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On Market Integration of Renewable Energies

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CHAPTER 1

Introduction

When the new Federeal Minister of Economic Affairs and Energy, Sigmar Gabriel, presented his reform plans for the promotion of renewable energies recently at the Handelsblatt Jahrestagung in Berlin, he made the motivation of the reform very clear: "Beside qualified employees and infrastructure, the Energiewende is the biggest challenge for Germany. It has the potential to become a great economic success or the biggest deindustrialisation of our country. […] The learning curve of the Energiewende led to costs of Euro 24 bn p.a. To my knowledge, there is no other economy in the world that is able to handle such a burden. […] Everyone should be aware, that – beside legitimate interests of all stakeholders – the macroeconomic stability of the whole country is at risk. […] In the past, we all underestimated the effects and difficulties of the Energiewende."

This thesis examines effects of renewable energies on existing energy markets. We assume that cost efficiency is a relevant side condition. As the speech of federal minister Gabriel indicated, this has not always been the case in the past. Today, cost efficiency is definitely relevant and might also be an essential target in the future as pointed out in the coalition agreement (see The Federal Government of Germany 2013, p. 50). Additionally, the thesis investigates the various other cost-efficient options that policy makers have in striving to reach energy and climate policy targets.

1 Fundamentals

Under specific conditions, markets fail to allocate resources efficiently. Energy markets are one example of this; the use of fossil fuels emits greenhouse gases (GHG) and hence contributes to global climate change. This means an external effect for energy suppliers, since they do not bear the costs of climate change. There are two possible ways of dealing with this market failure: first, accepting the consequences of climate change and perhaps adopting appropriate responses, and second, fighting climate change by cutting greenhouse gas emissions. From an economic standpoint, both possibilities call for a careful weighing of potential risks and benefits.

The Stern Review (2006) was the first publication to provide a detailed cost-benefit analysis of greenhouse gas emissions. It recommended taking action to stop climate change, since the costs of an unlimited climate change would outweigh those of cutting greenhouse gas emissions. Despite the controversy surrounding climate change, the need to fight it is recognized throughout the world, as the annual international climate conference shows. The essential point of discussion, however, is how to share the costs of cutting greenhouse gas emissions.

Apart from considerations of climate protection policy, reducing consumption of fossil energy sources is also in line with the energy policy targets of some countries, particularly those in the West. The motives for that are various.[1] The main reason is to ensure the security of supply. Fossil energy sources are finite, yet worldwide energy consumption is steadily increasing. Hence, the security of supply is endangered. Furthermore, energy prices may increase dramatically in the long run if sources are non-renewable. Another reason is to reduce dependency on exports of fossil energy sources, particularly from Eastern Europe, Asia and the Middle East. Also, the hope for increasing economic growth due to technical progress in the field of alternative energies and domestic added value is a reason often pointed out.

Renewable energies provide a means of cutting greenhouse gas emissions and reducing fossil fuel consumption. For a number of reasons, however, most renewable energies are not competitive yet. First, their production is still in small scale. Second, they depend on weather. Third, fossil energies do not carry the external costs of greenhouse gas emissions. In consequence, renewable energies must be promoted in order to ensure market introduction. Generally, there are two possibilities: first, direct subsidies could compensate the higher costs compared to fossil energy sources. Second, a

1 See for example Krause et al. (1980) or The Federal Government of Germany (2007).

market for greenhouse gas emissions would internalise the costs of greenhouse gas emissions and therefore create a level playing field for renewable and fossil energy sources.

Currently, the application of both options can be seen in many countries: direct subsidies and trading strategies for emissions permits. The co-existence of both options is often subject of discussion and controversy regarding efficiency.[2] It is overlooked, though, that two arguments speak for the co-existence of both options: first, promoting renewables is not the only policy target as stated above. Following the Tinbergen Rule, there should be at least the same number of instruments as there are targets.[3] Second, some economists argue that there are market imperfections connected with the external effect of emitting greenhouse gases – in particular, technical spillover and asymmetries of information. Hence, additional measures such as the promotion of renewables could accelerate or even enable the internalisation of greenhouse gas emissions and therefore justify overlap between measures.[4]

However, efficiency is important to maintain the public acceptance for replacing conventional power plants. Additionally, western economies emphasize maintaining the competitiveness of domestic firms that may compete with countries that do not invest in renewable energies.

Given these considerations, fighting climate change, and more specifically building up renewables energies, are complex tasks for policy makers. On the one hand, an effective strategy for promoting renewables must be established, and on the other hand, the costs of such a promotion must be kept as low as possible. Moreover, the security of supply must be ensured to maintain public acceptance as well as the competitiveness of domestic firms. In conclusion, policy makers face a triad of energy policy targets in efficiency, climate and environment protection as well as security of supply.

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2 See Weigt et al. (2013) for a literature overview on the effects of the overlapping measures.

3 See Tinbergen (1952).

4 See Bennear and Stavins (2007) for a discussion.

2 Building up Renewable Energies

So far, in most countries, political measures aiming on the replacement of fossil energy sources by renewables have been focussed on increasing the market share of renewables. Also, the focus was on electricity markets. However, a parallel structure of electricity generation was established rather than market integration, because current electricity markets are not designed to cope with renewable energies. This lack of market integration is a consequence of technical and economic boundaries. From a technical perspective, the most important reason is the inability of renewables to secure base load. Moreover, the promotional strategy in most countries gave no incentive to generate renewable electricity according to price signals. Hence, the share of renewables on electricity generation rose but conventional capacities were barely replaced.[5]

In Germany, the political decisions that were made shortly after the Fukushima incident gave rise to problems related to replacing conventional with renewable capacities. The government decided to shut down seven nuclear power plants immediately; the rest would be shut down by 2022. At the same time, climate protection targets were left unchanged. These decisions mean that renewable energies have to replace nuclear power plants as well as the majority of coal, lignite and gas power plants. Consequently, a quick market integration of renewables is needed to ensure the security of supply once nuclear and fossil power plants have been shut down.

While most economic impediments such as the design of the promotional strategy are easily removable[6], most technical impediments are not. This is a result of four specific characteristics of renewables that considerably affect market outcomes. First, aside

5 See Weigt (2009). Furthermore, see the actual discussion on increased coal use in Germany (for example Wacket 2013) which, however, has different reasons like decreasing costs of coal and CO_2 certificates and the replacement of nuclear power and may not be a long-run effect.

6 Clearly, a theoretical finding of an optimal promotional strategy must be distinguished from the political support that the implementation of such a strategy would require. A plurality of interests must be taken into consideration due to the vast number of stakeholders.

from hydropower and biomass/biogas, they lack the ability to secure base load. Hence, given a fix demand, a backup is needed as long as there is no competitive means of storing electricity. Second, electricity generation is extremely volatile due to the variability of weather conditions. Thus, there are special economic and technical requirements for the remaining power plant park if the demand for electricity is fixed. In addition to being extremely flexible, low deployment times must be sufficient to cover the fixed costs if there is no extra compensation for providing back-up capacities. Thirdly, their marginal costs of production are close to zero. This will decrease electricity prices – the so-called merit order effect[7] – which will have two implications. Rents will shift from producers to consumers, and incentives to invest in new power plants – for both conventional and renewable energies – will decrease. As a consequence, the market might eventually fail to ensure the politically desired level of security of supply. There will thus be a need for state intervention. Fourthly, the structure of power generation is rather decentralised, which has a fundamental affect on the grid architecture. Typically, grid extensions are very expensive. Moreover, they have predetermined the structure of electricity generation for decades.

3 Market Integration

Market integration is needed to replace fossil and nuclear energy sources by renewables. Although the term "market integration" is often heard during discussions of promotional strategies for renewables, its meaning is often unclear. Generally, market integration can be understood as the unification of two or more separate relevant product markets. Since renewable energies do not constitute a separate relevant market, the term market integration is not clear. The difference between renewable and conventional energies is that renewables are mostly not yet competitive. Hence, by using

[7] See for example Sensfuß (2008).

the term market integration of renewable energies in the public debate, it is meant that renewables should follow the same market rules as conventional energies. This is the case if electricity generation costs of renewables result from a market mechanism. Furthermore, it is also the case if renewables react to price signals. Hence, the absence of subsidies is not a necessary condition for market integration of renewables.

So far, there have been few measures to integrate renewable energies into existing energy markets, since the feed-in tariff "Eneuerbare-Energien-Gesetz (EEG)" concentrates on building up renewable capacities. As renewables reach substantial shares of electricity generation, the next phase of the promotion of renewables must concentrate on market integration to prevent the establishment of a permanent parallel structure.

Both the majority of current analyses of the market integration of renewable energies and the larger public debate are aimed at improving the current promotional strategy – in particular, at reducing costs and easing the current burden on consumers. In contrast, this thesis broadens the debate on market integration. The focus should be on minimising the costs of reducing carbon emissions and replacing nuclear power plants by renewable energies at a constant level of security of supply. To date, however, there has been no "big plan" on the part of governments that defines strategies and milestones to reach the targets for the share of renewables at total energy consumption and for cutting greenhouse gas emissions (The Federal Government of Germany 2011). There are only lead scenarios (Nitsch et al. 2012) that describe potential strategies for reaching goals. Hence, the achievement of the long-term energy and climate policy targets is a matter of short-term political measures that address the needs of the moment. Whether this approach will change in the future remains unclear.

4 Questions

This thesis deals with two questions to engender a long-term perspective on the debate on market integration:

1. What effects do renewable energies have on energy markets?
2. With regard to cost efficiency, what other options do policy maker have to reach the targets?

First, given the four specific features of renewables, as discussed above, it is interesting if and how renewables affect energy markets. Possible effects will become more visible with the increasing share of renewables. Some consequences are already evident, such as the well-known merit order effect. The merit order effect has clear impact on electricity prices and may also affect investment incentives over the long term. However, the literature on the merit order effect concentrates on adding renewable energies to an existing power plant park, which is in line with the energy policy targets that were in place prior to the decision to shut down all of Germany's nuclear power plants by 2022. This is a completely different case, since renewable energies have to replace assured conventional capacities by that time. It is therefore unclear how this will affect power prices. Currently, such effects may be invisible since there is a remarkably oversupply in the German power market which keeps prices low and base load assured. Furthermore, the market maturity of new technologies may have essential effects on power prices. Flexibility options to cope with the loss of assured capacities may be grid expansions, electricity storage, demand side management, power to heat, power to gas etc. However, the concrete price effects of flexibility options are unclear, but are highly important for long-term investment decisions.

Second, further options to reduce the costs of reaching the energy policy and climate protection targets without harming the security of supply may occur. Specifically, the timing of investments in renewable energies might have a great impact due to the rapid technological development. Also, the replacement of oil and especially coal by natural gas might be an efficient measure to reduce greenhouse gas emissions. Furthermore, the concentration on promoting the supply of renewable energies ignores the demand for energy that can be reduced by efficiency measures.

Against the background of the energy and climate policy targets, these two questions are essential and not independent of each other. This is because the effects of policy measures within the context of reaching the energy and climate policy targets are completely understood in the literature. Given that uncertainty, it is worthwhile to investigate potential effects of renewable energies on energy markets. Furthermore, a comparison of expected costs as well as benefits with potential effects of alternative measures is needed. Although this approach seems trivial, it has not always been taken in recent years.

5 Structure

Consequently, the thesis is divided into two parts that deal with the two questions. The first one consists of the articles that are presented in chapters two and three; the second part consists of the three articles presented in chapters four to six.

In chapter two, we analyse how replacing conventional capacities by renewable energies affects power prices. Therefore, we consider the nuclear phase-out in Germany and apply Monte Carlo simulations of spot market outcomes. In this context, we find increasing spot market prices in the case of renewable energy sources replacing conventional base load capacities due to the inability of renewable energies to secure base load. In addition to the well-known merit order effect, i.e. decreasing power prices when renewable energies are added to an existing power market, this is an important result when discussing reforms of the power market design.

In chapter three, we extend the research on this effect. Normally, the security of supply is in the focus when the replacement of renewables is discussed. In contrast, we concentrate on spot price effects and ask: how much secured renewable capacity or other flexibility options are necessary in order to keep spot prices stable when conventional capacities are replaced? This question is essential to clarify long-term price and cost impacts of the replacement of conventional capacities by renewables. Since renewable electricity generation fluctuates with a very low minimum load, spot market prices will increase if no cheap base load capacities are available. We apply the nuclear phase-out in Germany as an example for replacing conventional base load capacities by renewables in this chapter. Using Monte Carlo simulations of spot market outcomes to a stylized German power market, we find that 14.5 GW of secured renewable capacity would be necessary to replace the 15.03 GW of secured nuclear capacity in order to keep spot market prices steady. This is highly unrealistic since it is approximately fifty per cent more than the annual installed capacity of wind and solar power in the last years. Hence, it shows the huge need for flexibility options in order to reach the policy targets efficiently – assuming the design of power markets is maintained.

Chapters four to six deal with the second question of the thesis. The article presented in chapter four addresses the residential housing sector. This sector is of particular importance, since on the one hand it has high potential for reducing greenhouse gas emissions, and on the other, the current share of renewable energies is very low. In general, the residential building sector offers several possibilities to reach the climate and energy policy targets: reducing greenhouse gas emissions and the use of fossil fuels is possible due to the use of renewable energies. Moreover, efficiency measures, i.e. the use of advanced heating technologies and thermal insulation, offer another possibility. Hence, a cost-benefit analysis of the different options is essential to find the most cost-efficient way to reach the policy targets.

In order to achieve that policy targets in the building sector, a higher rate of building refurbishment is necessary to improve the energy standard of residential building stock in the European Union. Although subsidisation seems to be necessary, optimal measures concerning cost effectiveness are unclear. Using a stylised model of the German residential building stock, we analyse different refurbishment measures by simulating every relevant investment by 2030 in chapter four. In particular, we compare two different options that are relevant for political measures: first, comprehensive refurbishments that are expensive but achieve the greatest reductions in energy consumption and GHG emissions, and second, partial refurbishments which include only low-cost improvements but can be achieved on a wide scale. We conclude that comprehensive refurbishments will require the least amount of investment as well as abatement costs per ton of GHG emissions and provide the highest reductions in energy consumption in 2030. However, in terms of cumulated GHG emissions in the period considered, there is very little difference between the two options. This is due to their different dynamics: comprehensive refurbishments achieve fewer results in the first years, but catch up quickly, which means that the higher the refurbishment rate, the higher the advantage of comprehensive refurbishments. Hence, partial refurbishments are only optimal within very short periods of time. In other words, it is always optimal to apply comprehensive measures when long periods of time are concerned.

Chapter five presents an analysis of the timing of renewable energy promotion and its impact on the cost efficiency. Given the fact that the costs of renewable energies are constantly decreasing, the timing of investment decisions does matter. Since most of the policy targets are connected to certain dates like 2020 or 2030, there is an incentive to delay the investment decision to reduce the investment costs per capacity installed. Hence, policy makers, particularly in Germany, face a dilemma: on the one hand, quick investments in renewable energies promote the structural change of the energy sector and may yield technological progress. On the other hand, a late investment may lead to considerable cost savings. Furthermore, the timing decision becomes more complex when the relevance of economies of scale and strategic interactions are taken into account: assuming that a substantial proportion of cost decreases are due to economies of scale, there is an incentive to wait for investment decisions by others. Since Germany has a large share in the worldwide demand for renewable energies due to its first-mover status, other countries may wait for Germany to make investment decisions. However, this might not apply for all technologies. With regard to offshore wind energy, Germany is currently the only country of the world to invest in deep water sites.

The potential for cost reduction is analysed within the framework of the “Lead Study 2008” in which the German government set targets both for renewable energies and related technologies and hence affected the particular feed-in tariff. In this chapter, we use a static model to analyse the efficiency of the targets for 2020 regarding renewable energies. We show that postponing specific investments lowers the cost of achieving the promotional targets of 2020.

The application of state-of-the-art fossil technologies rather than expensive renewable energies is a further possibility that is in line with the reduction of costs, fossil energy consumption and GHG emissions. One option might be replacing coal, lignite and oil with natural gas for generating heat and power. In chapter six, we utilize several scenarios to investigate the impact of natural gas and the consequences for carbon emissions. The calculations show that the share of natural gas for the supply of heat will increase from 46 per cent to 56 per cent. Efficiency increases together with changes in the structure of power generation can reduce heating-related carbon emissions by 8.3 per cent by 2020. For power generation, we calculate alternative scenarios. If the current structure of power generation remains constant, carbon emissions will increase by 0.8 per cent per year. Conversely, if natural gas completely replaces coal and lignite, carbon emissions will be reduced by 1.9 per cent per year.

6 Conclusions

Since the liberalization of electricity and gas markets in Europe, the energy sector has changed in every respect with one constant: most actors have underestimated renewable energies with regard to their growth, their economies of scale and their impact on existing energy markets. If that trend continues, the urgency for policy measures will increase. Given the security of supply, integration of renewables into energy markets is necessary to replace fossil and nuclear capacities. However, the further development of renewable energies plays a crucial role in the ability to meet the energy and climate policy targets. Thus, it increases the need for regulation to achieve societally desirable outcomes.

This thesis has examined the effects of renewable energies on existing energy markets. It has also investigated the various other cost-efficient options that policy makers have in striving to reach energy and climate policy targets. We assumed that cost efficiency is a relevant side condition. In the past, this has not always been the case. Today, cost efficiency is definitely relevant and might also be an essential target in the future (see Bundesregierung 2013, p. 50).

We contributed to the analysis of power prices as a result of increasing shares of renewables by showing that shutting down conventional capacities will have a merit order effect. This is necessary if renewable energies are to replace fossil and nuclear capacities. Any discussion of a change of market design should make mention of this effect, since spot market revenues impact a company's behaviour within potential capacity markets. From a consumer perspective, we have shown that there is a substantial need for secured capacity with low marginal costs to keep spot prices stable. This outcome has important implications for policy makers if they are to provide consumers with low-cost renewable market integration.

Policy makers have numerous ways to reach policy targets than rapidly expanding renewable energies. This is particularly important for the residential sector – but also for mobility – where the share of renewables is currently very low. We have shown that efficiency measures could potentially greatly conserve GHG emissions and fossil fuels. This implicates a prioritized use of state-of-the-art fossil technologies rather than expensive renewable energies. This would allow sufficient time for technological progress and cost reduction for renewable energies. This applies not only to the residential, but also to the mobility sector, where renewable energies are expensive and still in an early stage of development. The same is true with regard to the power sector, where, on the one hand a substitution of coal by natural gas could reduce GHG emissions. On the other hand, a temporal optimization of building up the different renewable energies could cut investment costs given a substantial decrease of costs in time. Currently, this could apply for offshore wind energy. In both cases, we were able to show the potential for considerable savings of GHG emissions, and, respectively, investment costs. Still, it is also always possible to reduce GHG emissions and costs by reducing the demand for power via efficiency measures.

However, our results are subject to considerable uncertainty. As stated above, for the last ten years, the only constant in the rapidly changing energy sector has been the dynamic development of renewable energies. Empirical findings like Swanson's law[8] may persist for many years. This assumption seems plausible, since renewable technologies are still not mature. Hence, the fundamental element of uncertainty might no longer be energy and climate politics, but rather technological progress.

The evaluation of the importance of technological progress yields, however, to a fundamental question: what does "Energiewende" mean? There are two possible (extreme) points of view: on the one hand, one could argue that it is a destruction of a well performing system by policy makers for populist reasons. The change is therefore based on subsidies, and could be undone after a reduction of subsidies. On the other

[8] A learning curve concept that states that the price of solar photovoltaic modules tends to drop 20 per cent for every doubling of cumulative shipped volume (Swanson 2006).

hand, one could argue that it is a structural and irreversible change – one driven by technology and accelerated by subsidies.

Implicitly, the German government and the EU authorities hold the latter point of view. A fundamental conclusion would be that the integration of renewable energies into existing energy markets is the wrong concept. In fact, a market transformation, i.e. a creative destruction in the sense of Schumpeter (1942), is the best definition. Therefore, the question is how to deal with uncertainty in the face of rapid technological change, and moreover, with complex socio-political conditions. In such a situation, any advice for long-term, irreversible measures based on comparative static ceteris paribus analyses could prove risky. Hence, the development of a "master plan" for the implementation of the energy and climate policy targets seems inappropriate. As a result, short-term measures that are reversible and that ensure a quick reaction seem optimal. Consequently, in this trial-and-error approach, which chancellor Merkel once mentioned as "run on sight", there are no big plans – just targets.

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CHAPTER 2

Price Effects of Replacing Conventional Energy Supply by Renewables: The Case of the German Nuclear Phase-out

Daniel Comtesse • Sebastian Schröer

Abstract

We analyse how replacing conventional capacities by renewable energies affects power prices. Therefore, we consider the nuclear phase-out in Germany and apply Monte Carlo simulations of spot market outcomes. In this context, we find two results: First, we prove the well-known merit order effect, i.e. decreasing power prices when renewable energies are added to an existing power market. Second, we find increasing spot market prices in the case of renewable energy sources replacing conventional base load capacities, due to the inability of renewable energies to secure base load.

JEL Classification: D43, Q42, Q48, L94

Keywords: electricity, renewable energy, merit order effect, market integration, nuclear phase-out, Germany

1 Introduction

In light of the Fukushima incident, the German government decided a nuclear phase-out until 2022. At the same time, it was decided to replace the nuclear power plants by renewables. This decision is in line with energy and climate protection policies. Their targets are the reduction of greenhouse gas emissions as well as independency from fossil resources. As a consequence, the already ambitious targets to increase capacities of renewable electricity generation were raised even more.

