctions of mobile communications frequencies in Germany. The more bidders in any given auction, the more severe the winner's curse will be. Also in the case of the NFFO, it can be assumed that unduly low tariffs were offered, resulting in a number of

projects being cancelled. As pointed out in the literature, NFFO incentives were set in such a way that bidders failed to take account of breakdowns or delays in their bids, and instead made best-scenario bids to have more of a chance winning the auction (Mitchell 2000, p. 296 f.). The winner's curse phenomenon could be mitigated by applying the second-best tariff offer to the bidder that is awarded the contract (i.e. the best offer). In addition, the concept of having operators assume the planning phase costs, plus the threat of a contractual penalty if the operator fails to follow through on the project would provide incentives for operators to avoid underestimating the real project costs, as these costs would fall to the operators even in case they default on the project.

### **8.3.3 Promoting biogas electricity**

Electricity generation from biomass is less dependent on meteorological conditions than wind or solar power. Inasmuch as biogas can readily be stored in low demand periods without being converted and can then be used to generate electricity as needed (Mackensen et al. 2008, p. 9), biogas electricity fulfils balancing and storage needs particularly well. The level of biogas electricity production assumed in the SRU scenarios for 2050 is roughly the same as the amount being generated today and would thus require no capacity expansion. Biomass electricity generation accounts for only a fraction of the electricity demand projected in the scenarios. Nonetheless, building additional biogas installations during the process of transitioning to a wholly renewable electricity supply would be a way to safeguard against any unforeseen problems in realising electricity storage installations. Because of a high risk aversion against power failures, investments in biogas installations would be a sensible economic strategy even if the full capacity of such facilities is no longer needed in 2050. The discussion that follows applies solely to electricity production through biomass. Electricity generation only accounts for around one third of biomass energy applications; the remainder is used for heating and fuel. Subsidies for these applications will not be discussed further here. But it should nonetheless be noted that a holistic policy approach to biomass energy support is needed and an optimisation of all biomass applications be envisaged (SRU 2007a, p. 102 ff). Electricity from solid and liquid biomass likewise falls outside the scope of the present chapter. In view of the particular suitability of biogas for balancing and storage purposes, our discussion here centres on electricity generation from this energy source.

As previously noted, the use of biomass energy can entail specific risks for farmland biodiversity. Thus, it is essential that biomass support programs strive to minimise such risk. This goal can be best reached through the use of biomass from waste, suitable agricultural residues and post-harvest timber slash as well as urban and industrial residues, provided the latter are suited to the intended purpose. Liquid manure has proven to offer a particularly large unused potential. Furthermore, its use also brings nature conservation and environmental protection benefits. The biogas production levels projected by virtually all of the SRU scenarios for 2050 can be reached solely using biomass from waste and residues

and post-harvest timber slash. The only exceptions are scenarios 1a and 1b, which were realised for purposes of comparison only. Here, the use of energy crops would become necessary (DLR 2010a, p. 21).

A sustainable use of biogas for electricity generation requires to successfully transition to the use of biomass from waste and residues and to implement balancing mechanisms for intermittent solar and wind energy. However, the current support instrument lack the incentives needed to achieve this goal and should therefore be restructured. As the existing biogas installations with guaranteed feed-in tariffs for the next two decades will be unaffected by the reform process, restructuring current support programs would initially lead to further biogas capacity expansion and then to a gradual change in biogas electricity generation.

The SRU argues in favour of setting feed-in tariffs for a longer period to ensure investment planning certainty for a longer period. For this reason, changes that will take effect in two decades need to be introduced now. Hence the support instrument changes the SRU recommends below should be implemented as soon as possible.

### **8.3.3.1 Goal 1: load following operation**

The more the heat from biogas electricity generation is used, the more efficient the system as a whole will be. Thanks to heat storage, installations using combined heat and power (CHP) can use all of their heat, and can also provide system services. This approach has already been successfully realised in Denmark (Fragaki et al. 2005, p. 4; Sievers 2007, p. 1; Ritter 2007, p. 1), showing that CHP installations can be used to compensate for intermittent wind and photovoltaic electricity.

Today, biogas is temporarily stored for later electricity generation purposes by either feeding the gas into the natural gas grid or by storing it directly at the relevant site. Current biogas storage installations can hold an average of six hours worth of biogas production (Bofinger et al. 2010, p. 21), thus allowing for asynchronous electricity generation over the course of a day – but only if the relevant motor power is increased at the same time. Considerably greater storage capacity is needed, however, for residual load-operated electricity generation.

Renewable Energy Act (EEG) feed-in tariffs fail to create incentives that would prompt operators to respond to electricity system market signals (Sensfuss and Ragwitz 2009, p. 2). According to Article 17 of the Act, “Installation operators may sell the electricity generated in the installation to third parties on a calendar-monthly basis (direct selling) if they have reported this to the grid system operator before the start of the previous calendar month.” In such cases, no “... entitlement to payment of a tariff ... shall exist for that entire calendar month and for the entire electricity generated in the installation. The period in which the electricity is sold directly shall then be credited against the duration of payment of the tariffs ...”. Operators also have the option to “sell a certain percentage of the electricity generated

in the installation on a calendar-monthly basis and claim payment of a tariff for the remaining share in accordance with Article 16...”.

However, market price-based analyses of installation load profiles (Sensfuss and Ragwitz 2009, p. 6) have shown that the mean market prices of the electricity that is currently fed into the grid under the EEG are lower than the EEG feed-in tariff. However, it should also be noted that an operator of a variable output renewable energy installation can structure their feed-in profile in such a way as to obtain a higher price than with a steady feed-in as assumed here. However, the tepid response of installation operators to the possibility of directly selling their electricity EEG shows that the Act is short on incentives that would prompt installation operators to forego guaranteed feed-in tariff payment.

A restructured support system should strengthen the market and price signals that the current instruments institute only scarcely, and should at the same time provide incentives for installation operators to enlarge their biogas storage capacity and use the natural gas grid as a storage platform.

A distinction needs to be made here between existing installations with a guaranteed feed-in tariff already in place on one hand, and newly built installations on the other. For the former, necessary incentives to change behaviour have to be aligned to the amount of the feed-in tariff currently paid. In order for direct electricity marketing to be an attractive option, it will be necessary to pay a market premium in addition to the sales proceeds that takes account of the difference between the market price and the EEG feed-in tariff. Under such an arrangement, installation operators that feed electricity into the grid round the clock at a constant rate would be paid in the relevant month the feed-in tariff according to the fixed EEG rates, but would also have the option to increase their electricity sales earnings by feeding in electricity during high-price periods and by availing themselves of the market premium. This market premium, however, should be keyed to a market price indicator in order to avoid over- or under-funding (Sensfuss and Ragwitz 2009, p. 6 ff). The higher revenues, however, are also by higher costs. Aside from costs for installation upgrading, storage capacity expansion, and operating plan fulfilment (optimisation of operating timetables) costs for market monitoring and electricity marketing have to be added. These additional costs should be factored into the market premium.

New installations should be paid a premium on top of the market price from the outset. This would provide an incentive for operators to take advantage of energy market price fluctuations and to sell their own electricity on the balancing power market. The price premium would at the same time constitute a minimum per kilowatt hour price. While the transition from guaranteed revenue to a lower fixed per kilowatt hour premium may impinge upon installation operator certainty concerning the investments necessary to implement the requisite system services, the SRU nonetheless considers that such a change in biogas support schemes is necessary.

Optimisation of daily electricity installation operating timetables may prove to be unduly cost intensive for many smaller decentralised biogas installations that farmers use as a source of secondary income. Inasmuch as smaller installations will not be able to feed biogas into the natural-gas grid at any time in the foreseeable future owing to the requisite upstream biomethane processing, such operators will only be able to benefit from a tariff system that is oriented toward market requirements if they can outsource the treatment phase of the process. A possible measure of aid for such operators would be to establish marketing pools composed of various biogas producers whose electricity output would be monitored and marketed centrally. Software tools could be of assistance in selling electricity on the spot market and determining the relevant bids for the balancing power market (Andersen and Lund 2007, p. 291 ff; Fragaki et al. 2005, p. 4 ff).

Another option would be to have balancing group managers or other actors that centrally coordinate daily operating timetables for a large number of installations. The technical infrastructure for such an arrangement is already in place, but to implement it requires that organisational issues would still need to be resolved.

Feeding biogas into the natural-gas grid would also open up storage capacity and obviate the need for the aforementioned upgrading measures or for transfer of control rights. It would still be necessary, however, to convert the biogas into biomethane beforehand, and this in turn would necessitate investing in and installing a biomethane processing facility. The Renewable Energy Act (EEG) subsidises such investments via payment of a technology bonus for converting biogas into natural gas or feeding biomethane into the gas grid and using it for electricity generation elsewhere. This support scheme should be retained as it serves the cause of technological development and thus promotes learning curve effects.

For specific cost related reasons, feeding biomass into the natural-gas grid is only cost effective for installations whose raw biogas output is upwards of 500 Nm<sup>3</sup> per hour (Urban 2010, p. 16). This process could be made financially worthwhile for smaller biogas installations by clustering a number of them into a collective processing and feed-in installation. As increased liquid-manure use (which the SRU advocates) would severely limit the size of biogas installations, the possibility of directly promoting cooperative arrangements among farmers that produce biogas should be considered. In addition, it should be analysed which technical and institutional innovations could promote feeding biogas from smaller installations into the natural-gas grid.

Incentives for biogas feed-in do not only arise through the EEG, but also through other framework requirements. The *Gasnetzzugangsverordnung* (Gas Network Access Regulation, GasNZV), amended in 2008, has improved the conditions for biomethane input, draw-down and transport activities. This regulation (again amended in May 2010) governs priority grid connections via a transparent grid connection procedure, cost reductions, and information concerning gas quality. It stipulates that 75 percent of grid connection costs are to be

assumed by the grid operator and the remainder by the grid subscriber, providing that the relevant gas line is a maximum of 10 kilometres long. If this is not the case, the subscriber assumes the additional cost (Article 33 of the GasNZV). Grid operators pay biogas producers that feed biogas directly into the grid 0.0007 ct/kWh of input biogas for grid cost savings (Article 20a of the GasNZV). The regulation also requires grid operators and subscribers to disclose their planning and tendering documentation to each other, and allows for the streamlining of processes such as biomethane volume balancing. All of these various instruments provide incentives for biomethane producers to convert biogas to biomethane and feed it into the natural-gas grid.

### **8.3.3.2 Goal 2: recycling of residues**

The 2009 Renewable Energy Act (EEG) aimed to promote greater use of liquid manure by providing a bonus payment for biogas producers whose substrate is composed of at least 30 percent liquid manure. This measure, in conjunction with the increased overall support improved the profitability of biogas production, particularly in regions with high livestock densities. However, it also led to increased demand for renewable raw materials, which for beneficiaries of the liquid-manure bonus are allowed to comprise 70 percent of the total materials used (Isermeyer 2009, p. 12 ff). Consequently, the liquid manure bonus resulted in increased and intensified land use.

For both nature conservation and ethical reasons it is desirable to greatly increase the proportion of biogas that is produced from residues, and conversely to reduce the proportion of intensively cultivated energy crops. To this end, the bonus for renewable raw materials (in German: *NawaRo-Bonus*) should be abolished. The payments should instead be keyed to the proportion of residues in the substrate used. This measure would obviate the need for the current liquid-manure bonus, which could then likewise be abolished. In addition, biogas subsidies should mainly support biogas derived from residues such as manure, landscape conservation products, and industrial residues; this in turn would allow for abolition of the landscape conservation bonus. However, as liquid manure alone yields a relatively low methane output, additional substrate needs to be fermented in some cases in order for biogas production to be cost efficient. In the interest of avoiding intensive cultivation of corn and other biomass crops, the possibility should be considered of providing additional support for the use of farming methods that promote both nature conservation and climate protection – for example, extensive cultivation of perennial crops or of adapted species of wild plants.

Support schemes that focus on residues and thus manure use are particularly advantageous for smaller biogas installations. Larger installations, on the other hand, need to have large herds of cattle at their disposal in order to obtain a high proportion of liquid manure to compensate for its low energy yield resulting from its high water content. The cattle also need to be nearby since transporting liquid manure over long distances is not cost effective. This problem can potentially be overcome through the use of separation processes that

greatly reduce the water content of the manure, thus allowing for its efficient use in large biogas installations. However, such processes are still under development (Lootsma and Raussen 2008, p. 1; Albers 2010). Based on the distribution of herd size classes in Germany, and assuming biogas derived from biomass that is 50 percent liquid manure, in many cases even small 150 kW biogas installations currently lack ready access to the larger herds (Vogt et al. 2008, p. 373). Thus only relatively small biogas installations can be predominantly liquid-manure based. Even if such installations display the technical potential to be operated in load following mode via a centralised management platform and thus would not jeopardise the aforementioned load following operation goal, the mechanisms engendered by promoting residues use should be monitored closely and critically, so as to ensure that such mechanisms do not lead to disproportionately high costs.

Furthermore, installations that are in close proximity to urban areas should use industrial residues and organic and garden waste. This can serve as an adjunct to classic composting. These installations will mainly be large plants.

In the context of promoting residues use, the term “landscape conservation product” needs to be more clearly defined than is currently the case so as to ensure that the cultivation of renewable raw materials is not subsidised. For example, corn (though cultivated without ploughing) that is grown expressly for use in a biogas installation should not be classified as a residue and not a landscape conservation product – but exactly this classification is possible today simply by virtue of the fact that ploughless cultivation is recognised as an agri-environmental measure. Thus, a grower’s participation in an agri-environmental program should not automatically make his crops eligible for certification as residues but be treated and categorised in a more differentiated manner. To this end the term landscape conservation product should be defined as narrowly and clearly as possible (Veldhoff 2010, p. 4, 10).

According to Article 27 of the Renewable Energy Act (EEG), a biogas installation is not eligible for the renewable raw materials bonus (NawaRo-Bonus) if other substances such as organic waste are used in addition to renewable raw materials, liquid manure, and plant by-products that appear on the so called *Positivliste* in the EEG Annex . Hence it stands to reason that abolition of the bonus for renewable raw materials (NawaRo-Bonus) would automatically provide a stronger incentive to use non-agricultural residues.

### **8.3.3.3 Summarised recommendations**

In view of the special role that biogas will play for load following operation in the future energy mix and considering the nature conservation and environmental protection issues raised by the increased intensive cultivation of energy crops fostered by the amended EEG, the SRU recommends a radical shift of focus in the biogas electricity support scheme. Electricity production from biogas should be supported through a premium on the market

price. Furthermore, the support scheme should be structured in such a way that the sole economically competitive modality is largely residues-based biogas production. Use of residual materials should be promoted via premiums rising relative to the increase of the proportion of such materials in the substrate mass. The bonus for renewable raw materials (NawaRo-Bonus) and the liquid manure bonus should be abolished, however. Residues mainly comprise (liquid) manure, plant residues from landscape management activities and municipal or private green areas, crop residues, and bio-waste. In the interest of avoiding a situation where primarily intensive-cultivation materials are used as a supplement to low-energy residues, efforts should be made to promote the use of particularly ecologically compatible farming methods. In keeping with the Renewable Energy Act's direct marketing provisions, leveraging of price fluctuations should be made a more appealing option for biomass plant operators. The technology bonus, which provides targeted support for innovations, should be retained as an adjunct to the price premium. The list of technologies designated for support should be reviewed and updated continuously so as to ensure that only those new technologies that are eco-friendly are promoted. In the interest of ensuring the required receptiveness to new technologies, R&D subsidies for such technologies should be considered at first; and if they achieve success, they should then be supported according to the tenets of the Renewable Energy Act (EEG). This way activities such as converting biogas to biomethane and feeding the biogas into the natural gas grid can be specifically promoted.

Once implemented, support rates should be reviewed and if necessary modified to ensure that (a) they are neither too high nor too low; (b) they are promoting achievement of the mandated nature conservation and environmental protection targets. Moreover, support should be designed in such a way that competitive structures are maintained and that the mandated climate protection targets can be achieved at reasonable economic costs.

### **8.3.4 Promoting solar energy and onshore wind energy**

The SRU generally advocates photovoltaic and onshore wind energy feed-in tariffs in conjunction with the requirement that grid operators integrate PV installations and onshore parks into their grids and purchase the attendant electricity, in keeping with the provisions of Articles 2(1) and 9 of the Renewable Energy Act (EEG). Unlike offshore wind energy and electricity grid expansion, photovoltaic installations and onshore wind farms are often financed by small investors such as households and municipalities. They entail less centralised planning since the relevant decisions are normally made at the regional or local level. In this regard, the EEG provides adequate support in that large and small investors are placed on an equal footing, thus affording the latter the requisite investment certainty. This way the EEG has promoted cost reductions resulting from learning curve effects. However, owing to insufficient adjustment of PV feed-in tariffs, the current scheme led to over-funding. Hence, while the successful elements of the EEG in this regard should be retained, steps

should be taken to ensure that more recent evolutions are taken into account. To this end, the various problems and issues entailed by photovoltaic power and onshore wind energy need to be addressed. Great uncertainty exists surrounding the actual need and future costs of PV installations. For onshore wind energy, the available areas need to be used in an optimal fashion. Against this backdrop, photovoltaic energy and onshore wind power support will now be discussed, in separate sections.

#### **8.3.4.1 Promoting photovoltaic energy**

In 2009, photovoltaic energy support came in for increasing criticism (Reichmuth et al. 2010, p. 2). Drastic and unexpected PV installation price decreases in conjunction with the existing tariffs allowed for elevated return on equity. This in turn resulted in skyrocketing demand for PV installations and sales growth far exceeding expectations. Around 3,800 MW of photovoltaic capacity was added in 2009, double the amount in the prior year (Wenzel and Nitsch 2010, p. 22). Sales projections for 2010 far exceed all PV capacity expansion expectations and are being continuously corrected upwards. The federal government's national action plan for renewable energy anticipated an installed-capacity leap of 6 GW to a total of 15.8 GW (Bundesregierung 2010, p. 116), with more recent analyses even forecasting an increase of up to 9.5 GW for the year (50Hertz Transmission et al 2010b, p. 16; Erdmann et al 2010).

The boost in PV capacity expansion has increased the EEG cost apportionment. The PV share of this, apportionment was 29.3 percent in 2009 – although photovoltaic energy accounted for only 8.8 percent of the electricity in the EEG energy mix (see Table 8-4) – and is expected to rise to around 45 percent in 2010 (Wenzel and Nitsch 2010, p. 45). As for the apportionment, on 15 October 2010 transmission system operators announced that it will rise by around 75 percent to 3.353 ct/kWh in 2011 – an increase that is mainly attributable to the PV boom.

The high cost of photovoltaic support is putting at risk the acceptance of the support system as a whole (Reichmuth et al. 2010, p. 17). The feed-in tariff reductions amounting to up to 16 percent as of 1 October 2010 and up to an additional 13 percent as of 1 January 2011 appear to be insufficient. Therefore support should be strictly based on actual costs and needs, as proposed below.

The cost optimisation posited by the SRU scenarios translates into widely varying photovoltaic energy uses. If a wholly renewable electricity supply without imports is excluded as a viable scenario, photovoltaic energy use in Germany is not cost efficient for any scenario involving demand of 500 TWh. With a yearly electricity demand amounting to 700 TWh, excluding electricity imported from North Africa, photovoltaic energy output in Germany would be just under 100 TWh/year in the relevant scenarios. However, this relatively high

figure is attributable to, among other factors, the stringent import restrictions entailed by these scenarios.

The scope of photovoltaic energy that will be cost efficient in the long run is indeterminable at present. The key determining factors in this regard will be the scope of cross-border interconnection and electricity interchange and the amount of imports, and in particular the future costs of this technology. An optimistic learning factor of 25.9 percent was assumed for the scenario calculations, but also very high initial costs. There is general agreement that photovoltaic energy in future will be characterised by a steep learning curve as well as enormous cost reduction potential (Röttgen 2010, p. 27; IEA 2000; EPIA 2010; Mühlenhoff and Witzler 2010; Schott AG 2010; Neij 2008; Hobohm and Mellan 2010, p. 14; for a less optimistic view see Schlesinger et al. 2009). Electricity generation costs ranging from 5–9 ct/kWh are regarded as realistic (EREC 2008). If, in line with these cost decreases, photovoltaic energy became competitive with other renewable energies in Germany, then PV would become part of a cost optimised mix of renewables, even with a yearly electricity demand of 500 TWh and a cross-border supply network with Scandinavia.

Some hold the view that photovoltaic energy will be competitive once grid parity is achieved – a situation where solar electricity generation costs are on a par with household electricity rates (SolarServer 2007). This would be the case today with a price of around 0.22 ct/kWh. It is argued that grid parity would dynamise the energy market in that households would be provided with incentives to install PV systems. However, this assumption fails to reckon with the fact that household electricity demand and solar energy production are highly asynchronous. Without (expensive) batteries households can only use a portion of photovoltaic energy output, which would substantially increase the effective mean generation costs involved (Bode and Groscurth 2010, p. 22). Moreover, households with solar panels need to be able to draw energy from the grid at times, which would significantly reduce the economic benefit of home PV installations in the (likely) event that some household electricity needs to be drawn from the grid during high rate periods. Hence the achievement of electricity generation costs that can compete with the prices charged by power companies by no means indicates that photovoltaics deserve a place in the future energy mix.

Photovoltaic and onshore wind energy support in Germany are no longer justifiable on the grounds of learning curve effects, for the market for PV installations has grown considerably and is now international in scope. Even if Germany stopped promoting photovoltaic energy, the remaining PV installation market would be large enough to allow for further cost reductions (Chew 2010). On the other hand, the aim of photovoltaic energy support in Germany can still be to promote the transition to renewable energies without jeopardizing energy security. A tenfold PV capacity expansion – which is presumed to be a cost optimised solution in the scenarios with the largest share of photovoltaic energy – is unachievable in the short term. Hence, long-term planning will be needed which, while it may potentially

result in a certain amount of surplus capacity, will nonetheless ensure a wholly renewable electricity supply. "Backup" capacities of this magnitude would not be installed without support schemes.

However, the costs for potentially "unneeded" PV capacity must be kept as low as possible. The scope of PV expansion should be kept at a low level that however still ensures that installed capacity can be adjusted to potential changes in demand. However, there is no need at present for PV expansion efforts to be oriented toward a 700 TWh scenario that also assumes widespread use of electric vehicles. Instead measures aimed at limiting electricity demand to 500 TWh are needed. Only if a rise in electricity demand appears highly probable, PV capacity expansion should be promoted accordingly. The planning period for such a capacity expansion – which ideally would be realised as late as possible – should be keyed to the relationship between the capacity needed and the possible annual expansion rate. Experience in the exceptional year of 2010 seem to indicate that physical capacity is not a limiting factor for such an expansion. The technically and economically optimal share of energy from PV installations – just under 100 GW – could be reached within ten years. Therefore, it would make more sense to first aim for a more moderate expansion, whose rate could then be increased if need be.

It follows from the foregoing that in order to avoid undesirable developments, photovoltaic support urgently needs to be reined in. Such a measure, as noted before, does not contravene a potential need for further PV capacity expansion at a later stage as there as there would still be plenty of time to take the necessary measures.

If projections of large decreases in PV installation manufacturing costs are accurate, this would be yet another reason to rein in photovoltaic energy support. The later PV installations are installed the lower their social cost will be. However, in the interest of political credibility and preserving the relevant technical skills and know-how, PV capacity expansion should not be discontinued altogether.