Since nuclear power plants provided approximately half of the German base load capacity, this nuclear phase-out is unprecedented. So far, there has never been such a short-term replacement of conventional capacities by renewables. However, this is not merely a German topic, since renewables are promoted in many countries due to a common policy target: the replacement of fossil capacities by renewables. In line with this target, renewables should replace lignite and coal power plants in the first place. In Germany, however, this is unlikely to happen, since the nuclear phase-out makes fossil power plants indispensable for ensuring the security of supply. Nevertheless, the German phase-out might be an example for other countries that plan to replace nuclear and fossil capacities by renewables in the very long run. Still, there are substantial technological and economic problems to be solved in order to attain such a technology shift.

There are some evident effects of renewable electricity generation, especially since the promotion of renewable energies has, in many countries, led to a substantial share of renewable energy consumption. For example, there is a broad body of literature on the so-called "merit order effect" that implies that renewable energies have the effect of decreasing electricity prices at spot markets. This outcome is obvious, since renewable energies usually have very low marginal costs of electricity generation. Their addition to an established power plant fleet consisting of nuclear, coal, lignite and gas power plants means an excess supply at very low marginal costs. Hence, spot market electricity prices will fall.

However, this is a static effect resulting from the assumption of a constant power plant fleet. This is unlikely in the long run, since renewable energies have three specific features compared to fossil and nuclear fuels: Firstly, they lack the ability to secure base load. Secondly, their supply is extremely volatile. Thirdly, their marginal costs of production are close to zero. The weather condition-related characteristics have substantial impact on other power plants: renewables erode the prices at spot markets and also reduce the time of utilization and, hence, decrease revenues of conventional capacities. If fossil and nuclear power plants are to be replaced by renewables in the long run, renewables will, therefore, need back-up capacities that can cope with these characteristics as long as electricity cannot be stored in large amounts economically. Additionally, political measures like emissions trading (ETS) or market conditions such as the development of fuel prices or costs and carbon capture and storage (CCS) are unpredictable. Hence, the future structure of the remaining power plant fleet is uncertain. Since the electricity price at spot markets highly depends on the cost structure of the power plants, particular for peak-load, the long-run price effect of renewable energies is unknown.

Although it is the target of climate and energy policy in many countries to replace conventional capacities by renewables, there are very few studies on the price impact of such a replacement.[1] This seems surprising since there is a broad body of literature on the merit order effect.[2] One of the very few exceptions is Kemfert and Traber (2011) who calculated an effect on spot market prices up to 22 % if all nuclear power plants were shut down using the ESYMMETRY model, which is described in Traber and Kemfert (2010). However, this outcome is hypothetical since the remaining capacities are not sufficient to ensure supply for peak demand. Kemfert and Traber (2011) also calculated an increase of 6.3 % as a result of the shutdown of seven older nuclear power

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1 See Nestle (2012) for a literature overview of the expected effect of nuclear power on the electricity price. Also, there are some studies that focus on aspects like technical feasibility, see for example Bruninx et al. (2012).

2 See Sensfuß et al. (2008) or Traber and Kemfert (2009) for example.

plants that took place shortly after the Fukushima incident. This outcome seems logical since wind speed and sun intensity fluctuate over time, making electricity generation extremely volatile. Hence, a one-to-one replacement of conventional capacities by renewables is impossible. Some studies analysed the capacity effect of renewables and mostly concluded a very low or quite insignificant reduction of conventional capacities.[3]

The aim of this paper is to investigate price effects of replacing conventional energy supply by renewables, particularly wind and solar energy. Hence, we use the nuclear phase-out in Germany as an example for replacing conventional base load capacities by renewables and calculate the price effects for a hypothetical complete nuclear phase-out in 2011.

2 Model and Data

We develop a stylised German power market within a spot market setting, where prices are based on the marginal costs of the power plants. We use Monte Carlo simulations to calculate the price effect of a nuclear phase-out ("Phase-out") in contrast to the "Status Quo" case. By Status Quo we mean the current power plant park in 2011. Consequently, Phase-out denotes the current power plant park without nuclear power plants. Due to data availability, renewable energy is assumed to be only wind and solar power in the model. Therefore, old hydro-electric power plants are not considered to be renewable. Furthermore, we compare two more scenarios: "Status Quo Without Renewables" denotes the current power plant park in 2011, but without solar and wind power. By comparing this scenario to Status Quo, we can quantify the merit order effect for 2011. Also, we calculate the scenario "Moratorium" which is the power plant park in 2011 with restricted nuclear capacity. This scenario is in line with the shutdown of seven old nuclear power plants by the German Government shortly after the Fukushima incident.

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3 See Weigt (2009) for a literature overview.

The supply is defined by the merit order curve that aggregates power plant capacities according to their marginal costs. Hence, the supply function in the Status Quo (index SQ) spot market ($S_{SQ\,i}$) sums up power plants in relation to their marginal costs which leads to an upward sloping supply function. Index i denotes the simulation. We tried several numbers of simulations up to several millions. Since detailed information of the German power plants is unavailable, we assign each power plant to a power plant type according to its fuel and technology. In line with this assumption, marginal costs are the same within a power plant type, but differ across the various types. For reasons of simplicity the secured capacity of every power plant type is always available except for wind and solar power. Table 1 shows marginal costs and capacities for the different power plant types. Given these capacities, demand for electricity might exceed electricity generation, thus the model fills any supply gap through importing from other countries. To simplify, importing has no capacity limit and the same marginal costs as Peak Load II power plants.

Table 1: Installed Capacities and Marginal Costs at the End of 2010

Power Plant Type	Power Plant Fuel	Installed Capacity (GW)	Secured Capacity (GW)	Marginal Costs (€/MWh)
Renewable	Wind	27.70	2.08	1
	Solar	17.30	0	1
Base Load I	Hydro	3.47	1.39	1
	Nuclear	18.10	15.03	12.5
Base Load II	Coal	19.18	17.65	20
Medium Load I	Lignite	25.08	21.57	25
Medium Load II	Gas Combined Cycle	9.36	8.06	30
Peak Load I	Pumped Hydro Storage	6.40	5.76	50
	Gas Turbine	14.58	10.15	60
Peak Load II	Oil	2.73	2.04	80
Imported Energy				80
Σ		143.90	83.73	
Nuclear Power Plants				
End of 2010		18.10	15.03	12.05
Moratorium		11.87	9.86	12.05
Nuclear Phase-out		0	0	0
Source: Kemfert and Traber (2011); own calculations				

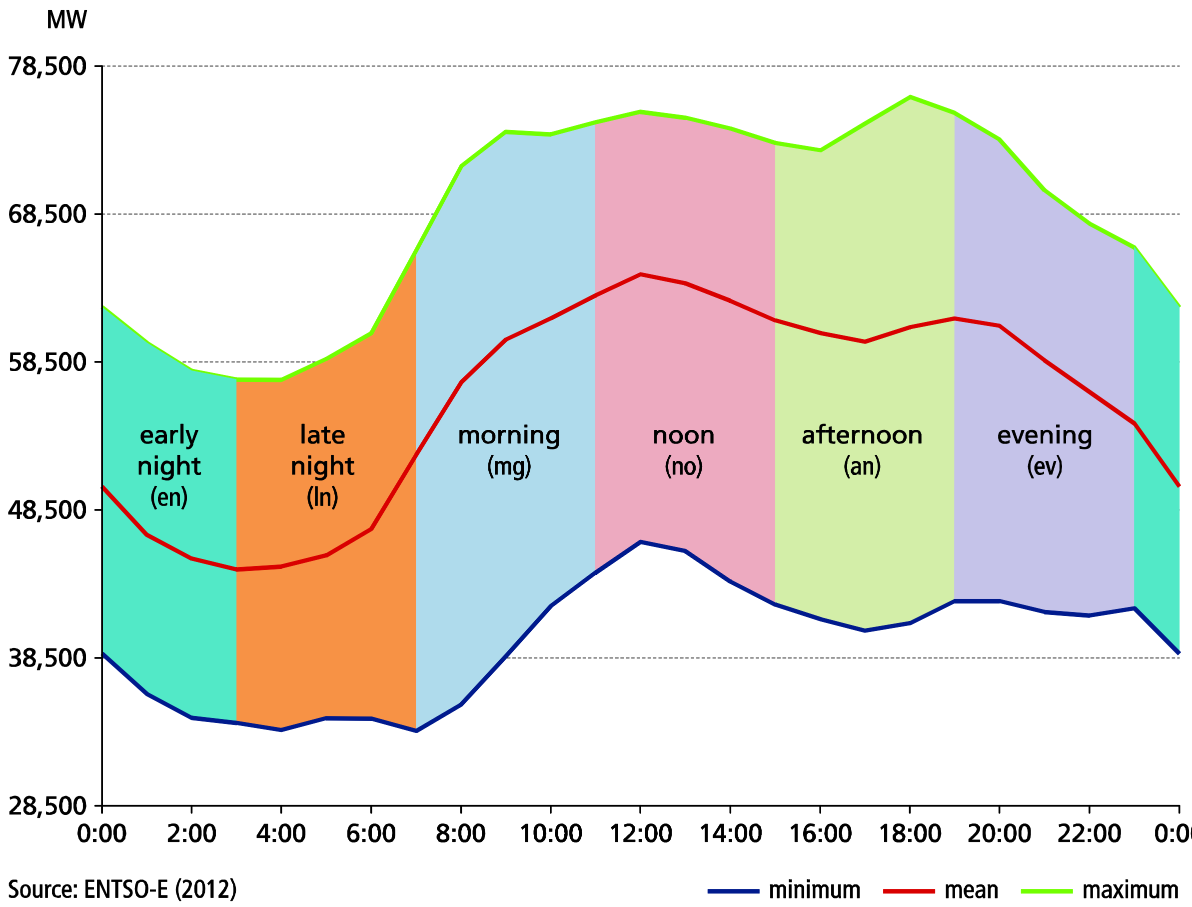
The supply function ($S_{SQ\,i}$) is therefore denoted as:

$$S_{SQ\,i} = S_{RE\,i} + S_{BLI\,i} + S_{BLII\,i} + S_{MLI\,i} + S_{MLII\,i} + S_{PLI\,i} + S_{PLII\,i} + IM_i \qquad (1)$$

The supply function ($S_{PO\,i}$) of scenario Phase-out is equal to Status Quo but without nuclear power plant. The same applies for the scenarios Phase-out Without Renewables ($S_{SQwoRE\,i}$) as well as Moratorium ($S_{MO\,i}$) as described above.

The electricity demand is divided into peak and off peak time during a day. Figure 1 shows the minimum, mean, and the maximum amount of electricity in the power grid by hour. For further analysis of peak and off-peak effects, the demand of a day is divided into six time intervals (T): Early Night (en, 23:00–2:00), Late Night (ln, 3:00–6:00), Morning (mg, 7:00–10:00), Noon (no, 11:00–14:00), Afternoon (an, 15:00–18:00) and Evening (ev, 19:00–22:00) (cf. Figure 1 and formula (2)). Since consumers cannot change their electrical equipment and additionally do not change their behaviour in the short run, the demand is assumed to be completely inelastic. Therefore, the demand function (D_{Ti}) is a vertical straight line in every time interval (T) (cf. formula (3)) and is also equal in every scenario. We use real data of the amount of electricity in the German transmission network grid as stated by the European Network of Transmission System Operators for Electricity (ENTSO-E, 2012) in 2011.

Figure 1: Electricity in the German Transmission Grid in 2011



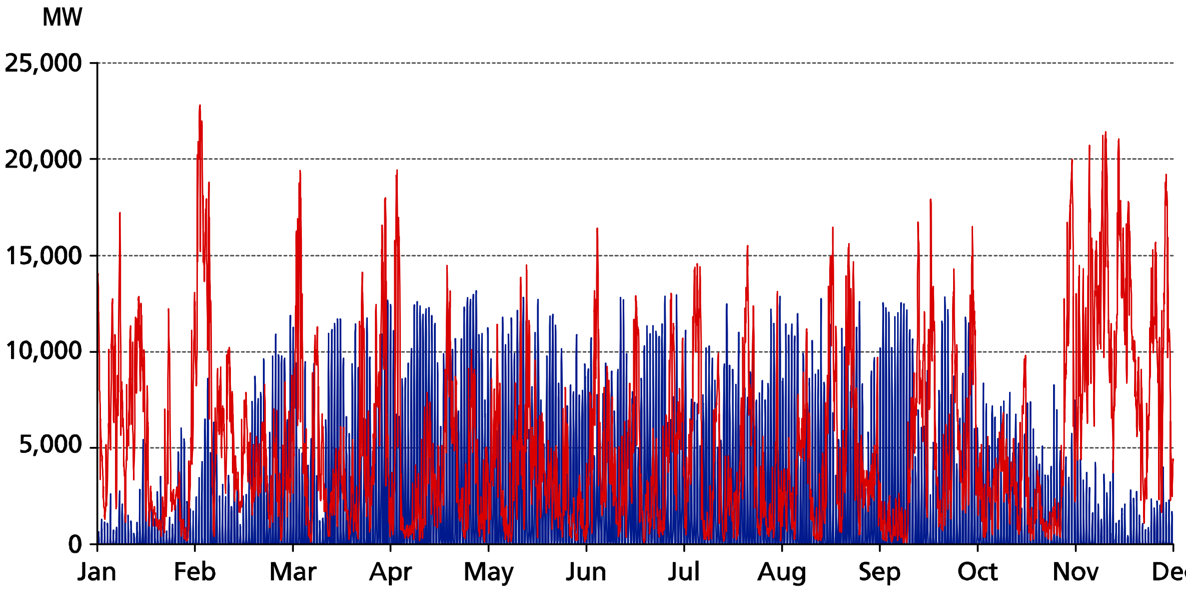
$$T = \{\text{en, ln, mg, ev, an, no}\} \qquad (2)$$

$$D_{Ti} \in \{\text{hourly load values}\} \qquad (3)$$

As all power plants have an incentive to offer at marginal costs at spot markets, the Status Quo price (P_{SQi}) equals the marginal costs (MC) of the price setting power plant. This marginal power plant is at the intersection of the demand (D_{Ti}) and the supply function ($S_{SQ\,i}$). Although the German market is an oligopoly, this model does not allow for strategic pricing. By assumption, all power plants, except wind and solar power plants, generate at their secured capacity except for the marginal power plant which only generates the amount necessary to clear the market. Since wind and solar power depend on weather conditions, electricity generation is very volatile. In contrast to conventional capacities, we use real data for wind and solar feed-in on an hourly basis provided by the German TSO's 50 Hertz Transmission (2012), Amprion (2012), Tennet TSO (2012) and TransnetBW (2012). Figure 2 shows the electricity generation in 2011 while the combined generation of wind and solar power by day can be seen in Figure 3.

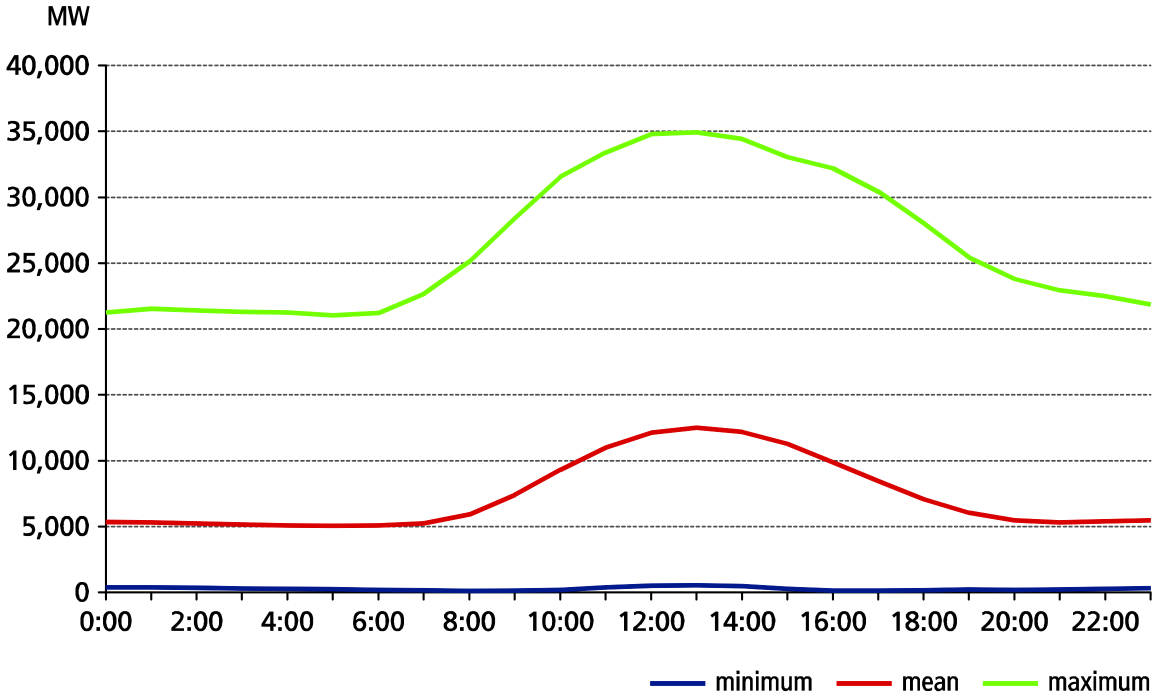
$$P_{SQ\,i} = f\left(D_{T\,i}, MC, S_{SQ\,i}\right) \qquad (4)$$

Figure 2: Renewable Electricity Generation (Wind and Solar) in 2011



Source: 50 Hertz Transmission, Amprion, Tennet TSO, TransnetBW

Figure 3: Renewable Electricity Generation (Wind and Solar) Throughout a Day in 2011



Source: 50 Hertz Transmission, Amprion, Tennet TSO, TransnetBW

Based on these market settings, the model calculates the price change of Phase-out (ΔP_{PO}) in comparison to Status Quo by simulating the price during Phase-out ($P_{PO\,i}$) as well as the price during Status Quo ($P_{SQ\,i}$) k times. To ensure the comparative static setting of the model, the same electricity demand within each simulation i and the same time interval is assumed. Therefore, in a price simulation i, the demand for electricity is the same in both Phase-out and Status Quo, but electricity demand differs across all k simulations. Given the prior assumptions, each difference in price is defined by the different marginal power plants in Phase-out and Status Quo. The calculated price difference is a mean of the k price differences for every time interval. The changes in price of Moratorium and Status Quo Without Renewables follow the same derivation.

$$\Delta P_{PO} = \sum_{i=1}^{k} \frac{P_{PO\,i} - P_{SQ\,i}}{k} \quad (5)$$

3 Results

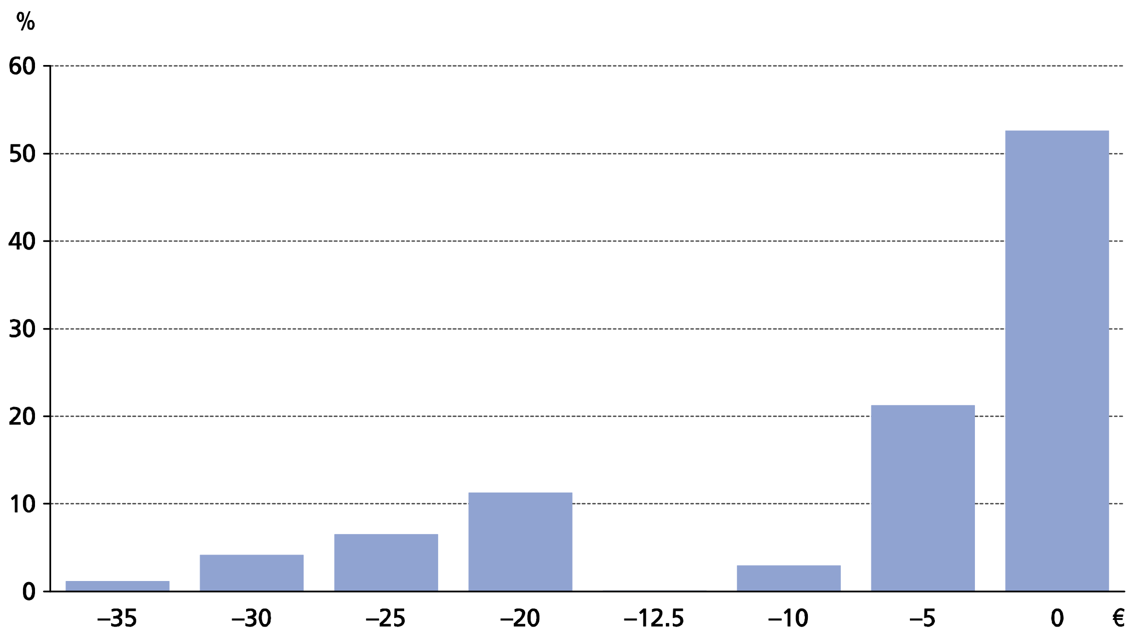
Table 2 summarises the obtained results. We analysed four scenarios. First, we calculated the price for the Status Quo case as a reference case. We found a mean of € 27.33 per MWh and slightly different amounts for each of the time intervals. Second, we calculated a Status Quo case without renewable energies in order to find the merit order effect. The absence of wind and solar energy yields to a mean price of € 34.26 per MWh, which is a plus of 25.37 %. At the same time, the price volatility increases, which is in line with the marginal costs of the specific generation technologies. While there is just a small increase of 4.60 % and 3.68 % for off-peak intervals Early Night and Late Night, peak prices for Noon and Afternoon increases by 57.60 % and 36.50 %. Hence, renewables not only decrease overall prices but also have a downward effect on the variance of the average prices. Without renewables, capacities with high marginal costs would increase the price during peak times. In contrast, wind and solar power only depend on weather conditions which can be seen in Figure 2 and thus decrease average peak prices but simultaneously increase price volatility. However, there is a pattern that partly follows the demand for electricity as shown in Figure 1: Solar power is generated during the morning, noon and afternoon which are also peak times. Nonetheless, solar power generation is concentrated during the summer months. Wind power is partly complementary since the most wind blows in winter while there is no pattern during a day. However, there is also a strong variation between the years as wind and sun intensity differ. Figure 4 shows a combined renewable electricity generation. The merit order effect can also be observed in the variation of the marginal plant.