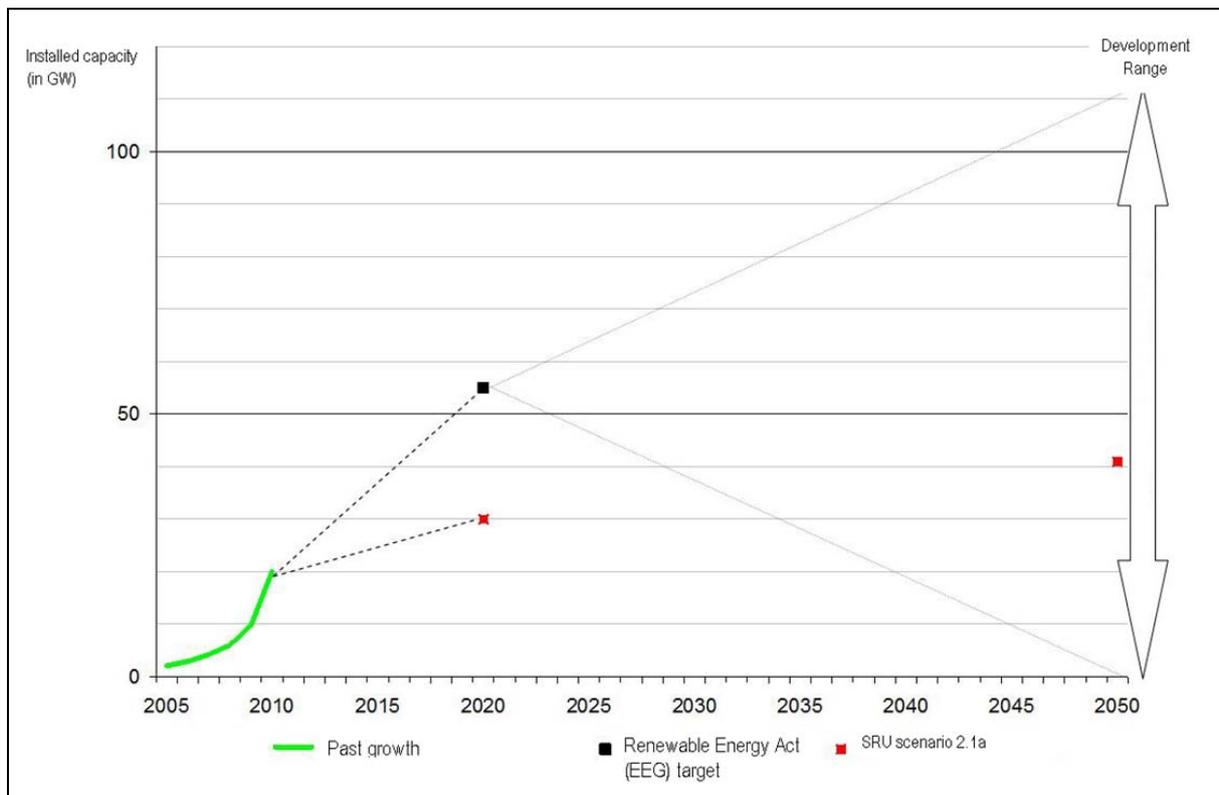
The federal government's 2,500–3,500 MW annual photovoltaic energy expansion target (*Kabinett stimmt neuer Vergütung für Solarstrom zu*, BMU press release of 3 March 2010) is not justifiable. According to the SRU scenario calculations, an annual expansion rate of 3,500 MW would not even be cost efficient for the electricity autarky scenarios as well as those involving demand amounting to 700 TWh/a.

Based on SRU calculations, figure 8-12 displays a comparison of cost efficient installed PV capacity and the capacity that would result from adding 3,500 MW of capacity annually as envisioned by the federal government's target. In 2020, this target would translate into installed PV capacity that not only far exceeds the capacity in the SRU scenario 2.1.a for the same year (factor of 1.8), but also the capacity that was estimated for this moderate scenario for the year 2050. Figure 8-12 also shows the great range of potential cost optimised PV use in 2050 according to the results of *all* SRU scenarios. This range from 0 to 109 GW is a

result of the various technical and economic optimisation parameters in the REMix model – namely electricity demand, countries included, and allowable share of imported electricity. The PV development path should be mapped out in such a way as to allow for a timely response to trends in electricity demand. The current PV capacity expansion rate is too high. It would result in half the capacity that is needed for a wholly renewable electricity supply in 2050 in the high electricity demand scenarios to be already installed in 2020. This means that unnecessary capacity would be installed prematurely, which in turn would increase long-term renewable electricity costs and jeopardise acceptance of a wholly renewable electricity supply. This situation will be aggravated if the projected expansion amounting to an additional 9.5 GW in 2011 proves true (50Hertz Transmission et al. 2010b, p. 16).

Figure 8-12

**PV expansion as per the government's target,  
compared to SRU scenarios**



SRU/SG 2011-1/Fig. 8-12

The government's PV expansion target would substantially increase EEG costs – the feed-in tariff cuts called for by the 2010 EEG notwithstanding – since PV energy will remain the most cost intensive renewable energy source. With a 33 ct/kWh feed-in tariff, photovoltaic energy would cost around four times as much as electricity from wind farms along the shore.

Although the new flexibility in setting the support level provided for by the EEG – flexible because the level of support would automatically be adjusted in accordance with the progress made toward reaching the government's target – is a step in the right direction, it

does not ensure cost efficiency. The EEG calls for a 9 percent feed-in tariff reduction per annum if yearly capacity expansion lies within the 2.5–3.5 GW target area. Additionally, a new variable has been introduced whereby the reduction factor would be automatically adjusted for the following year in accordance with the progress made towards the target. This mechanism in turn also couples the support cost reductions to market developments. The reduction factor would increase if PV capacity expansion exceeds 3.5 GW, and would decrease if cumulative expansion is less than 2.5 GW.

The problem with this kind of adjustment, however, is that fast changing PV module prices in further surplus capacity, which can work to the disadvantage of less cost intensive renewable electricity generation technologies. The experience of 2009–2010 showed that over-funding can result in massive surplus capacity in a very brief space of time.

For this reason, the SRU recommends that in addition to a yearly reduction factor an absolute limit be placed on annual PV capacity expansion support. Moreover, this limit should not be keyed to the federal government's capacity expansion target. As previously noted, the cost optimised share of photovoltaic in the EEG mix is difficult to predict. Hence, the federal government should set incentives within the EEG that prevent expensive PV capacity from being added too early – capacity that would very likely (i.e. in case of slowed-down electricity demand growth and/or Germany's electricity system being integrated into a European network) not be needed.

Such an undesirable development would also not serve the case of renewable energy capacity expansion. Inasmuch as the EEG cost apportionment cannot be increased without meeting political opposition, perpetuating the current photovoltaic support framework would deprive renewables of funding that have the capacity to produce electricity far more efficiently.

The federal government should set the limit for PV expansion in accordance with the projected required need for photovoltaic electricity. In view of the uncertainty in this regard, a certain amount of surplus capacity would be acceptable. Against this backdrop, the 500 MW annual limit proposed in one study (Bode and Groscurth 2010, p. 22) may be too low.

In the event such a limit is instituted, support would have to be awarded solely on a first come first serve basis. An annual reduction of the feed-in tariff should also be retained so that the amount of support can take account of manufacturing and installation cost reductions. The amount of photovoltaic support and adjustments thereto can be based to some extent on PV module prices on the international market. If the allowable expansion capacity is exhausted relatively early in any given year, this can be taken as an indicator of excess support and should prompt further tariff reductions.

Should photovoltaic energy expansion fall far short of the upper limit, it may be necessary to slow the pace of feed-in tariff reductions. Another option worth considering is having 50

percent of the expansion limit apply to six months of each year, since this would provide PV system contractors with a better planning timeline.

In line with the new feed-in tariff regulations for solar power promulgated by the 2010 EEG, support for PV systems should exclude farmland-use changes since such arrangements would intensify the conflict between electricity generation and food production (as is already the case with biomass) to the detriment of nature conservation.

### 8.3.4.2 Promoting onshore wind energy

Onshore wind energy support under the Renewable Energy Act (EEG) has proven to be successful. Wind energy accounts for more than 50 percent of Germany's renewables electricity, but makes up only around 25 percent of the 2010 EEG cost apportionment (Wenzel and Nitsch 2010, p. 45). Onshore wind energy support has also opened up considerable cost reduction potential in this sector. According to Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) estimates, the specific costs per kilowatt hour of annual electricity output have been halved since 1990, with electricity generation costing between 5 and 12 ct/kWh at a good onshore sites (BMU 2009, p. 70).

According to all of the SRU scenarios, the lowest onshore wind energy should have a capacity amounting to about 40 GW in 2050. This would equate to an approximately 45 percent increase relative to today's installed capacity and electricity generation of around 90 TWh/a. In view of the competitiveness of onshore wind energy relative to other renewables, this relatively modest projected expansion is attributable not so much to cost factors but rather to the supposition that greater expansion would be precluded owing to public opposition. Onshore wind energy expansion should be stepped up if it is environmentally neutral and if no lower-cost renewable electricity sources are available. In addition to building new wind farms, repowering existing onshore wind energy installations will also play a major role.

The existing EEG support framework has the potential to promote the onshore wind energy expansion necessary for a wholly renewable electricity supply. Assuming that the mean annual expansion rate of the past decade amounting to around 2,000 MW continues unabated (see Table 8-7), an installed capacity of around 40 GW found cost-efficient in the scenario calculations will be reached quickly.

Table 8-7

#### Expansion of onshore wind energy capacity, 1999–2009

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Installed capacity (in MW)	4.439	6.104	8.754	11.994	14.609	16.629	18.415	20.622	22.247	23.897	25.777
Source: BMU 2010b											

Hence current EEG provisions for onshore wind energy should be retained, as they offer reasonable return on equity and thus adequate certainty in terms of expansion capacity. The possibility of over-funding is virtually ruled out since onshore wind energy technology costs are less uncertain than the corresponding PV costs.

More important for onshore wind energy will be to meet environmental and nature conservation requirements. In addition to a circumspective use of additional land for onshore wind farms that factors in nature conservation and environmental protection concerns, repowering of existing wind farms is likely to take on greater importance. The extent to which wind farm repowering is compatible with the environment and nearby residents will need to be determined on a case by case basis.

Since the EEG contains a de facto incentive to produce as much electricity as possible (in the form of guaranteed feed-in tariffs for each additional unit), it also provides for an incentive for wind farm repowering. However, determining whether wind turbine repowering will be profitable always involves case by case micro-economic assessments. Repowering is economically reasonable in cases where the profit margin of a new, more powerful wind energy installation is so large that even parks that are not yet fully depreciated can be amortised. However, article 30 EEG provides an additional repowering incentive of 0.5 ct/kWh for initial feed-in tariffs. Another consideration here is that investors should prefer repowering over development of a new site since the former entails less elaborate planning.

As wind farm construction projects often encounter public opposition, the possibility of involving municipalities and local investors via so called citizens' wind farms should be considered, for experience has shown that this model can promote winning public acceptance.

It is becoming increasingly important for intermittent wind energy to be able to perform system services for ensuring electricity system functionality such as frequency and voltage stabilisation, re-establishing supply post power failure, and system and operational management. In contrast to some criticism (Börkey and Jahn 2010, p. 14 f.), the EEG at present actually lays down the relevant requirements in respect to such functions. The EEG amendment in 2009 implemented the System Service Ordinance (*Verordnung zu Systemdienstleistungen durch Windenergieanlagen, SDLWindV*), adherence to which for wind farms is mandatory pursuant to Article 6 EEG. The wind farm requirements laid down in this instrument relate to frequency stabilisation, voltage stabilisation and system behaviour in the event of grid disturbances. Frequency fluctuations result from an imbalance between power generation and electricity use. Deviations from the nominal frequency are corrected through the use of balancing power. Wind farms have – unlike conventional power stations – thus far not been involved in the provision of balancing power. It becomes more difficult to stabilise grid voltage if conventional power stations that participate in voltage stabilisation via synchronous generators come under pressure from wind farms and new facilities providing

reactive power are not installed. In the past, grid disturbances induced by a short circuit resulted in wind farms being simply shut down. This mechanism posed no problem as long as relatively little wind power was being fed into the grid, but does cause problems when large amounts of electricity abruptly disappear from the grid owing to a short circuit. Short circuits are a relatively frequent occurrence in overhead power lines. But the growing amount of wind energy being fed into the grid has complicated the task of maintaining network security in cases of large-scale wind farm capacity shut downs resulting in a power short-fall.

According to the aforementioned ordinance (SDLWindV), the technical requirements of the *TransmissionCode VDN 2007* and the Medium Voltage Directive (*Mittelspannungsrichtlinie 2008*) issued by the *Forum Netztechnik/Netzbetrieb* (FNN) are applicable. However, it also provides some clarifications and adjustments as to wind energy. Although these voltage stabilisation requirements can be met by installing additional electronic components facilitating the provision of reactive power, meeting the frequency stabilisation requirements is no easy matter. Even if wind turbine output can be reduced in an emergency for frequency stabilisation, owing to the intermittence problems they cannot be used to generate balancing power that is available at all times. Thus it is all the more important that storage capacity, as well as renewables such as biomass, be available whose electricity generation capacity can be keyed to demand at any given time.

## **8.4 Incentives for storage capacity expansion**

The growing proportion of intermittent renewable energy will make it increasingly necessary for the entire power station fleet to be flexible, since energy security hinges on electricity generation being keyed to electricity demand at all times. Although this task is nowadays mainly performed by conventional thermal power stations, various instruments, apart from flexible use of such installations, that help to harmonise electricity supply and demand are available – namely energy storage installations, cross-border grid expansion, and demand-side management (DSM).

As the transition to a wholly renewable electricity supply will undoubtedly be marked by a decreasing share of electricity being produced by conventional power stations and since the potential for DSM measures is regarded as small (Grimm 2007, p. 16; Paulus and Borggreffe 2010, p. 4), grid and energy storage installation expansion will take on major importance. Which mix of these options will be most economically efficient cannot be ultimately judged yet. However, it can be concluded from the results of the scenarios – which are based on cost optimised use of storage capacity, an expanded European grid, and various renewable resources – that the storage capacity needed by 2050 will far exceed the capacity of pump storage available in Germany today (around 7 GW of storage installation output and 40 GWh of storage installation capacity).

Although energy storage installations may serve numerous energy supply purposes, this report focused on centralised storage of large amounts of energy for the following purposes: to compensate for seasonal energy intermittence; to bridge longer periods of downturn; for electricity trading (particularly to offset daily fluctuations); and balancing functions via system services. Relative to decentralised storage, the advantage of large scale storage installations in tandem with grid expansion of adequate scope is that they lend themselves to optimisation of the electricity supply system as a whole and are generally less cost intensive thanks to economies of scale (R2B and CONSENTEC 2010, p. 3; Agricola et al. 2010, p. 74).

The technologies that appear to be suitable for large centralised storage installations are pump storage systems, advanced adiabatic compressed air energy storage (AA-CAES) and hydrogen and methane storage installations. However the investment costs for all of these technologies are high, their write-down periods are lengthy, and the extent to which they would be subject to competition and the scope of actual storage needs are difficult to determine – factors that add up to a major investment risk for such technologies (Leonhard et al. 2008, p. 7). To make matters worse, the relevant technologies display widely varying degrees of market maturity and market potential. While pump storage systems represent the state of the art at present and have been successfully used. AA-CAES and hydrogen/methane storage technologies are still under development. Most of Germany's pump storage system potential has already been exhausted, whilst both these other technologies offer promising opportunities. Cross-border grid expansion would allow for exploitation of the considerable potential in Scandinavian states (up to 120 TWh), as well as in Alpine countries.

In view of the high investment risk and varying degrees of market maturity involved, the geographical distribution of exploitable potential, and the grid expansion needed to develop it, it is uncertain whether market forces alone would provide sufficient incentives for the development of the storage capacity necessary for renewable energy expansion. In the interest of shedding light on this matter, the following will now discuss the electricity market forces that could potentially serve as incentives for such development. This is followed by an analysis of the economic potential of linking the German grid with Norwegian pump storage system capacity and of possible support instruments in Germany.

#### **8.4.1 Economic incentives for storage capacity in the electricity sector**

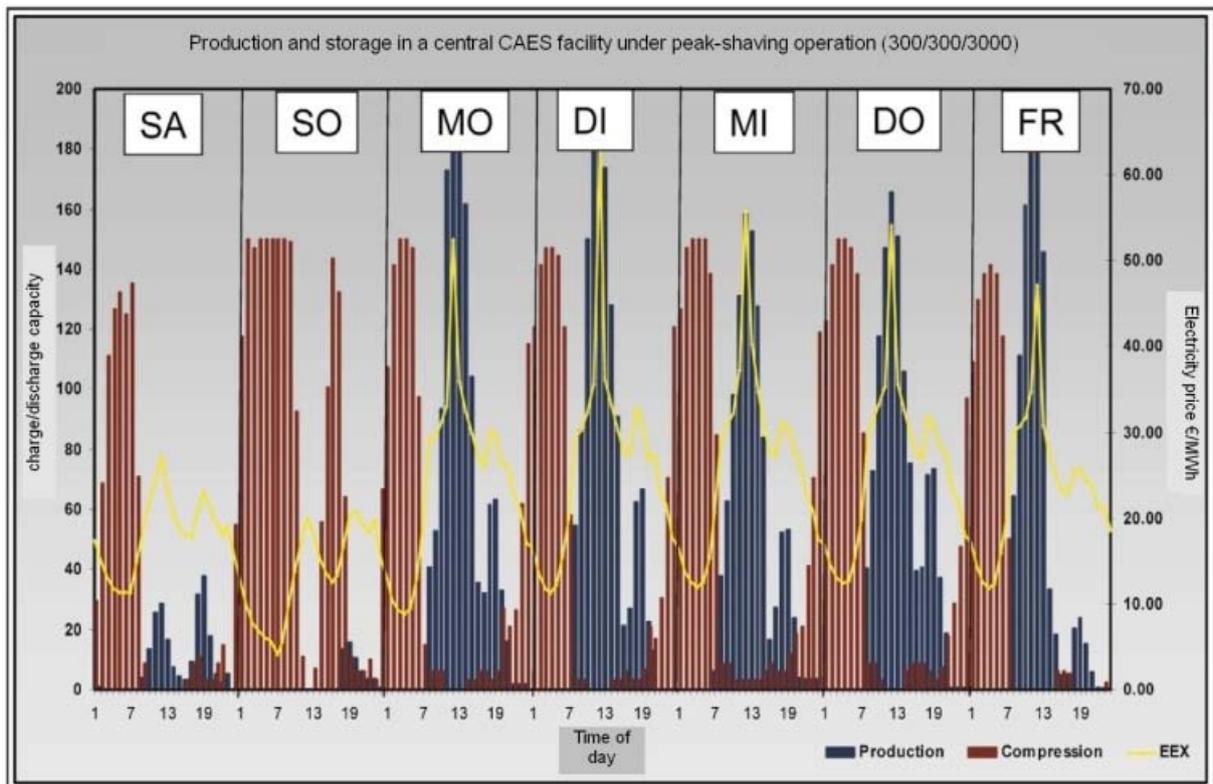
The two main application domains for large stationary electricity storage installations are energy trading and balancing functions. The most commonly used and economically oriented instrument in the realm of energy trading is known as inter-temporal arbitrage, whereby, in a process known as peak shaving, during low-load periods inexpensive electricity from power stations with low variable electricity generation costs is converted into high priced peak load electricity (Gatzen 2008, p. 25). The profit margin resulting from this mechanism comprises

the price difference minus storage loss and variable operating costs. This margin is used to finance the investment costs.

A common compressed air energy storage (CAAE) use case for peak shaving operation is illustrated in Figure 8-13, which shows that the low weekend and nocturnal price is leveraged to store electricity, which is then fed back into the grid at a higher price. But this use case also shows that energy storage tends to bring about greater demand price elasticity and thus helps to even out intra-day price differences. In other words, storage capacity growth reduces storage capacity profitability and in so doing ultimately robs such capacity of its economic viability (Leonhard et al. 2008, p. 16). Unlike other sectors that display such effects, there is at present no scientific evidence concerning (a) the interplay between storage capacity growth that is necessary from a technical standpoint in order to assure grid stability and the impact of such growth on spot market prices; and by extension (b) the economic incentives that would potentially promote investments in system security technologies.

Figure 8-13

**Common compressed air energy storage (CAAE)  
peak shaving use case for spot trading**

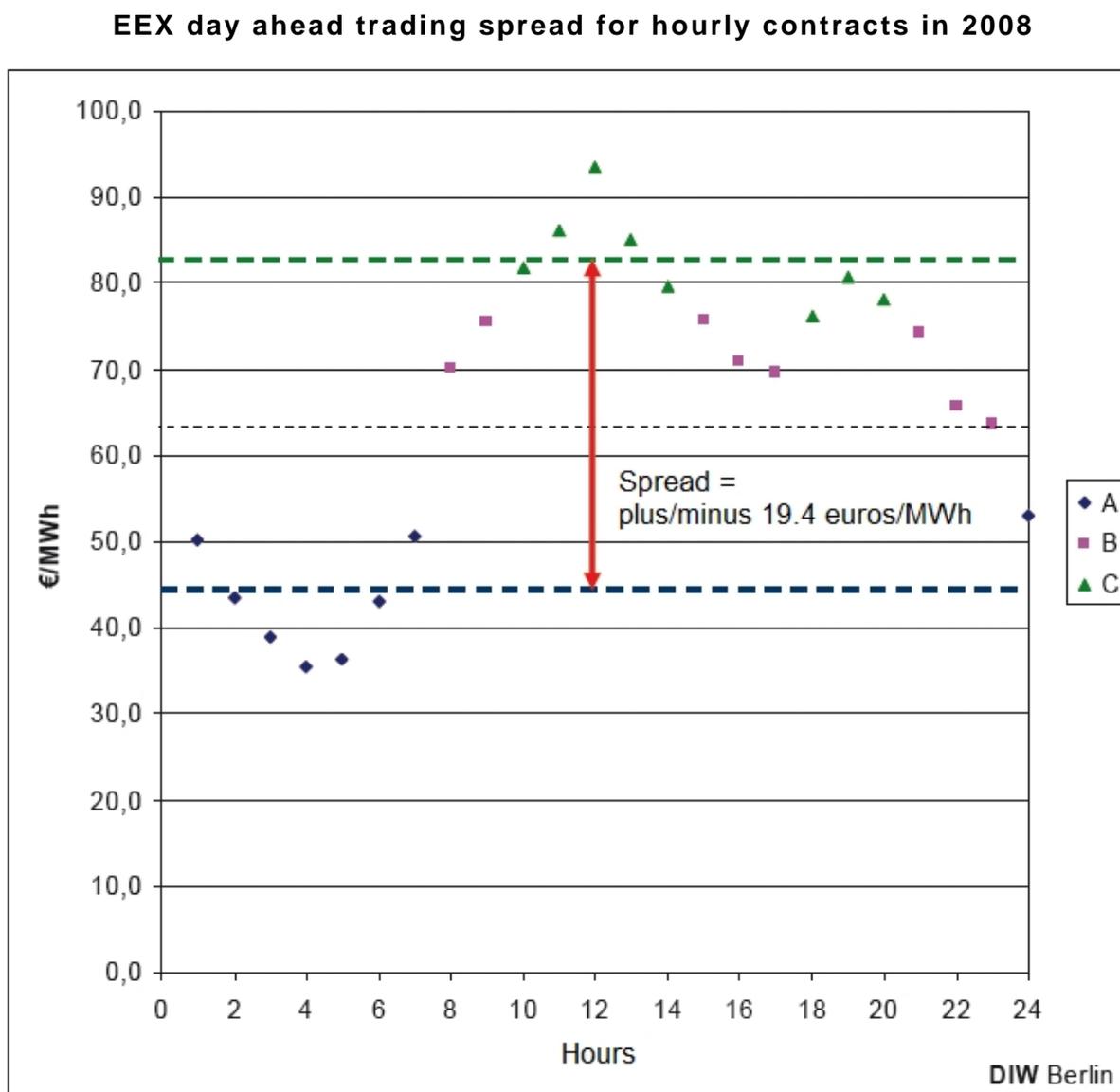


Source: Leonhard et al. 2008, p. 16, based on EWI

Using historical spot market prices, it is possible to investigate whether investing in storage technologies under current market conditions would be economically viable. In one such study, concerning the combined cycle thermal power station bonus, the mean spread

between the eight hours with the highest prices for 2008 EEX day ahead hourly contracts (category C: 82.7 €/MWh) and the eight hours with the lowest prices (category A: 43.9 €/MWh) for the same day was calculated (Schmidt et al. 2009); the spread was around 39 €/MWh ( $\approx 4$  ct/kWh) (see Figure 8-14).

Figure 8-14



Source: Schmidt et al. 2009, p. 46, based on DIW

Around 70 percent efficiency for adiabatic compressed air energy storage (AA-CAES) installations is being sought. This efficiency level means that only 70 percent of stored electricity would be fed back into the grid. In the use case described above (for spot market year 2008) an AA-CAES operator's margin on the mean spread of around 4 ct/kWh would have been only 1.4 ct/kWh ( $0.7 \cdot C - A$ ) after deduction of storage losses. Revenue from this margin would still have to cover variable costs and investment costs. It is doubtful that this 2008 spread would have provided a sufficient incentive for investments in storage capacity growth. However, pump storage systems – albeit ones with higher efficiency ranging up to 80

percent – are being operated in a cost effective manner already today, and thus renewable energy expansion above and beyond today's levels would likely translate into larger spreads in future.

But this use case also clearly shows that inter-temporal arbitrage operation of electricity storage installations is only cost effective if only a few days or hours elapse between electricity input and output cycles. Hence, according to VDE calculations, long term electricity storage involving less than one cycle weekly to compensate for general weather situations and seasonal fluctuations would not be cost effective in Germany under current market conditions (Leonhard et al. 2008, p. 7). However, long term storage capacity will be needed in order for thermal power plants to be replaced by renewables in the long run.