Table 2: Model Results

	Status Quo	Status Quo Without Renewables		Nuclear Phase-out		Moratorium	
	Price (€/MWh)	Price (€/MW)	Difference to Status Quo (%)	Price (€/MWh)	Difference to Status Quo (%)	Price (€/MWh)	Difference to Status Quo (%)
Mean	27.33	34.26	25.37	42.90	56.89	31.34	14.70
Early Night	24.81	25.95	4.60	34.51	39.10	26.09	5.17
Late Night	24.23	25.13	3.68	29.22	20.60	25.02	3.27
Morning	28.23	36.18	28.18	46.76	65.65	33.86	19.94
Noon	28.02	44.16	57.60	47.44	69.29	33.54	19.70
Afternoon	28.44	38.82	36.50	47.82	68.14	33.91	19.24
Evening	30.23	35.31	16.82	51.64	70.81	35.63	17.87

Figure 4 shows the relative quantity of the marginal plant's cost reduction due to renewable energies which virtually represents the shift of the supply curve to the right. While in 52.6 % of the simulations, the marginal plant does not change, in 47.4 % the marginal plant has lower costs when wind and solar power is added to the existing power market.

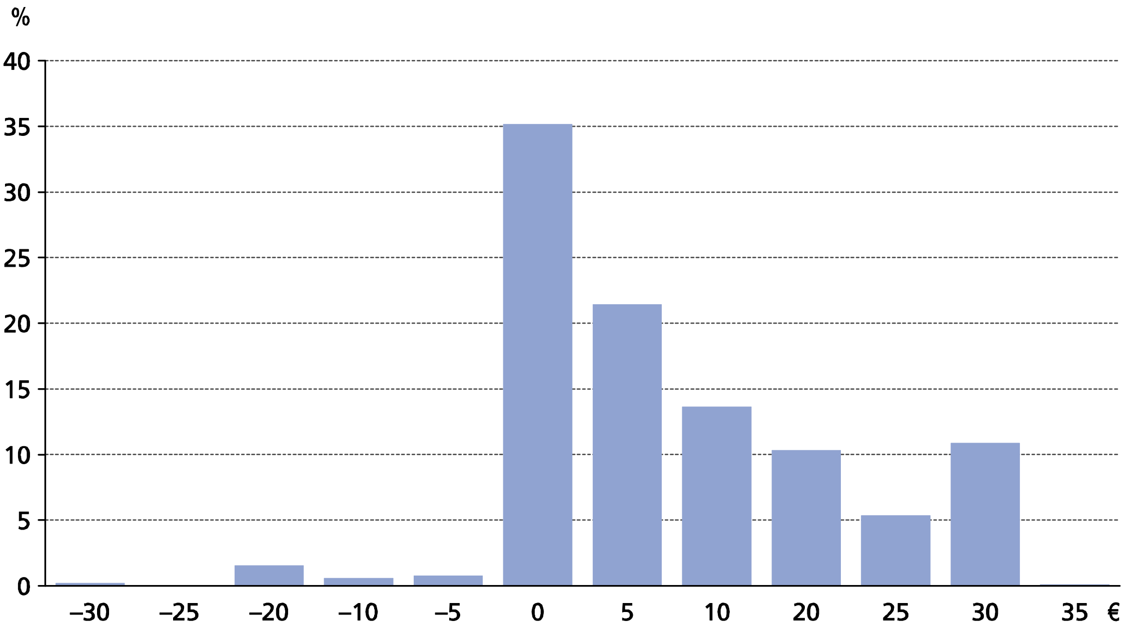
Figure 4: Price Effect of Status Quo With and Without Renewables



Third, we simulated the Phase-out case and calculated a mean price of € 42.90 per MWh, i.e. a plus of 56.98 % compared to the Status Quo case. There is a clear price increase in every time interval. Moreover, the downward effect on peak prices partly has less impact as also off-peak prices for Early Night and Late Night increase by 39.10 % and 20.60 %. Obviously, the nuclear phase-out induces a shift of the merit order curve to the left, which overcompensates the counter-effect of renewable energies.

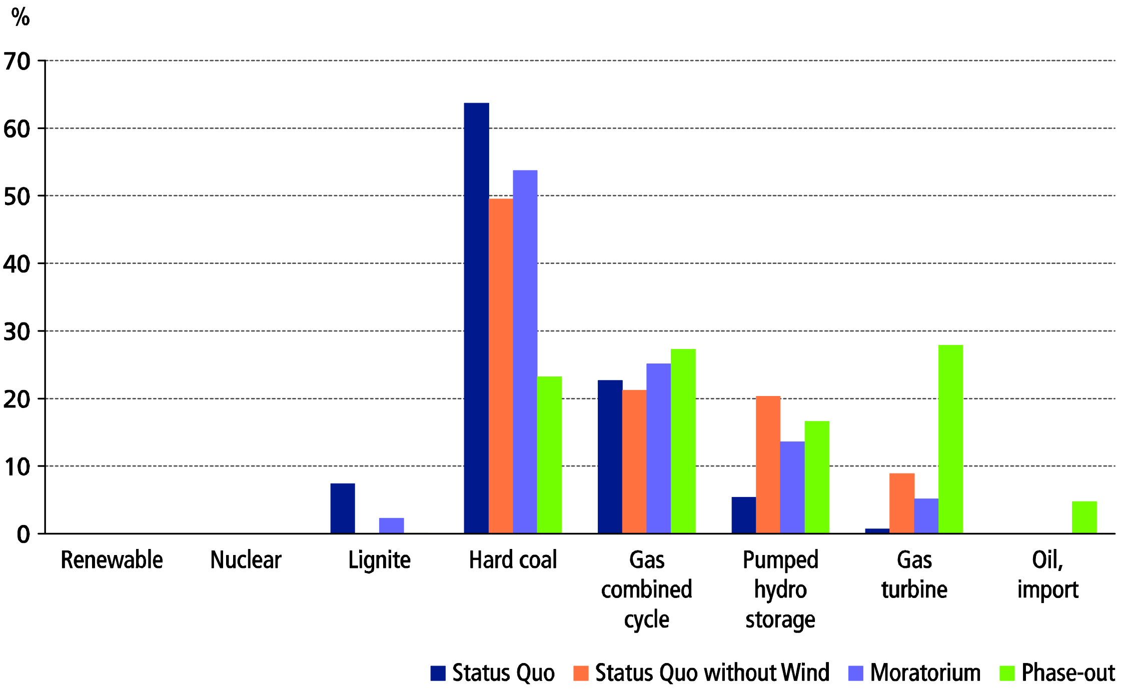
Figure 5 illustrates this context using the frequency of the marginal plant: in 35 % of all simulations, there is no change of the marginal plant. In contrast, a plant with lower marginal costs is the marginal plant in only in 3 % of all simulations, while in 62 %, a plant with higher marginal costs determines the price and, hence, increases average electricity prices.

Figure 5: Price Effect of Nuclear Phase-out in Comparison to Status Quo Without Renewables



Fourth, we also calculated the Moratorium case to analyse the price impact of the shutdown of seven nuclear power plants shortly after the Fukushima incident. However, we calculated the price effect for the whole year and found a mean price of € 31.34 per MWh which equals a plus of 17.70 % compared to the Status Quo case. Remarkably, the price of Moratorium is clearly higher than Status Quo Without Renewables which means that the installed capacity of 45 GW of wind and solar power can replace 6.23 GW of nuclear power. Nevertheless, the pattern of renewable energy feed-in, particularly solar power, can be seen when the different time intervals are compared for both scenarios. While there is no great difference within the off-peak time intervals Early Night and Late Night, the main impact of renewables is evident for peak intervals Morning, Noon and Afternoon. However, the combination of peak load and little sun in the evening results in a price increase. Figure 6 summarises all scenarios by showing the relative frequency of the marginal plant.

Figure 6: Relative Frequency of the Marginal Plant for all Scenarios



4 Discussion

Our results are obviously different to Kemfert and Traber (2011) who calculated a price increase of 22 % for a nuclear phase-out and 6.3 % for the case of Moratorium. However, this difference is not necessarily a consequence of different model approaches. Other reasons might be different assumptions. As Sensfuß et al. (2008) showed, the merit order effect is very sensitive to underlying assumptions like fuel prices etc., which could explain the different results in the literature. However, our analysis comes to the same conclusion as Kemfert and Traber (2011): Whereas the addition of renewable energies to an existing power market will decrease spot market prices, the opposite is true for the replacement of conventional base load capacities. Furthermore, a replacement of secured capacities is not possible without endangering the security of supply.

However, our analysis is based on simplifications and assumptions that may over- or underestimates our results: the increasing European market integration will expand the geographic area and, therefore, increase the secured capacity of renewable energies. Nevertheless, delaying necessary grid extensions could prevent further installation of renewables and, therefore, increase prices. Grid extensions are also important to get access to hydro storage facilities in Northern Europe, which will increase the potential to replace conventional capacities. This may also decrease prices if the marginal costs of these facilities are lower than domestic peak-load capacities. Furthermore, the incentive to invest in storage capacities will increase with volatile electricity prices, since electricity storage is based on arbitrary profits. We also ignored biomass power that could be used additionally to fluctuating wind and solar power. This may become a policy objective since the current feed-in tariff does not give an incentive to deploy demand-related biomass power plants. Furthermore, a higher share of biomass power plants may decrease the price remarkably if these power plants achieve a cost advantage over fossil peak-load capacities in the future. We also assumed that the demand was completely inelastic which does not hold true, at least not in the long run. There might be a substantial decrease in demand. In particular, there are some very energy-intensive firms in Germany that might transfer its production to other locations. This transfer may have a price decreasing effect. In addition, fuel prices, particularly coal and gas, have an essential influence on spot market prices. Also, coal and gas prices influence spot market outcomes via emission permit prices. As Rathmann (2007) showed, deploying renewable energies can decrease emission allowance prices and, thus, decrease electricity prices for certain parameter values. Since the demand for emission allowances will increase due to the German nuclear phase-out, permit prices may increase and, thus, affect power prices. In fact, permit prices are also important for Germany's neighboring countries as Traber and Kemfert (2009) indicated. They calculated that the German support for renewable energies had the effect of decreasing electricity prices in several European countries.

Fundamentally, the effect the nuclear phase-out in Germany has on foreign countries is a point for future research. Some effects on electricity prices, firms' profits and welfare are conceivable: the loss of capacities in Germany means a loss of importing capacities for many countries. This shortage of supply may increase prices in several countries and may increase foreign firms' profits. Additionally, these firms may also benefit if they have access to the German market. Also, the increasing share of fluctuating renewable energies will affect foreign grids and markets. Moreover, as the German nuclear phase-out may increase carbon emissions, permit prices will increase for the whole of Europe.

Another aspect that is rarely discussed is the effect on market power and market structure. There could be two kinds of effects: In the long run, the nuclear phase-out but also the replacement of fossil capacities will change the market structure, since the capacities are mostly owned by dominant firms. While dominant firms lose, newcomers have the chance to build up new renewable capacities. Given the decentralized character of renewables, many small firms can become generators, which may change the structure of the market completely and, therefore, would lead to less market power of the currently dominant firms. In the short run, however, the reduction of conventional capacities may increase market power of the remaining power plant operators and, hence, increase prices.

Nevertheless, the discussion of spot market prices could be superfluous if the market design changes. This is likely to happen if the share of renewables continues to increase. In the long run, the power plant park will consist of renewable energies plus highly flexible peak load capacities, which will probably be gas power plants. With regard to the cost structure, this would be a mix of two extremes: on the one hand, renewables with marginal costs of close to zero in combination with very high fixed costs and, on the other hand, gas power plants with high marginal costs but considerably low fixed costs. Since fixed costs do not matter on spot markets, increasing renewable energy supply could lead to fewer gas power plants and, therefore, could decrease the incentive to invest in new capacities.[4] However, the same would apply for renewables when the funding ends: Energy prices must be sufficiently high to cover their fixed costs. Therefore, the market design of spot markets might collapse in the long run, which could change the conditions to keep electricity prices low.

5 Conclusion

We investigated price effects of replacing conventional energy supply capacities by renewables, particularly wind energy. Therefore, we used the nuclear phase-out in Germany as an example for replacing conventional base load capacities by renewables. Our analysis complements the extensive literature on the merit order effect, since previous work only considered price effects of adding renewable energy supply to a given power plant park but ignored replacing conventional capacity. This, however, is decisive, since replacing conventional and particularly fossil capacities is the declared reason for funding renewables.

The results of our model show substantial price effects due to the inability of renewable energies to secure base load. First, it reveals the well-known merit order effect. We calculated an average price decrease of € 6.93 per MWh in the German spot market for 2011 with wind and solar energy compared to a hypothetical market without wind and solar energy supply, which means a reduction of 25.37 %. However, the downward price trend does not hold true if renewable energies replace conventional capacities. This effect is driven by the low availability of wind and solar energy, which causes a shift in the merit order. Furthermore, replacing secured capacities is not possible with-

4 Cf. Traber and Kemfert (2010).

out endangering the security of supply. Since the merit order is normally a convex function, the peak load capacities dominate the price formation. Although the installed renewable energy capacities of 45 GW are more than twice as high as the 18.1 GW of nuclear power in the period observed, the price increases to € 42.9 per MWh, i.e. 56.98 %. We also calculated the Moratorium case, i.e. the shutdown of seven nuclear power plants (6.23 GW) shortly after the Fukushima incident, and found a mean price of € 31.34 per MWh which equals a plus of 17.70 % compared to the Status Quo case. Nevertheless, it is to be noted that this price is clearly lower than the price of € 34.26 per MWh of a potential power market without renewable energies.

Despite the limitations of our model, policy implications can be derived: First, while the merit order effect in a static setting, i.e. adding renewables to a given power plant park, yields a lower electricity price and a rent shifting from producers to consumers, the opposite is true for a replacement of base load capacities. This is due to the high impact of peak load pricing. Second, replacing base load capacities will lead to more volatile electricity prices. By increasing the share of renewables, there will be two kinds of price effects: On the one hand, the price will increase in times of little wind and sun and, on the other hand, the price will decrease when a lot of renewables are deployed. The latter will have an additional effect: The more often a renewable or low cost power plant is the marginal plant, the lower is the possibility of a peak load plant to cover its fixed costs. Therefore, the incentive to build a new one decreases. The same applies for renewables if support schemes end. Hence, a pricing mechanism based on marginal costs might collapse and a new mechanism must be developed. Third, the importance of peak load capacities is highlighted. It would make sense for policy makers to create incentives to build peak load power plants with low costs in order to decrease energy prices and increase consumer welfare. Fourth, the replacement of conventional capacities is also important for considering market power: in the short run, the shutdown of conventional power plants may simplify strategic power plant deployment. In times of little wind and sun the incentive to set prices strategically increases. Nevertheless, in the long run, due to the decentralized character of renewable energies, new and small firms can enter the market and reduce market concentration. Fifth, it might also be important to note that the differences in prices can be interpreted as a demand for storage capacities. Hence, it works as a market-based incentive for the market integration of renewables and is, therefore, a complement to governmental actions to promote renewables. Hence, a policy implication could be to refrain from actions to soften price effects of renewable energies in order to not decrease incentives for renewables market integration.

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CHAPTER 3

Replacing Conventional Capacities by Renewables: Spot Market Price Impact of Fluctuating Electricity Generation

Sebastian Schröer

Abstract

In the long run, renewables are intended to replace fossil capacities in order to meet climate protection targets. Since renewable electricity generation fluctuates with a very low minimum load, spot market prices will increase if no cheap base load capacities are available. We analyse the potential price impact for the case that renewables increase their ability to secure base load. Therefore, we consider the nuclear phase-out in Germany as an example for replacing conventional base load capacities by renewables. Our analysis applies Monte Carlo simulations of spot market outcomes to a stylised German power market. We find that 14.5 GW of secured renewable capacity is necessary to replace 15.03 GW of secured nuclear capacity in order to keep spot market prices steady. This is approximately one third of the 45 GW of wind and solar power installed in 2011.

JEL classification: D43, Q42, Q48, L94

Keywords: electricity, renewable energy, market integration, nuclear phase-out, Germany

1 Introduction

In order to meet climate protection and energy policy targets, the share of renewable energy supply is increasing in many countries. In the long run, renewables are intended to replace fossil power generation capacities. However, a fundamental characteristic of renewable energies may prevent this replacement: except for biomass, biogas and water, renewable energy sources lack the ability to secure base load. This has a detrimental effect on security of supply and also on electricity prices. Conventional fossil capacities, in particular coal and lignite power plants, provide base load at comparatively low marginal costs. Replacing these capacities by fluctuating renewables requires a suitable solution. Since storage facilities are restricted in most countries, the state of the art solution would be to balance fluctuating renewables by highly flexible power plants. Given that these capacities typically have high marginal costs, average prices would increase substantially.

The electricity price impact of replacing conventional base load capacities is a current topic in Germany since the government decided a nuclear phase-out until 2022. At the same time, it was decided to replace the nuclear power plants by renewables. Therefore, a solution has to cover two fields of interest. On the one hand, the solution has to ensure the security of supply and low prices. On the other hand, it has to be in line with the climate protection targets. This task has to be accomplished in less than 10 years. Hence, the German nuclear phase-out is a unique case in the world where base load capable power plants are replaced by fluctuating renewables. Therefore, the German phase-out is an example for other countries that plan to replace conventional base load capacities by renewables.

The aim of this paper is to provide information on price effects of the potential ability of renewables to secure base load. Since we concentrate on price effects, it does not matter for our analysis which technological solution is found for this ability to be reached. We simulate different amounts of secured capacities by calculating a minimum supply level of renewable energy feed-in. We use the nuclear phase-out in Germany as an example for replacing conventional base load capacities by renewables. Hence, our analysis shows the price effect of the increasing ability of renewables to secure base load when all nuclear power plants are shut down. The remainder of this paper is organised as follows: section 2 gives an overview on technological possibilities to increase the ability of renewables to secure base load. Section 3 describes the model used in our analysis. Our main findings are presented in section 4 and discussed in section 5. The last section summarises and concludes.

2 How to deal with fluctuating renewables?

Currently, there are four main possibilities to deal with the characteristics of renewable energy sources in order to ensure base load: first, building back-up capacities that can cope with the characteristics of renewables, second, integration of the European market to use foreign capacities, third, building up storage capacities and fourth, reducing the demand via efficiency measures.

Each of these possibilities contains substantial technological and economic difficulties. Building up highly flexible power plants would be problematic for two reasons: first, natural gas fuelled plants emit greenhouse gases. This contradicts climate policy targets at least in the very long run given the huge amount of necessary balancing capacities. Using biogas as fuel would be a solution. In that case, the question is whether enough biogas can be produced sustainably. Second, highly flexible power plants typically have high marginal costs and would, hence, increase electricity prices substantially. Also, the incentive to invest in new plants might be too low if increasing shares of renewables decrease the deployment of gas power plants.[1]

The integration of the European market will be beneficial for two reasons: first, base load capacities from other countries can be used. Second, an enhanced geographical area may increase the minimum load of the installed renewables.[2] Both effects

1 See Traber and Kemfert (2010).

2 See Østergaard (2008).

might not be sufficient in the long run if every country was to replace its conventional capacities by renewables. In that case, installed conventional capacities would decrease and at the same time, the demand would increase. Moreover, the installed capacity of renewables must be immense to secure a substantial base load, which might be an inefficiently high investment.

An appropriate solution would be to invest in storage capacities. This would also be in line with increasing price volatility of a power market that has a substantial share of renewables. Since the incentive to operate a storage facility is driven by arbitrage profits, increasing price volatility would increase expected profits for storage operators. Furthermore, storage capacities would decrease peak prices and, therefore, create a rent shifting from producers to consumers, minimise deadweight losses and, thus, increase welfare. However, since the capacities for pumped hydro storage are limited in several countries, huge investments are needed to develop a technology that leads to sufficiently low costs to store electricity in large amounts.

However, while the interest in energy storage is increasing in order to integrate fluctuating renewable energies, the tangible effects in terms of price and welfare are unclear. So far the economic research on electricity storage is also limited. Particularly the impact of market power on storage capacities is poorly analysed while there is extensive literature on strategic pricing of conventional electricity generation. There are some studies on the effect of market power of hydro reservoir operators. Rangel (2008) provides a literature overview of strategic scheduling of hydro reservoirs. However, the capacity of such facilities is highly restricted in most countries. In contrast, there are only few studies that deal with the effect of storage that is driven by arbitrage such as pumped hydro storage. Operators not only have to decide on when to sell electricity but also on when to buy electricity. This will complicate strategic behaviour enormously. A number of articles deal with the economic value of investments in storage capacities like Walawalkar, Apt and Mancini (2007) or Figueiredo, Flynn and Cabral (2006). These studies use historical data and consider only small facilities, which be-have as price takers. For a perfect competitive setting, Sioshansi et al. (2009) show that storage decreases peak prices and increases off-peak prices. Hence, producers loose while consumers benefit. Yet, in most countries with deregulated energy markets, market power is a common characteristic. Ownership structure may, therefore, have substantial impact on the use of storage and, hence, on welfare. As Sioshansi (2010) points out, there are three possible types of agents to operate storage capacities, which have different incentives for the use of storage. First, a generator who also runs conventional power generation facilities will maximise not only arbitrage profits but also the generation profits. Second, a merchant operator has no other intentions but to maximise arbitrage profits. Third, there may be an operator that works on behalf of electricity consumers and, therefore, maximises the sum of arbitrage profits and the consumer surplus change. Sioshansi (2010) shows that generators and merchant operators will underuse their storage devices when compared to welfare optimum while consumers will overuse storage. Consequently, investing in storage capacities is not attractive for players that also hold other generation capacities as Schill and Kemfert (2011) show for the German market using a Cournot model.