On closer scrutiny, it turns out that the pump storage systems in operation in Germany today are pursuing operating strategies apart from the use of inter-temporal arbitrage. Table 8-8 displays the storage installation usage options in today's market and the attendant competing modalities.

Table 8-8

#### **Profitability options for energy storage technologies**

<b>Potentially profitable energy storage strategy</b>	<b>Characteristic storage technologies</b>	<b>Competing modalities</b>
Inter-temporal arbitrage (peak shaving, load management)	Pump storage systems, compressed air energy storage (CCAЕ)	Gas turbines (OCGT); demand side management (DSM); flexible operation of thermal power plants; cross-border electricity trading
Provisioning of balancing power and reserve capacity and energy	Pump storage systems, compressed air energy storage (CCAЕ)	Gas turbines (OCGT); demand side management (DSM); flexible operation of thermal power plants
Provisioning of other system services (voltage stabilisation, black start capability)	Pump storage systems, compressed air energy storage (CCAЕ), batteries	Thermal power plants; flexible three-phase current transmission systems
SRU/SG Strom 2011-1, as translated from Gatzen 2008, p. 25		

Operators in the relevant markets can also offer balancing power and system services, depending on the specific storage technologies. While pump storage systems are often used nowadays for secondary balancing power services, compressed air energy storage (CCAЕ) systems are mainly suitable for minute reserves owing to their relatively lengthy start-up times ranging up to 15 minutes. Both of these technologies can be used for reactive power and for black starts, although the latter technology makes no contribution to cost effective operation owing to the low demand for it (Leonhard et al. 2008, p. 17).

System services, such as balancing power, for centralised large scale storage systems (such as pump storage systems or AA-CAES storage installations) can help to optimise system profitability. But as this is only a minute and highly risky market segment in Germany, peak shaving is the state of the art mechanism for profitability optimisation of large scale storage installations (Gatzen 2008, p. 50). This segment is of little appeal at present, despite the technological necessity of integrating storage installations into the balancing power market segment (Sterner et al. 2010, p. 114).

The extent to which renewable energy expansion will affect sales growth in the system services segment, particularly for balancing power needs, is currently unclear. According to one projection, the balancing power market will grow very little if renewables account for 30 percent of energy demand or less, owing to the improved outlook for wind and solar energy input into the grid. However, if the share of renewables rises above 30 percent, minute reserve demand is likely to rise (R2B and CONSENTEC 2010, p. 15); and this in turn may make system services more attractive for the operation of large scale storage facilities.

#### **8.4.2 Norwegian pump storage capacity**

Pump storage is the most cost efficient technology for both short and long term storage of large amounts of energy (Agricola et al. 2010, p. 75), and also has the virtue of being technically compatible with all system service provisioning modalities. While most of Germany's pump storage system potential has already been developed, massive amounts of pump storage capacity are still available in Norway. Essentially the same economic incentives in terms of pump storage system cost efficiency apply in both Norway and Germany (assuming that the grid is expanded to the requisite extent and the relevant market sectors are integrated into the grid infrastructure), with one important exception – namely that Norway's storage hydroelectric power stations and their attendant lake systems could be converted into pump storage systems at a far lower cost relative to Germany's compressed air energy storage (CCAES) potential, and would also be far more efficient; which means that with even a low variable gross margin from inter-temporal arbitrage operation would yield a robust ROI.

Hence conversion and use of Norwegian pump storage system capacity already offers financial advantages under today's market conditions – providing, that is, that the German government dependably commits itself to this goal and the requisite development of cross-border transmission capacity occurs.

A scenario whereby Norwegian storage installation operators would charge “exorbitant prices” (Joseph 2010) is less likely to occur since Norway's installations are mainly financed via inter-temporal arbitrage (as in Germany), and thus profit margins are determined by spot market prices and spreads. Moreover, even if Norwegian operators dominate the electricity storage sector and are in a position to exercise their economic power, storage costs are

unlikely to rise unduly since each instance of storage capacity use reduces the attendant price spread and holding back such capacity would undermine its cost effectiveness. Moreover, market domination by Norwegian operators is unlikely since storage services in the run-up to 2050 will still be competing with conventional thermal power plants. Additionally, other storage capacity is expected to be developed in Germany during this transitional phase (i.e. AA-CAES). This competition scenario also applies to storage installation use in the system services sector. However, this does not change the fact that that greater use of Norwegian storage capacity at the expense of Germany's will result in German storage and system services sector value creation being lost to that of Norway.

### **8.4.3 Support schemes in Germany**

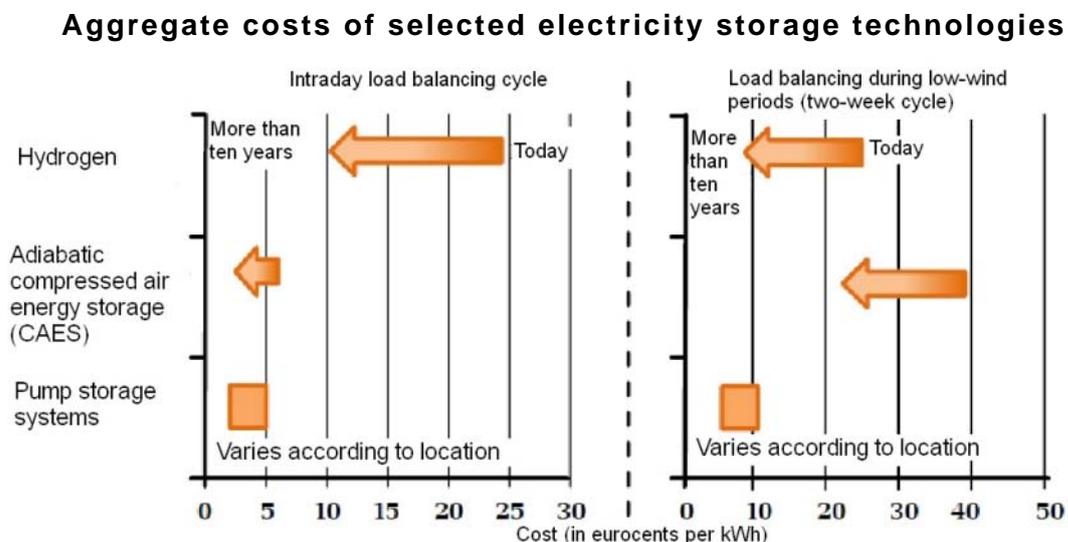
Although pump storage systems cost less to operate – over the long run thanks to their higher efficiency – than adiabatic compressed air energy storage (AA-CAES) or renewable energy installations that recapture methane, it may still make sense in the medium term to expand Germany's storage capacity potential. This would be justifiable on the grounds of reducing dependence on foreign imports, promoting value creation in our own economy, and ensuring network stabilisation via providing system services local.

Whether market-based incentives alone will be enough to spur expansion of German storage capacity, is not undisputed. In the literature one can find varying assessments concerning the cost efficiency of electricity storage installations in Germany. For example a study commissioned by the Federal Ministry of Economics and Technology came to the following conclusion in this regard: "The electricity and balancing power sectors will be able to generate sufficient incentives to spur storage technology development to the requisite degree. Hence this sector is by no means threatened with collapse, nor will technology support be needed, particularly for small decentralised installations" (R2B and CONSENTEC 2010, p. 110). The VDE came to the opposite conclusion: "The long term statutory and energy-sector groundwork for storage installation operation remains to be laid; but this process cannot be set in motion without robust start-up support and incentives" (Leonhard et al. 2008, p. 7). The Boston Consulting Group (BCG) concurs in this view: "Because the financial logic for investing aggressively to advance storage technologies is currently not compelling, incentives will be necessary to ensure that sufficient storage capacity is online in time to meet governments' green-energy targets" (Pieper and Rubel 2010, p. 1).

The foregoing analysis of 2008 spot market prices (spread approximately 4 ct/kWh) in conjunction with projected aggregate compressed air energy storage (CAAE) and hydrogen costs as per Figure 8-15 clearly shows that current electricity sector incentives alone at best set only unclear signals for investing in storage installations. Hence the question arises as to whether further support may be necessary in order to appropriately expand storage installations to the requisite degree. This situation is complicated by the fact that compressed

air energy (CCAEE) and hydrogen storage technologies lack market maturity so far and need further research and development.

Figure 8-15



Source: Agricola et al. 2010, p. 75, after VDE

In Germany, the possibility of promoting storage capacity expansion is mainly being investigated at present in the context of the Renewable Energy Act (EEG), with current discourse in this regard centring around the combined cycle thermal power station bonus and the flexible market premium.

The main purpose of the flexible market premium is to facilitate market integration of renewable energies by keying renewable electricity generation more closely to market price signals – but without affecting the investment certainty entailed by EEG support (Sensfuss et al. 2007, p. 1; R2B and CONSENTEC 2010, p. 49). Hence this model is seen as an optional support instrument, second to feed-in tariffs (Sensfuss and Ragwitz 2009, p. 2), offering every EEG installation operator to choose each month between the feed-in tariff and market premium mechanisms.

The market premium enables EEG installation operators to sell their electricity on the spot market and also receive a premium that is intended to compensate for the difference between the EEG feed-in tariff and the operator's sale proceeds so as to ensure that the operator's revenue is at least on a par with what it would be with a fixed feed-in tariff (R2B and CONSENTEC 2010, p. 50). Moreover, the amount and components of the market premium can vary (for a detailed description of one such variant, see Sensfuss and Ragwitz 2009, p. 6). The market premium instrument affords EEG installation operators the opportunity to increase their installation's revenue by providing an incentive to key their electricity generation more closely to electricity demand and thus to market prices, by changing their operating strategies through measures such as market optimised

maintenance, or adopting innovative solutions such as the use of energy storage installations (Dietrich and Ansehl 2010, p. 63).

Under certain conditions, the market premium also provides biomass and biogas electricity installation operators with an incentive to run their installations in load following mode by leveraging the natural storage properties and low storage loss of these energy sources. However, when it comes to photovoltaic and wind energy there is only limited opportunity to react to load balancing-related market signals (Sensfuss and Ragwitz 2009, p. 12). Maximum wind farm or photovoltaic installation output is determined by the relevant weather conditions. Hence, owing to low marginal costs, it does not make economic sense for their operators to curb output when electricity prices are relatively high (R2B and CONSENTEC 2010, p. 66). Installation operators will only be prompted to invest more capital into storage capacity if the market signals unambiguously indicate, not only to these operators but also to third parties not eligible for market premiums, that such investments are financially attractive.

Market premiums pave the way for the integration of renewables (particularly biomass and biogas) into the relevant markets more effectively than is the case with fixed feed-in tariffs. They may also open up the possibility of instituting new organisational structures and business models such as partnerships with large energy installation operators or with manufacturing companies that display considerable DSM potential (R2B and CONSENTEC 2010, p. 67). However, flexible market premiums promote decentralised energy storage only indirectly and, in their present form, provide virtually only negligible investment incentives for large centralised storage installation technologies. Hence such premiums can at best play only a supporting role when it comes to promoting the development of storage technologies for large amounts of electricity.

Like market premiums, combined cycle thermal power station bonuses are intended to provide incentives for operators of renewable energy installations to key their output to electricity demand, and to promote the development of electricity, heat and gas storage installations under the EEG (R2B and CONSENTEC 2010, p. 77). "Combined cycle thermal power station" in this context refers to an EEG installation that is coupled with an electricity, fuel or heat storage installation being fed by the EEG installation to at least 95% (Dietrich and Ansehl 2010, p. 62). Examples are biomass installations with gas storage facilities, combined heat and power (CHP) installations with heat storage facilities, and wind farms with electricity storage installations. The installation and its storage facility must also be located in the same region, e.g. balancing zone (Schmidt et al. 2009, p. 24).

In order for the operators of combined cycle thermal power stations to be incentivised to key their energy storage operations to market demand, an artificial price signal needs to be generated that prompts these operators to hold back their energy for a later demand optimised period (Schmidt et al. 2009, p. 30). To this end, the combined cycle thermal power station bonus provides for a demand component and a technology component. The first is

determined by the time at which the electricity is fed into the grid, e.g. 2 ct/kWh for electricity input during the eight hours of the day with high residual load; the latter is paid as a technical performance-related investment grant (Schmidt et al. 2009, p. 24).

In contrast to how market premiums work, the technology component of the combined cycle thermal power station bonus in particular provides a direct incentive for storage capacity technology investments. However, owing to the model-specific simplification of the market signal in this model (which indicates relative scarcities only), it is uncertain to what degree the actual need for balancing electricity supply and demand is correctly depicted (R2B and CONSENTEC 2010, p. 78). The incentive is aimed solely at balancing intra-day fluctuations in residual load; an incentive for operators to balance seasonal and other longer term fluctuations is not provided. Moreover, this model does not aim to promote optimisation of the electricity system as a whole in that it applies solely to EEG installation energy output and focuses on decentralised storage capacity owing to the current design of its technology component. Hence combined cycle thermal power station bonuses can make only a limited contribution to promoting the development of large centralised energy storage installations that have been the focus in this report.

Direct storage support under the EEG is inevitably limited to renewable energies – an arrangement that leads to certain economic inefficiencies in the support system as a whole. Hence in our view the EEG is not an appropriate platform for the expansion of centralised storage capacity. For existing adiabatic compressed air energy and hydrogen storage potential to be exploited cost efficiently in Germany (along with storage installations for methane from renewables) it is necessary to first promote their competitiveness – which is why the SRU recommend a dedicated research program.

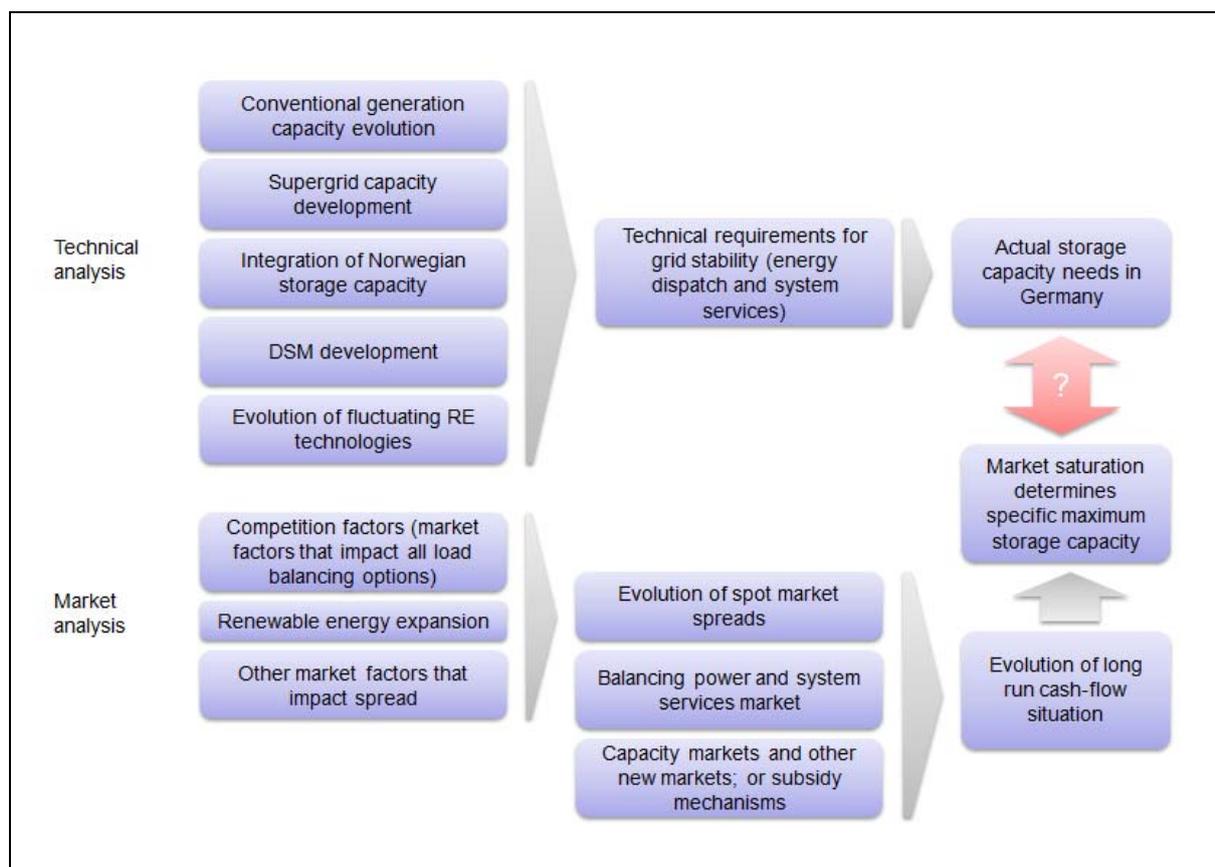
To date, the strategic importance of energy storage to the energy sector has so far been reflected to only a limited degree in research promotion in this area (Oertel 2008, p. 142). However, greater success could be achieved by prioritizing and bundling specific application areas of storage research. For example, research is needed in the field of the development of high temperature storage installations as used in the construction of adiabatic compressed air energy storage (AA-CAES) installations (Oertel 2008, p. 142). A research program in this realm should fund not only applied research but also demo and pilot installations. In the interest of preventing unsuccessful projects from being funded, as has often happened in the past, the most promising projects should be prioritised and continued support should be contingent upon the project achieving its mandated milestones. As for pilot projects, they also offer the opportunity of to gaining experience concerning the economic optimisation of storage installation in various market sectors.

As noted, the complex interplay between the risk factors entailed by the operation of large storage installations in Germany (see Figure 8-16) makes it impossible to assess reliably whether market incentives alone can spur the requisite level of energy storage capacity

expansion. Hence, detailed studies should be conducted, in tandem with the aforementioned research programs. Such studies should focus on the technical needs and actual developments as well as on the revenue situation in the storage technology arena. In particular, they should consider the impact of other storage capacity (e.g. in Norway) and of competing technologies (such as conventional power plants) on revenues (i.e., the price spreads).

Figure 8-16

**Investment uncertainty concerning large storage installations  
in Germany**



.....SRU/SG 2011-1/Fig. 8-16

Even if the relevant price spreads increase substantially over today's levels (see Figure 8-14), investors are still likely to remain hesitant to invest in storage installation projects owing to their complex risk structure and the attendant risk premium. This is also likely to hold true even if operating revenues cover installation refinancing costs, so that measures to optimise investment certainty would be required. This could be achieved by, for example, instituting a fund for protection against operational risk along the lines of the offshore wind energy support scheme as proposed in this report.

It is hardly possible today to determine whether the highly technical system reliability requirements of a high-renewables electricity system in terms of seasonal (or, as in the case of low wind years even multiyear) balancing of large amounts of energy are reflected in the

price spread under the current market design. This matter should be the subject of a detailed study that also seeks to devise instruments that will allow for the internalisation of system reliability costs. Potential instruments should be oriented toward the entire market. Small-scale solutions such as storage promotion under the EEG would result in undesirable inefficiency and should thus be avoided. Such studies could focus on structural changes in the market such as expanding the balancing power sector or creating a market for services to ensure system security (e.g. backup capacity provisioning and energy storage across seasonal or multi-year cycles). Such services could be purchased by grid operators, who are legally responsible for system reliability pursuant to the Energy Industry Act (EnWG).

#### **8.4.4 Conclusions**

All of the storage technologies necessary for security of supply in an electricity system with a large share of renewables are available, but in some cases bringing them to market maturity will require a major effort (Leonhard et al. 2008, p. 6).

Pump storage is the most cost efficient technology currently available for supply and demand harmonisation and system services provisioning. The economic incentives to operate existing pump storage systems are adequate already under current market conditions. However, in view of the limited pump storage system potential in Germany, the SRU considers it pre-conditional for further renewables expansion that Germany uses and integrates Norway's potential in this domain. Hence the grid expansion necessary for this integration is absolutely pivotal for achievement of a wholly renewable electricity supply in Germany.

The development of centralised large scale storage installations in Germany will also take on growing importance in the future. In view of the uncertain state of technological and economic development of adiabatic compressed air energy storage (AA-CAES) and hydrogen storage installations it would make good sense to promote R&D and the realisation of demo installations in this realm. Support for storage installations under the EEG is not recommendable.

If storage installation expansion is to be spurred by market incentives alone, it is absolutely essential that robust policy and legal frameworks be established in this realm. For centralised large scale storage installations have long depreciation periods, actual needs and the scope of competing technologies are difficult to determine and the earnings potential is complex – and thus the economic stakes are high. If market incentives alone fail to ensure the expansion of sufficient energy storage capacity that assures system reliability, then additional measures will need to be taken that reduce investment risk and internalise system security costs. Such measures could include the following: establishing a fund to mitigate the effects of system failure; expansion of the balancing power sector; and establishing a market for services ensuring system reliability (such as backup capacity provisioning or energy storage

across seasonal or multi-year cycles). However, extensive research in this field is still needed (BMW and BMU 2010, p. 25).

In view of the analysis presented in this chapter, we recommend that the following actions be taken:

- The electricity grid should be expanded so as to allow for integration of Norwegian energy storage capacity.
- Applied research should be conducted with a view to bringing German AA-CAES, hydrogen, and methane storage capacity to market maturity.
- German storage capacity demand and the interplay between this demand and the development of existing market incentives should be studied.
- In the event market incentives should be insufficient, instruments aimed at mitigating investment risks for large scale storage installation and internalizing system reliability costs should be developed.

## 9 The conditions of electricity grid expansion

Electricity grid expansion is one of the main obstacles to achieving a wholly renewable electricity supply, for which, as previously noted, it is vital to step up the pace of grid and storage capacity development. In the interest of enabling our nation to achieve security of supply, our electricity supply infrastructure will need to have the capacity to adjust to decentralised generation modalities and greater fluctuation in generation capacity. However, grid expansion is necessary not only due to the additional renewable energy that would be fed into the system, but also owing to the grid capacity needs attributable to changes in energy generation modalities resulting from envisaged new power plants (Schmitz 2010, p. 200) and to the development of transit flows (Bundesnetzagentur 2008b, p. 2; Deutscher Bundestag 2008a). Expansion of the transmission grid will prove unavoidable in any case, even if renewable capacity is expanded to only a moderate extent. As political leaders and policymakers have often stated, extensive development of electricity transmission capacity is a matter of both domestic and international importance (Oettinger 2010; Röttgen 2010; BMU et al. 2002; Kurth 2010; dena 2005; Wagner 2009; Blass and Scheerer 2010, p. 46).

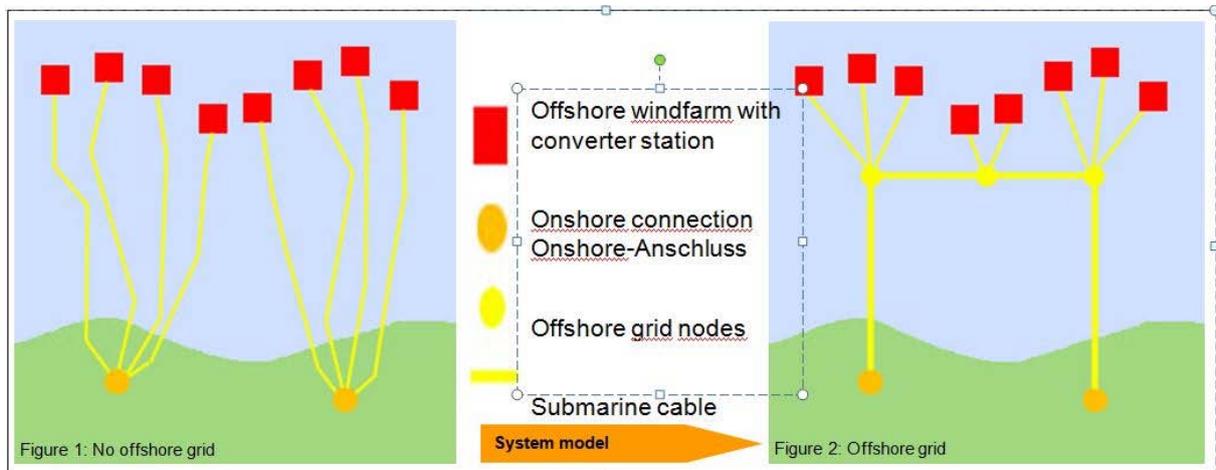
The SRU proposes that grid infrastructure development measures should unfold as follows. First, over the next decade domestic and trans-regional development (objectives 1 and 2) via new point to point connections should be given top priority. These installations will set the stage for the next step, which is realisation of a Europe-North Africa high capacity network (objective 3), whereby the following milestones would come into play:

- At the national level (goal 1), offshore wind farms should be integrated into the German electricity grid, while at the same time the transmission capacity between Germany's North Sea coast and electricity demand centres in western, central and southern Germany would be expanded.
- At the trans-regional level (goal 2), a trans-regional electricity network should be established between Germany and Scandinavia by expanding transmission capacity.
- At the international level (goal 3), efforts should be made to gain support for establishment of a Europe-North Africa supergrid (overlay grid), which would lend itself to being incrementally expanded eastward and southward from western and northern Europe, until such time as across the board international cooperation is achieved.

At the national level over the next decade, the requisite grid expansion will chiefly be influenced by the rapid growth of wind farms (dena 2005), which must meet extremely stringent ecological and economic requirements. To this end, the connection of offshore wind farms to the onshore grid must be carefully coordinated, and any lack of coordination in this regard must be strictly avoided. It is more cost efficient and environmentally sounder to have a number of wind farms connected via nodes to transmit electricity to the mainland via only a few submarine cables in the Wadden Sea (see Figure 9-1).

Figure 9-1

### Line proliferation versus efficient grid planning



Source: dena 2009

In addition to connecting offshore wind farms to the national grid, it will also be necessary to install an overlay network along Germany's existing north-south transmission lines so as to allow for the transport of current from new electricity generation centres in northern and northeast Germany to demand centres in western and southern Germany; for there will be an influx of additional electricity not only from offshore wind farms, but also from high output onshore installations, mainly on the German coast.

There is a strong consensus concerning the need for new north-south transmission lines (Barth 2010; dena 2005, p. 64; BMWi and BMU 2010, p. 21; Bundesnetzagentur 2008a, p. 6). In addition, as noted, extensive transmission capacity to Scandinavia will be needed in the short term, followed in the longer term by a comprehensive Europe-North Africa high capacity network. These new transmission lines will be necessary even if the European-wide share of renewables will be smaller, as demonstrated in the European Commission's assessment of the necessary expansion of interregional and cross-border electricity lines (in its Communication to the Council and the European Parliament on the priority interconnection plan (see European Commission 2007).

It is generally assumed that the establishment of an internal European electricity market and the attendant free-market competition will result in lower electricity prices (Geden and Fischer 2008, p. 20). Under a renewables perspective, however, the extension of cross-border interconnectors must be given priority so as to allow for cross-border electricity interchange.. (BMU 2002, p. 19; Bundesnetzagentur 2008a, p. 14 f). This applies in particular to establishing transmission capacity northward to Scandinavia and southward to Austria and Switzerland.

## Grid expansion versus grid optimisation

In addition to systemic grid point to point connections, greater grid transmission capacity will also be needed in a number of regions, particularly near major onshore wind farms, and new transmission lines may also have to be built (Bundesnetzagentur 2008a, p. 39 f). To increase grid transmission capacity, according to Articles 5(4) and 9(1) of the Renewable Energy Act (EEG) and Article 11 of the Energy Industry Act (EnWG), the potentials of grid optimisation and strengthening measures should be utilised so as to ensure that the aforementioned capacity expansion is realised as cost effectively and ecologically as possible. The said statutes call for a stepwise approach, whereby each step entails higher costs (for Transpower also see: Fuchs 2009; Jarass et al. 2009; for a critical view by Amprion see Barth 2010; concerning the relevant technical options see Ensslin et al. 2008):

- Grid optimisation: The existing grid can be optimised via measures such as (a) increasing nominal grid voltage; (b) load flow regulation by means of regulators; or (c) using grid reserves that are for the most part already available, via line monitoring.
- Grid strengthening: If grid optimisation is not sufficient, overhead lines can be equipped with high temperature instead of conventional cables.
- Building new lines: If the two aforementioned (and less cost intensive) options are not effectual, new power lines have to be installed.

Ramping up transmission capacity in this order is a cost optimised and ecological approach, which has been prescribed by law since 2009. In addition, the cause of persuading the public to accept new power lines will be served if alternative solutions are explored first.

Renewable energy development will also entail expansion of distribution grids (Schmiesing 2010; Kurrat 2010). Modifications will be particularly needed in areas where the share of solar and wind energy is growing and current often flows back into the transmission network from the distribution grid (Igel et al. 2010). However, this issue falls outside the scope of the present report.

The following paragraphs explain the key policy recommendations for reforming grid regulations in Germany. A detailed analysis of the functioning of regulation and planning in Germany can be found in the German version of this report.

### **9.1 Improved incentives for transmission grid expansion**

The German incentive-based regulation aims to give network operators the opportunity to increase their net earnings by optimizing the efficiency of their installations. However, as the current incentive system was introduced only recently, it may thus be necessary to develop the existing framework further so as to allow for the requisite development of the transmission network. It should also be noted that a system based on a series of separate decisions may well engender uncertainty as to the expansion of the electricity grid as a

whole. To avert this problem, the Federal Network Agency (Bundesnetzagentur) grid expansion model referred to in the guidelines to the investment budget applications should be implemented without delay, so that the regulatory authority can use it, if necessary, to assess envisaged line installation projects. In our view such assessments should be based on the relevant federal grid planning for transmission networks.

Establishment of an overlay grid will necessitate incentives that the current incentive-based regulation was not designed to provide. In addition to lacking adequate incentives in this regulation, obstacles to investments may be created as a result of (a) the vested interests of companies that are not fully unbundled; (b) diverging interests of transmission system operators; and (c) public opposition to such a grid. The SRU therefore recommends that policy instruments clearly differentiate between the existing grid and new point to point connections.

As with offshore wind farms, the SRU considers public tendering for the relevant transmission lines the proper way to build cost intensive national and cross-border point to point connections. Under such a system, the bidder that offers the requisite investment in conjunction with the lowest grid charges over a 20 year period would be awarded the contract. The tender should be based on a federal sectoral plan that allows for determination of demand at an early stage, the transmission line route planning and a debate on alternative routes. Such a national grid development plan, which is also envisaged in the government's master energy plan (BMWi and BMU 2010, p. 20 f), could then serve as a basis for the public contracts according to the existing demand for lines with a minimum capacity.

The advantage of public tendering in this realm is that the overall restructuring of the electricity grid can be strategically coordinated based on the aforementioned demand analysis. In this way the process is no longer determined by corporate interests and can thus be carried out in accordance with actual requirements. This in turn will allow for an expedited and ecofriendly grid integration of offshore wind farms as well as an expeditious establishment of cross-border transmission lines between Germany and regions such as Scandinavia, in cooperation with the relevant partner states. To minimise risks it should be evaluated whether the projects should be split into project development on one hand and construction and operation on the other, similar to what the SRU proposed for offshore wind parks. The aforementioned demand analysis would reveal the scope of the requisite transmission capacity and thus would guarantee optimal capacity use of all grids in the network. The two-stage planning procedure, the SRU recommends would in all likelihood also be more expeditious than the current planning and approval process.

Public tenders for transmission grid development would entail the following further advantages: (a) they would promote competition between bidders that in turn would promote cost efficiency and ultimately reduce electricity prices; (b) as is the case with offshore wind farms, transmission grid expansion could be financed not only by German and international

grid operators but also by consortiums, comprising banks in particular; (c) calls for tenders could be formulated in a manner that promotes the development of new advanced technologies by including qualitative criteria into the tendering process.

In the interest of avoiding the winner's curse phenomenon, for the first 20 years of the contract the winning bidder should be paid the network fees offered by the second best offer bidder. Thereafter the tariff regulations that apply on expiration of this period would come into effect. It is also crucial that a contractual penalty for failure to follow through on a project be instituted, so as to prevent a company that has no intention of constructing the line in question from strategically offering a low price. A contractual penalty would also contribute to ensuring that bidding companies calculate their costs carefully. To ensure the construction of the line, it would also be useful to stipulate that the second company that made the second best offer will automatically be granted the construction permit for the relevant transmission line if the company that made the best offer fails to follow through on the mandated milestones. The expenses incurred up to that point by the company that is awarded the contract will not be reimbursed.

## **9.2 Proposed reforms to the transmission line planning and approval procedure**

As previously noted, transitioning the German electricity system to renewables will entail extensive expansion of the German electricity transmission grid, even in the event Germany falls short of the wholly renewable electricity supply called for by our 2050 scenario. But unfortunately numerous planned transmission system operator investments in such expansion have either not been realized at all or have been subject to considerable delay (Bundesnetzagentur 2009a, p. 134 f) – a situation that has been repeatedly ascribed to (among other factors) an overly lengthy planning and approval process. In view of this problem, in the following we explore ways to expedite this process so as to render it more compatible with the goal of integrating renewables into Germany's electricity supply.

Hereinafter reforms of the current planning and approval procedure for electricity lines will be discussed. First, the main principles that such a reform should adhere to will be discussed. Second, factual as well as legal standards will be described that are needed to assess the reforms proposed. Third, we will conclude by presenting a modest reform scenario whose main aim is to improve planning coordination as well as a much farther reaching reform scenario that calls for a two-tier planning process.

### **9.2.1 Reform principles**

Hereinafter, the main considerations that are relevant for reforming the grid expansion planning process are presented. The key yardsticks for assessing such a proposed reform are whether the reform (a) will satisfactorily expedite the planning process and correct its current problems, (b) can adequately be implemented and (c) has the capacity to address

the existing problems. Hence the reformed procedure will need to ensure in particular that expediting the process does not get in the way of making good decisions (SRU 2007, pp. 281 and 407).

Toward a two-stage plan approval procedure with clearly defined spheres of responsibility and without redundant assessments

One of the main problems with the current legal framework for planning and approving electricity transmission lines is the considerable time that is wasted by redundant assessments. Redundant assessments result from the lack of differentiation between sectoral planning and overall land use planning. The main feature of land use planning is that it is not sectoral, a feature which fails to provide the necessary differentiation. Inclusion of phase 1 environmental impact assessment in the regional planning procedure prevents it from serving as an internal administrative approval process as intended, and instead turns it into a detailed quasi-sectoral planning procedure (Wahl 1991, p. 213 f) that, for private sector stakeholders, is practically indistinguishable from the ensuing plan approval procedure – which, to make matters worse, is applied in widely varying fashions. Hence the various phases of the planning process should be clearly differentiated and transparent for authorities and citizens concerned. The land use planning procedure could for this purpose be reduced to basically balancing different land use needs, as is done in the somewhat cursory and schematic procedure for high-level land use and regional planning (concerning this procedure see Lautner 1999, p. 88 ff; for an argument against overtaxing the land use planning procedure, see Buchner et al. 2008, p. 2). The sectoral planning process should clearly differentiate between the planning of demand that includes the identification of relatively conflict-free transmission line routes on the one hand and the small-scale plan approval process which aims at solving local conflicts.

Toward a two-stage plan approval procedure that allows for sufficient participation by the relevant actors as well as the general public

It is crucial in this context to analyse which consequences different options have for public participation. With a view to the required decision, this process should be adequately structured, substantive and conducive to public acceptance of grid expansion projects. A high-level decision making process involving debates on transmission routes calls for a different type of participatory procedure than small-scale planning that possibly entails expropriation procedures or a direct impact on specific pieces of property. However, high-level processes should also be formalised (but reasonably so) to a greater extent than is currently the case and should allow for early stage participation on the part of all stakeholders, so as to ensure that such processes (a) adequately address the relevant issues; (b) disclose all relevant information; and (c) display an adequate capacity to win acceptance of the project in question.

## Strengthening of European and national transmission line route planning processes

The grid expansion demand identified in the dena *Netzstudie I*, in the UCTE (Union for the Coordination of the Transmission of Electricity) transmission development plan, the TEN-E guidelines and in EnLAG would for the most part involve the construction of transmission lines that cross both German Bundesland (regional state) and international borders, particularly for scenarios involving a northern European or Mediterranean supergrid (Weinhold 2010) – a circumstance that has prompted discussions concerning new planning competences at both the German federal and EU level.

Experience in Switzerland and the U.S. has demonstrated the clear need for grid expansion to be catalysed and conducted at the national level through the institution of overarching policymaking competences. Such an overarching national perspective is unachievable under Germany's current Bundesland (regional state) based land use planning procedure with its badly defined coordination mechanisms – a procedure that has in some cases resulted in a situation where two neighbouring regional states reach differing conclusions as to the grid interconnectors on their common border. In view of the urgency of grid development, it would seem that the competence for planning electricity grids should lie at the federal level (Schneller 2007, p. 532). Lacking that, a more stringent coordination mechanism should be established for the interdependent planning processes carried out by the Länder.

On the other hand, granting the EU land use planning authority above and beyond the financial incentives that are provided by the TEN-competences is unnecessary (at least for Central Europe), and the proposals that have been made in this regard would appear to hold out little promise of political success for the foreseeable future. However, the observation and signaling functions of the EU in the framework of further developing TEN and for ENTSO-E grid expansion planning are undoubtedly useful instruments. In addition, the EU can spur the development of cross-border infrastructures in the sphere of grid regulation. That said, EU intervention would be helpful in terms of developing European technical standards aimed at ensuring that electricity grid expansion in Europe is coordinated and that the various national grids will be interoperable.

## Improved coordination between land use planning, technical planning, and grid regulation

It is crucial that land use and technical planning be coordinated more efficiently with the incentive-based regulation. The aim of the former two processes is to avoid and manage conflicts between various land use needs (concerning a similar coordination optimisation need for the expansion of offshore wind farms and their grid connections see under "F" in Schneider 2010a). Thereby, they provide the legal certainty needed for investments, albeit ultimately only in the guise of an offer for potential investors. The function of the incentive-based regulation is to allow for or even create adequate investment incentives while at the

same time protect grid users against unjustified monopoly profits. In order to avoid overinvestment, stringent demand analyses for new transmission lines are necessary as they are required for the plan approval. Moreover, in view of the fact that the choice of transmission line route or deciding whether to opt for overhead or underground lines can have far reaching cost repercussions, the currently inadequate coordination of planning and network regulation activities needs to be strengthened via the following measures in particular:

- The competent regulatory authorities should reciprocally be involved in the relevant procedures and their decisions should be reciprocally binding.
- The timelines of planning and regulatory activities should be efficiently intermeshed.

#### Optimisation of project procedures

As experience in Switzerland and elsewhere has shown (Schneider 2010b), it can be very useful to institute flexible procedures that can be adapted to the complexity of the relevant project, actual realisation needs, and conflicts that may arise or that have occurred in the past. By this token, the land use procedure for electricity lines should not be completely abolished, as it may still be suited for smaller projects in some cases. However, land use planning can be foregone if a well structured high-level sectoral planning procedure is employed (Schneller 2007, p. 534).

### **9.2.2 A modest proposal: improved coordination**

A modest reform scenario would involve the planning of sectoral demand at the federal level, but would leave electricity line route planning to the *Länder*. However, it would then be necessary to improve coordination of land use planning, possibly by creating and institutionalizing regional-state (*Länder*) agencies that would be in charge of the relevant coordination activities. As the example of *Länder* cooperation for purposes of monitoring nationwide private-sector TV broadcasts has shown, such arrangements are eminently realizable, but in order to be stable presumably need to be based on complex inter-state agreements. Alternatively, *Länder* planning entities could be institutionalised under the Federal Land Use Planning Act (Bundesraumordnungsgesetz), although the requisite analysis of the relevant legislative competences needed for such an option lies beyond the scope of the present report. Yet another option would be a joint informal planning process within the meaning of Article 8(3) of this Act, although the functionality of this process leaves a great deal to be desired. The fact that *Länder* regulations concerning trans-regional electricity lines – as per, for example, Article 43b(4) of the Energy Industry Act (EnWG) – have not been particularly successful thus far suggests that such planning should be carried out via federal sectoral planning (Schneller 2007, p. 532).

### **9.2.3 A far reaching reform scenario: two-stage sectoral planning**

In the view of many observers, the possibilities for expediting individual land use planning or sectoral planning processes have been exhausted for the most part. Therefore, we need to look at the bigger picture and consider the exclusion of individual procedural steps. This however, taking into account the assumably great importance of informal route option decision processes, need not impede on good decision making in a scenario where such decisions are concurrently made using a formal procedure in connection with high-level planning that adequately addresses the relevant issues. In the final analysis, greater transparency on the part of the respective subjects of the relevant procedures and early stage participation on the part of a broad range of stakeholders may well represent an improvement over the current regulatory framework. In this regard, an exemplary reform scenario that is altogether suitable and is at least partly based on practical experience is the procedurally formal two-stage Swiss procedure that is used for high level grid and route planning.

The main new element of our two-stage technical planning procedure would involve a federal transmission grid sectoral plan that would allow for high-level demand analysis, line route planning, and a debate concerning alternative solutions (de Witt 2006, p. 143). Grid expansion aimed at renewables integration is only one of a number of integration strategies (the others being storage installation use, load management, and generation management); moreover, it will be necessary to choose between grid optimisation, strengthening, and expansion. In view of this situation, institution of a demand analysis procedure at the highest planning levels that is binding upon all actors is indispensable and can provide a framework of certainty for implementing the requisite measures. This will not only expedite realisation of these measures, but will also, and above all, result in the federal government assuming its infrastructure development responsibilities (Hermes 1998). This also applies to determining transmission line routes on a larger geographical scale and at the federal level and making key overhead and underground line installation decisions.

Unlike transport infrastructure planning, the planning of a nationwide electricity transmission grid is not contingent upon traffic load reducing or energy saving spatial structures; nor does it fall within the scope of potential federal land use planning, as is the case with converting distribution grids to smart grids. Hence, unlike our proposed transport infrastructure planning model (SRU 2005), it is not necessary to integrate nationwide transmission grid planning into land use planning rather than sectoral planning.

This in turn means that a federal electricity transmission sector plan need not be integrated into a master federal land use plan. However, in the event federal land use planning assumes more responsibilities than at present, then consideration should be given to such integration of federal sectoral planning for the energy industry.

Moreover, the attendant planning procedures should be structured in a manner that promotes problem solving; and this applies first to the statutory framework for administrative planning procedures, with final decisions being made at the federal level, as envisaged, e.g., by the commission's draft environmental code for transport planning (BMU 1998, pp. 1323 ff and Sections 530 ff). This would make use of the administrative capacities as well as of the democratic legitimation of the government. Solutions established through legislation such as circumventing Stendal are only appropriate in exceptional cases and should not serve as a model for large scale transmission line route planning, as is also held by one study which obviously regards its corresponding proposal as an exception (Salje 2006, pp. 115 and 123). In view of the close connection between grid demand analyses and long-distance transmission line planning, decisions in regard to both should be intermeshed in lieu of the current practice of differentiating between statutory demand planning and executive transmission line route planning. However, by no means does this preclude a scenario where – in order to expedite a procedure by simplifying it and breaking it down into its component issues – the competent authorities decide to divide a regulatory procedure into a demand analysis concerning transmission line connections between specific areas and a route determination process.

Another key factor here is the allocation of administrative competencies to the federal authorities. Only in this way can large scale interdependencies between the grid demand assessment and large-scale transmission line route identification be optimally realised. As experience with transport planning has shown, in the absence of a clear normative planning competence of the federal level, the relevant actors inevitably turn to informal processes whose main drawbacks are that they do not foster the same level of accountability as a formal process and do not guarantee the broad balancing of interests that is necessary to gain acceptance.

When it comes to determining which government body should be responsible for elaboration of a federal sectoral plan for transmission development, legislators have a choice between entities such as the Ministry of the Economy (Bundeswirtschaftsministerium), Ministry of the Environment (Bundsumweltministerium), Federal Network Agency (Bundesnetzagentur), and Federal Agency for Construction and Land use planning (Bundesamt für Bauwesen und Raumordnung). If doubt has been raised as to whether the Federal Network Agency (Bundesnetzagentur) has jurisdiction over transmission grid expansion (Hermes 2010), the potential benefits of extending its jurisdiction to include the transmission line approval procedure should nonetheless not be underestimated; consideration should also be given to the internal legitimation potentials such as offered by the advisory panel. A more important consideration in this regard, however, is the interplay between the authorities involved in the formulation of a federal electricity transmission sector plan and other relevant public bodies. To promote this aim, the main actors could be involved into the process at an early stage and in a coordinated fashion as is done in Switzerland. Here, master grid development planning

(Sachplan Übertragungsleitungen, SÜL) is supported by a task force composed of the following actors: transmission system operator representatives; important power companies and electricity users; and environmental and nature conservation groups that are active nationwide. Involving the latter in the actual planning approval procedure should not be given short shrift. A panel of this type could also be formed in Germany and carry out its work on an ongoing basis – an arrangement that would allow for more rapid decision making at the organisational level, and would at the same time facilitate cooperation between the various actors and promote mutual understanding and trust among them. Moreover, such a panel could institutionalise and thus promote information sharing among the various actors (SRU 2007, nos. 408, 411 f., 449; no. 370). Worth considering could be involving *Länder* representatives in such a group. In any case they, like local actors, would need to be included in advisory panels for specific federal electricity transmission sectoral plan projects (Schneider 2010b).

Transmission line routes may fall within the purview of *Länder* land use planning and must at any rate be consistent with their land use objectives, which lends more importance to the coordination instruments between the federal and *Länder* levels. Hence, in the context of a federal electricity transmission sectoral plan and in keeping with federal transmission development planning jurisdiction, the purview of such instruments can be limited to this less complex internal administrative coordination task and do no longer necessitate plan substitution mechanisms along the lines of the current regional planning procedures. Hence, there should be no regional use planning procedure for projects that are included in the federal sectoral plan.

A federal electricity transmission sectoral plan could be based on the transmission system operator investment plans that are prescribed by law and which would need to be adapted to the relevant requirements of a federal sectoral planning. In this way, transmission system operator know-how would be used and at the same time their influence on the assessment of the planning alternatives provided for by law would be kept within reasonable procedural bounds. This scenario would – via its repercussions on transmission system operator investment plans and the plan implementation concretisation provided for in Article 12(3a) of the Energy Industry Act (EnWG), which also provides a basis for regulatory control measures – optimise the above described systemic grid planning. Hence, on implementation of the grid expansion concept discussed in this report, the specific and at any rate suboptimal and rather symbolic investment obligations – pursuant to Article 9 EEG, as well as the Combined Heat and Power (KWKG) Act and the Power Plant Grid Connection Regulation (KraftNAV) – could be dispensed with.

There is likewise relevant interplay between a federal electricity transmission sectoral plan and the Federal Network Agency's regulatory grid expansion model. On the one hand, a strictly efficiency oriented grid development concept would provide an important decision

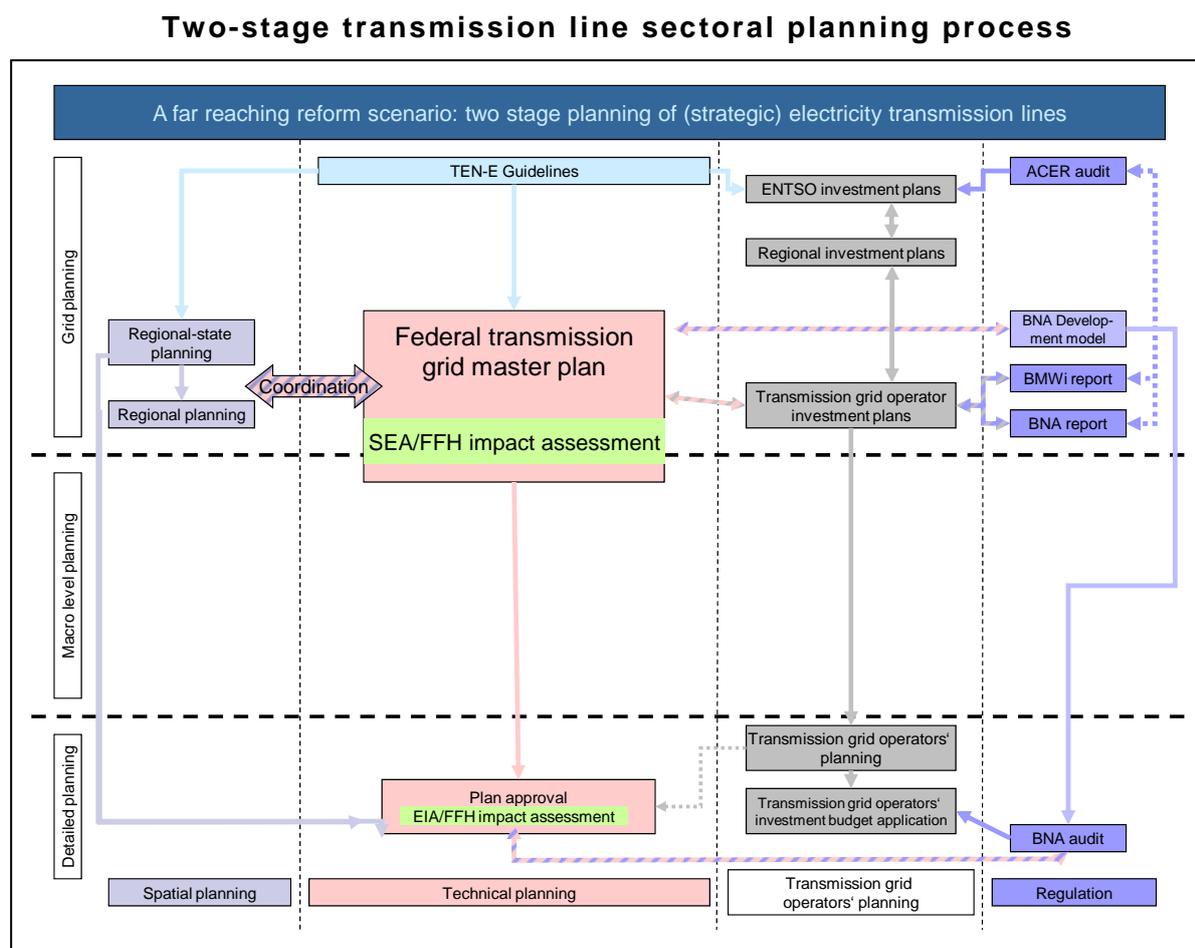
making platform (inter alia) in the process of federal sectoral planning. On the other hand, once adopted, a federal sectoral plan should form the basis for such a grid expansion model. This in turn would enhance the model's legitimacy and render the ensuing regulatory decisions, particularly those concerning investment budgets, more readily quantifiable; this in turn would promote investment certainty and improve the incentives for grid operators to make the requisite investments.