These results indicate that market power is highly important for energy storage, which may cause a potential underinvestment in storage capacities. This result should be considered by policy makers. Two kinds of conclusions can be drawn from this. First, incentivizing investments in storage capacities in order to increase welfare may be useful, and second, it may be beneficial to divide storage assets between all types of agents rather than having all capacities owned by merchant operators. However, measures to deal with effects of market power should be well considered. Particularly, the potential effect of storage capacities on electricity prices and welfare should be clear in the first place, since there are little capacities in most countries at the moment.

A further possibility for decoupling electricity generation and consumption would be to implement demand management activities. However, that would require complex equipment such as "smart" meters and probably high investments in order to enable load control. The expected profits are currently unclear and subject to present research. Walawalkar et al. (2010) for example provide an overview of the evolution of demand management programs in PJM and NYISO markets in the USA. They point out that demand response programs can play a role in the future but need both technology and policy changes. Also, advances in building technologies and energy storage in combination with appropriate price signals may increase demand response measures. However, Schroeder (2011) finds that, for a stylised medium-voltage grid, central storage facilities are a better choice for generation cost reductions compared to demand management.

Nevertheless, a mixture of several possibilities may increase the ability of renewables to secure base load in the near future. This may not only include existing technologies, but also new ones. Some of them might become a game changer for the whole energy market. "Power to gas", for example, might be one of these potential technologies, which could combine gas and electricity markets. However, since we do not know what kind of technology will be used in the future, we concentrate on potential effects on electricity prices in this article. Consequently, we do not know the cost structure of these technologies. However, price effects are always determined by marginal costs in a spot market setting. Hence, for simplicity, we assume the ability of renewables to secure base load to be costless. The value added of our analysis is, therefore, to estimate price impacts of different amounts of secured capacity.

3 Model and Data

The model presented here is an extension of the one used in Comtesse and Schröer (2012). We develop a stylised German power market within a spot market setting, where prices are based on the marginal costs of the power plants. We use Monte Carlo simulations to calculate the price effect of an increasing ability of renewable energies to secure base load when fossil and nuclear power plants are replaced. For our analysis, it does not matter which technological solution is used for this ability to be reached.

Since the renewables are intended to replace conventional capacities, we use the German nuclear phase-out as an example for replacing conventional capacities by renewables. In particular, we compare two cases, first, “Status Quo” and second “Phase-out”. By “Status Quo” we mean the current power plant park in 2011 including renewables and nuclear power plants. We also calculate a “Status Quo Without Renewables” case. This case denotes “Status Quo” but without renewables. Furthermore, we ignore the “Moratorium” by the German government, which led to the shutdown of seven old nuclear power plants shortly after the Fukushima incident. Consequently, “Phase-out” denotes the current power plant park without nuclear power plants but with renewable energies. Due to data availability, renewable energy is assumed to be wind and solar power only in the model. Therefore, we do not consider old hydro-electric power plants to be renewable.

The supply is defined by the merit order curve that aggregates power plant capacities according to their marginal costs. Hence, the supply function in the Status Quo spot market ($S_{SQ\,i}$) sums up power plants in relation to their marginal costs, which leads to an upward sloping supply function. Since detailed information of the German power plants is unavailable, we assign each power plant to a power plant type according to its fuel and technology. In line with this assumption, marginal costs are the same within a power plant type, but differ across the various types. For reasons of simplicity the secured capacity of every power plant type is always available except for wind and solar power. Table 1 shows marginal costs and capacities for the different power plant types. Given these capacities, demand for electricity might exceed electricity generation, thus the model fills any supply gap through importing from other countries. To simplify, importing has no capacity limit and the same marginal costs as Peak Load II power plants.

Table 1: Installed Capacities and Marginal Costs at the End of 2010

Power Plant Type	Power Plant Fuel	Installed Capacity (GW)	Secured Capacity (GW)	Marginal Costs (€/MWh)
Renewable	Wind	27.70	2.08	1.0
	Solar	17.30	0	1.0
Base Load I	Hydro	3.47	1.39	1.0
	Nuclear	18.10	15.03	12.5
Base Load II	Coal	19.18	17.65	20.0
Medium Load I	Lignite	25.08	21.57	25.0
Medium Load II	Gas Combined Cycle	9.36	8.06	30.0
Peak Load I	Pumped Hydro Storage	6.40	5.76	50.0
	Gas Turbine	14.58	10.15	60.0
Peak Load II	Oil	2.73	2.04	80.0
Imported Energy				80.0
Σ		143.90	83.73	
Nuclear Power Plants				
End of 2010		18.10	15.03	12.05
Moratorium		11.87	9.86	12.05
Nuclear Phase-out		0	0	0
Source: Kemfert and Traber (2011); own calculations				

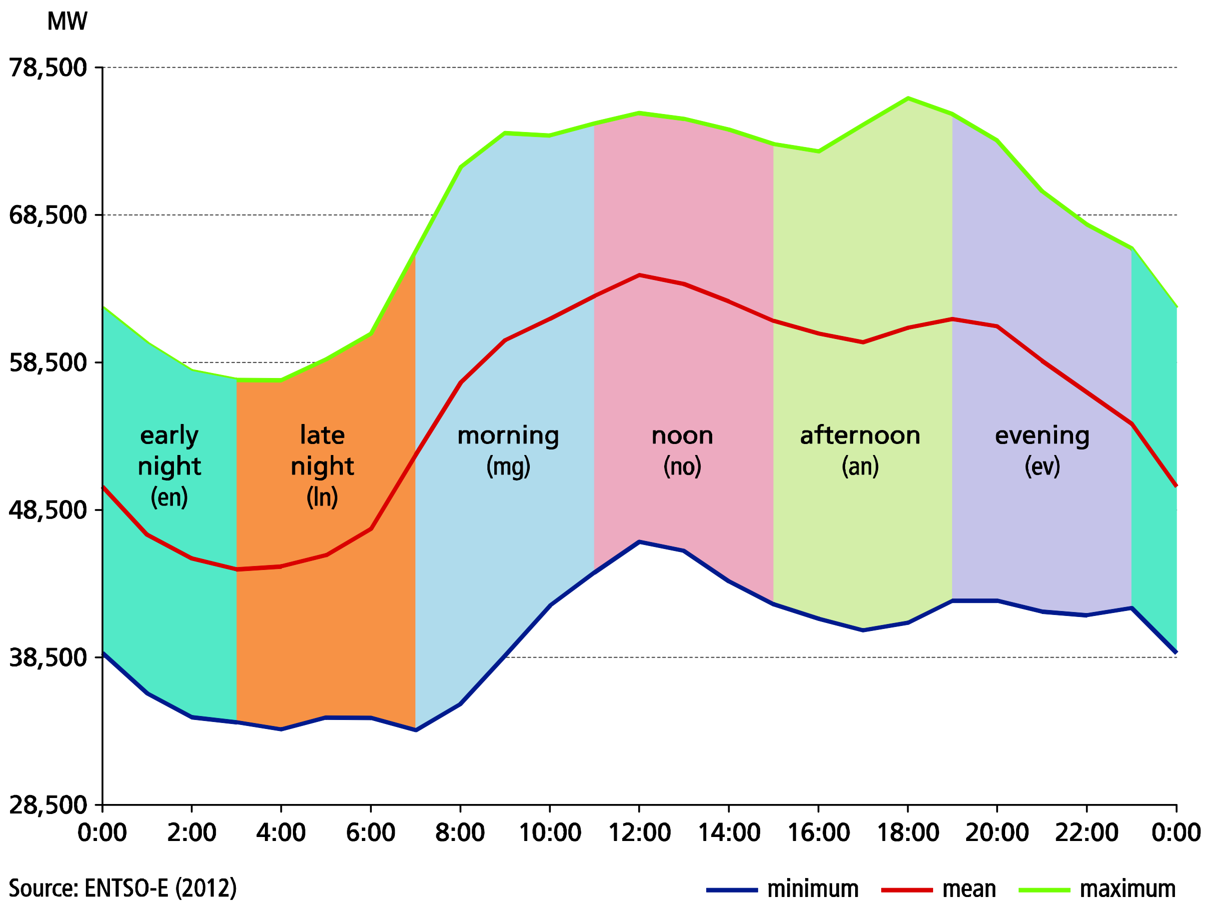
The supply function ($S_{SQ\,i}$) is therefore denoted as

$$S_{SQ\,i} = S_{RE\,i} + S_{BLI\,i} + S_{BLII\,i} + S_{MLI\,i} + S_{MLII\,i} + S_{PLI\,i} + S_{PLII\,i} + IM_i \qquad (1)$$

where i denotes the simulation. The supply function ($S_{PO\,i}$) of scenario Phase-out is equal to Status Quo but without nuclear power plants. The same applies for the scenario Status Quo Without Renewables ($S_{SQwoRE\,i}$) as described above.

The electricity demand is divided into peak and off-peak time during a day. Figure 1 shows the minimum, mean, and the maximum amount of electricity in the power grid by hour. For further analysis of peak and off-peak effects, the demand of a day is divided into six time intervals (T): Early Night (en, 23:00–2:00), Late Night (ln, 3:00–6:00), Morning (mg, 7:00–10:00), Noon (no, 11:00–14:00), Afternoon (an, 15:00–18:00) and Evening (ev, 19:00–22:00) (cf. Figure 1 and formula (2)). Since consumers cannot change their electrical equipment and additionally do not change their behaviour in the short run, the demand is assumed to be completely inelastic. Therefore, the demand function ($D_{T\,i}$) is a vertical straight line in every time interval (T) (cf. equation(3)) and is also equal in every scenario. We use real data of the amount of electricity in the German transmission network grid as stated by the European Network of Transmission System Operators for Electricity (ENTSO-E) in 2011.

Figure 1: Electricity in the German Transmission Grid in 2011



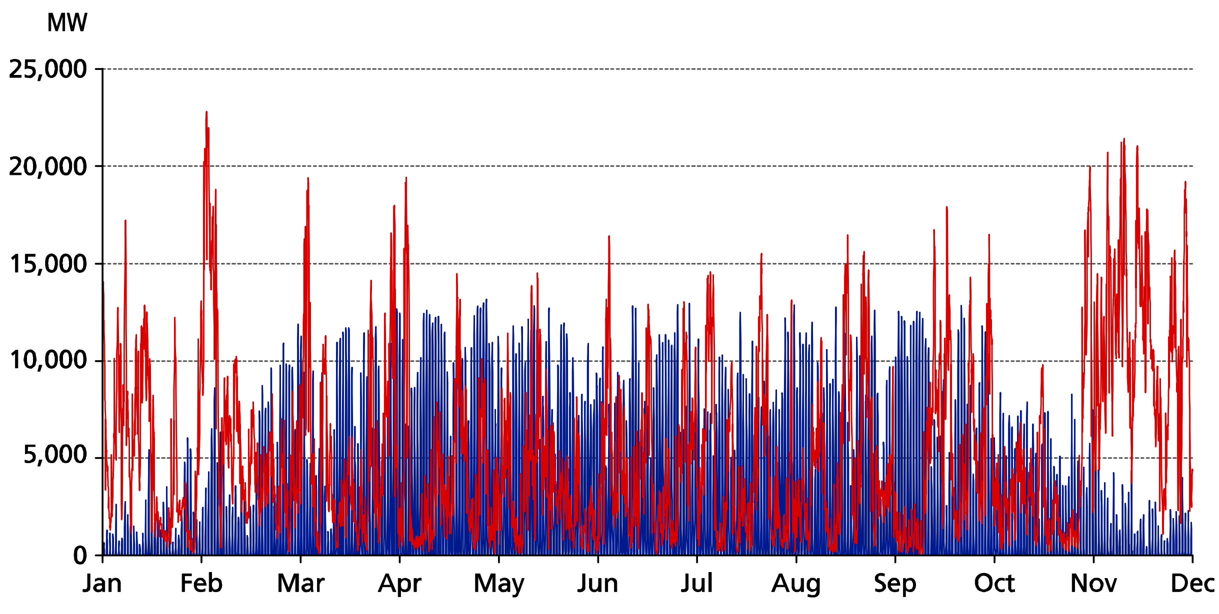
$$T = \{\text{en, ln, mg, ev, an, no}\} \qquad (2)$$

$$D_{T\,i} \in \{\text{hourly load values}\} \qquad (3)$$

As all power plants have an incentive to offer at marginal costs at spot markets, the Status Quo price ($P_{SQ\,i}$) equals the marginal costs (MC) of the price setting power plant. This marginal power plant is at the intersection of the demand ($D_{T\,i}$) and the supply function ($S_{SQ\,i}$). Although the German market is an oligopoly, this model does not allow for strategic pricing. By assumption, all power plants, except wind and solar power plants, generate at their secured capacity except for the marginal power plant, which only generates the amount necessary to clear the market. Since wind and solar power depend on weather conditions, electricity generation is very volatile. In contrast to conventional capacities, we use real data for wind and solar feed-in on an hourly basis provided by the German TSO's 50 Hertz Transmission (2012), Amprion (2012), Tennet TSO (2012) and TransnetBW (2012). Figure 2 shows the electricity generation in 2011 while the combined generation of wind and solar power by day can be seen in Figure 3.

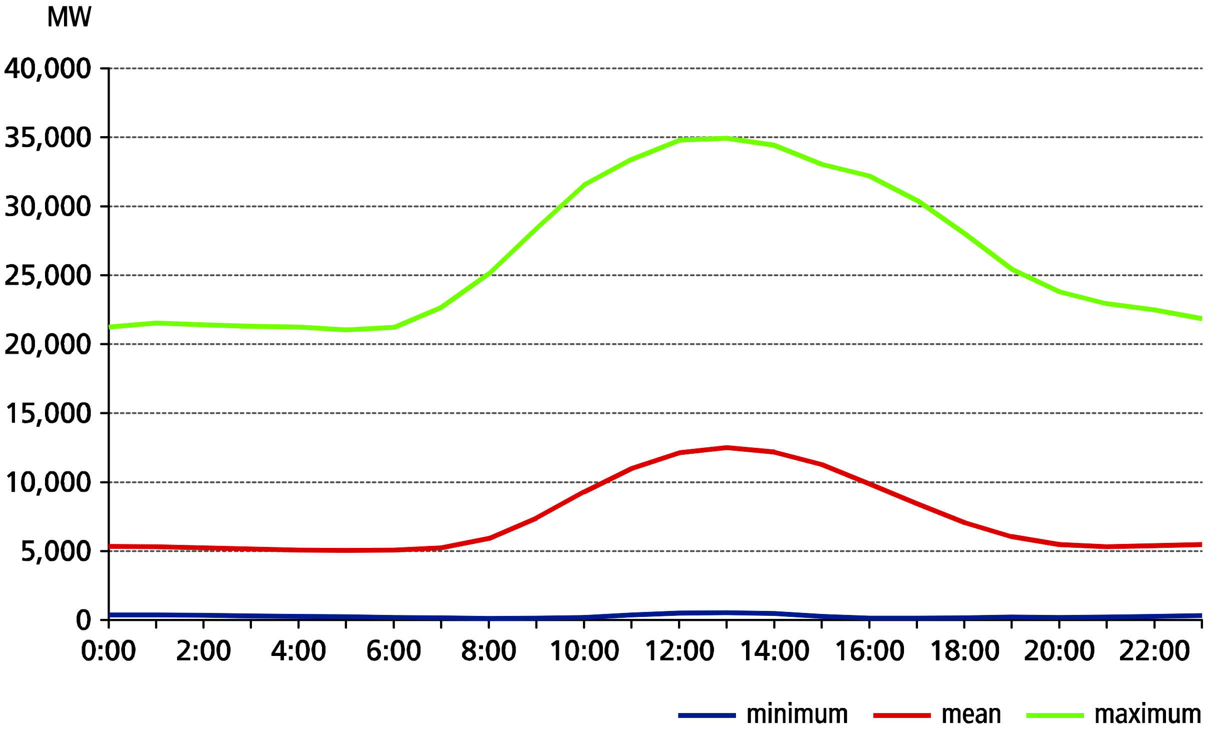
$$P_{SQ\,i} = f\left(D_{T\,i}, MC, S_{SQ\,i}\right) \qquad (4)$$

Figure 2: Renewable Electricity Generation (Wind and Solar) in 2011



Source: 50 Hertz Transmission, Amprion, Tennet TSO, TransnetBW

Figure 3: Renewable Electricity Generation (Wind and Solar) Throughout a Day in 2011



Source: 50 Hertz Transmission, Amprion, Tennet TSO, TransnetBW

Based on these market settings, the model calculates the price change of Phase-out (ΔP_{PO}) in comparison to Status Quo by simulating the price during Phase-out ($P_{PO\,i}$) as well as the price during Status Quo ($P_{SQ\,i}$) k times. To ensure the comparative static setting of the model, the same electricity demand within each simulation i and the same time interval is assumed. Therefore, in a price simulation i, the demand for electricity is the same in both Phase-out and Status Quo, but electricity demand differs across all k simulations. Given the prior assumptions, each difference in price is defined by the different marginal power plants in Phase-out and Status Quo. The calculated price difference is a mean of the k price differences for every time interval.

$$\Delta P_{PO} = \sum_{i=1}^{k} \frac{P_{PO\,i} - P_{SQ\,i}}{k} \qquad (5)$$

We then introduce a "Minimum Supply Threshold" (MST) for renewables. This threshold compares the hourly wind and solar supply in the year 2011 ($hourlyRE_i$) with an ex ante defined minimum supply level ($MinS_{RE}$) in order to guarantee a minimum supply by renewables at any time. As a result, the renewable supply in every hour ($S_{RE\,i}$) equals the defined minimum supply threshold if the hourly renewable supply ($hourlyRE_i$) is lower than the defined minimum supply threshold ($MinS_{RE}$). In order to calculate a steady price curve, we increase the minimum supply threshold in steps of 200 MW until the entire installed capacity of 45 GW can be generated at any time. We assume the MST to be costless. Hence, at any MST, the marginal cost is always € 1 per MWh.

$$MinS_{RE} = \{0\ ;\ 200\ ;\ \ldots\ ;\ 45.000\} \qquad (6)$$

$$hourlyRE_i \in \{\text{ hourly wind and solar supply}\} \qquad (7)$$

$$S_{RE\,i} = \begin{cases} MinS_{RE} & \text{if } hourlyRE_i \leq MinS_{RE} \\ hourlyRE_i & \text{if } hourlyRE_i > MinS_{RE} \end{cases} \qquad (8)$$

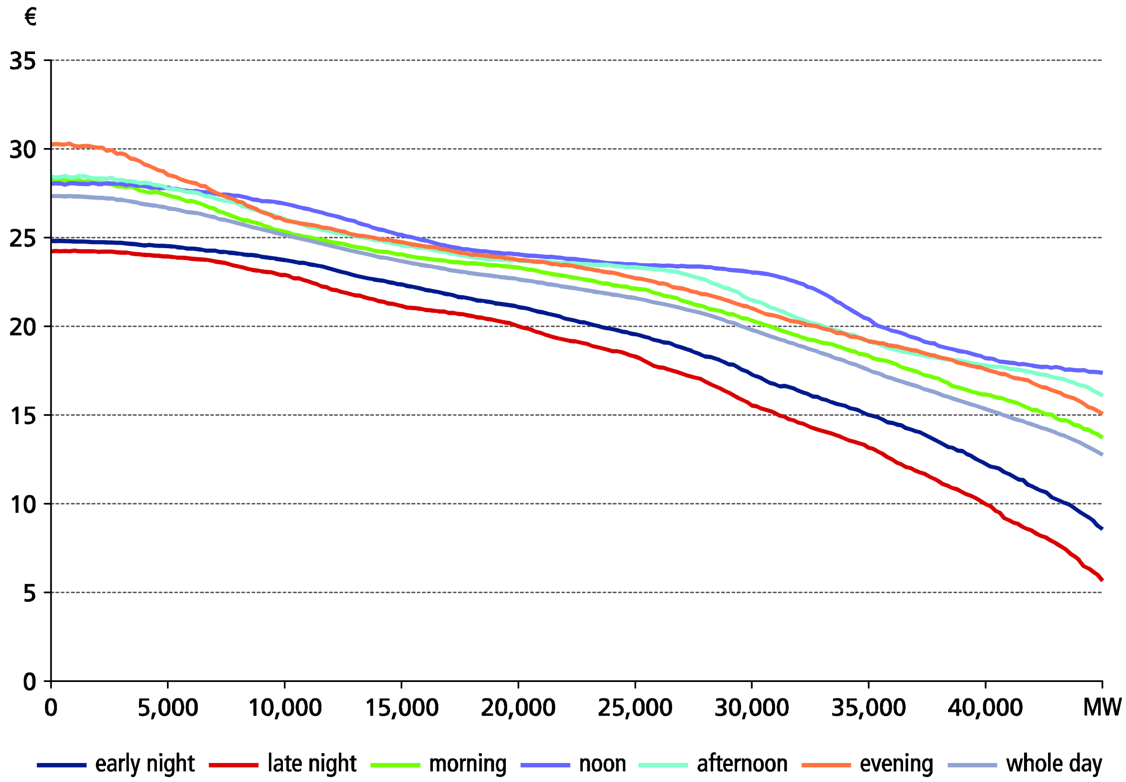
4 Results

We first calculated the impact of a MST for Status Quo (Figure 4). Based on the power plant park in 2011, the price curve would fall concave with an increasing MST. If all of the installed wind and solar power was available at any time, the overall price would halve from € 27.33 to € 12.76 per MWh. Remarkably, there would be a secured capacity of 126.65 GW in the market, which is nearly 50 GW more than the expected peak load of 77 GW (see Table 1 and Figure 1). Second, we analysed price effects of a MST for Phase-out, i.e. if all nuclear power plants were closed down (Figure 5). Consequently, the overall price would increase from € 27.33 to € 42.90 per MWh (a plus of 56.98 %) if the nuclear power plants were replaced by fluctuating renewables. This effect is studied in detail in Comtesse and Schröer (2012). Third, we also calculated the price impact of wind and solar power on spot market prices in 2011 by comparing Status Quo to a Status Quo case without renewables. This case is known as the merit order effect. The calculation of the merit order effect is necessary to estimate the MST for a price-neutral replacement of the nuclear power plants by renewables. Therefore, we had to compare the price of Phase-out and Status Quo Without Renewables. We found a price increase from € 27.33 to € 34.26 per MWh (a plus of 25.37 %) if wind and solar power were not available in 2011.[3]

We calculated a MST of 14.5 GW to ensure a price-neutral nuclear phase-out in Germany, which is 32.2 % of all installed wind and solar power capacities in 2011. At this level of secured renewable capacity, the average price would be € 34.26 per MWh, which is equal to the price in Status Quo Without Renewables. This amount is nearly the same as the secured share of installed nuclear power at the end of 2010 (15.03 GW). This is not surprising for two reasons: first, nuclear power plants are rarely marginal plants. Therefore, the cost advantage of renewables does not create a big price impact. Second, wind and solar power rarely generated more than 14.5 GW in 2011. Hence, apart from the MST, there is no substantial price effect. Furthermore, we calculated a MST of 22.1 GW to reach the price level of Status Quo, i.e. € 27.33 per MWh. This means that 49.1 % of all installed wind and solar power capacities in 2011 must be available at any time to maintain the current price if all nuclear power plants were closed down.