In view of the fact that the concept discussed here would entail statutory regional planning at federal government level, strategic environmental impact assessments and flora-fauna habitat site impact assessments should be incorporated into the federal sectoral planning procedure. This would also be commensurate with the nature of this process in that it would involve the assessment and selection of large scale line route alternatives and promote the procedure's capacity to gain acceptance; in addition, it would open up the opportunity for broad public participation. However, this high level rough-cut planning would not concern individual issues and could not be challenged by individuals in the court. This would unavoidably provoke the familiar problem of having to integrate once more alternative plans into the planning approval process (de Witt 2006, pp. 142 and 144). Nonetheless, planning approval authorities could confine their efforts to the assessment of small scale alternatives, since large scale alternatives would have already been analysed in the preceding formal procedure, in which the variant chosen had to be justified. In this setting, only in rare cases could the large scale alternatives be subject to a serious challenge by approval authorities or in court (see the empirical results in Lewin 2003, p. 134 f). This is also acceptable from a legal protection standpoint in that, relative to the current informal route determination processes, the procedural differentiation entailed by federal sectoral planning would be procedurally provide for a far better position of, inter alia, environmental matters in the context of the oft-called for protection of basic rights via procedures.

The provisions governing the ensuing planning approval procedure could remain essentially unchanged in this scenario. However, consideration should be given to the possibility of extending the scope of statutory planning approval obligations to include all overhead and underground high voltage power lines. This would facilitate defining overarching planning sections and establishing *Länder* authority competence centres for planning approval procedures concerning transmission lines.

The graphic below displays the basic structure of the transmission line planning process.

Figure 9-2



Source: Schneider 2010b

### 9.3 Public acceptance of grid expansion

Construction of the overhead power lines necessary to integrate renewable electricity into the public grid has already met with widespread public opposition. The continuous expansion of wind energy capacity in particular entails modification of the grid to allow for transmission of wind power generated in northern Germany to the relevant electricity demand centres. Hence grid expansion demand is concentrated in certain regions (Nitsch et al. 2004, p. 237; DUH 2010a). Various action groups have formed in opposition to high voltage power line construction (see DUH 2010a for an overview), and it has often been pointed out that such opposition is the major bottleneck for renewable energy expansion.

Opposition in this area stems from nature conservation organisations, which regard high voltage power lines as a threat to birds in migration and resting areas, particularly in ecologically sensitive zones such as coastal flatlands and wetlands. It further stems from local residents, who fear that the electromagnetic radiation emitted by high voltage power lines could have adverse health effects and lower property values in areas near the lines.

The fact that pylons affect landscape sceneries negatively is also a key cause of opposition to high voltage power lines (Zewe 1996).

In addition, the long distances traversed by the envisaged power lines in many cases mean that large numbers of residents would be affected, who, unlike those affected by electricity generation installations, see no economic advantage in the power lines. Moreover, such high voltage power lines would not offer any benefits for the affected regions per se.

Before we discuss possible solutions to these problems, a number of other aspects of the matter will be explored in more detail, including the public consultation process that now accompanies new power line planning and construction, as well as underground power lines, which could potentially go a long way toward defusing opposition to power line construction. We will conclude by considering whether, apart from the socially integrated strategy elements discussed in Section 8.5., public acceptance of grid expansion calls for complementary measures .

### **9.3.1 Public consultation in connection with transmission line construction**

Power line zoning legislation was put on a nationally uniform basis in Germany not before 2001, via the Energy Industry Act (EnWG) and the attendant *UVP-Änderungsgesetz* for specific types of power lines (Kämper 2007, p. 112). Other types of energy lines that are not governed by the EnWG fall within the scope of *Länder* law. Section 43 of the EnWG stipulates the circumstances under which an installation must undergo a planning approval procedure, in which the competent authority assesses the legality of the envisaged project and weighs the relevant public and private interests (Schlacke et al. 2010, p. 180).

The planning approval provisions of the Energy Industry Act (EnWG) were reformulated via adoption in December 2006 of the Act on Expediting Infrastructure Project Planning Procedures (Gesetz zur Beschleunigung von Planungsverfahren für Infrastrukturvorhaben), and in particular for all planning approval procedures pursuant to Article 72 ff of the *Verwaltungsverfahrensgesetz* (Law on Administrative Procedure, VwVfG), via Article 43a ff of the EnWG. Planning and approval procedures were tightened up still further in 2009 via passage of the Power Grid Expansion Act (Energieleitungsausbaugesetz, EnLAG). Procedures are abridged, inter alia, by a binding assessment provided for in the act, as to whether currently 24 priority line construction projects are in fact necessary for the energy supply. This in turn means that it is not required to verify the necessity of these projects on the basis of a planning approval procedure. The EnLAG also authorises the *Länder* to forego a regional planning procedure for energy transmission networks.

In the interest of expediting grid expansion, the Act also further limits the rights of action and participation – relative to these rights under a planning approval procedure pursuant to Article 72 ff of the VwVfG – by truncating objection and preclusion filing deadlines. Moreover,

it is up to the competent authority to decide whether a hearing will be held, and the Federal Administrative Court is given the last word concerning grid expansion projects (for a critical view of the constitutional limits on expediting approval procedures, see Holznager and Nagel (2010). This contradicts both the principle of giving those affected by expansion measures a genuine opportunity to participate in the relevant approval process and general transparency of planning procedures for grid expansion measures. There is, however, empirical evidence that the vast majority of local residents affected by a development project want to see their opportunities for participation expanded rather than reduced, as regards the following: posting plans online; ensuring that such plans are posted for a period and at a time that meets the needs of the persons concerned; and support from planning experts (Schweizer-Ries et al. 2010, p. 24 f).

Planning approval procedures and the ensuing expropriation procedure for construction of overhead power lines normally take upwards of eight to ten years (Jarass and Obermair 2005, p. 5; Schneller 2007). So far, it is not possible to determine conclusively whether or not the new law has actually speeded up the process. Be this as it may, even network operators are critical of foregoing a hearing, which they find to be serving their own plans and helping to resolve any conflicts early on (Schneller 2007). Moreover, limiting the participatory rights of environmental organisations can prevent the nature conservation aspects of the project from being aired and taken sufficiently into account in the project planning process. Hence, it will become more difficult than before to resolve conflicts between nature conservation and grid expansion. As has been pointed out repeatedly in the literature in this regard, in order for the electricity grid – or for that matter renewable energy – to be expanded, it is crucial that public acceptance of such projects be promoted; reducing the scope of public participation in the approval process, on the other hand, runs counter to this goal (Holznager and Nagel 2010). Instead, reduced procedural quality will affect public acceptance negatively (Holznager and Nagel 2010, p. 677).

### **9.3.2 Underground power lines and public acceptance of grid development**

The issue of underground power lines, which plays a central role in the debate concerning public acceptance of high voltage power lines (Schweizer-Ries et al. 2010, p. 30), has generated intense controversy resulting from the (albeit disputed) presumption that underground cables are more readily acceptable to local residents and thus can be installed more expeditiously than overhead lines (Schneller 2007).

Underground power lines have come in for criticism on varying grounds. The Federal Network Agency (Bundesnetzagentur) objects that they cost far more than overhead power lines. Some studies have shown their cost to be greater by a magnitude of upwards of six (Bundesnetzagentur 2008b, p. 9). This is ascribed to the higher investment costs, the presumably shorter service life, and the higher maintenance and repair costs relative to

overhead lines. Cost levels will be determined by the extent to which capacity expansion can keep pace with demand (Bundesnetzagentur 2008b). Assuming a seven-fold cost difference between underground and overhead power lines, the grid expansion necessary for wind power until 2015 would bring about costs of around 5 billion euros for underground cables, as opposed to 720 million euros for overhead power lines (Schneller 2007). Even underground power lines for only partial routes would raise costs. However, if the Federal Network Agency (Bundesnetzagentur) approves these additional costs, they could be passed on to electricity customers.

A hybrid solution involving overhead and underground lines along the same route is regarded as unsatisfactory since interconnecting these two types of lines requires extensive technical effort and is cost intensive. This has prompted calls in many quarters for the use of underground power lines only – an approach contested by other authors on the grounds that the technology for transmitting electricity over long distances via underground power lines has yet to reach technical maturity owing to lack of experience (Bundesnetzagentur 2008b). According to anecdotal reports (no empirical data are available in this regard), relative to overhead lines underground cables display a higher failure rate due to damage incurred by the sockets that connect the various segments.

Moreover, the Federal Network Agency fears that underground power lines will undermine the desired acceleration of grid expansion due to the fact that standardised underground cables are not available on an off the shelf basis, and need to be custom ordered once the exact route has been determined, i.e. after the project has been approved. It is estimated that this will result in underground cable projects taking around 12 months longer to complete than overhead line projects (Bundesnetzagentur 2008b, p. 10).

It has also been observed, however, that the planning process is likely to be much shorter for underground power lines as they are more readily accepted by local residents. This is supported by the fact that almost all of the petitions that have been filed against the construction of 380 kV power lines call for the installation of underground power lines rather than for a ban on power line installation in general (DUH 2010a). According to empirical studies, local residents greatly prefer underground power lines, including in cases where the study respondents know little about such power lines (Schweizer-Ries et al. 2010, p. 18). Accordingly, the main goal of a law passed in the regional state of Lower Saxony was to improve public acceptance of grid expansion. The act provided for the installation of underground power lines exceeding 110 kV intended for “technically and economically suitable for portions of routes” (Schörshusen 2010); this law, however, has since been rendered obsolete by the Energy Line Construction Act (EnLAG).

There are also far more conservative cost estimates for underground power lines. One technical expert report investigated a use case involving a 500 kilometre 3,000 MW overlay line for varying transmission technologies. The study design differentiated between 300 kV

DC (HVDC-VSC), 380 and 500 kV unipolar current, and bipolar AC (HVAC), in each case for a scenario where underground power lines made up 0, 20, 50 or 100 percent of the entire route. The absolute cost of all variants investigated (investment costs plus transmission loss) was found to range from 1.1–4.2 billion euros. The HVAC variant with a fully underground power line would cost 3.5 to 4 times more than the equivalent overhead line, but only 1.5 times as high for a 20 % underground line, and a very low 1.2 more for the 100 % underground direct current (HVDC-VSC) variant.

Assuming that grid expansion can be significantly expedited through the use of underground power lines, the attendant higher initial investment relative to overhead lines might be amortised in the medium term since underground lines avoid the losses incurred by renewable electricity installation operators when their installations are shut down due to grid bottlenecks.

Another advantage of underground power lines is that they have a lower impact on the landscape. In contrast, virtually wherever overhead power lines are built (except those installed on moors or rocky ground) they are less advantageous by virtue of the following factors: they affect landscape sceneries negatively; birds can be electrocuted by them; they emit magnetic and electrical fields; and they cannot be built without removing copses (Vollmer 2010). Underground power lines also take up less space, and do not produce the negative effects entailed by overhead lines such as noise and the risk of electric shocks.

Hence the question of whether overhead or underground lines should be used is essentially one of weighing a considerably lower cost technology on one hand against a technology that is far more acceptable to the general public on the other. Both the Umweltbundesamt (Federal Environment Agency), as well as those affected by power line projects have stated that decisions in favour of one technology or the other should not be reduced to the technological and economic dimension, but should instead give full weight to ecological and public-acceptance issues (Vollmer 2010).

However, underground power lines are currently envisaged only to a limited extent: Apart from specific derogations for extending undersea cables onto land (Article 43 of the EnWG), underground power lines are only allowed at present for four EnLAG pilot routes. According to the federal government, it will not be possible to assess these power lines – including in terms of their total construction costs and the cost of operating the underground line portions of the route – until the entire installation has been completed and the EnLAG underground line projects have gone into operation (Deutscher Bundestag 2010).

As previously noted, one way to render decisions in favour of underground power lines more transparent and understandable would be to experiment with a standardised assessment instrument of the type that has been proposed in Switzerland, and if it works, institute it permanently (Merker 2010). Apart from the aspects discussed above, the Swiss assessment instrument takes account of the impact on regional and local interests (recreation, tourism

and the like) , of land depreciation as well as of investment and operating costs. If such an instrument were developed and piloted using a transparent process, it could be instituted permanently and thus allow decisions concerning underground versus overhead power lines to be based on empirical criteria.

### **9.3.3 Innovative instruments for promoting public acceptance of grid expansion projects**

Innovative strategies are essential if grid expansion projects are not to be hampered or even brought to a standstill by lacking public acceptance or other difficulties. For example, construction of overhead power lines is conflict-ridden because the attendant negative impact on local residents and nature and landscape cannot be offset by direct benefits. Also, other strain on regions and residents caused by infrastructure elements such as highways, high-speed train tracks, and waste dumps needs to be taken into account.

According to recent proposals, regions that are traversed by overhead power lines should receive also financial compensation, which would be financed by folding the relevant costs into Federal Network Agency-approved investment budgets (Holznagel and Nagel 2010, p. 676). On the other hand, it has been shown more recently that such compensation would not achieve the desired results, since residents' willingness to accept a high voltage line in their immediate environment will not necessarily increase simply because financial compensation for this unwanted element is offered. On the other hand, once residents know that such an overhead power line is definitely going to be built, they do in fact wish to receive financial compensation (Schweizer-Ries et al. 2010, p. 28). Hence financial compensation is desired, but on its own is insufficient. Moreover, local residents may find it peculiar or objectionable if compensation is offered for overhead lines while financing for the additional cost of underground lines is denied.

Hence what is needed is a hybrid approach that takes account of the special characteristics of electricity grid expansion projects. This approach should first and foremost be based on transparent and long-term concepts that are supported by and readily understandable for all concerned. It must also be made clear which electricity generation installations the lines are being built for, as those realised for renewables are far more likely to garner local support than lines used to transmit conventional electricity (Schweizer-Ries et al. 2010).

Public acceptance for grid expansion is also more likely to be improved if it can be plausibly demonstrated that during the planning phase and before the decision was made to go ahead with the project line all other available avenues were pursued, such as the following: optimisation, modernisation, and strengthening of existing electricity infrastructure elements; leveraging synergies between grid operators; and more efficient handling of energy along the value creation chain, from electricity generation, transmission and distribution to consumption (DUH 2010b, p. 22).

In addition, power line route planning should be carried out in a transparent manner, and it should be convincingly demonstrated that all possible route configurations were seriously considered. In some cases, there have been complaints that planning authorities fail to disclose to local residents the information available to them despite them being entitled to such disclosure. Our proposed federal sectoral plan could be of good use in this regard, as it helps to render long term planning processes transparent and sets the stage for a broad public debate concerning alternative power line routes. The options, advantages and drawbacks concerning overhead versus underground cables should also be disclosed.

Although such measures do not guarantee public acceptance for new powers, despite extensive and transparent information, the planning process for such projects should nonetheless be sufficiently transparent for all of their various aspects to be readily understandable for the populations affected – residents are more likely to support such projects if they are perceived as being necessary (Schweizer-Ries et al. 2010, p. 24 ff).

Although early stage public involvement is important, particularly in terms of the debate on different power line route options, it alone is not enough. Hence it is essential to put innovative participatory instruments to the test that promote citizen involvement in power line planning. Mediation aimed at reaching a consensus at an early stage is regarded to be particularly productive (Holznagel and Nagel 2010, p. 674 ff), although it remains to be seen whether this method will be used and prove successful.

#### **9.3.4. Conclusions**

While renewable energy generally enjoys a high level of public acceptance, the prospect of expanding transmission network grids to allow for the integration of offshore wind power provokes strong protest. One of the main effects of Germany's so-called fast-track planning law has been to limit public participation and litigation rights. The restriction on opportunities for public input resulting from this law has also reduced the scope of nature conservation expertise that is folded into the process, and has done nothing to increase public acceptance of a renewables expansion. It is essential in this regard to solicit public input before all project related decisions have been made, so that the public can still have some say about how a given project is to be carried out.

Moreover, the possibility of using underground power lines should be looked into more thoroughly, as the use of such cables considerably shortens the planning phase since the public accepts them more readily. A suitable instrument to this end might be a standardised assessment framework for decision making, which should be based on transparent and readily understandable criteria, as has been discussed in Switzerland.

Grid expansion should be based on transparent and durable concepts that are supported by and readily understandable for all concerned. Ancillary instruments such as mediation can also make a significant contribution in this regard.

## **10 Executive summary; suggested course of action**

### **10.1 A wholly renewable electricity supply: a worthy energy policy and climate protection objective**

#### **10.1.1 Scope of this report**

Climate policymakers are facing the challenge that greenhouse gas emissions in industrial countries need to be reduced by 80 to 95 percent in order to avert what is widely regarded as a dangerous rise in global temperature amounting to more than 2 °C relative to the pre-industrial level. The European Council officially endorsed this objective in 2009. In the view of the European Commission, only a minute proportion of the attendant reductions can be achieved through implementation of flexible mechanisms outside the EU. In Germany, there is a broad political consensus about ambitious climate protection objectives. The Federal Government has endorsed the national goal of reducing greenhouse gases by 40 percent by 2010 relative to 1990 levels and has also recognised the need to further reduce greenhouse gases by at least 80 percent by 2050.

In its current form, electricity accounts for roughly 40 percent of total German carbon emissions, thus making electricity supply a touchstone of energy and climate policies. In order for carbon emissions to be reduced by 80 to 95 percent, German power plants would need to be virtually emission free since for technical reasons, emissions cannot be reduced sufficiently by 2050 in other sectors such as agriculture and goods transport, or the costs of such reductions would be prohibitive, whereas the requisite technological solutions are already available to electricity companies. Hence the present report addresses the issue as to whether a sustainable and climate friendly electricity supply can be achieved in Germany, without taking account of the heating or transportation sectors.

Germany will be facing key decisions in the coming years concerning the structure of its power supply much of whose generation capacity will need to be replaced over the next two decades since many power plants will be nearing retirement by then. The investments that are made in the coming years will have a major impact not only on the structure but also the emissions associated with the electricity sector for decades. This situation presents an opportunity to set in motion a relatively low cost but far reaching structural change of the sector.

We can only achieve a sustainable and climate friendly electricity supply system over the long term if it is based on renewables. The vast majority of Germans support the concept of a power supply that is mainly based on renewables and this goal has also been endorsed by the current coalition government. Such a goal represents an opportunity for sustainable technological and infrastructure innovation here in Germany that will help ready our country to face future challenges in this sphere.

The present report is one in a series of recent studies that show that in Germany and Europe a complete or nearly complete shift of the power supply to renewables could be achieved. But the following issues which are key, are not being given the attention they deserve:

- Is a wholly renewables based electricity supply technically feasible for and in Germany? Would such a system ensure security of supply that is on a par with today's?
- How much would a wholly renewable electricity supply and the transition thereto cost?
- What would be a realistic timeline for the transition to such an electricity supply and which measures would this transition entail?
- Which challenges would have to be met in transitioning to a renewables based electricity supply? Which political and legal frameworks would need to be taken into account for such a transition in the European context and how much leeway do they allow?
- Which political measures and instruments of policy control could be used to bring about this transformation smoothly and efficiently?

In September 2010, the German government issued an energy scenario-based energy concept containing a far reaching electricity supply roadmap that the German Advisory Council on the Environment (*Sachverständigenrat für Umweltfragen, SRU*) assessed in a separate comment. Many elements of the government's energy concept, particularly those relating to the period to 2050, the long term objectives laid down in the concept, and the proposed electricity grid expansion measures could potentially come to be regarded as exemplary at the international level. That said, the present report goes further than the government's energy concept in terms of both climate protection objectives and the envisaged energy mix, while at the same completely parting ways with the government's strategies for the transition to renewables by 2050. In our view, the prospects for this transition are far brighter than the government would have us believe; and we are far less persuaded than the government appears to be concerning the compatibility of nuclear power and renewables. But many of the recommendations and concepts in the present report are relevant regardless of whether the goal is to achieve 80 or 100 percent renewable electricity.

### **10.1.2 The prospects for achievement of a sustainable and climate friendly electricity supply in Germany by 2050**

Transitioning towards a low carbon power sector is currently at the centre of the political debate and is also a key issue for the German Advisory Council on the Environment (*Sachverständigenrat für Umweltfragen, SRU*). The only way to reduce Germany's overall carbon emissions over the long term is to completely decarbonise our country's electricity supply system. The low carbon technologies needed to do this are already available, or will be in the foreseeable future; these technologies include renewable energy such as wind,

solar, biomass and geothermal energy, nuclear power, and fossil fuel power generation using carbon capture and storage technology.

That said, energy policymakers should be basing their technology decisions not just on how climate friendly a particular technology happens to be, but also on the overall statutory framework for environmental sustainability at the international level (Rio Declaration, UNFCCC), EU level, and national level (article 20a of the German Constitution; the German government's sustainability strategy). The main sustainability factors that come into play in this regard are as follows: compliance with the absolute sustainability and input limits of natural systems; taking steps to ensure intergenerational and global justice (instituting equal per-capita usage levels for common-pool resources). The Earth's climate system and biodiversity are natural systems whose ecological input limits have already been exceeded and that are urgently in need of protection. Needless to say, in order to meet the aforementioned sustainability criteria in particular (maintaining the sustainability of natural systems; achieving generational equality), it will be necessary to minimise the risk of irreversible or catastrophic events.

In view of the fact all energy generation technologies affect the ecobalance in one way or another, there is simply no such thing as 100 percent environmentally neutral energy generation. That said, the comparative sustainability assessment that we carried out shows that renewables constitute the only sustainable energy option.

The main goal that we need to be aiming at – fully decarbonised electricity generation – cannot be reached either through more efficient conventional coal fired power plants or carbon capture and storage (CSS) technology. Moreover, the use of coal fired power plants entails large-scale raw material extraction operations which despite improved air purity efforts result in significant air quality problems. As for CCS, its use is limited by the available storage capacity and competition from other potential uses of this capacity. Although greenhouse gas emissions from nuclear power plants are far lower than for coal fired power plants, the use of nuclear power entails the risk of accidents – an eventuality that cannot be completely ruled out and that could have consequences for large areas and for extended periods of time; plus no viable solution has been found for long term storage of nuclear waste. In our view, this is a high price to pay; and what's more, nuclear power may not be a sustainable solution in view of the limited supply of uranium. Hence in our view neither coal fired power plants nor nuclear power can be qualified as sustainable energy resources.

But renewables are not always without problems either, notably in that growing energy crops (a) may provoke land use changes that have a substantially negative climate warming effect; (b) may have a deleterious impact on natural capital; (c) may cause considerable environmental damage; and (d) may run afoul of the principle of equal usage rights by competing with food crop production. Other renewables and the transmission and storage

capacity expansion needed for them can also provoke conflicts in terms of land or ocean use. Moreover, renewables entail the use of resources such as water and rare metals.

That said, in the view of the SRU, the ecological problems associated with renewables are manageable and could be minimised through policy and planning measures. The environmental problems posed by coal fired power plants and nuclear power plants are mainly of a technological nature and the same, regardless of location, whereas renewables provide some leeway in terms of localisation – providing, that is, that actual energy consumption is far lower than the putative potential offered by renewables. Ecological conflicts could be largely mitigated if power plant construction was supported by regional planning.

Another key factor here is that renewable-energy power plants are normally smaller and easier to dismantle than the counterpart conventional facilities, and thus are more flexible infrastructure components. Whereas nuclear and CCS coal plants are associated with long term consequential environmental damage and risk resulting from coal mining, nuclear waste storage, and carbon storage, the environmental impact of renewable energy is generally confined to the service life of the installation. And at least for solar and wind power, their environmental impact is confined to the plant construction phase, whereas fossil and nuclear power plants necessitate sustained land and natural resource use to mine the fuels needed. Renewables are not only sustainable, but are also in line with the precautionary principle in that, in view of the present uncertainties, they can be adapted more flexibly to changing conditions and have a greater tolerance for error. Hence renewables are superior to conventional energy resources in terms of generational equity and risk avoidance, thus making renewables more sustainable. And this in turn means that renewables are the only viable sustainable solution for electricity generation.

When it comes to determining the way forward for implementation of an electricity system that will make a major contribution in the fight against global warming, the government needs to opt for solutions that are maximally compatible with the sustainability and precautionary principles laid down in article 20a of the German constitution . In the present report, we make the case for an energy policy that promotes anything other than renewable energy sources over the long term is at odds with the stipulations of the aforementioned constitutional clause.

But needless to say, transitioning to a renewables based electricity supply needs to be (a) widely accepted by the general public; and (b) consistent with the classic energy policy goal of assuring a reliable supply of affordable energy. In view of this key exigency, the present report assesses the technical, economic and political feasibility of instituting a fully renewables based electricity system in Germany.

### **10.1.3 A secure and affordable wholly renewable electricity supply is well within reach**

The scenarios laid out in this report show that there are various options for institution of a wholly renewable electricity supply in Germany. These scenarios were developed at our request by the German Aerospace Centre (DLR) using the DLR's REMix model.

#### Methodology of the REMix model

The REMix model is based on a geoinformation system which, using a high resolution grid, documents the electricity generation potential of all renewable energy sources in Germany, Europe and North Africa, and then uses the results to compute a cost optimised (i.e. lowest possible cost) energy portfolio for the defined conditions.

Inasmuch as the model uses one hour time intervals, it can correlate annual electricity generation with electricity demand down to the hour. This in turn meets the challenges posed by an electricity system that makes increased use of wind and solar energy whose availability varies over time. An electricity supply that satisfies demand at all times must be achieved either through the use of overlapping renewable electricity resources and/or stored electricity. To this end, for the target year 2050 we modelled (a) the use of hydro power, in conjunction with wind, solar, biomass and geothermal energy as well as electricity storage technologies; and (b) cost optimised constellations of these energy technologies for each relevant instance. These calculations presupposed that learning curve effects will drive down the cost of renewable energy over the long term. The cost suppositions used by the DLR in the REMix model are the fruit of thorough research and continuous updating, but are regarded in some quarters as overly optimistic and in others as unduly pessimistic. Hence the actual costs associated with renewable energy technologies going forward may turn out to be higher than those predicated here, and the actual cost-optimised portfolio of renewable energy sources may differ from the structure that was modelled for the present report.

Our scenarios are confined to those renewable energy technologies that are already well established and for which a reasonably reliable estimate of future costs can be effected. Although other renewable energy technologies such as wave and tidal energy are in the pipeline that offer additional options and leeway for implementation of a fully renewable electricity supply, these technologies were excluded from the DLR model owing to a lack of reliable data.

All eight of the scenarios we present here presuppose that Germany can and will implement a wholly renewable electricity supply by 2050, albeit under varying conditions in respect to grid connections with other countries and the electricity demand that will need to be met (see Table 10-1). We also compare the following putative models with each other: German energy self sufficiency (scenario group 1); a regional network involving Germany and Scandinavia (scenario group 2); and a Europe-North African network (scenario group 3). Scenario group 1

can be regarded as a last-resort worst case scenario; for even if 700 TWh electricity demand in 2050 (a high estimate) can be met with domestic renewables alone, it follows that things will be much easier under less restrictive conditions. That said, scenario group 1 is not a desirable solution for economic reasons and from the standpoint of EU law.

All of the scenarios presuppose that all participating countries will jointly seek to transition to renewables and that for reasons of security of supply each such country has a vested interest in generating a minimum percentage of its energy from domestic resources. Maximum net import of 15 percent of total generated electricity was predicated for Germany.

All of the scenario computations are based on projected total electricity demand in Germany amounting to 500 and 700 TWh. We presume that a German electricity demand plateau of 500 TWh is achievable over the long term, even if electricity demand rises substantially in the heating and transportation sectors. But to do this, we will need to leverage the efficiency optimisation potential not only for electricity use but also in the building renovation and heating and hot water provisioning domains. The scenarios based on electricity demand amounting to 700 TWh clearly show that a wholly renewable electricity supply would be within reach from a technical standpoint even if energy efficiency and savings policies are not successfully implemented and electricity demand rises far more sharply than expected.

However, as is always the case with long range scenario studies, the findings we present here are subject to significant uncertainty as it was necessary to make a series of suppositions concerning evolutions that are difficult to forecast. Our scenarios are intended to show that a wholly renewable electricity supply is within reach under various conditions; and (a) do not constitute a forecast of the evolutions that might come into play here; (b) do not indicate a preference on the part of our organisation for a specific portfolio of renewables or for any particular cross-border energy supply network solution; and (c) are not intended as a blueprint for the transition to a wholly renewable electricity supply. Instead, our scenarios merely provide a selection of the many possible solutions that come into play here.

Table 10-1

**Eight scenarios for a wholly renewable electricity supply by 2050**

	<b>German electricity demand in 2050: 500 TWh</b>	<b>German electricity demand in 2050: 700 TWh</b>
<b>Self sufficiency</b>	Scenario 1.a: DE 100% SV-500	Scenario 1.b: DE 100% SV-700
<b>Net self sufficiency Interchange with Denmark and Norway</b>	Scenario 2.1.a: DE–DK–NO 100% SV-500	Scenario 2.1.b: DE–DK–NO 100% SV-700
<b>Maximum 15% net import from Denmark and Norway</b>	Scenario 2.2.a: DE–DK–NO 85% SV-500	Scenario 2.2.b: DE–DK–NO 85% SV-700
<b>Maximum 15% net import from the Europe-North Africa region (EUNA)</b>	Scenario 3.a: DE–EUNA 85% SV-500	Scenario 3.b: DE–EUNA 85% SV-700
DE: Germany; DK: Denmark; NO: Norway; EUNA: Europe and North Africa; SV: self sufficiency SRU/SG 2011-1/Table 10-1		

In a second step, the findings from the 2050 scenarios were used to determine how the available electricity generation, transmission and storage capacities would need to evolve in order to achieve the defined target state by 2050. Based on the characteristics of the existing power plant fleet, we show how conventional generation capacity could be replaced incrementally by renewable energy.

### Findings

Our scenario computations show that Germany could readily achieve a wholly renewable electricity supply that is both reliable and affordable. Providing that the relevant storage facilities and grids are implemented, the renewable energy potential in Germany and Europe would allow for the satisfaction of maximum posited electricity demand at all times throughout the year, using wind turbines, solar collectors, and other currently available technologies and despite fluctuations in the availability of renewable electricity. As the lowest cost energy resource in the run-up to 2050, wind energy, particularly from offshore wind turbines, plays a pivotal role in all of the scenarios discussed in the present report. On the other hand, the level of solar energy use in the various scenarios varies according to electricity demand and the amount of electricity that is imported. Biomass use in the scenarios involving transnational energy supply networks accounts for no more than 7% of electricity demand, largely owing to land use conflicts and the relatively high cost of this energy resource.

The envisaged upgrading of Germany's power plant fleet offers a golden opportunity to transition to a wholly renewable electricity supply at a relatively low cost and without engendering any discontinuities in supply structures.

In view of the fact that ambitious energy saving and efficiency policies would go a long way toward easing the transition to a wholly renewable electricity supply, efforts should be made to reduce and (over the long term) stabilise German energy demand. This would lower the economic and ecological costs of the system, improve its robustness, and promote rapid implementation of the necessary transformation process.

Although a wholly renewable domestic electricity supply without any electricity importing would be feasible, this option should definitely not be pursued in light of the evolving EU-wide internal market for energy. Although various European inter-regional networks may well be feasible, we have elected to illustrate the feasibility of only two such scenarios. A Germany-Denmark-Norway energy network would allow for the use of the enormous pump storage system capacity in Scandinavia. This option, which has been largely neglected in the energy policy debate, has been analysed by our scenarios in detail. That said, a more far flung European energy supply network with a number of EU states availing themselves of low cost response power (particularly from Norway) would help Germany to achieve a wholly renewable electricity supply – which in any case can only be achieved by expanding offshore wind power capacity and high capacity lines in the North Sea region, and through the use of pump storage systems.

In the view of the SRU, instituting a wholly renewable electricity supply in Germany by 2050 would entail economic advantages in addition to promoting climate protection, whereby the aggregate costs of such a system would be largely determined by the extent to which a network comprising other European countries is established. Inflation adjusted, a wholly renewable electricity supply using German resources only would be relatively cost intensive, ranging from 9 to 12 euro-cents per kWh, depending on demand. On the other hand, an inter-regional smaller-scale German-Danish-Norwegian or larger-scale Europe-North Africa network would provide electricity at a cost of only 6 to 7 euro-cents per kWh, including the cost of international grid and storage capacity expansion. Our rough estimates indicate that expanding the German grid would entail additional costs amounting to approximately 1 to 2 euro-cents per kWh.

Over the long term, renewable electricity will prove to be less cost intensive than conventional low carbon technologies such as CCS power plants and new nuclear power plants, whose costs will rise owing respectively to limited uranium resources and storage facilities. The price of nuclear energy will also be driven upward by the currently unforeseeable costs of long-term nuclear waste storage, whereas renewable energy costs will decline owing to the effects of learning curves and economies of scale. Whereas timely short term expansion of renewable energy resources will entail higher near-term investment and generation costs than the cost of extending the service life of existing power plants, it will nonetheless allow for long term cost savings not only in terms of direct costs but even more so in terms of social costs, and is thus a worthwhile investment in the future. In our

estimation, we will begin to see such savings from a wholly renewable electricity supply between 2030 and 2040 if the attendant costs decrease as per the timeline in chapter 4.2, and somewhat later if these costs decline more slowly than forecast in the said chapter.

#### **10.1.4 Transitioning to renewables would not entail either significant service life extension for existing conventional power plants or the construction of new coal fired power plants**

A smooth and incremental transition to renewable electricity can be readily achieved by successively shutting down conventional power plants when they reach the end of their service lives and replacing these facilities with renewable electricity capacity. Our transition scenarios presuppose that the mean service life of conventional power plants will be 35 years and that the current rate of renewable electricity expansion will be maintained (which are rather restrictive conditions). To do this the annual absolute capacity expansion rate for renewable electricity would have to increase to an average of 6 GW per year by 2020 (scenario 2.1.a), a rate that is consistent with that achieved in past years; and in the unlikely event that no electricity saving measures are instituted, this figure would be 8 GW a year, as per scenario 2.1.b. In our estimation, even this elevated expansion rate could be successfully achieved by the relevant industries. But if German and EU energy efficiency objectives are steadfastly implemented; or if the altogether realistic scenario comes true that operators of conventional fossil fuel fired power plants will want to keep their facilities in operation for longer than an average of 35 years, annual renewable energy capacity expansion clearly below 6 GW will suffice between now and 2020.

These scenarios (2.1.a and 2.1.b) obviate the need to extend the service life of nuclear power plants or to build new coal fired power plants with carbon capture and storage (CCS) systems. In other words, our existing fleet of conventional power plants, combined with a handful of newly built gas turbine plants, would provide a sufficient bridge for a transition to a wholly renewable electricity supply. Hence a transition scenario based on a relatively brief average service life amounting to 35 years for conventional power plants offers sufficient leeway and flexibility for the eventuality that network, storage capacity and generation capacity expansion for renewable energy will proceed more slowly than expected.

A largely renewables based system would have less of a need for base load power plants. The high volatility of renewables will necessitate a substantially higher level of flexibility on the part of all conventional power plants. The number of shutdowns required and rapid startup and shutdown procedures will rise in accordance with the increasing residual load, and will obviate the need for a permanently available and consistent base load. Hence, once renewable electricity begins accounting for approximately 30 percent of aggregate electricity capacity, the construction of new conventional power plants will become unprofitable since it will no longer be possible to operate them at a sufficiently high capacity use level. And if

proportional renewable electricity use rises further still, base load power plant operation will become problematic from a technical standpoint as well. Moreover, extending nuclear power plant service life or building new coal fired power plants would entail the risk of surplus capacity over increasingly longer periods, thus necessitating renewable capacity downtime or cost intensive underuse of conventional capacity and unnecessarily ramping up the costs of the transitional phase. Hence a blanket and pronounced extension of the service life of our nuclear power plant fleet would be incompatible with our scenarios involving a transition to a wholly renewable electricity supply.

## **10.2 Transitioning to renewables: the challenges**

### **10.2.1 A new balance between market forces, government planning and public participation**

The main political challenge entailed by the transition from a non-sustainable to a sustainable energy system is overcoming the path dependency of our current electricity generation system – which, if continued will be the death knoll for achievement of the mandated climate policy objectives.

The German government will need to handle a host of new challenges and tasks if it wants to set in motion and coordinate the process of transitioning to a renewable electricity system. Extensive transformations of this nature can only be accomplished with strong political leadership, clearly defined goals, and the necessary political will, all of which must be wholeheartedly supported by the majority of the population. Even if regulated markets and private sector market actors continue to play the same central role that they do today, market forces alone will not suffice to drive the transition to renewables. For apart from fulfilling its classic role of establishing the requisite conditions and providing the necessary incentives for market actors, the government will also need to perform additional forward looking coordination and planning tasks so as to ensure outcomes and, above all, provide investment certainty for market actors. The government's brief in this regard also includes making fundamental technology policy decisions that will promote a sustainable electricity supply. This in turn will necessitate considerable orchestration of capacity expansion for renewables and the attendant infrastructure projects, which require considerable planning lead time. In this sense energy and climate policy cannot be technology neutral as electricity grid expansion needs partly depend on the electricity generation technologies and generation locations that come into play. And thus it will be necessary to rethink the strategic role played by public planning, who should seek to avoid the mistakes provoked by the top-down approach to planning of past years and who should instead embrace successful, learning-friendly, and participatory modalities that are already in wide use. Over the long term, following a successful transitional phase, the decentralised and standalone organisational modalities promoted by market forces will regain relevance.

The policy thrust entailed by such a transformation has the following overarching dimensions:

- Germany's energy and climate policies are intertwined with those of the EU, in that certain key ground rules are predetermined or prescribed by EU law, particularly those concerning emissions trading and the EU energy market. Hence any attempt at transitioning to a wholly renewable electricity supply will need to intermesh with EU energy law and climate policies, which are currently in a profound state of flux. Instituting favourable conditions at the EU level could ease the task of management at the national level, whereas setting opposing policy objectives at the EU level could jeopardise German implementation of a national energy concept.
- One of the central factors for successful grid and storage capacity expansion in Germany is regional cooperation within the EU, particularly with Norway and Switzerland, but also possibly with partner states in North Africa and Eastern Europe. This would open up new possibilities for a proactive German foreign policy in the energy domain, which would need to be in keeping with the allocation of powers and responsibilities in the EU. Public-private partnerships for such projects have already recognised the supreme importance of such cooperative arrangements.
- The transition to a wholly renewable electricity supply must be fully in keeping with German Constitutional principles and will also need broad political support. In this respect, a cross-party consensus is about to emerge, at least for the transition towards a renewable power supply in the long run. And as this goal can readily be reached by 2050, it should be unstintingly enshrined in the government's policy agenda and in party platforms. Sustaining this kind of radical transformation across numerous legislative sessions will necessitate broad support among the electorate and a nonpartisan consensus; and to accomplish this, we will need a fundamental debate concerning the long term benefits of a wholly renewable electricity supply.
- This process is essential if we are to pave the way for better acceptance of the transition at the local level, since energy policy dissent at the federal level is oftentimes mirrored by local resistance to essential infrastructure investments. Hence transforming our electricity sector simply must go hand in hand with an open, frank, transparent and pluralistic public discussion of the relevant issues. Electricity infrastructure planning and investment should translate into opportunities for participatory activities at all levels. In the end, our political leaders will need to make clear decisions, which may encounter resistance at the local level. But it is crucial to clearly convey to the citizenry the supreme energy and climate policy importance of the proposed measures for implementation of the necessary overarching climate policy concept. Transforming the electricity supply system will also require political leaders to devise policies that extend a helping hand and offer new opportunities to those members of the population who are left holding the short end of the stick as a result of the structural changes entailed by the transformation.

Following are a number of energy and climate policy considerations that we feel are particularly important when it comes to placing Germany's electricity system on a fully sustainable footing:

- Inasmuch as energy efficiency is the actual (so to speak) bridging technology for and to a wholly renewable electricity supply, it must be vigorously promoted.
- In order to lay the groundwork for such a transformation and create the key economic incentives necessitated by it, statutory climate protection and decarbonisation objectives should be set for Germany and the EU for 2050 and translated into emissions trading policies.
- Moreover, in order to pave the way for a secure, efficient and wholly renewable electricity supply, EU and German support schemes should be developed for renewable energy.
- No new power plants should be constructed which, for technical and economic reasons, do not allow for highly flexible electricity generation and that are inconsistent with Germany's long term climate protection objectives. Moreover, the envisaged service life extensions for nuclear power plants are likewise incompatible with the flexibility requirements that need to be met for the transition to renewable energy.
- In order to have at our disposal a reliable supply of electricity, in tandem with the expansion of renewables it will also be necessary to expedite the process of adequately expanding and above all converting the electricity grid. To do this, investment incentive and grid planning modalities will have to be fundamentally altered.
- In order to move forward with the process of connecting our electricity grid with and leveraging Scandinavia's extensive and relatively low cost pump storage potential, it is in Germany's strategic energy policy interest to enter into cooperative arrangements with North Sea states.

### **10.2.2 New incentives for energy efficiency policies**

The least cost intensive "bridging technology" available today for renewable electricity is scaling back electricity demand by improving energy efficiency. Leveraging available electricity savings potential could greatly help set the stage for the transition to a wholly renewable electricity supply, in view of the fact that (a) the lower the electricity demand, the less renewable electricity costs; and (b) the task of transitioning our electricity system would be eased by energy saving measures, as this would allow more time for the expansion of renewable energy capacity and the attendant grid and storage capacity. Hence the Federal Government should institute policies aimed at putting a cap on energy demand throughout Germany.

To this end, the SRU recommends that an absolute electricity demand limit be set and that the government seek to stabilise electricity demand over the long term, via policy goals that

would be achieved one decade at a time. For 2020, then, efforts should be made to reduce net energy demand by 10 %, i.e. to roughly 500 TWh, which would be lower than in 2008. This goal should then be adjusted for 2030 in light of the projected energy savings potential and the development of electrically powered motor vehicles. In our view, a long term energy demand plateau around 500 TWh is well within reach, even if fossil and other combustible fuels are largely replaced by electricity.

Reducing national electricity consumption to this level will necessitate (a) the institution of across the board efficiency policies that make full use of the available management and coordination instruments; and (b) devising new policy instruments that increase the leeway for action on the part of key political actors. Taking rule of law-provisions into account (particularly the constitutional rights of those affected by the attendant measures), energy efficiency and energy saving instruments need to be optimised in such a way as to ensure sustainable and long term levelling off and reduction of electricity demand.

One example of such an instrument is household electricity account framework proposed by the SRU, which would impose an upper limit on total household electricity consumption and takes its cue from the basic concept of White Certificates and expands it into a genuine cap and trade system, where power companies would be given certificates for specific amounts of electricity based on the number of households served by the companies. Each company would be credited with a bulk amount of electricity per household.

This system would (a) allow for the requisite flexibility via electricity trading between power companies and (b) even out electricity consumption on the part of individual customers via price mechanisms. Household electricity consumption would not be rationed, and thus the instrument would not limit consumption (and thus customers' freedom of choice in this regard) to any greater extent than prices now do.

The customer electricity account framework would be the main controlling lever for overall household electricity demand and could thus make a direct and verifiable contribution to implementation of a nationwide cap on electricity demand. In addition, this system would not only create incentives for the implementation of electricity efficiency measures, but would also promote energy savings resulting from changes in consumer behaviour – which is where the low cost savings potential actually lies.

We recommend that this model be studied and refined, particularly from a statutory standpoint.

### **10.2.3 Optimisation of EU climate policy and the emissions trading framework**

It is essential that renewable energy capacity expansion and the expansion of incentive and subsidy programs are keyed to statutory medium term EU climate objectives whose benchmark should be the position taken by the European Council in October 2009 and the

forthcoming European Commission's Decarbonisation Roadmap 2050, according to which greenhouse gas reductions by 80 to 95 percent by 2050 compared to 1990 levels are on the EU policy agenda. This is the only reduction target that is consistent with the global reduction of greenhouse gases needed to achieve the 2 °C objective. And it provides an appropriate and necessary benchmark for technological development in this domain particularly since it would mitigate the technological lock-in effects (whose reversal is extremely cost intensive) that would arise if the requisite greenhouse gas reductions only become mandatory later on. Hence this overarching objective should be anchored more firmly in EU policy and ideally should be made mandatory.

Unfortunately, in terms of reaching this overarching objective, the modalities that have been defined for emissions trading for the third trading period do not go far enough, particularly since unduly high emission limits, the transferability of unused emission rights into the third trading period, and the continuation of surplus allocations in the industrial sector will result in a weak incentive effective owing to unduly low certificate prices. This situation has been exacerbated by (a) the economic crisis; (b) a glut of new certificates from the New Entrants Reserve (NER) and the flexible mechanisms called for by the Kyoto Agreement. Hence the emissions trading scheme is in desperate need of reform, notably via the following measures:

- A more stringent carbon emissions limit in conjunction with no less than a 30 percent reduction by 2020.
- A mandatory long-term emissions trading reduction goal for greenhouse gases that lays the groundwork for full decarbonisation.
- Implementation of measures (in accordance with the German Constitution) to stem the tide of emission certificates. Such measures could include invalidating certificates left over from the New Entrants Reserve, auctioning industrial sector and other certificates at an earlier stage, and more stringent ex-ante benchmarks for certificate allocation rules.
- Quality assurance measures for carbon emission rights that are traded at the international level.
- Hybridisation of the emissions trading framework through institution of a minimum price with a view to creating more sustainable incentives to reduce emissions.

#### **10.2.4 Stable and efficient support for renewable energy expansion**

By attaching a price to carbon emissions, emissions trading will indubitably make renewable electricity more profitable and will avoid what would otherwise be a significant cost increase for other mechanisms. However, while emissions trading is still an important instrument, others are urgently needed, particularly in the electricity sector. For in the context of a

transition to a renewables based electricity system, emissions trading alone (even if optimised) will not lead to long term minimisation of the social costs of avoiding carbon emissions. This inadequate dynamic efficiency of emissions trading is attributable to a number of factors, the most important being the lock-in effect engendered by emissions trading as a standalone instrument, i.e. one that tends to bring about incremental improvements in power plant fleets that are environmentally unfriendly over the long term, rather than promoting fundamental innovation. As a result, during the transition phase renewables would not be economically competitive even if emissions trading would send the right price signals, and would achieve this state only secondary to cost depressions engendered by broad based market penetration – for which emissions trading alone cannot hope to create the necessary level of incentives. Moreover, it is doubtful that corporations have already begun factoring into their decision making processes the kinds of emissions prices that would follow from the required long-term carbon cap. Owing to the great uncertainty as to how emissions certificate prices will evolve going forward, investors tend to favour incremental improvements for specific development pathways of conventional power plants in lieu of fundamental and radical technological innovation. And even though new conventional power plants are normally more efficient and have lower carbon emissions than their predecessors, their emission levels still remain incompatible with the goal of long term decarbonisation. Moreover, pre-amortisation shutdown of such power plants in compliance with stringent climate objectives would result in unnecessarily cost intensive destruction of capital. This situation is complicated by the fact that (a) in order for our highly intermeshed electricity system to achieve network effects, it will be necessary to coordinate generation technology and infrastructure development decisions at an early stage; and (b) the low marginal cost-based prices that prevail on electricity exchanges will make it necessary to refinance capital investments for wind and solar installations.

Germany's Renewable Energy Act (EEG) as well as EU policy will have a major influence on how expansion of renewable energy unfolds. The EU's Renewable Energy Directive (2009/28/EC) will go a long way toward keeping such expansion on track for the remainder of this decade and achieving partial convergence of renewable-energy support schemes. This policy should in any case be extended beyond 2020. A European roadmap that lays down a framework for renewable-energy expansion up to 2030 should be developed, particularly in terms of national and European infrastructure development beyond 2030. Moreover, the EU framework for renewable energy should take account of the subsidiarity principle and should be formulated in a manner that at the same time respects autonomy of EU Member States and is "community compatible". The Renewable Energy Directive charts a viable compromise course for the foreseeable future between the goal of harmonizing internal European market ground rules and that of giving EU Member States the leeway necessary to shape their renewable energy support schemes, in that the Directive (a) favours a target of 35 percent of Europe's electricity demand being met by renewable energy by 2020, while allowing for

differences in the various Member States' contribution to achievement of this goal; and (b) allows, and indeed encourages the Member States to enter into cooperative regional arrangements that could potentially resolve problems associated with cross-border electricity trading and joint infrastructure projects. The German government should make all-out efforts to forge such alliances.