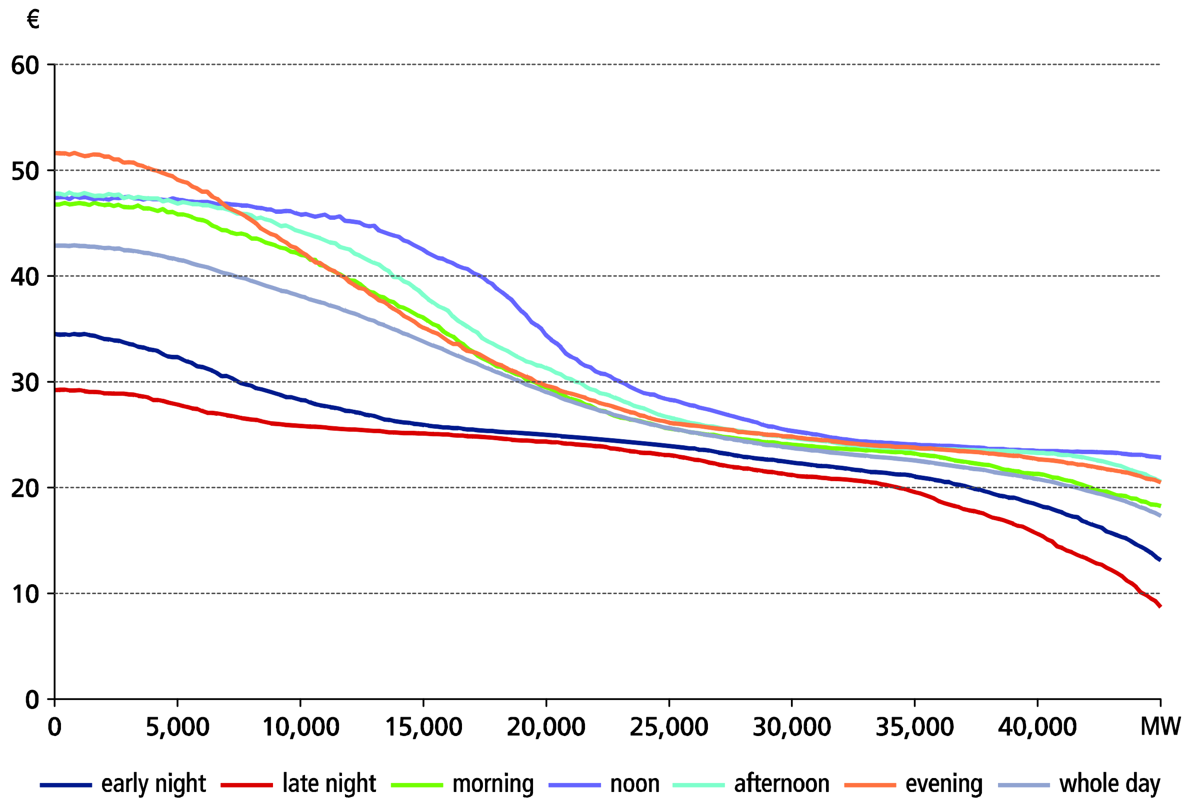
3 See Comtesse and Schröer (2012).

Figure 4: Price of the Scenario Status Quo by MST and Time Interval



Apart from the pure price effect, the MST effects provide some valuable insights in the pricing dynamics of renewables: first, it can be seen that an increasing MST will shift the supply curve and, hence, displace gas power plants. This contradicts the climate policy objective to replace fossil energy sources, especially coal and lignite. However, a more moderate effect might be observed for two reasons. On the one hand, gas power plant operators may evade to balancing power markets. On the other hand, increasing emission permit prices may change the merit order and create a price advantage for gas power plants. Second, the shape of the curves changes when comparing Figure 4 and Figure 5. This is due to the absence of nuclear power. In Status Quo, the prices are dominated by base and medium load capacities while in Phase-out, the prices are dominated by peak load capacities. Hence, an increasing MST leads to higher price effects in Phase-out since the high cost peak load capacities are displaced. This displacement ends at approximately 25 GW where decreasing slopes of price reductions can be seen. At this capacity, the price is predominantly determined by renewables, coal and lignite. Since the costs of coal and lignite power plants are already relatively low, further price reductions are only possible by displacing lignite and coal. This can be seen for off-peak times Late Night and Early Night.

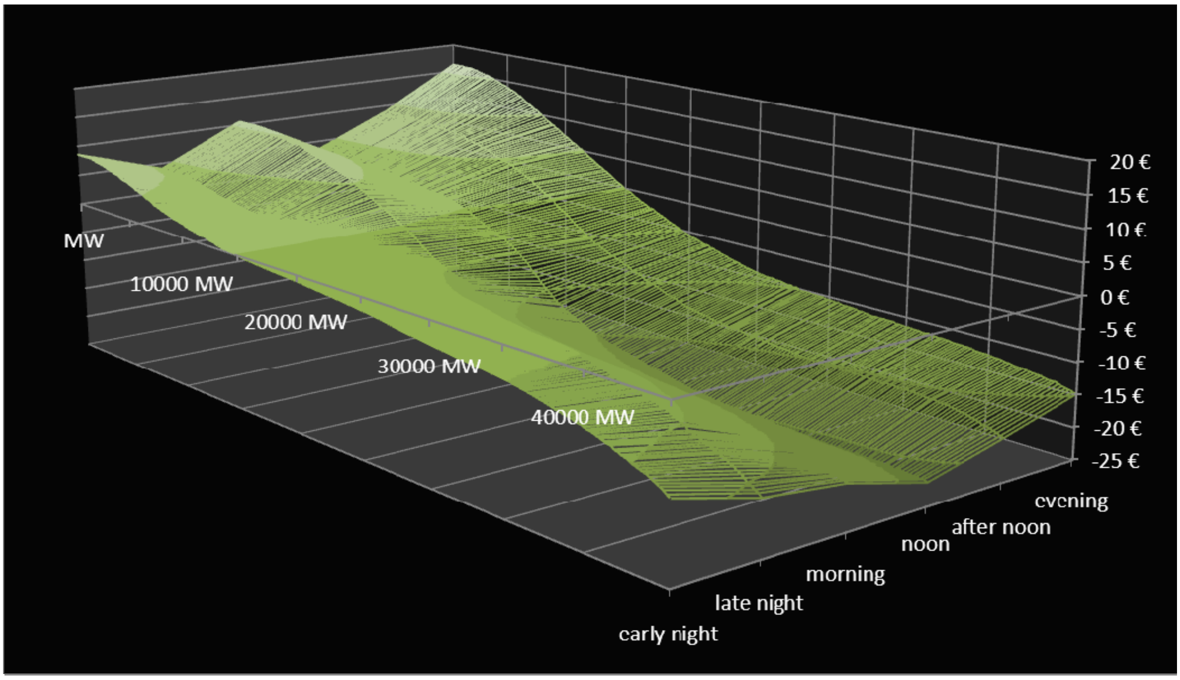
Figure 5: Price of the Scenario Phase-out by MST and Time Interval



Third, the range of the average prices for the different time intervals also decreases due to the changing pattern of renewable generation. It is well known that adding renewables to an existing power plant park has a downward effect on peak prices.[4] This is due to the specific pattern of solar power: In the summer, the sun shines during the morning, noon and afternoon, which are peak times. Also, most wind blows during the winter, which is also a peak time. This pattern vanishes with increasing MST since also off-peak times benefit from renewable generation and, hence, leads to a smaller range of average prices as Figure 5 shows. The decreasing range of the different time intervals can also be seen in Figure 6. This figure shows the price effect of a MST in Phase-out compared to Status Quo.

4 See for example Comtesse and Schröer (2012).

Figure 6: Price Effect of the Scenario Phase-out by MST and Time Interval



5 Discussion

Our results reveal a substantial need for secured capacities to keep electricity prices low when conventional capacities are replaced by fluctuating renewables. However, we used a very simple model of the actual power market to simulate secured capacity of renewable power generation. We also did not specifically define how secured capacities are to be reached. Therefore, we made assumptions that are crucial for the outcome. Some of them clearly have led to an overestimation of the price effect. If storage was to be used to secure capacities, we would assume storage to be costless according to our approach. This, however, ignores two effects: first, discharging must cover at least the off-peak price for storage loading plus the efficiency loss. If off-peak prices were to be determined by renewables, however, the prices would be close to zero. Second, there is a price-increasing effect when storage capacities charge. Also, we assumed no technical restrictions; i. e. we assumed that storage capacities are always available, which is doubtful especially for longer periods of calm and cloud. Additionally, the assumption of costless generation is also implausible for biomass and biogas power plants that are likely to provide a substantial part of the secured capacity in the future. Furthermore, we assumed a welfare optimal deployment of secured capacities, which is unlikely for storage facilities, as pointed out in the literature mentioned above.

Moreover, grid extensions are essential, since we did not take any network constraints into account. However, grid congestion would be a substantial storage limitation and would be detrimental for secured capacity deployment. Given the fact that wind power is highly aggregated along the coast line and that solar and biomass power is decentralized across the country, the grid must ensure an efficient transport of electricity to potential locations of storage capacities. Furthermore, substantial consumption of electricity is located in the industrial centres of the south and west of Germany and must be easily accessible.

In contrast, some assumptions might have led to an underestimation of the price effect: for example, we ignored the 5.76 GW of secured capacity of pumped hydro storage installed in the period observed. Instead, we assumed the pumped hydro storage facilities to be simple base load capacities. Also, we ignored the existing renewable capacities of biomass and biogas power plants that are able to secure base load. Moreover, our analysis was based on an installed capacity of renewables of 45 GW. With steadily increasing shares of renewables, the price-neutral MST will decrease, since renewables will more often be marginal plants and, hence, decrease overall prices. Therefore, the difference between the overall prices of Status Quo and Phase-out will decrease when the share of renewables increases.

Apart from the limitations of our model, an important insight was gained regarding the increase of secured capacities of renewable electricity generation: The price effect of replacing fossil and nuclear power by renewables is driven by demand, on the one hand, and feed-in pattern of the renewables, on the other hand. While solar power is mostly generated during noon and in the afternoon, it is not generated during the night and only very little during the morning and evening. Also, there is more wind during the winter compared to summer. Hence, renewables have a downward effect on electricity prices since this pattern follows the demand for electricity. However, this pattern vanishes when the minimum supply level is increasing. In that case, the demand for electricity becomes the key driver for pricing dynamics, as is the case without renewables: The price increases exponentially with the demand since the supply is dominated by flexible peak load capacities that typically have high costs.

In general, our results contribute to the on-going debate on how to replace the fossil and nuclear base load capacities. This debate is usually focused on the security of supply, whereas our analysis concentrated on electricity prices. We showed that prices would increase extensively if conventional capacities were replaced by renewables. Basically, marginal cost is the only price-influencing difference between the options in order to deal with fluctuating renewables. For storage capacities, they depend on the off-peak electricity price. Hence, storage is cheap if the off-peak price is driven by renewables and the efficiency loss is low. In contrast, highly flexible power plants generally have high marginal costs. In order to keep electricity prices low, storage would, therefore, be a better option to deal with fluctuating renewables. In any case, there is always an incentive to invest in storage capacities if the price of charging and the efficiency loss are lower than the marginal costs of highly flexible power plants. When considering incentivizing investments, this should be taken into account by policy makers.

However, a key result of our analysis is that an increasing MST leads to substantial price decreases at spot markets. At the same time, due to the increasing share of renewables, fixed costs of capacity installation increase. This will have an important effect on market effectiveness and, hence, shows a central problem for the replacement of fossil and nuclear capacities by renewables: the possibility of a power plant to cover its fixed costs will decrease when power prices go down. Consequently, there will be less incentive to invest in new power plants. This is true for fossil power plants and for renewables. Also, a power plant park consisting of renewables and storage facilities would not work. On the one hand, storage facilities might ensure the security of supply but on the other hand, renewables would not cover their fixed costs. Therefore, a market design must be established that focuses on average costs rather than marginal costs to ensure an effective power market.

6 Conclusion

Fluctuating electricity generation of renewable energies is still the biggest obstacle for replacing fossil as well as nuclear power plants. However, the dependency on weather conditions in the cases of wind and solar power does not only affect the security of supply but also electricity prices. If fossil and nuclear power plants are to be replaced by renewables, secured base load is needed. One solution would be to invest in highly flexible back-up capacities. However, these power plants typically have high marginal costs and, hence, increase overall prices. Another possible solution would be to build up storage capacities. Also, the increasing European market integration will expand the geographic area and, therefore, might increase the secured capacity of renewable energies.

In this article, we examined the potential spot market price impact of increasing the ability of renewables to secure base load. For our analysis, it does not matter if this is achieved either by increasing storage capacities or by increasing market integration. Since renewables are intended to replace conventional capacities, we used the German nuclear phase-out as an example for such a replacement. We found that for a stylised German power market, 14.5 GW of secured renewable capacity is necessary to replace 15.03 GW of secured nuclear capacity in order to keep spot market prices steady. This is approximately one third of the 45 GW of wind and solar power installed in 2011. Although renewables have a substantial cost advantage, the necessity of a one-to-one replacement does not surprise for two reasons: first, nuclear power plants are rarely marginal plants. Therefore, the cost advantage of renewables does not create a big price impact. Second, wind and solar power rarely generated more than 14.5 GW in 2011. Hence, there is no substantial additional price effect. In conclusion, a price-neutral replacement of secured conventional base load capacities by renewables is possible, if the same capacity of secured generation or electricity storage with sufficiently low marginal costs is installed.

Although our model is a simplification of the actual power market, we add to the existing body of literature on how to deal with fluctuating renewable electricity generation. Our results reveal that the increasing ability of renewables to secure base load can have a substantial impact on electricity prices. The remaining question for future research is under what conditions highly flexible power plants are more efficient than storage capacities. One essential point might be market design, since the incentive to invest in new plants might be too low if increasing shares of renewables decrease the deployment of gas power plants.[5] Also, since the marginal costs of storage capacities depend on the off-peak price of electricity, storage would be cheap if the off-peak price is driven by renewables and the efficiency loss of the storage technology is small. Then, storage might have a competitive advantage since highly flexible power plants typically have high marginal costs.

However, the government generally faces a dilemma regarding electricity prices: on the one hand, the government wants to keep prices low. This is important in order to maintain public acceptance for replacing conventional power plants and, additionally, not to endanger the competitiveness of German firms. On the other hand, low prices decrease the possibility to cover fixed costs and, hence, decrease incentives to invest in new power plants. This dilemma will emphasise the need to develop a new market design in order to organise energy supply efficiently.

[5] See Traber and Kemfert (2010).

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CHAPTER 4

Policy Options for Climate Policy in the Residential Building Sector: The Case of Germany

Sebastian Schröer

Abstract

In order to achieve the climate protection goals in the building sector, a higher rate of building refurbishment is necessary to improve the energy standard of residential building stock in the European Union. Although subsidisation seems to be necessary, optimal measures concerning cost effectiveness are unclear. Using a stylised model of the German residential building stock, we analyse different refurbishment measures by simulating every relevant investment until 2030. In particular, we compare two different options that are relevant for political measures: first, comprehensive refurbishments that are expensive but achieve the greatest reductions in energy consumption and GHG emissions and second, partial refurbishments which include only low-cost improvements but can be achieved on a wide scale. We conclude that comprehensive refurbishments will require the least amount of investment as well as abatement costs per ton of GHG emissions and provide the highest reductions in energy consumption in 2030. Hence, partial refurbishments are never optimal. However, in terms of cumulated GHG emissions in the period considered, the difference between both options is very small because of their different dynamics: comprehensive refurbishments achieve fewer results in the first years but catch up quickly, which means that the higher the refurbishment rate the higher the advantage of comprehensive refurbishments.

JEL classification: C60, H30, O33, Q40, Q58

Keywords: residential building sector, refurbishment, climate policy, energy saving, policy scenarios

1 Introduction

The European Union and Germany have established very ambitious targets on climate protection. To cut greenhouse gas emissions by 80 % of 1990 levels by 2050, the residential building sector cannot be ignored. In Germany, private households account for 28.5 % of final energy consumption and cause 14.2 % of all energy-related greenhouse gas (GHG) emissions – mainly for space heating. At the same time, up to 90 % of space heating is based on fossil energies.

There are three ways for national governments to reduce GHG emissions in the residential building sector: First, the minimum performance requirements for new buildings could be increased and the demolition of old and energy-inefficient buildings encouraged. Second, energy-related refurbishments could be promoted, and third, the share of renewable energy carriers could be increased.

In past decades, the average annual demolition rate was 0.5 % of the entire housing stock. At the same time, about 1 % of the housing stock was built, which means that housing stock increases annually by 0.5 %. This is by far too little to reduce GHG emissions in order to reach the target. In addition, the use of renewable energy carriers in the short term and the capacities for producing biofuels in a sustainably way are limited. Therefore, the climate targets cannot be achieved without increasing the rate of energy-related refurbishments.

Currently, the refurbishment rate is at approximately 1 % in Germany. Rational house owners and landlords will invest in energy-related refurbishments only if there is a pay-off. The costs of refurbishment must be overcompensated by decreasing heating costs, higher rental income, increase in value, etc. The German government has therefore decided to promote energy-related refurbishments by reducing the costs for house owners and landlords.

While it is obvious that the refurbishment rate must be increased, it is unclear what specific measures the national governments or the European Union, respectively, should implement. This question is not a trivial one, since there are a lot of trade-offs and dilemmas to be considered. In general, the definition of energy-related refurbishments is vague. In principle, due to technological progress, a lot of conservation measures produce energy savings and therefore could be considered as an energy-related refurbishment. Hence, funding such measures that would have been taken anyway would be a misuse of subsidies. Also, promoting cheap measures could result in failure to achieve the targets. This is so because refurbishments are long-term investments, and once the investment is made, it will prevent further investments until it has paid off even if it hardly reduces energy consumption and GHG emissions. Assuming that cost curve of emission reductions is convex, it is possible for comprehensive measures that public funding would have to be very high to ensure investments. Also, from a social perspective, refurbishment measures could entail a new cost burden for tenants. Especially for comprehensive measures, the subsiding must be relatively high to prevent significant increases in rents. Furthermore, an unclear funding scheme could cause investment decisions to be delayed and thus prevent an increase of the refurbishment rate.

The definition of the GHG emission reduction target may also be considered. Usually the target is defined as a reduction at a certain point in time, for example the year 2030. However, as Meinshausen et al. (2009) pointed out, it could make more sense to consider the emission budget in the sense of cumulated emissions until 2050. These two approaches could make a difference for policy makers.

As a result, policy makers can, in principle, choose between two options: to promote comprehensive refurbishments that are expensive but achieve the greatest reductions in energy consumption and GHG emissions or also to promote partial refurbishments which include only low-cost improvements but can be achieved on a wide scale.

This, of course, assumes that house owners react on the promotion of energy-related refurbishments. Although the social benefit of such measures is positive as Kronenberg et al. (2010) showed, the success of such policies can be considered as limited in Germany. There is still a great potential for energy savings and GHG emission reductions. Generally, according to Simons (2012), p. 6, there are two reasons for house owners to invest in energy-related refurbishments: thermal comfort and economic reasons. Furthermore, aesthetic reasons might also be relevant, either for or against refurbishment measures. However, decisions on energy-related refurbishments are individual. Hence, a mix of instruments is necessary to improve the effectiveness of policy instruments.[1]

Although the topic is important and of current interest especially for policymakers, there is very little literature on optimal policy measures.[2] One of the very few exceptions is Uihlein and Eder (2010). They aim at a replacement of building elements (roofs and windows) rather than major refurbishments. They conclude that these measures offer the potential for substantial additional energy savings. Furthermore, they conclude that, on the one hand, a replacement of energy-inefficient windows and roofs that have not reached their end of life leads to additional costs at comparably low energy savings. On the other hand, the installation of energy-efficient building elements comes at negative net cost. However, Uihlein and Eder (2010) calculated a period of 25 to 30 years for net costs to become negative. This might be too long for house owners to present a substantial incentive to invest in energy-efficient measures. A further article on optimal refurbishment options is Shimschar et al. (2011). They concentrate on very high energy performance houses and calculate scenarios of both new constructions and ambitious refurbishments and the effect on emission and primary energy reductions until 2020. They conclude that in the most ambitious scenario, the share of such buildings can increase by up to 30 per cent of the total stock in 2020. This may lead to emission reductions of more than 50 per cent of the 1990 level and primary energy reductions of 25 per cent compared with today.