The Renewable Energy Act (EEG) has proven to be an effective and relatively efficient instrument and is regarded by other nations as a shining example of a successful renewable energy support framework. The Act's main elements – priority feed-in for renewables and guaranteed prices– should be retained at least for the intermitting renewable sources. However, in view of growing renewables shares in the electricity system new challenges have to be addressed. Especially cost efficiency of support schemes will have to become an important criterion as the rise in the proportional use of renewables will also engender higher household electricity bills. The goal here should be long term portfolio optimisation of renewables with a view to achieving greater cost efficiency. Our scenarios presuppose that wind power will in any case predominate in a cost optimised electricity portfolio, although photovoltaic energy, biomass and geothermal energy will also come into play to one degree or another depending on cost and demand. The greater the proportion of German energy demand met by renewable energy, the greater the impact of other users on renewable energy markets (and thereby on renewable energy costs), the more important it will become to strive for a renewable energy portfolio that offers low costs over the long term. Germany's Renewable Energy Act (EEG) should be amended with this goal in mind, but should also permit sufficient flexibility to fold new renewable electricity technologies into subsidy programs while avoiding further excess subsidies for photovoltaic energy. Germany's renewable energy subsidy policies should also continue to promote a stable framework and should promote planning and investment certainty. Furthermore, Germany's renewable energy subsidy programs need to exhibit sufficient flexibility in the face of technological advances. In the interest of taking into account the differing characteristics of the various forms of renewable energy and the impact of renewable energy expansion on the electricity market, we feel that separate support instruments should be developed for each type of renewable energy.

In order to ensure offshore wind energy expansion and in the interest of achieving investment certainty, the Renewable Energy Act (EEG) support scheme for offshore wind energy should be retained for the coming years. Moreover, in view of the high financial risk entailed by offshore wind farms, the possibility of instituting a government risk fund should be considered that would protect wind turbine operators against unforeseen problems that are beyond their control and would enable them to continue paying off their loans in the event of operational breakdowns. If the Renewable Energy Act's cost provisions or incentive effects continue to fail to adequately promote offshore wind energy expansion, the possibility should be considered of issuing tenders for so called fixed-cost compensation, whereby operators

competing for licenses for tendered wind farm zones would bid at auction on a specific guaranteed feed-in tariff that would enable them to amortise their investment costs. The license would then be granted to the operator with the lowest tariff, and this operator would then embark upon the actual planning approval procedure. In such a case, the full feed-in tariff would apply for the 15 year minimum service life of an offshore wind farm and a reduced tariff would apply thereafter. Awarding a public contract would be subject to the condition that the operating license would be granted automatically to the operator that makes the second best offer if the zone for which the license was granted is not used within two years; in which case the operator that was originally awarded the license would not be compensated for the costs incurred and would be required to pay a penalty. Apart from ensuring that public-contract wind farm zones are actually used and that the attendant projects come to fruition, this contract award mechanism would build in the success of feed-in tariffs while at the same time pursuing the goal of strengthening the competitiveness provisions of the Renewable Energy Act (EEG) with the aim of achieving cost optimised wind power capacity expansion. Furthermore tendering will allow for more efficient coordination of grid planning and offshore wind power extension.

In order for wind farm zones to be tendered for auction as described above, the government would have to establish conditions that are conducive to such a procedure, the most important being the promulgation of medium and long term renewable energy expansion goals, as well as specific objectives for offshore wind power. To this end, the government should draw up an offshore wind energy expansion plan that will promote establishment of a wholly renewable electricity supply and that is consonant with a European roadmap for renewable energy. Apart from providing companies with investment certainty, such a plan would also allow for early stage planning with a view to assuring efficient and consolidated coordination of network expansion activities. Likewise a key factor in promoting investment certainty for offshore wind power is designating additional priority areas.

As regards biomass electricity little growth is expected in the SRU-our scenarios for cost and nature conservation reasons. Instead the following two biomass support objectives should be prioritised: (1) Residuals should be recycled in lieu of the ecologically problematic use of energy crops; and (2) better leveraging of the fact that bioenergy production is conducive to regulation for use in load following operation. In the interest of providing more robust incentives for load-following operation, biogas installation support should be paid as a market price premium. Use of residual materials should be promoted via premiums rising relative to the increase of the proportion of such materials in the substrate mass. However the bonus for use of renewable raw materials ("NaWaRo" bonus) should be abolished. Residues mainly comprise liquid manure, plant waste from landscape management activities and municipal or private green areas, crop residues, and biowaste. In the interest of avoiding a situation where primarily intensive-cultivation materials are used as a supplement to low-energy residues, such as manure in particular, efforts should be made to promote the use of particularly

ecologically compatible farming methods. And as financial compensation for existing installations is guaranteed, leveraging of price fluctuations should be made a more appealing option for biomass plant operators, in line with the Renewable Energy Act's direct marketing provisions. The Act's technology bonus, which provides targeted subsidies for innovations, should be retained as an adjunct to the aforementioned price premium with a view to promoting activities such as converting biogas to biomethane that can then be fed into the natural gas grid.

Photovoltaic support should be drastically reduced so as to rectify mismanagement in this domain, whose current expansion rate far exceeds that deemed necessary (according to the current state of knowledge) for achievement of a cost optimised renewable energy portfolio. The government's decision to adjust the annual feed-in tariff reduction to market growth is, though insufficient, a step in the right direction. We also advocate an annual cap on subsidised photovoltaic capacity. The government's defined annual expansion rate of 2,500 to 3,500 MW is far too high and could increase the costs of implementing a wholly renewable electricity supply. That said, photovoltaic capacity expansion should continue at a low but steady rate, with a view to preserving existing manual (contractor) and manufacturing expertise in the event future evolutions necessitate a rapid expansion of photovoltaic capacity.

Our existing onshore wind energy subsidy programs will allow for the expansion activities needed to achieve a solely renewables based electricity supply system. The main challenges here are meeting the relevant legal and policy requirements in terms of environmental protection and nature conservation, and fostering public acceptance of onshore wind farms. To this end, existing wind turbines should be repowered whenever possible, in lieu of installing them in zones not heretofore used for this purpose. Moreover, new wind turbine construction projects should strive to gain public acceptance, preferably via measures such as involving municipalities and local investors in so called citizens' wind farms.

### **10.2.5 Socially acceptable and reliable phasing-out of conventional power plants**

Emissions trading has unfortunately not deterred investments in new power plants that contribute to climate change and whose load balancing capabilities are extremely limited. This is mainly attributable to deficiencies in the current framework that provoke a weak price signal, with the result that emissions trading has only a limited impact on the transition from coal-fired to gas turbine power plants or to renewable energy. Moreover, it is doubtful that corporations have already begun factoring into their long term decision making the kinds of emissions prices that would be necessary to achieve the mandated climate protection objectives. In the interest of counteracting this evolution and keeping open the option of transitioning to a renewables-based electricity system, it may be necessary to institute regulatory and planning frameworks in addition to the existing emissions trading and subsidy

frameworks that would allow for the management of coal fired power plant construction activities, if necessary.

In the view of the SRU, measures such as introducing national carbon emission limits for power plants – a measure currently under discussion both in Germany and abroad – would be admissible under EU law if greatly strengthening the incentive effects of emissions trading proves to be impossible.

In the Environmental Report 2004, the SRU called for a sectoral dialogue with the coal industry which aims to offer viable alternatives to affected regions and to explore ways of mitigating the negative social effects of the structural change. The economic and political conditions for the construction of new coal fired power plants have worsened in the interim, without the government having instituted such a dialogue. There is a need for a clear political signal that the construction of any power plant that does not lend itself to flexible load balancing will be realised at the company's own risk (in keeping with the relevant principles for the protection of assets and legitimate interests) and that no government subsidies will be forthcoming for such projects if the investments prove uneconomic in a changed climate policy environment and in the face of increased competition from renewables. In addition, there is a need for measures that will compensate actors that are adversely affected by the process of transitioning to a renewables-based electricity system. For example, regions that suffer from a decline in the electricity generation sector could be compensated by growth in the relevant supply sectors. This kind of development could be encouraged through industrial policies and would need to be proactively communicated. This implies that any climate policy-driven transformation process is knowledge-intensive. Therefore, the process of managing such a should be implemented from the get-go with a view to enlisting the support of the scientific community and a broad range of actors for a transparent process that strives for binding agreements.

### **10.2.6 Expedited grid expansion**

A transition towards a fully renewables-based electricity system requires that the pace of expansion of our electricity grid be stepped up. In the interest of achieving security of supply, the electricity supply infrastructure will need to be able to adjust to more decentralised and more intermittent power generation. Key to reaching this goal is an extensive expansion of both domestic and international transmission capacity. And this in turn will require us to overcome the following major obstacles:

- Political and economic obstacles to investment arising from grid regulation
- Planning approval procedure delays
- Public acceptance issues

## Reform of German grid regulation

Although transmission system operators are required by law to build electricity transmission networks that will allow for an efficient integration of renewables, it is difficult to oblige them to build a specific connection which is thought to be necessary for achieving a certain energy policy goal. Hence, in addition to existing legal obligations, it is essential to institute investment incentives that will sufficiently attract investors to build the desired sections of transmission networks. However, there are doubts whether the incentive-based regulation adopted in 2009 in Germany is able to accomplish this aim.

This regulation aims to create incentives that will scale back the cost drivers of network charges. This is done by setting a cap on transmission system operator revenues. Those operators that successfully lower their costs below the revenue cap are permitted to keep the monetary difference between this limit and their actual costs. This way they have a chance to increase their profits. Investment budgets have been introduced to ensure that sufficient capital investment is geared towards network expansion and modernisation projects. The budgets are subject to approval by the Bundesnetzagentur (Federal Network Agency). Approved budgets allow for an increase in network operator revenue above the cap and are intended to attract investments in conjunction with relatively constant and secure earnings from operating electricity grids. However, operators complain that various Bundesnetzagentur deductions from the investment budgets reduce revenues to a point where grid investments are no longer sufficiently profitable. This problem is particularly acute for unbundled transmission system operators. For them, banks demand a risk margin on possible loans as these operators have a greater need for external funds owing to lower ratings from international rating agencies. The financial crisis has exacerbated this situation even further.

The pace of the requisite grid expansion could be stepped up by instituting a federal loan program via the Kreditanstalt für Wiederaufbau (KfW). This could bring down the higher borrowing costs which unbundled transmission system operators are currently subject to. In addition, all actors concerned should enter into a dialogue regarding an acceptable rate of return on equity. Moreover, the SRU recommends a public tendering process for the construction of high power point-to-point connections and the realisation of an overlay grid.

## Tendering for high-power grid connections

The current regulatory system fails to co-ordinate long-term the development of renewable energy and the electricity grid restructuring needs arising therefrom. This co-ordination cannot solely be left to corporate interests. Similarly to the tendering process for offshore wind farms,, the SRU considers that cost intensive domestic and cross-border point-to-point transmissions lines should be tendered via public contracts for predefined lines. Under such a system, the bidder that offers the requisite investment in conjunction with the lowest grid charges over a 20 year period would be awarded the contract.

This system should be based on a federal sectoral plan that defines the relevant need for transmission lines and their routes and allows a public debate concerning alternative routes (more on this below). Such a nationwide network expansion strategy would enable the government to coordinate grid expansion by tendering contracts with a required minimum capacity for lines needed. Such a process would also generate competition between bidders and thereby secure cost efficiency for the various expansion projects. Furthermore, this would obviate the need for the government to set a specific rate of return. In the end, tendering for transmission lines would also promote the development of new technologies by including qualitative criteria into the contracts.

#### Power grid planning and approval procedures

One of the central weaknesses of the current legal framework for planning and approval procedures for power transmission grids is the loss of time that results from assessments that are repeated at different stages of the approval procedure. This is mainly attributable to the fact that the tasks of land use planning on the one hand and sectoral planning on the other hand are not always clearly differentiated. Thus, the various phases of the planning and approval procedure should be clearly distinguished and thereby transparent for the authorities and interested parties.

To this end, it is particularly important to further develop meaningful and appropriate public participation procedures involving the general public as well as persons concerned that help to gain acceptance for the projects. For high-level decision processes in which alternative routes of power transmission lines are discussed call for a different type of participatory procedure than planning on a small scale which has direct consequences for specific pieces of real estate and may entail expropriation procedures. Unlike current practice, high-level decision making processes need to be appropriately formalised. They should allow for involvement early on of the relevant interest groups as well. For this is the only way such processes can hope to meet the measure of the problems, generate all requisite information, and promote public acceptance of the grid expansion.

In view of the fact that the necessary power grid expansion mostly exceeds the boundaries of individual German states and even of Germany itself, and also its extreme urgency, grid planning should be carried out at the federal level. Alternatively, stringent coordination mechanisms would be necessary between the interdependent planning processes carried out by the German states.

#### A far reaching reform scenario: two-stage sectoral planning

Against this backdrop, the SRU recommends that a federal plan titled "The electricity transmission grid for 2030" be established. It should at a high level define the relevant needs for transmission lines and the transmission line routes and should allow for a debate concerning alternative routes. This plan should take account of private sector grid planning,

the requirements entailed by trans-European energy networks as well as the grid model to be elaborated by the Bundesnetzagentur (Federal Network Agency). The federal plan defines the scope of the requisite grid expansion on the basis of an open and transparent participatory procedure that includes the strategic environmental assessments (SEA) and takes account of the applicable nature conservation laws. A legally binding identification of the grid expansion required for 2030 at the highest planning level is essential for all actors. This is necessary because storage capacity expansion, load management, electricity generation management, and grid expansion activities must be coordinated. In doing so, the government assumes its responsibility to provide the requisite infrastructure. This also applies to the process of defining transmission line routes and the fundamental choice between underground cables and overhead lines.

Moreover, the planning procedure should be structured in a manner that promotes problem solving. This concerns firstly its legal design as an administrative planning procedure with final decisions being made by the federal government. This would make use of the administrative capacities as well as of the democratic legitimation of the government. In view of the close connection between the needs assessment and the large-scale transmission line routes planning, decisions in regard to both should be bundled in lieu of differentiating between statutory needs planning and executive transmission line route planning.

Another key factor here is the allocation of administrative competencies to the federal authorities. Only in this way can large scale interdependencies between the grid needs assessment and large-scale transmission line route identification be optimally realised. As experience with traffic planning has shown, in the absence of a clear normative planning competence of the federal level, the actors concerned switch to informal processes whose main drawbacks are that they do not foster the same level of accountability as a formal process and do not guarantee the broad balancing of interests that is necessary to gain acceptance.

In view of the fact that the aforementioned concept would entail statutory land use planning at the federal level, the strategic environmental assessments and the flora-fauna-habitat impact assessments should be integrated into the federal sectoral planning procedure. This would also enable a broad public participation. However, such a high-level rough-cut planning would not concern individual issues and could not be challenged by individuals in the court. Therefore, alternatives would have to be examined again in the planning approval procedure. Nonetheless, planning approval authorities could confine their efforts to the assessment of small scale alternatives, since large-scale alternatives would have already been analysed in the preceding formal procedure, in which the variant chosen had to be justified.

The applicable law for the subsequent planning approval procedure would remain essentially unchanged.

### Planning and approval for offshore cable connections

Most of Germany's offshore wind farms are built in the exclusive economic zone (EEZ) for reasons related to the tourist trade, nature conservation and coastal protection. Hence the requisite cable connections traverse the EEZ and then proceed through coastal waters to the onshore feed-in point. The standard planning approval procedure does not apply to cables connecting offshore wind farms in the EEZ, where virtually all offshore wind farms have been built. Instead, approval for offshore cables is governed by the Seeanlagenverordnung (Offshore Installations Ordinance). Moreover, in the interest of taking some of the financial burden off wind farm operators, article 17(2a) of the Energiewirtschaftsgesetz (Energy Industry Act, EnWG) stipulates that network connections for offshore wind farms are the responsibility of the transmission system operators.

The current regulatory framework guarantees sufficiently standardised and formalised planning procedures for offshore cables. But it is in need of reform, because it does not allow to sufficiently steer the process. Hence a planning approval procedure should be instituted in the near term that prioritises networked solutions based on discretionary considerations. To this end, the SRU recommended in 2003 that management discretion with regard to the construction of wind farms and thus also to their cable connections be instituted. This would not only provide for planning discretion but also for a suitable planning procedure that entails a concentration of the procedure at one administration as well as a public participation process. It would also be preferable if a unified cable approval procedure could be instituted, although this would be difficult to achieve as the relevant competencies are divided between the federal government and state governments.

There is also a lack of coordination with regard to the offshore connections necessary for the offshore wind parks. Here too, central planning should be instituted along the lines of what we have proposed here for onshore grid expansion. This would necessitate coordination between federal land use planning efforts for the EEZ and land use planning in the German coastal states. This could potentially be achieved via the proposed approach to tendering for public contracts for offshore wind farms.

### Further development of long-distance trans-European connections

The EU should promote the development of trans-European electricity grids and key long-distance connections and facilitate cooperation to support this objective. The EU's sphere of responsibility in this context is limited to relatively soft governance instruments, notably through selection and promotion of projects of common or European interest in the guidelines for trans-European energy networks. Grid planning and investment are still mainly the responsibility of the Member States and private enterprises. The scope of article 194 of the Treaty on the Functioning of the European Union, whose incorporation in this document was promulgated by the Lisbon Treaty, remains to be explored.

In this regard, Member State grid expansion programs should be bolstered by improved coordination, notably as regards cross-border expansion needs for renewables and high capacity long distance connections. Efforts should focus on the following in particular:

- More tightly intermeshed coordination for renewable energy expansion and grid planning for the period after 2020
- The European Commission or its subordinate authorities should conduct dedicated needs analyses, based on information from transmission network operators, concerning expansion and further development of the trans-European grid, with a view to achieving efficient quality assurance for EU energy policy objectives
- Cross-border cooperation for public contracts and notably for new cross-border high capacity long distance connections should be bolstered
- The groundwork should be laid for regional cooperation among grid operators notably in the North Sea and Mediterranean regions

#### Acceptance

While renewable energy is a technology that the general public readily embraces, the prospect of expanding transmission network grids to allow for the integration of offshore wind power provokes strong protest. One of the main effects of Germany's fast-track planning law has been to limit public participation and litigation rights. The restriction on opportunities for public input resulting from this law has also reduced the scope of nature conservation expertise that is folded into the process, and has done nothing to increase public acceptance of a renewables expansion. It is essential in this regard to solicit public input before all project related decisions have been made so that the public can still have some say about how a given project is to be carried out.

Moreover, the possibility of using underground onshore cables should be looked into more thoroughly, as the use of such cables considerably shortens the planning phase since the public accepts them more readily. A suitable instrument to this end might be a standardised assessment framework for decision making, which would be based on transparent and readily understandable criteria, as has been discussed in Switzerland.

### **10.2.7 Regional cooperation with Norway and neighbouring states for the use of pump storage systems as the backbone of a reliable electricity supply**

In an electricity system with a high proportion of intermittent wind and solar energy, load balancing is one of the main challenges for achieving a reliable and low cost supply of electricity. Various load balancing methods are available: energy storage systems; large-scale networks; load dispatching; and variable output power plants. In the long term, these various options can either strengthen each other or be in competition with each other. Energy

storage systems play a key role here, as they (a) allow for the storage of low cost wind and solar power, which can then be fed back into the system during peak demand periods; and (b) provide system services by ensuring grid stability.

The use of pump storage systems should be prioritised in this regard as these systems are proven, low cost, and exhibit very low energy loss. According to the estimations of the SRU, the specific storage costs for AA-CAES (advanced adiabatic compressed air energy storage) technology or other storage technologies would far exceed that of suitably localised pump storage systems, even after such technologies become commercially viable.

Inasmuch as Germany offers little in the way of suitable locations for low cost expansion of pump storage systems, such facilities would need to be expanded primarily in countries with natural areas that would allow for a very extensive expansion. The most promising locations in this regard are in Scandinavia, but also in Switzerland and Austria. In Norway in particular, numerous extensive water storage systems are available that could be converted into pump storage systems at a relatively low cost and without undue ecological impact – which in turn would mean that there would probably be relatively little public opposition to such projects.

Current renewable energy expansion plans, particularly in the North Sea region, and today's market design already make investments in pump storage systems and grids an appealing prospect for Norwegian hydroelectric power station and network operators – other than in Germany, where signals from the energy sector and our politicians are insufficiently clear in this regard.

What is thus needed is a clear political signal from Germany to the effect that (a) connecting the German and the Scandinavian grid and the use of pump storage systems are central to the German strategy for the expansion of renewable energy; and (b) a proactive energy foreign policy aimed at establishing the investment certainty needed by private investors is a must.

The North Sea wind belt extending from Scotland to Denmark could potentially play a pivotal role for the expansion of renewable energy in the EU. However this can only come to pass expeditiously if this expansion is embedded in a coordinated grid planning in the North Sea region as well as an integration of Norwegian pump storage system capacity. The German government should promote an integrated capacity and grid planning for the North Sea region by instituting clear-cut, binding policy measures. Grid operators should be encouraged to enter into cooperative arrangements that will further this aim. In the interest of promoting regional cooperation, European network planning instruments (which should be further developed) and the regional cooperation modalities called for by the Renewable Energy Directive should be used proactively.

### **10.2.8 The prospects for a further Europeanisation of energy and climate policy**

The climate and energy package adopted by the EU in 2008 gave Europeanisation a robust boost that supports Member States' renewable energy expansion policies. Key forward looking initiatives such as the *Decarbonisation and Energy Roadmaps 2050*, to be launched by the European Commission in 2011, the envisaged pan-European high capacity long distance electricity transmission grid, and the further development of the Emissions Trading System and the Renewable Energy Directive offer further opportunities for bolstering Member States' energy policies via European climate and energy policies. A European energy strategy that places particular emphasis on climate protection and renewable energy would have numerous advantages: it would level the playing field in terms of market competition; it would provide Europe with access to cheaper energy and energy storage resources; and it would open up new markets across the entire renewable energy value chain.

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## Chapter 4

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## Chapter 5

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## Chapter 6

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## Chapter 9

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## **ANNEX: Results for the EUNA region (scenario 3.a)**

### **1 Introduction**

In spring 2009, the German Advisory Council on the Environment commissioned the German Aerospace Centre (Deutsches Zentrum für Luft und Raumfahrt, DLR) to develop several scenarios of a 100 % renewable electricity system for Germany for the year 2050, using their REMix model (as presented in chapter 3). The scenarios follow the logic of a backcasting approach. In this case the scenarios analyse if and how a given electricity demand in a country can be provided by renewable sources and what the respective costs will be, assuming an optimized combination of renewable power sources, storage capacities and international grid connections.

In scenario group 3 Germany was assumed to be part of an electricity system covering the whole of Europe and a part of North African (EUNA region, altogether 36 countries and country clusters, respectively). At the outset it was defined for this scenario group that each country utilises its renewable energy potential but is allowed to import electricity produced from renewable energy sources up to 15 % of its annual demand. Furthermore, the exchange of electricity for temporary storage was not restricted as long as each country fulfilled the 85 % renewable production minimum.

In chapter 3.4 the results for Germany are presented. However, results for the whole EUNA region have been analysed on a country specific level for each of the 36 countries included after the Special Report had been published in German language. As the results are now available, they are summarised and presented here.

### **2 Methodological Caveats**

The modelling of electricity demand and renewable electricity supply of 36 countries, including the application of detailed weather and technology data, with high time resolution requires large processing capacities. In order to keep computing times at acceptable levels, the modelling of scenario group 3 was slightly modified compared to the other scenario groups. First of all, the time resolution was reduced to 2 hours, i.e. results from every second hour of the year were developed (in contrast to the other scenario groups in which every single hour was modelled). Secondly, the optimisation of one year was split up into five parts. Each part was optimised separately from the others. That, again, had an effect on the further processing of these partial results. The assembly of a country's five result fractions needed to be adjusted slightly in order to get sound overall results. As the optimisation using this approach resulted in differences in capacity (hence cost) values in the five result fractions for particular technologies in the single countries, the average of those five values needed to be used for further calculations.

These sound results also needed to answer the question how much a kWh imported would cost. Therefore, approximations on the lengths of transmission lines were conducted for every country combination. These transmission lines were priced and, again, related to the amount of electricity transmitted, which was calculated by the model for each pair of countries. The specific costs for imported electricity were assumed to be even in the entire region.

Additionally, the value of Norway's natural inflow into hydro storage basins have been to be readjusted slightly by utilising historical data from Norway' statistical office.