1 See Weiss et al. (2012) for lessons from a case study in Germany. In contrast, lessons from ineffective measures may be learned from the Green Deal in the UK, see Dowson et al. (2012).

2 However, there is an extensive body of literature on willingness to pay for energy-related refurbishments, which is important in order to understand the dynamics of investment decisions of house owners. See Achtnicht (2011) for a recent literature overview.

In this paper, we analyse the efficiency of different refurbishment measures in the residential building stock by evaluating the basic options for comprehensive and partial refurbishments. Using a stylised model of German housing stock, we compare the investment needed to reduce energy consumption and GHG emissions and calculate gains of lower consumption of oil and gas. Furthermore, we calculate GHG abatement costs. We also analyse the effect of biofuels on GHG emissions and find a small but significant benefit. Since our paper is the first to offer a stylized model of German residential building,[3] it provides a reliable basis for analysing refurbishment measures, which, in turn, can be used to derive efficient policy options for the achievement of the climate targets in residential building stock.

2 The Model

2.1 Methodological Background

The energy demand of private households for heating purposes is basically determined by the building efficiency, i.e., heat engineering and heat insulation, and by the living space to be heated. As the central indicator for heating efficiency, we use the space-related final energy consumption, i.e., the actual energy consumed per living space within one year. The living space in question is divided up according to the source of heating energy. Subsequently, efficiency classes are formed within the respective source of heating energy. These classes differ in respect to building efficiency and heat producer and therefore have different levels of specific energy consumption.

For the scenarios, refurbishment methods are defined that either illustrate present trends or appear to be plausible in the future. A refurbishment method may mean a change of efficiency classes within an energy source or a change of energy source. The

[3] There are numerous papers that calculate benefits for efficiency measures for specific buildings. Some papers focus on specific regions or cities. Other papers use projections of measures and scale for the whole residential building stock. To our knowledge, there is no paper using a model of the whole German residential building stock as a basis for refurbishment options. This might be a result of the limited data availability for the German residential building stock.

living space-related energy consumption is determined by the refurbishments methods and refurbishment rate. The total energy consumption for 2030 can be calculated from this in combination with an assessment of the living space to be heated. This refers only to heating in rooms and does not include the energy used to produce hot water.

The emission of greenhouse gases for the energy sources and for the total energy consumption both per year and for the total period under consideration is calculated on the basis of energy source-specific greenhouse gas factors. The applied emission factors take into account not only the direct emissions, but also the individual pre-chain emissions of the fuel supply including conversion losses.

For the economic evaluation of refurbishment options, investment costs for the relevant refurbishment steps are determined on the basis of the current estimates in technical publications. Macroeconomic investment needs can then be extrapolated from the refurbishment steps and the annual refurbishment rate. These are put in relation to the saved greenhouse gas emissions in order to estimate the cost efficiency of the individual refurbishment options. This estimation concerns only the fixed investment for the refurbishment, however, and not the variable earnings resulting from the refurbishment, for example, through energy conservation.

By adjusting the refurbishment methods that can currently be observed and the present refurbishment rate of approximately 1 %, a trend scenario can be calculated for 2030 and another scenario of “2 %”, which assumes the same refurbishments methods but a refurbishment rate of 2 % as desired by the German government. Subsequently, the opposite refurbishment options “Quick” and “Comprehensive” are reviewed for a basic evaluation of refurbishments. For each relevant refurbishment rate, the emissions, energy saving, and incurred costs are compared for both options.

Another way to reduce emissions is to feed in biogenic oil or biogas in addition. For this reason, this possibility is also tested. Since the costs for this are difficult to quantify, the analysis is confined to the illustration of emission reductions.

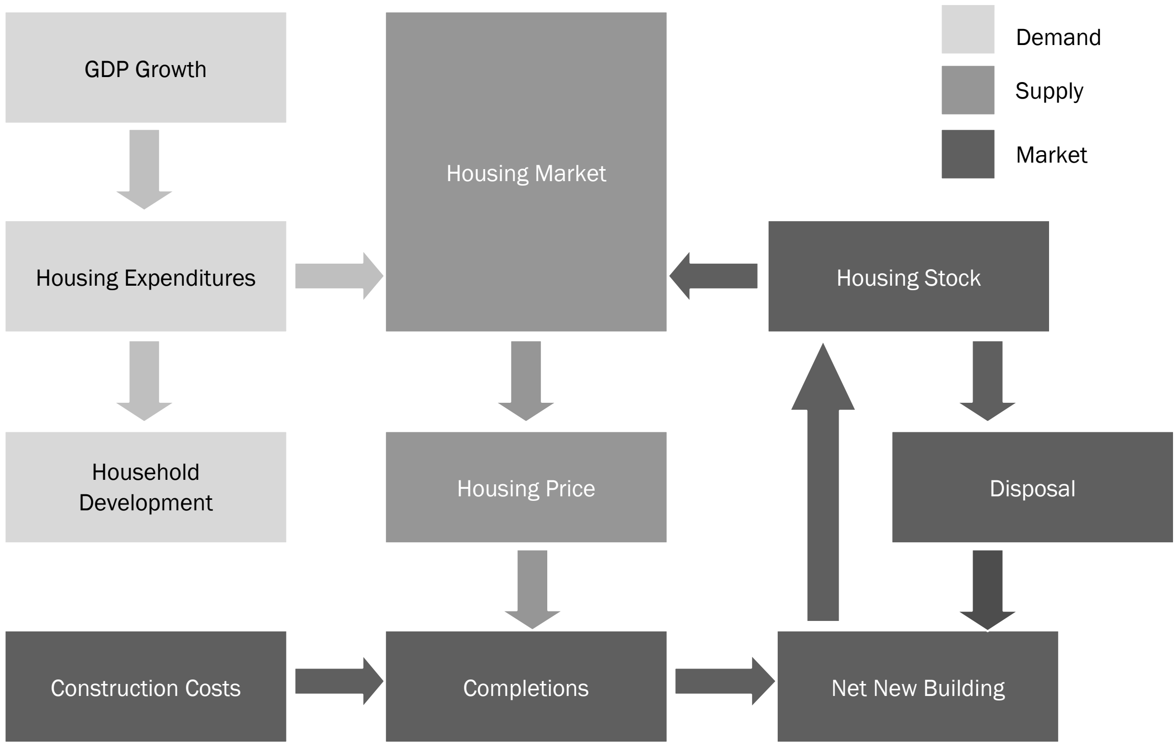
2.2 Data

2.2.1 Living Space

Housing markets are influenced by the economic and demographic development of the region in question. High economic growth tends to lead to rising housing prices and to a delayed increase in available housing. The demographic development affects the housing demand through population and age structure.

The model used here is based on the historically observed supply and demand in the regional housing market. A detailed explanation is provided in Bräuninger et al. (2006). The development of demand on the housing market, which is calculated in square meters living space, is determined by the income growth and the number and structure of households. The forecast of housing expenditures is based on the forecasts of household income, which is measured in regional growth, and forecasts of households, provide by the Federal Institute for Research on Building, Urban Affairs and Spatial Development (2012). The causal structure of the model can be seen in figure 1. Assuming that the behavioural pattern of market players is consistent over time and considering forecasts on the development of the regional framework conditions and economic growth, conclusions can be drawn for the future development of real estate markets and combined to obtain a pan-German result.

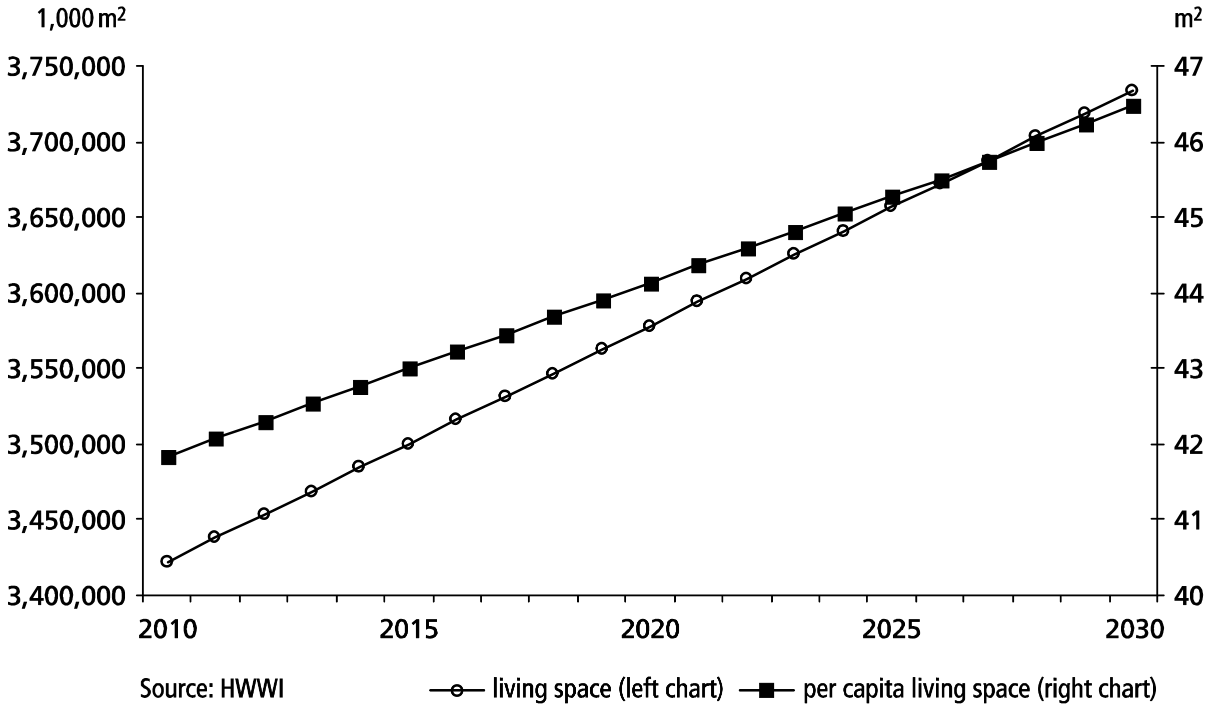
Figure 1: Causal Structure of the Model



Source: HWWI

As a result of an ageing population, there will be an increase in one-person and two-person households; therefore, the per capita living space will exceed 46 m^2 by 2030 compared to less than 42 m^2 in 2010. Assuming a moderate annual economic growth of 1.25 % on average at the same time, the German living space will increase by 9 % from 3.42 billion m^2 to 3.73 billion m^2 between 2010 and 2030 according to our model, despite a decrease in population over the same period of time.

Figure 2: Projection of Living Space in Germany



2.2.2 Heating Structure

In Germany, there are about 17.8 million central heating systems. According to Brennstoffspiegel (2011), the association of German chimney sweepers estimates that 6 million are oil-fired heating systems (5.7 million oil standard and low-temperature boilers and 0.3 million oil condensing boilers) and 7.7 million gas standard and low-temperature boilers. Additionally, approximately 3 million gas condensing boilers are not included in the statistics of the association of German chimney sweepers because they have to be inspected only once after first-time operation. Gas and oil-fired heating systems thus make up the majority of the all existing central heating systems. In contrast, the 400,000 heat pumps account for only roughly 2 % and the 700,000 biomass boilers account for approximately 4 % of all existing heating systems.

The energy consumption of private households is illustrated in different limits and classifications depending on the source. If possible, the data of the environmental-economic accounting of the German Federal Statistical Office serve as a basis. According to our calculations for the base year 2008, we calculated the following specific consumption depending on the source of heating energy and distribution of the different sources of heating energy on the living space.

Table 1: Distribution of Sources of Heating Energy on Living Space in 2008

Source of Heating Energy	*Share of Living Space (%)*	*Average Consumption (kWh/m²a)*
Oil	25.6	171.70
Gas	53.6	144.35
District heating	12.0	102.55
Electricity	3.6	135.56
Coal	0.7	175.11
Biomass	3.6	619.50
Source: Federal Statistical Office (2010)		

The efficiency classes of the energy sources are made up of different combinations of heat engineering and building efficiency standards, which is why they differ in specific energy consumption. The classification and the distribution of living space among the efficiency classes follow a wide range of sources, expert interviews, and plausible estimates.

Oil- and Gas-Fired Heating Systems, District Heating

For oil- and gas-fired heating systems, there are four classes each. For spaces heated with district heating, there are just three classes, because homes heated with district heating differ only in building efficiency.

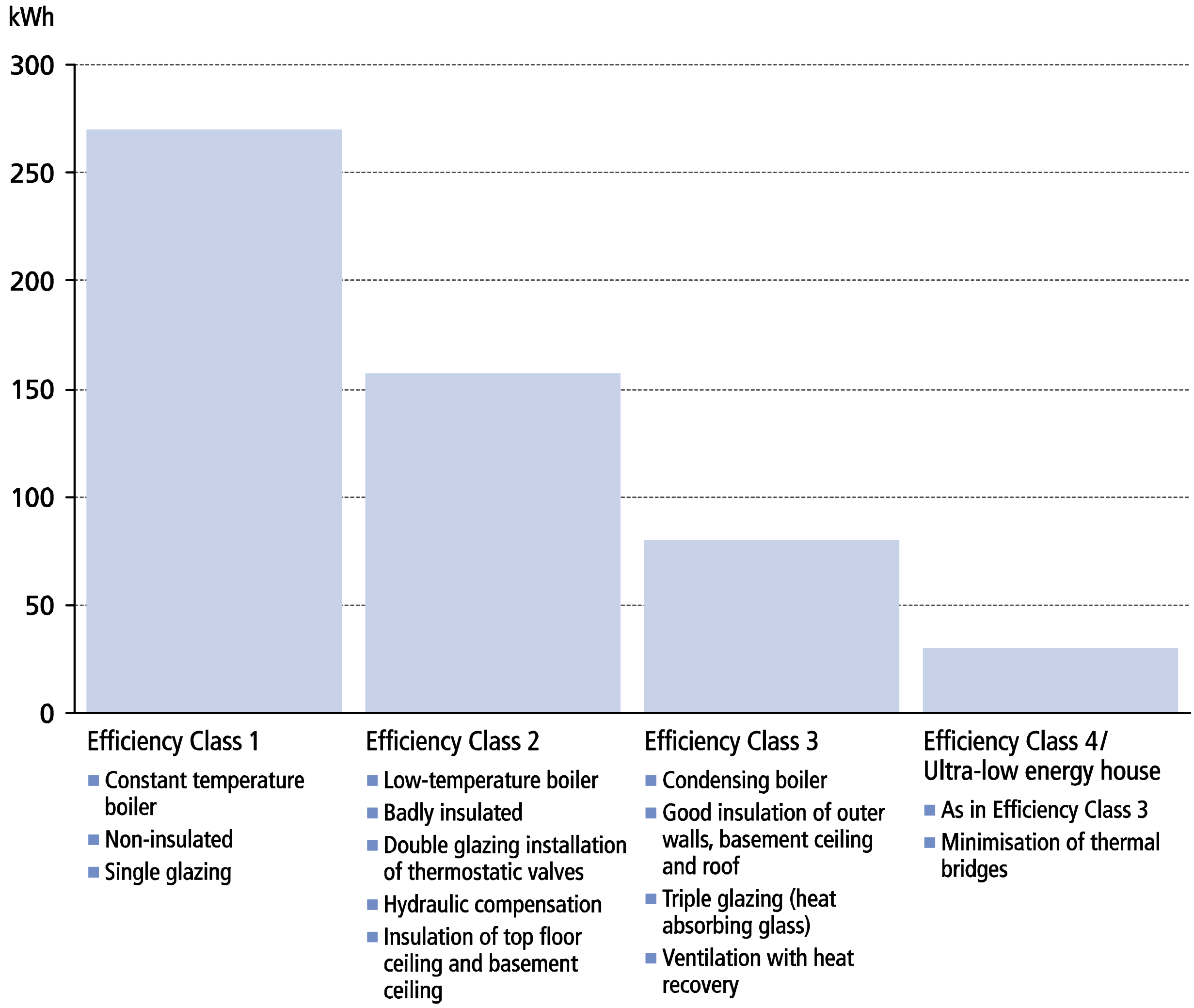
In Efficiency Class 1, the energy source oil has a consumption rate of 270 kWh/m²a, whereas gas rates 5 % higher with a consumption rate of 283.5 kWh/m²a. Older gas boilers are slightly less efficient than old oil boilers, because the unused condensation energy of steam contained in flue gas has a greater effect (see dena (2010); Interessengemeinschaft IG Energie Umwelt Feuerungen GmbH (2011); IWO (2010)). For district heating, the energy consumption amounts to 159.28 kWh/m²a. In this class, a standard boiler with an indirectly heated drinking water reservoir is installed. Typically, these houses are heated with constant temperature boilers, and the insulation is very poor.

In Efficiency Class 2, low-temperature boilers or modern condensing boilers are used. The top floor ceiling, the distribution pipelines, and the basement ceiling are insulated. A hydraulic compensation takes place, and single glazing has been replaced by double glazing. In addition, new thermostatic valves and possibly a solar drinking water heater and a support heating system have been installed. Oil-fired heating systems consume 150 kWh/m²a and gas-fired heating systems 157.5 kWh/m²a (see Schlesinger et al. (2010), pp. 61–76; IG Energie Umwelt Feuerungen GmbH (2011), loc. cit.). The energy consumption of district heating is 100 kWh/m²a.

In Efficiency Class 3, only boilers with condensing heating technology are installed in the buildings. In addition to the Efficiency Class 2 measures, there is a controlled ventilation system with heat recovery in some cases. The outer walls, the basement ceiling, and the roof are very well insulated, and the windows are fitted with triple glazing. The energy consumption amounts to 80 kWh/m²a (see IG Energie Umwelt Feuerungen GmbH (2011), loc. cit.) for oil and gas and 65 kWh/m²a for district heating.

In Efficiency Class 4, energy consumption is only 30 kWh/m²a. Only buildings with very high overall energy efficiency are included. On the European level, these ultra-low energy houses aim at covering their energy needs primarily with renewable energy sources. In addition to having a controlled ventilation system with heat recovery and, if applicable, solar heat for additional room heating, thermal bridges are minimised, for example, where the outer walls are connected to the roof structure (see HMUELV (2011); Official Journal of the European Union, Directive 2010/31/EU (2010)).

Figure 3: Efficiency Classes of Heating Energy Sources Using Oil as an Example



Source: HWWI

In the distribution of the living space among the efficiency classes, the number of houses in the respective efficiency classes serves as an approximation of the living space, and the age structure of the gas-fired and oil-fired heating systems in German houses is used.[4] Since district heating and gas are grid-bound and the connection took place simultaneously, we assume that the output distribution of district heating lies between oil and gas. We disregard the currently available housing in Efficiency Class 4 and assume that such housing will consist only of new buildings as of 2021.

[4] A current estimation can be found in Diefenbach et al. (2010), p. 98.

Table 2: Share of Efficiency Classes in Houses Heated With Oil, Gas or District Heating

	Oil (%)	*Gas/District heating (%)*
Efficiency Class 1 High energy demand	21.7	14.6
Efficiency Class 2 Medium energy demand	72.1	44.7
Efficiency Class 3 Low energy demand	6.1	40.7
Source: Bremer Energieinstitut (2010); compiled by the author		

Solid fuels: Coal and Wood

Coal-fired heating systems are typically old and inefficient. Average consumption is 175.11 kWh/m^{2}a. We assume that houses with coal-fired heating systems will be torn down and that such systems will be neither refurbished nor installed in new buildings, which will lead to a continuous decrease in houses with coal heating.

A large number of wood-fired heating systems or fireplaces are used in addition to other heating systems. Our focus is on primary heating sources, and we differentiate between old (inefficient) and new (efficient) systems. We assume that half of all existing houses heated with wood as primary heating source have been rebuilt and are efficient by 2008. According to statistics, houses heated with old systems consume 1,194 kWh/m^{2}a. Like houses heated with coal, the inefficient wood-fired heating systems are simply demolished. New biomass heating systems are installed only in efficient buildings and thus consume an average of 45 kWh/m^2 per year.

Electricity

Houses heated with electricity are divided into three classes. About 75 % of houses heated with electricity are fitted with night storage heaters. These are comparatively inefficient and use 169.08 kWh/m^{2}a. The other 25 % are heated via heat pumps. Both new and refurbished buildings using heat pumps are highly efficient.

However, heat pumps differ in efficiency. The most efficient heat pumps are brine-water heat pumps used in new buildings. Since installation in existing buildings is often difficult, air-water heat pumps are primarily installed in such buildings. This is why heat pumps consume 35 kWh/m²a in refurbished buildings, whereas their consumption is only 20 kWh/m²a in new buildings. This assumption is based on numerous expert opinions.

2.2.3 New Buildings and Demolition

Since technical standards are getting ever higher, demolishing old buildings and constructing new buildings lead to an energetic improvement. Calculations on the basis of the Federal Statistical Office (2011) show, that an average of about 0.5 % of existing houses was demolished per year during the last decades. This figure is reflected in the scenarios. The construction forecasts presented above show that available housing will increase by an average of 0.5 % per annum over the next few years. Hence, new buildings will account for approximately 1 % of existing houses. Based on current technological trends and building law, we assume the following distribution of new buildings up to 2030:

Table 3: Distribution of New Buildings

Efficiency Class	*Share until 2020 (%)*	*After 2021 (%)*
Oil class 3	5	0
Oil class 4	0	5
Gas class 3	45	0
Gas class 4	0	25
District heating	5	0
Electricity (heat pumps)	40	60
Biomass	5	10
Source: HWWI		

Assuming that older and non-refurbished houses, in particular, are torn down, demolitions always take place in the lower efficiency classes. The energy sources are affected in proportion to their shares in living space heated by them in the lower efficiency classes.

2.2.4 Refurbishment Methods

Refurbishment generally implies structural or technical modernisation of a building in order to repair damages or to raise the standard of living. Energetic refurbishment refers exclusively to reducing energy consumption and/or energy-induced emissions. This is achieved by improving the heating system, changing the energy source or refurbishing the building. We define energetic refurbishment as a residential building's upgrade to at least one higher efficiency class. We distinguish between small and large refurbishments. A small refurbishment improves the efficiency class by one class, and a large refurbishment implies an improvement by at least two classes.

The Trend scenario

As Diefenbach et al. (2010), pp. 69–74, calculated, a mixture of smaller and larger refurbishments at approximately 1 % average annual refurbishment rate can currently be observed. In order to evaluate the current refurbishment measures, we therefore develop a trend scenario with the following assumptions:

- There are refurbishments improving the energy class by one or two classes, refurbishments improving the energy class by two classes being carried out only half as often.
- Within oil/gas, refurbishments take place up to Class 3, thus from Class 1 to Class 2 and Class 3 and from Class 2 to Class 3. At most, the average current new building standard is achieved.
- During refurbishments of oil-heated living spaces, a 25 % switch to gas is assumed based on expert opinions.
- Due to the absence of a boiler, there are only three categories, differing only in insulation, for district heating. It is therefore assumed that no refurbishments to outdated insulation standards are carried out. Refurbishment is therefore possible only from Class 1 to Class 3 or Class 2 to Class 3.

The Quick scenario

The scenario "Quick" consists of measures that can be implemented quick in terms of cost-effectiveness. It builds on the scenario "Trend", but differs in the following:

- Each refurbishment for the energy sources oil and gas allows only for changes into one higher class, thus from Class 1 to Class 2 and from Class 2 to Class 3.

The Comprehensive scenario

This scenario can be regarded as the opposite to the scenario "Quick". In this case, priority is given to maximum energy conservation or emission reductions per refurbished housing unit. Therefore, the most inefficient housing units are brought into the best condition. This scenario differs in two points from the scenario "Trend":

- Half of each refurbishment for the energy sources oil and gas leads to the biomass or heat pump efficiency class.
- It is begun in the most inefficient classes, until they no longer exist, and then continued in the next, thus first from oil/gas Class 1 and then oil/gas Class 2.[5]

2.2.5 Costs

Distinguishing refurbishment costs from normal maintenance costs is difficult, since it is not clear whether refurbishments are energy-related or not (see for example Discher et al. (2010), pp. 32–37; Neuhoff et al. (2011), pp. 7–11). The replacement of a heating system for reasons of age becomes necessary someday, but it cannot be determined whether the costs for a new heating system are energy-related or would have been incurred anyway. In light of increasing energy prices, heating systems are sooner re-

[5] This is a strong assumption. On the one hand, it is conceivable that a central planer pay the highest subsidy for energy-related refurbishments for the most inefficient buildings. As the need for a "normal" refurbishment may be higher than in other buildings, investment incentives may therefore be higher than for "normal" houses. On the other hand, there are no means for a central planer to ensure that the most inefficient buildings are refurbished first. Hence, this scenario is an optimal scenario. However, it seems to have no great impact on the results, assuming that all buildings are refurbished during their life cycle.

placed by heating systems with less consumption. However, only the costs for making the exchange earlier and for the improved heating system are energy-related as such.

Furthermore, it should be considered whether to factor in the expected variable savings and additional expenditure, in addition to the fixed investment costs. Since it is difficult to predict the variable costs, we choose a very simple approach and use the price forecasts for oil and gas provided by the International Energy Agency (2012). At the same time, we do not consider any costs for new buildings and demolition. Although this can be regarded as the maximum refurbishment, heating costs, for one thing, are usually not the decisive criterion for demolition and, for another, every new building implies an energetic improvement even without an energetic motive. We also assume that refurbishment costs will remain steady until 2030. Although it is true that technical developments may lead to a decrease in costs, refurbishments are dominated by labour costs, which are more likely to increase in Germany.

Our cost assumptions are based on different studies and expert opinions. In particular, these include:

Refurbishment Efficiency Class 1 to 2: € 100 per m²

This is equivalent to installing a condensing boiler plus additional smaller measures, possibly a solar thermal water heating system, total costs approximately € 15,000 (see Mailach, Rosenkranz and Oschatz (2010), p. 28; Walberg et al. (2011), pp. 73–81; IG Energie Umwelt Feuerungen GmbH (2011), loc. cit.).

Refurbishment Efficiency Class 1 to 3: € 480 per m²

This approximates the refurbishment of a not or only little refurbished house to a KfW-100-standard. The costs result from the average refurbishment costs for different house types (single-family home, multi-family house, etc.) and age group (see Walberg et al. (2011), loc. cit., pp. 64–69; IG Energie Umwelt Feuerungen GmbH (2011), loc. cit.).

Refurbishment Efficiency Class 2 to 3: € 430 per m²

This intermediate step builds on the measures from the first refurbishment. Basically, only the boiler (approximately € 7,500) and possibly the solar thermal water heating system can be used. Plus the additional expenses, we assess that half of the costs (€ 7,500) can be included, thus 480 – 50 = € 430.

Refurbishment to Heat Pump

It is generally possible to install heat pumps in existing buildings. However, this is economically and ecologically feasible only if the installation of heat pumps is part of an extensive refurbishment of the building. For this reason, heat pumps belong to the most efficient class in existing buildings and new buildings, although they differ considerably in terms of efficiency. Relatively high refurbishment costs, € 600 per m², irrespective of the previous efficiency class, are the consequence (see Walberg et al. (2011), loc. cit., pp. 73–81; IG Energie Umwelt Feuerungen GmbH (2011), loc. cit.).

Refurbishment to Biomass

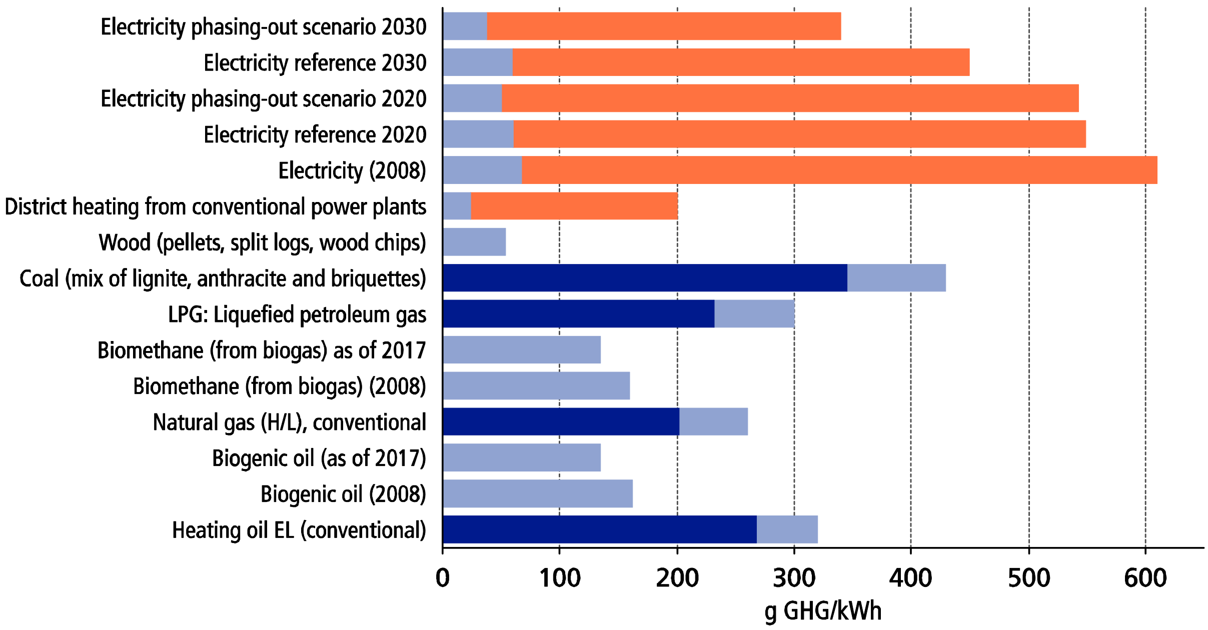
Generally, biomass installations (usually wood-fired heating systems) can be installed in buildings with different refurbishment standards. Since the conversion of the heating system is expensive, this is economically and ecologically feasible only if the installation of biomass systems is part of an extensive refurbishment of the building. In the scenarios, it is therefore assumed that a refurbishment with biomass is always done into the most efficient class. Refurbishment costs amount to € 600 per m², irrespective of the previous energy efficiency class of the building (see Walberg et al. (2011), loc. cit., pp. 73–81; IG Energie Umwelt Feuerungen GmbH (2011), loc. cit.).

2.2.6 Specific Greenhouse Gas Emissions Factors

GHG emissions are calculated on the basis of Fehrenbach et al. (2011) The entire life cycle, including the pre-chain and emitted greenhouse gases during the utilisation phase, are included in the calculation. In the transport sector, the concepts Well-to-

Wheels (WTW) for the entire life cycle, Well-to-Tank (WTT) for the pre-chain and Tank-to-Wheels (TTW) for the utilisation phase have been established as demonstrated in EUCAR, CONCAWE, JRC/IES, (2008). Analogously, the Well-to-Warmth concept is the concept for fuels (also WTW), i.e., from the raw material source to the release of thermal heat in a building.

Figure 4: GHG Emission Factors



Source: Fehrenbach (2011)

3 Results

In this section, we will present the results of the scenario “Trend”. Additionally, we calculate the effect of a doubled refurbishment rate, as desired by the German Federal Government (see BMWi/BMU (2010)), i.e. the scenario “2 %”. Then, we show the results of the comparison of Comprehensive and Quick. We furthermore illustrate fuel savings and GHG abatement costs of the different refurbishment options. The last part presents the effects of biofuels.

3.1 Trend and "2 %"

If this trend is to be continued in the long run, thus an annual refurbishment rate of approximately 1 % of the living space by 2030, the specific energy consumption for the entire living space (including new buildings) would drop from an average of 162.04 kWh/m²a to 108.6 kWh/m²a. This is a decrease of 33 %. In the event of a doubled refurbishment rate, as desired by the German Federal Government, energy consumption would fall to 93.2 kWh/m²a or 42.5 %.

Table 4: Results of the Scenarios "Trend" and "2 %"

		Consumption (kWh/m²a)	*Emissions Reduction compared to 2008 (%)*	*Total Refurbishment Costs (Billions of €)*	*Refurbished Space (m²)*	*Share of Refurbished Space of Total Space (%)*	*Average Annual Investment Costs (€/t GHG)*
Scenario "Trend"	2008	162.04					
	2020	126.40	18.53	252.2	511,241	1.13	9,297
	2030	108.56	26.97	385.8	815,707	1.00	10,474
Scenario "2 %"	2080	162.04					
	2020	114.08	27.33	511.3	1,083,908	2.40	15,017
	2030	93.16	39.18	743.5	1,623,990	2.00	14,561

The specific consumption figures should not be overrated, since the total living space is likely to increase by 10.1 % compared to 2008 by 2030. The absolute consumption figures make this clear: in 2008, total consumption was at 549 billion kWh. If refurbishments were not to take place by 2030, then about 493 billion kWh would still be necessary to supply the German heating sector. This is equivalent to a reduction of 10.4 %. In the "Trend" scenario, this would be tantamount to a reduction of 26.2 % (405 billion kWh) and 33.7 % in the "2 %" scenario (348 billion kWh).

There are only slight differences among the energy sources. This is because during most current refurbishments, it is about heat producers being modernised and insulation being improved, but energy sources are not changed. Houses heated by oil are the exception, and some buildings are switched to gas. In this respect, the share of heat producers is changed mainly when new buildings are built, where gas and electricity currently dominate, the importance of electricity resulting from the installation of heat pumps. Since the living space increases at the same time, the share of gas in new buildings is not sufficient for its already dominant position to be expanded. Figure 5 illustrates the shares and the total energy consumption of the energy sources.

GHG emissions are also reduced owing to technological progress. By 2030, they would amount to 9.5 % compared to 2008 due to demolitions and new buildings without any refurbishments taking place. Savings would be at 27 % in the "Trend" scenario and at 39 % in the "2 %" scenario. Considering the absolute GHG emissions, these figures seem to be low given the objective to achieve almost zero emissions by 2050.

Figure 5: Energy Consumption of "2 %"

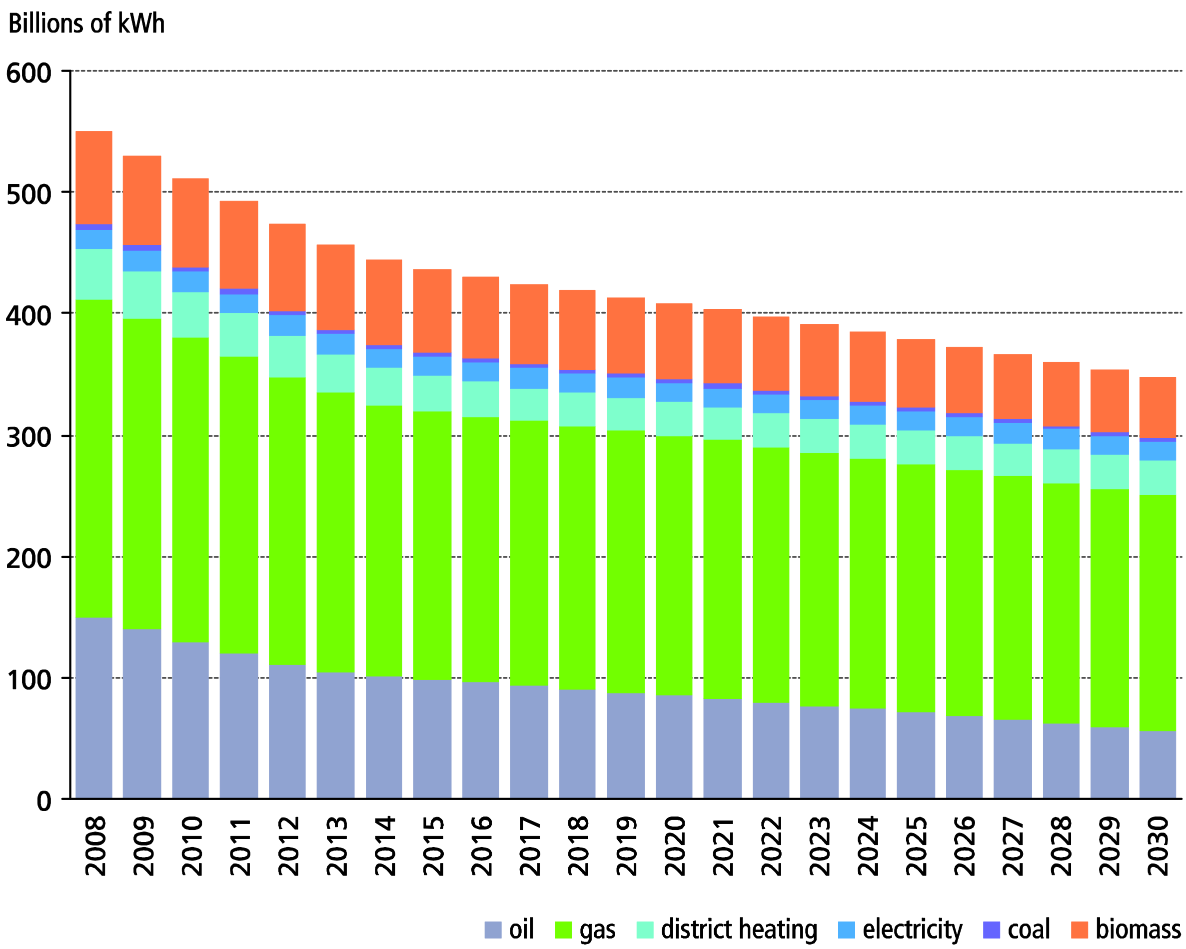
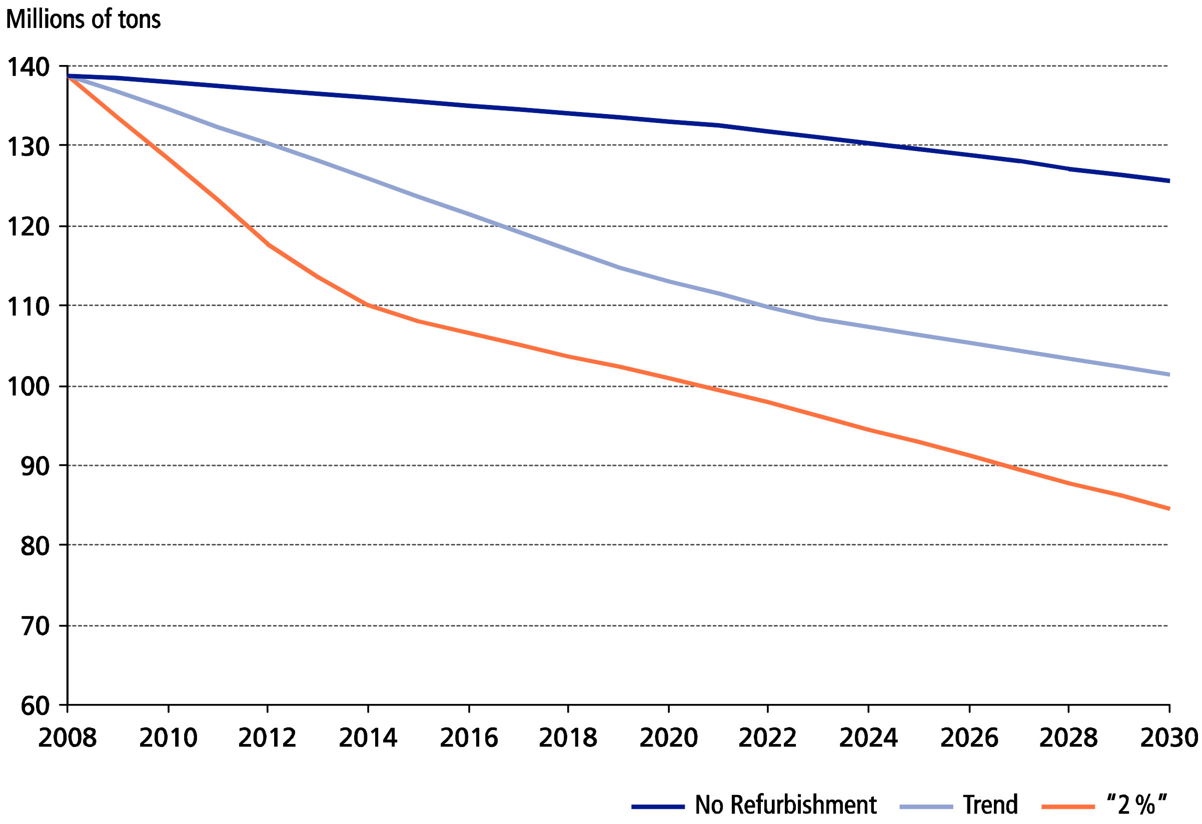


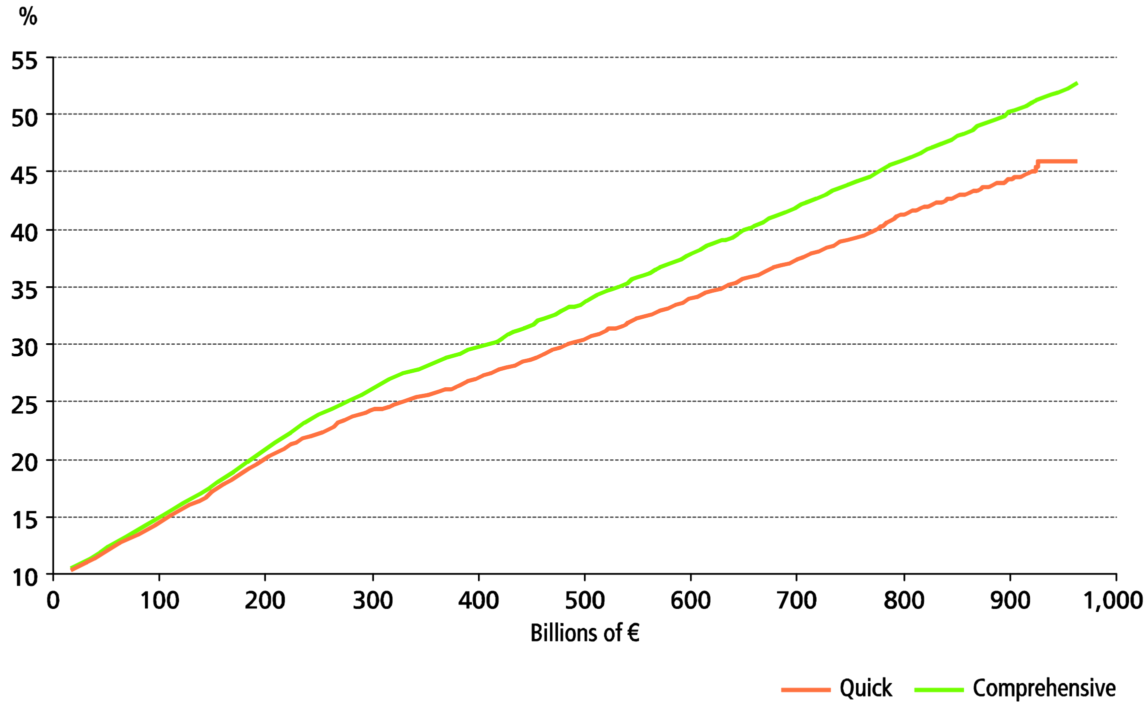
Figure 6: GHG Emissions



3.2 Quick vs. Comprehensive

In this section, we compare Quick and Comprehensive by calculating every relevant investment in refurbishments from € 0 up to almost € 1,000 billion. Although investment levels are equivalent to refurbishment rates, the refurbishment rates are different for both options. We therefore compare every outcome with respect to the investment of refurbishments. Figure 7 shows GHG emissions reduction in 2030 compared to 2008. We simulated the reduction for every relevant investment in refurbishments. It can easily be seen that Comprehensive is optimal for every investment cost since GHG reduction in the case of Comprehensive is always higher than in the case of Quick. Both options are nearly equal with very low investment costs, i.e. up to € 150 billion. If more than € 150 billion are invested in refurbishments, the advantage of Comprehensive increases. At € 900 billion, the difference is more than 5 %.