Electricity demand in the 36 EUNA countries and country clusters, respectively, has been extrapolated from the German situation. For Germany, the SRU assumed an efficiency scenario, slightly reducing electricity demand to 2050 (from ca. 550 in 2008 to 500 TWh in 2050) and a high demand scenario (from ca. 550 to 700 TWh). For scenario 3.a the efficiency scenario has been modelled. As the efficiency scenario tends towards the higher end of available scenarios for Europe (Chapter 3.2), the assumptions tend to err at the safe side.

### **3 Results**

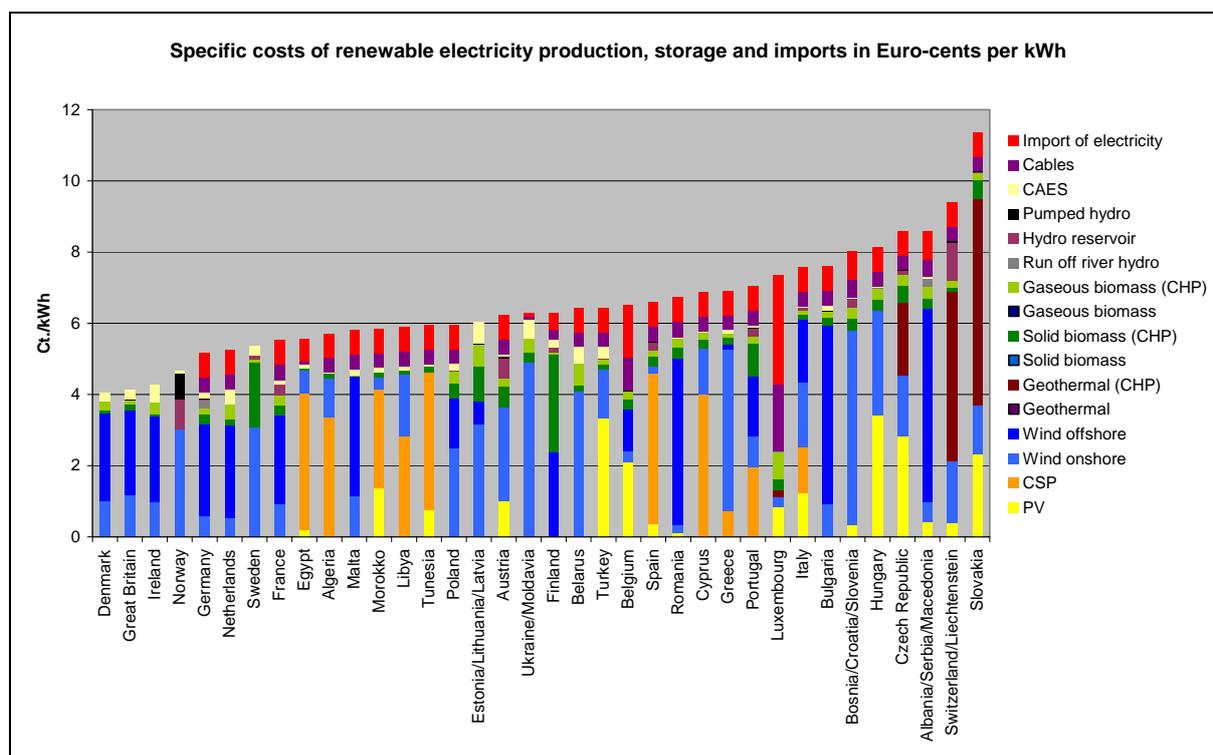
Basically, a huge amount of modelling data have been analysed, processed, and refined. The main result categories are capacity installed, production costs, and electricity production – for every single country and every single technology. From those data, further results could be gathered, such as specific electricity costs. In this section, the most relevant results are presented.

For the target year 2050, the specific costs of renewable electricity generation vary between approximately 4.1 and 11.4 Euro-cents per kWh. As predefined, countries were assumed to rely on a minimum share of 85 % on their domestic production. Thus, imports up to 15 % occur, if domestic production is more expensive than imported electricity. That is why net electricity costs of importing countries are mainly driven by their domestic production. If the assumption of 15 % net imports was relaxed, more low cost electricity would be available to the high cost countries. So differences of the specific electricity costs in the single countries (as shown in figure 1 in ascending order) could be reduced by relaxing the trade-restrictive assumption of the scenario. The figure reveals that even very cost intense technologies are being used in some countries due to the import restrictions mentioned above. For instance, Slovakia's electricity costs are the highest of all countries (11.4 Euro-cents per kWh) as rather expensive geothermal electricity generation is needed to supply a large share of the domestic production, being responsible for half of the overall costs. The red areas on top of most of the country bars illustrate that the majority of the countries (30 out of 36) are net importers.

The average specific costs of all countries are 6.5 Euro-cents per kWh. Countries with the lowest specific costs are Denmark, the UK, Ireland and Norway as they have a large wind energy potential with high average wind speeds.

Figure 1

**Scenario 3.a: Specific costs of renewable electricity production, storage and imports in Euro-cents per kWh**



SRU/SG 2011-1engl./Fig. 1 (annex)

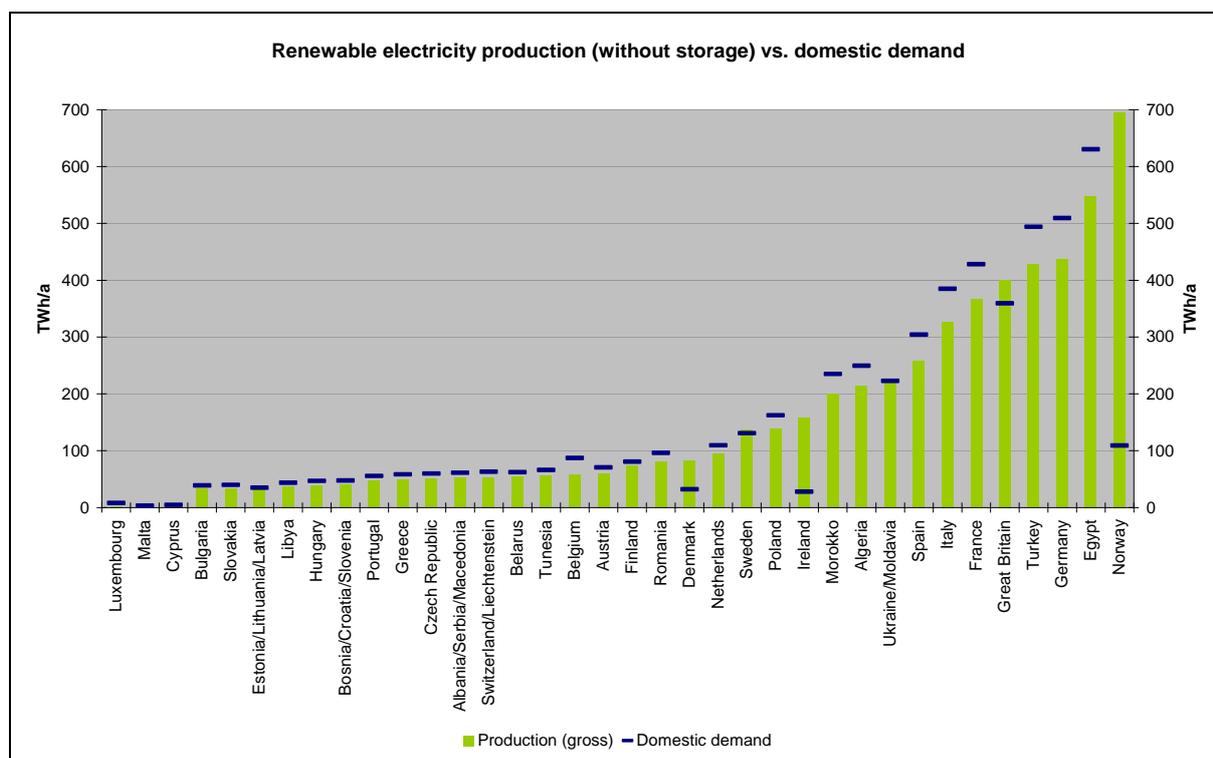
Taking into account the restrictions presented earlier, the annual renewable electricity production for every single of the 36 EUNA countries was modelled. In some of the countries renewable electricity production is higher than domestic demand, so they are net exporting countries. As most of the countries are net importers, though, their domestic renewable electricity production is smaller than their domestic demand. The green bars in figure 2 represent each country's annual renewable electricity production; the short blue lines represent their annual domestic demand. Secondary electricity production from storage is not taken into account here. If the green bar and the blue line do not cross, the country is a net importer. It becomes obvious that there are only few countries that are net exporters.

Depending on size of the countries, domestic electricity demand spans from 3.3 (Malta) to 630 TWh/a (Egypt), while renewable electricity production spans from 2.6 (Luxembourg) to 695 TWh/a (Norway). There are countries with a rather high electricity demand that still depend on imports, too. A country of that category would be France with a renewable production of 366 TWh/a at a domestic demand of 428 TWh/a. The country that produces most is Norway with 695 TWh/a, using its large onshore wind and reservoir hydro potential.

As Norway's domestic demand of 109 TWh/a is much lower than its amount produced, it can export more than 588 TWh/a to other countries. Possible slight deviations between the figures of electricity produced, imports and domestic demand result from storage losses.

Figure 2

**Scenario 3.a: renewable electricity production (without storage)  
vs. domestic demand**



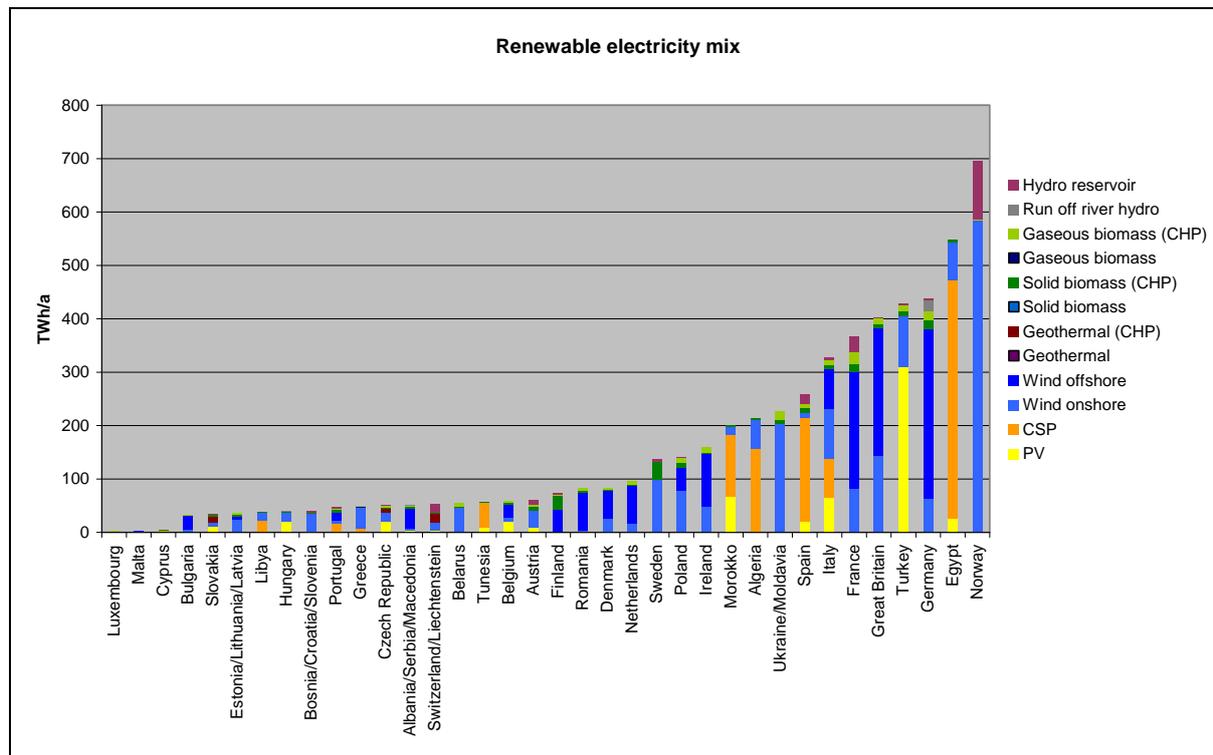
SRU/SG 2011-1engl./Fig. 2 (annex)

Figure 3 displays the same production quantities of the EUNA countries as figure 2., Each bar in the diagram is segmented according to the production shares of the different technologies. It becomes obvious that there are four main groups of countries that can be distinguished by the use of their renewable potential: one country group consists of countries located north or south of the Mediterranean using mainly solar technologies such as CSP and PV (especially Egypt, Spain, Algeria, and Morokko). A second group consists of countries using mainly wind technologies (on-shore and off-shore) such as Norway, Germany, the UK, France and Ukraine/Moldavia, a third group of countries using a more even mix of different renewable energy sources like Italy and Hungary. A fourth group consists of countries or country clusters with a high share of geothermal power production making for high costs like Slovakia and Switzerland/Liechtenstein.

The countries with comparably low production can be sorted into those groups, too. There are exceptions, though, too. For instance, Italy's production consists of a large solar share and a large wind share at the same time as the costs of both technologies do not differ a lot in Italy.

Figure 3

### Scenario 3.a: Renewable electricity mix



SRU/SG 2011-1engl./Fig. 3 (annex)

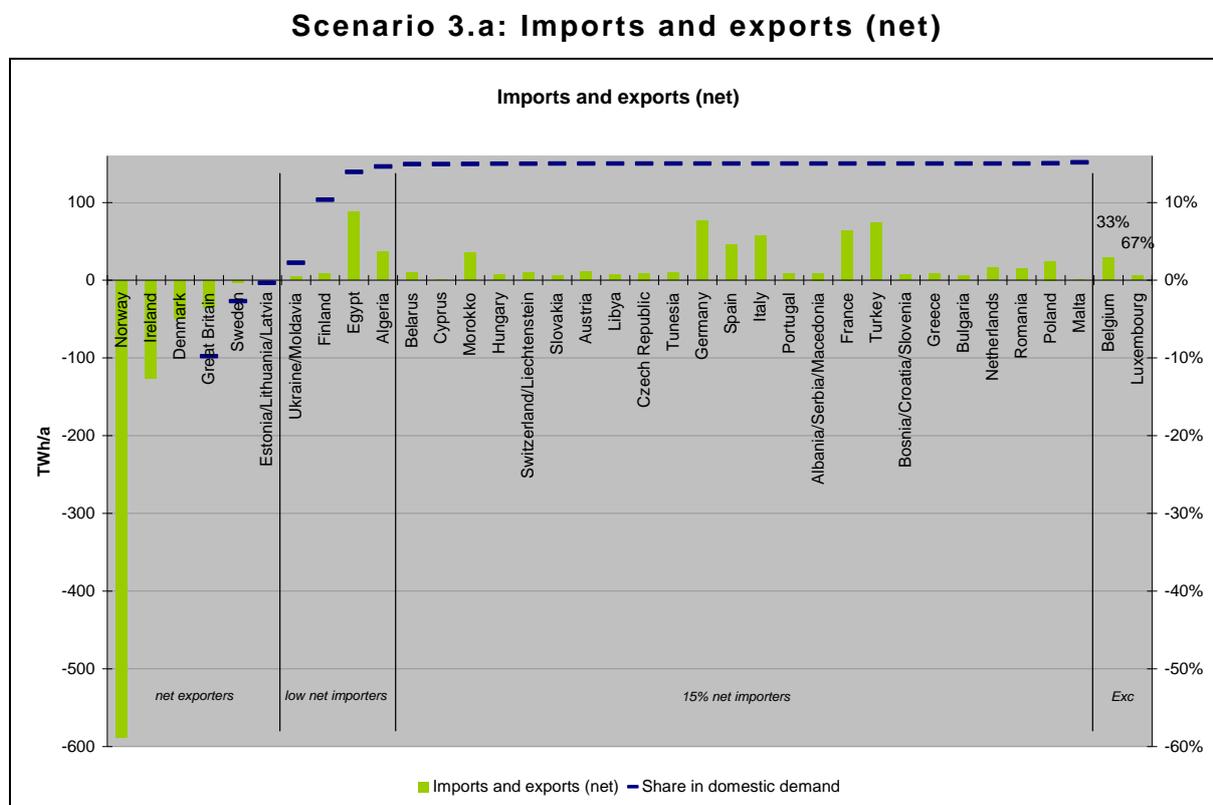
As presented earlier, most of the countries are net importers. In figure 4 each country's annual import/export balance is related to its share of imports in their domestic demand. 34 out of 36 countries are able to supply at least the required quota of 85 % renewable electricity from domestic sources. Only Belgium (66 % domestic production) and Luxembourg (33 % domestic production) need to rely more heavily on their neighbours.

It becomes obvious that they can be segmented in four groups:

- net exporters: the renewable electricity production of Norway, the Republic of Ireland, Denmark, the UK and Sweden is higher than their domestic demand. In these countries and their off-shore territories, mainly wind energy is being used. The export quantities summed up equal the import quantities of the net importing countries.
- Low net importers: Ukraine/Moldavia, Finland, and Egypt do not reach the 15 % imports allowed. They are net importers but on a lower level due to substantial cheap domestic resources.
- 15 % net importers: the optimisation results in a net 15 % import share for most of the countries. Their imported electricity is generated in the net exporting countries as it is cheaper than domestic supplies.
- Exceptions: as their renewable potential is very limited, Belgium and Luxembourg need to import more than the 15 % originally allowed in order to satisfy their electricity demand.

The model therefore admits the exception that a country can import more than this predefined share after having used its full domestic renewable potential. That is why Belgium imports one third of its electricity and Luxembourg even two thirds.

Figure 4



SRU/SG 2011-1engl./Fig. 4 (annex)

## 4 Interpretation of results

The model results of the 36 countries in scenario 3.a document the feasibility of a 100 % renewable electricity supply of the entire EUNA region. This security of supply has been calculated for every second hour of the year. Additional model runs (taking months with present processing power) would show rather similar results for every hour of the year.

Due to their large renewable potential and very low production costs, there are five countries/ country clusters that act as net exporters in the system: Norway, Ireland, Denmark, the UK, Sweden and the Estonia/Lithuania/Latvia cluster. The other countries are net importers, most of them use the maximum 15 % share allowed. However, there are two exceptions: due to their very limited renewable potential Belgium and Luxembourg need to have a higher import share to achieve a 100 % renewable electricity supply.

As only gross costs were regarded, the figures presented above do not include the income the net exporting countries generated from their exports. Countries that have large potentials of rather expensive renewable electricity production such as geothermal tend to have higher specific electricity costs.

It needs to be highlighted that all the numbers and figures presented result from the REMix modelling under the constraints presented in chapter 3 and the modelling limitations (chapter 2). The scenarios calculated show that a 100 % renewable electricity supply is possible and feasible for the entire region by 2050. Nevertheless, depending on the assumptions made, other cost-optimized 100 % scenarios could be designed, allowing for a different composition of the renewables used in each country or for more trade. The assumptions on future cost relations of the different technologies as well as the quantitative limits assumed especially for the cheaper renewable resources drive the composition of the model results. In Germany, for example, the severe restriction of on-shore wind to approximately 40 GW result in a relatively low share of this resource in the final electricity consumption. Latest discussions and developments show that capacities of more than 80 GW may be realized.

In that sense, the results of those scenarios should be regarded as an indicator for the strength of the overall method, the model applied and the robustness of the overall result: Security of electricity supply, competitiveness and sustainability are achievable by an electricity system based upon 100 % renewable sources. However for national energy debates we recommend a more tailor made set of assumptions especially as regards future electricity demand.

Ministry of the Environment, Nature Conservation and Nuclear Safety

## **Charter Establishing an Advisory Council on the Environment at the Ministry of the Environment, Nature Conservation and Nuclear Safety**

1 March 2005

### Article 1

The Advisory Council on the Environment has been established to periodically assess the environmental situation and environmental conditions in the Federal Republic of Germany and to facilitate opinion formation in all government ministries, departments and offices that have jurisdiction over the environment, and in the general public.

### Article 2

(1) The Advisory Council on the Environment shall comprise seven members who have special scientific knowledge and experience with respect to environmental protection.

(2) The members of the Advisory Council on the Environment shall not be members of the government, a legislative body of the government or the civil service of the Federal Government, state governments or of any another public entity, universities and scientific institutes excepted. Further, they shall not represent any trade association, or employers' or employees' association, nor shall they be in the permanent employ of or party to any non-gratuitous contract or agreement with any such association, nor shall they have done so in the 12 months prior to their appointment to the Advisory Council on the Environment.

### Article 3

The task with which the Advisory Council on the Environment is charged shall be to describe the current environmental situation and environmental trends, and to point out environmentally related problems and suggest possible ways and means of preventing or correcting them.

### Article 4

The Advisory Council on the Environment is charged exclusively with the mission stated in this charter and may determine its activities independently.

### Article 5

The Advisory Council on the Environment shall provide the federal ministries whose area of competence is involved, or their representatives, the opportunity to comment on important issues that emerge as a result of the Council's performing its task, and to do so before the Council publishes its reports on these issues.

## Article 6

The Advisory Council on the Environment may arrange hearings for federal offices and *Länder* offices concerning particular issues, as well as invite the opinions of non-governmentally affiliated experts, particularly those who represent business and environmental associations.

## Article 7

(1) The Advisory Council on the Environment shall draw up a report every four years, to be submitted to the Federal Government in May. The report is to be published by the Council.

(2) The Advisory Council on the Environment may make additional reports or statements on particular issues. The Federal Ministry of the Environment, Nature Conservation and Nuclear Safety may commission the Council to make further reports and statements. The Council is to submit the reports and statements mentioned in clauses (1) and (2) of this article to the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety.

## Article 8

(1) Upon approval by the Federal Cabinet, the members of the Advisory Council on the Environment shall be appointed by the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety for the period of four years. Equal participation of women and men shall be aimed for as provided for in the law governing appointments to federal bodies (the *Bundesgremienbesetzungsgesetz*). Reappointment shall be possible.

(2) The members of the Council may give written notice to resign from the Council to the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety at any time.

(3) Should a member of the Council resign before serving the full four-year period, a new member shall be appointed for the remaining period. Reappointment shall be possible.

## Article 9

(1) The Advisory Council on the Environment shall elect, by secret ballot, a chairperson who shall serve for a period of four years. Re-election shall be possible.

(2) The Advisory Council on the Environment shall set its own agenda, which shall be subject to approval by the Federal Minister of the Environment, Nature Conservation and Nuclear Safety.

(3) Should a minority of the members of the Council be of a different opinion from the majority of the members when preparing a report, they are to be given an opportunity to express this opinion in the report.

#### Article 10

The Advisory Council on the Environment shall be provided with a secretariat to assist it in the performance of its work.

#### Article 11

The members of the Advisory Council on the Environment and its secretariat are sworn to secrecy as concerns the Council's advisory activities and any advisory documents that it classifies as confidential, and as concerns any information given to the Council that is classified as confidential.

#### Article 12

(1) The members of the Advisory Council on the Environment are to be paid a lump-sum compensation and to be reimbursed for their travel expenses. The amount of compensation and reimbursement shall be determined by the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety, with the consent of the Federal Ministry of the Interior and the Federal Minister of Finances.

(2) The financial funding for the Advisory Council on the Environment shall be provided by the Federal Government.

#### Article 13

To accommodate the new date of submission to the Federal Government under Article 7 (1), the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety may extend the appointments of the Council members in office when this Charter enters into force to 30 June 2008 without requiring the approval of the Federal Cabinet.

#### Article 14

The Charter Establishing an Advisory Council on the Environment at the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (GMBI. 1990, no. 32, p. 831), issued on 10 August 1990, is superseded by this charter. Bonn, 1 March 2005

The Federal Minister of the Environment, Nature Conservation and Nuclear Safety

Jürgen Trittin

## Publications

### **Environmental Reports, Special Reports, Research Materials and Statements**

The Council's environmental reports and special reports published **from 2007** onwards are available both from book shops and directly from the publisher: Erich-Schmidt-Verlag GmbH und Co., Genthiner Str. 30 G, 10785 Berlin, Germany.

They are also available online at <http://www.esv.info/neuerscheinungen.html>.

Environmental reports and special reports published **between 2004 and 2006** are available from book shops or from the publisher: Nomos-Verlagsgesellschaft Baden-Baden; Postfach 10 03 10, 76484 Baden-Baden, Germany or [www.nomos.de](http://www.nomos.de).

*Bundestagsdrucksachen* are available from: Bundesanzeiger Verlagsgesellschaft mbH, Postfach 100534, 50445 Köln, Germany or [www.bundesanzeiger.de](http://www.bundesanzeiger.de)

Most publications issued since 1998 are available as PDF files and can be downloaded from the SRU website ([www.umweltrat.de](http://www.umweltrat.de)).

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