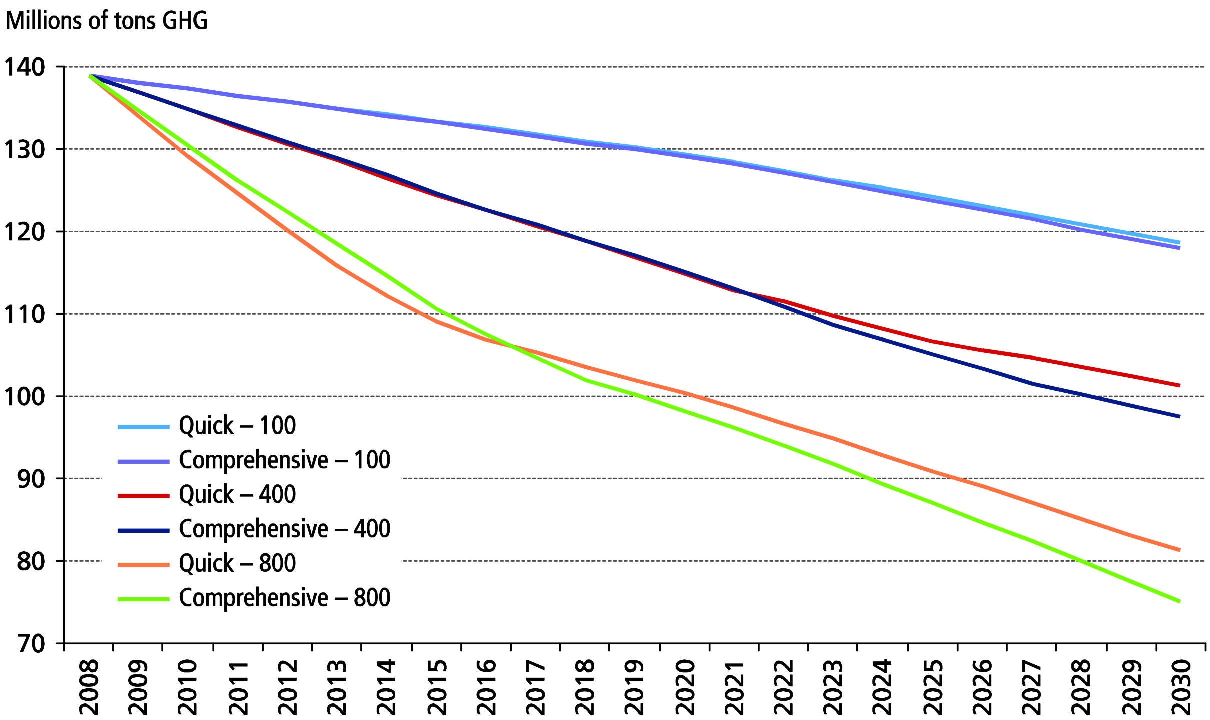
Figure 7: Reductions of GHG Emissions (2030 compared to 2008)



Furthermore, it can be easily seen that the reduction of Quick stabilises at € 925 billion. At this point, which corresponds to 3.13 % annual refurbishment rate, the maximum possible refurbishment of Quick is reached, since Efficiency Class 1 or 2 of oil, gas or district heating no longer exists. As defined in our model, the amount of € 925 billion is therefore the limit of stepwise refurbishments. In fact, this is a considerable investment level, as it equals € 40.2 billion per year, which is 2.4 times higher than the current investment level of € 16.7 billion in Trend.

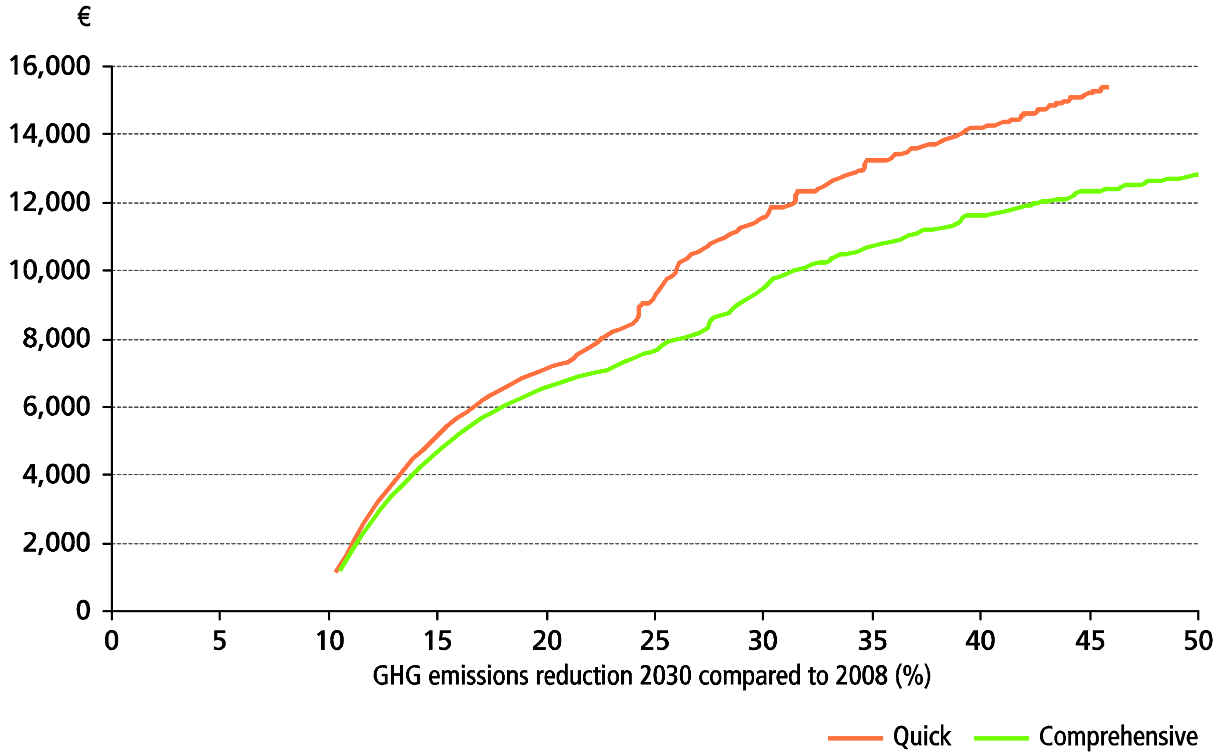
The difference between Quick and Comprehensive becomes clearer when examining the GHG emissions per year. Figure 8 shows the emissions per year at three different investments levels. If € 100 billion are invested up to 2030, the difference between Quick and Comprehensive can be neglected. If € 400 billion are invested, Comprehensive will emit more until 2020 and will afterwards quickly improve. The same dynamics can clearly be seen at an investment level of € 800 billion: Comprehensive makes less progress than Quick in the first years but catches up quickly. The explanation is simple: with increasing refurbishment rates, Quick needs to refurbish living space twice, i.e. from Efficiency Class 1 to Efficiency Class 2 and then to Efficiency Class 3. It is assumed that it is always efficient to reach a certain energy standard in one big step rather than step by step. However, the time period of 23 years considered in our model is too long for Quick to benefit from the advantage of the first years. This leads to the conclusion that stepwise refurbishments are only optimal if the time period is relatively short or, in other words, it is always optimal to apply comprehensive measures if long periods of time are considered.

Figure 8: GHG Emissions per Year (Millions of Tons GHG)



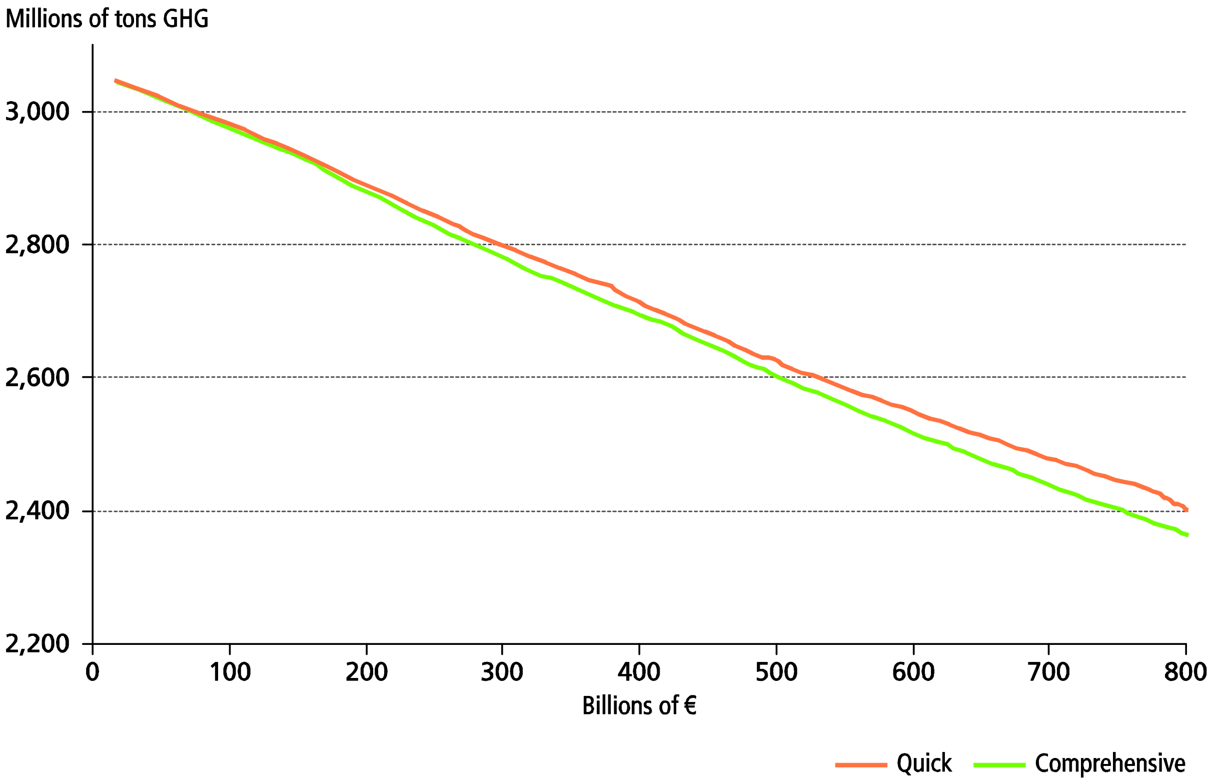
As a result, the investment costs per ton GHG emissions are always lower if comprehensive refurbishment measures are applied. Figure 9 shows the investment costs per ton GHG for any possible amount of GHG reduction in 2030 compared to 2008. It should be noted that these costs are not abatement costs. Instead, we only calculate the fixed investment costs that are required to reduce GHG emissions.

Figure 9: Investment Costs per Ton GHG Emissions



However, a different conclusion might be drawn when considering cumulated GHG emissions. Figure 10 shows the cumulated GHG emissions for all relevant investments. Since the maximum difference is less than 2 % for an amount of € 800 billion, the difference can be neglected. This result may seem surprising, but is, in fact, entirely in line with our findings above. While the period of 23 years is enough to create a significant advantage for Comprehensive in terms of emission reduction, it is not long enough in order to create a clear distinction when considering cumulated emissions.

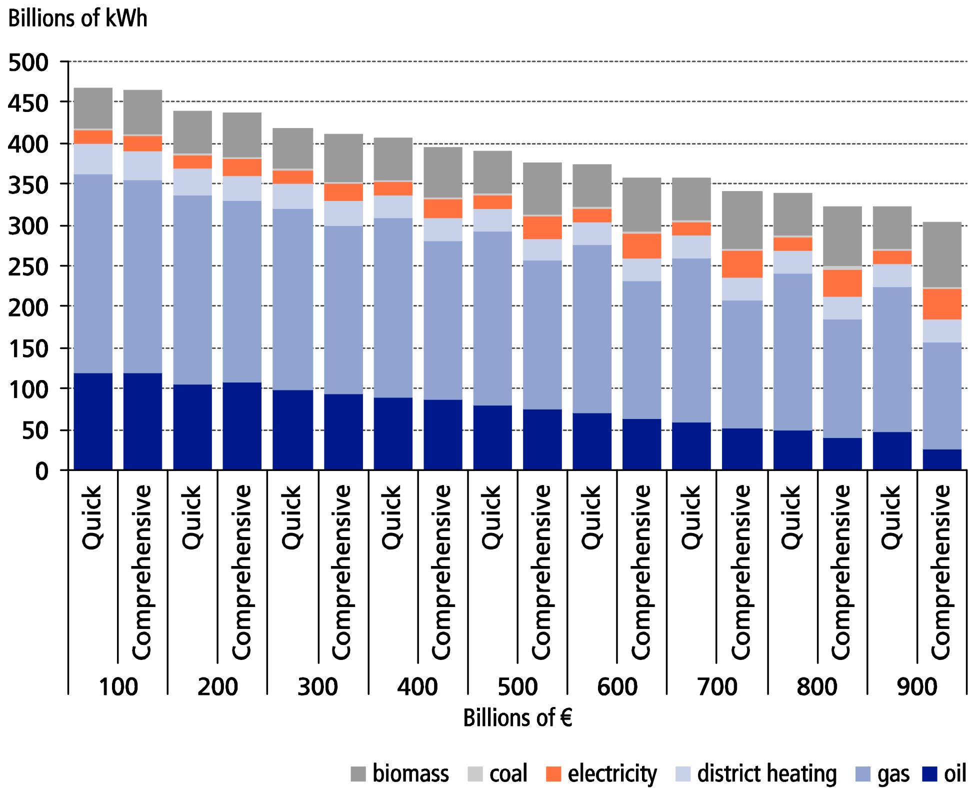
Figure 10: Cumulated Emissions 2008–2030



Energy consumption is another indicator revealing the small difference between the two options. Figure 11 shows the energy consumption of all energy sources for both options at different investment levels in 2030. In accordance with the emission reductions, the difference between the two options increases with increasing investment levels, but remains very small. However, the different structure of energy consumption in both options is evident. The larger share of fossil energy sources, especially gas, can be easily seen in Quick. Hence, the share of renewable energies, i.e. biomass and heat pumps[6] is larger in Comprehensive. This shows the general difference of both options: While Quick is based mainly on increasing energy efficiency of the established fossil technologies with a slight shift from oil to gas, Comprehensive, in contrast, implies a shift from fossil energy sources to renewable energy sources.

6 Note that, in this case, heat pumps are considered a renewable energy source, even if they are powered by electricity that is not generated from renewable energy sources. The GHG emission factor of electricity will decrease with the increasing share of renewable electricity in the electricity mix.

Figure 11: Energy Consumption



3.3 Fuel Savings and GHG Abatement Costs

Since investments in refurbishments have effects on energy consumption, fuel savings are also calculated which is important for policy conclusions. First, a comparison of the scenarios "Trend" and "2 %" is provided. Then, the results for Quick and Comprehensive are represented. The analysis concentrates on the most important fuels oil and gas and uses the price forecasts provided by the International Energy Agency (2012).

In order to be in line with the results of investment needs and GHG emissions, only fuel savings within the time period of 2008 to 2030 are considered. Therefore, investments might be overestimated in comparison with fuel savings since the life cycle of a refurbishment investment lasts longer. However, for the analysis provided here, the aim is to compare the different policy options.

Table 5 shows the aggregated results of the time period of 2008 to 2030 for the scenarios "Trend" and "2 %". Both scenarios are compared with a hypothetical case where no refurbishments take place. In Trend, there is a saving of 628.7 billion kWh oil which equals 19.4 % and a saving of 484.9 billion kWh gas which equals 8.9 %. In "2 %", the fuel savings in kWh increases to 53.8 % for oil and 17.4 % for gas. As expected, the calculated GHG abatement costs are very low and might be lower or even negative when the life cycle of the refurbishment measures are taken into account. Also, it is intuitive that the GHG abatement costs of the refurbishment of oil-fired living space are much cheaper than gas-fired living space.

Table 5: Aggregated Results of the Time Period 2008 to 2030 for the Scenarios "Trend" and "2 %" in Comparison with no Refurbishment

		Fuel Savings (Billions of kWh)	*Fuel Savings (Billions of €)*	*GHG Abatement Costs (€ per Ton)*
Scenario "Trend"	Oil	628.7	34.2	20.5
	Gas	484.9	14.2	42.4
Scenario "2 %"	Oil	1,133.3	61.3	21.3
	Gas	878.2	25.3	42.8

Table 6 shows the results for Quick and Comprehensive. For comparison, two investment levels are chosen: 400 and 800 billion €. Regarding the fuel savings, the results are in line with those presented in 3.2: The differences are relatively small with a small advantage for Comprehensive. It must be kept in mind that the share of fuels like biomass and electricity is higher in Comprehensive compared to Quick as shown in Figure 11. Hence, the future price risk of these energy sources is essential for an evaluation of both policy options.

Concerning GHG abatement costs, Comprehensive is always better than Quick since the total consumption of oil and gas is lower in Comprehensive compared to Quick. However, the future price risk of biomass and electricity is essential.

Table 6: Aggregated Results of the Time Period 2008 to 2030 for the Scenarios "Quick" and "Comprehensive" for € 400 and € 800 Billion invested in Comparison with no Refurbishment

			Fuel Savings (Billions of kWh)	*Fuel Savings (Billions of €)*	*GHG Abatement Costs (€ per Ton)*
400	Quick	Oil	604.2	32.9	21.4
		Gas	397.2	11.6	49.9
	Comprehensive	Oil	601.2	32.9	22.7
		Gas	666.7	19.6	28.2
800	Quick	Oil	1,201	65.2	23.1
		Gas	817.7	23.7	52.2
	Comprehensive	Oil	1,221.5	66.5	24.7
		Gas	1,383.7	40.4	29.8

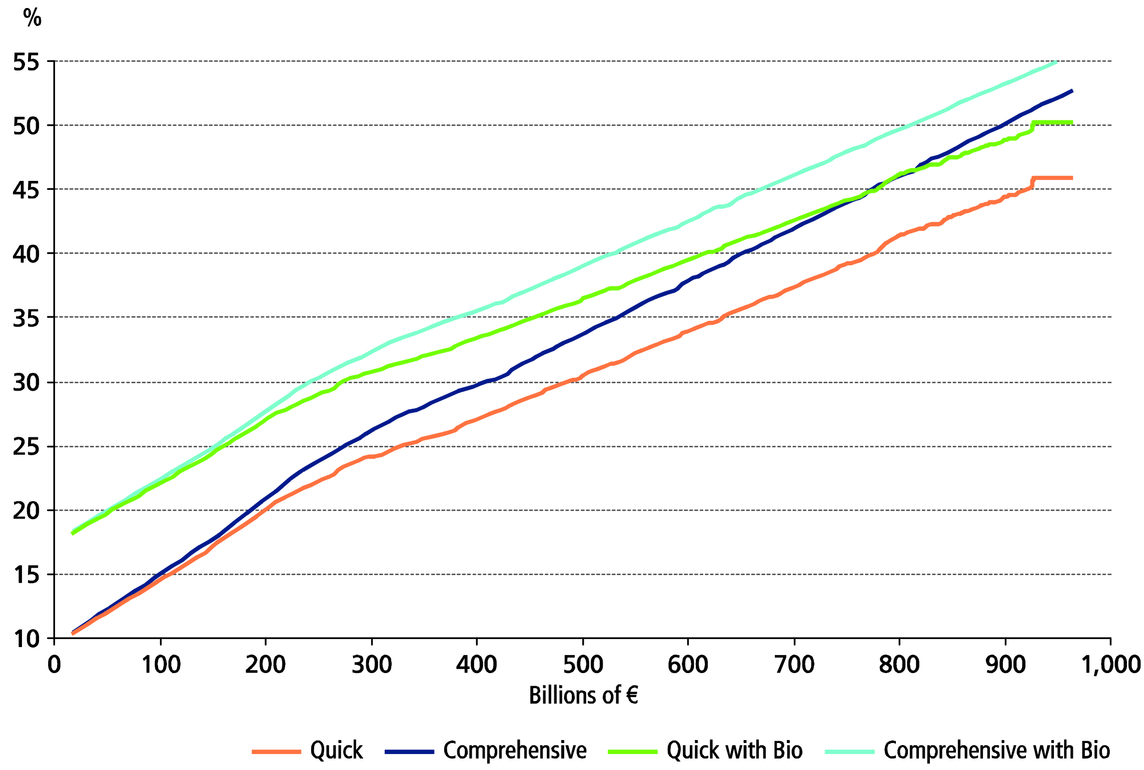
3.4 Biofuels

As an alternative to refurbishment measures, the reduction of GHG emissions is also facilitated by using renewable energies. Besides solid biomass, there are biogenic oil and biogas, insofar as they are produced sustainably. Given the increasing significance of heat pumps, an improved electricity mix can have a positive impact. These measures make sense if they are more cost-effective than refurbishments. This does not apply to the electricity mix since the climate protection goals concerning electricity generation are already very ambitious.

Since costs are difficult to forecast, we focus on investigating the potential GHG emissions reductions, assuming an admixture of 2 % of biogenic oil and biogas as of 2012 and an annual increase of 1 %, which leads to a 10 % share in 2020 and 20 % in 2030.

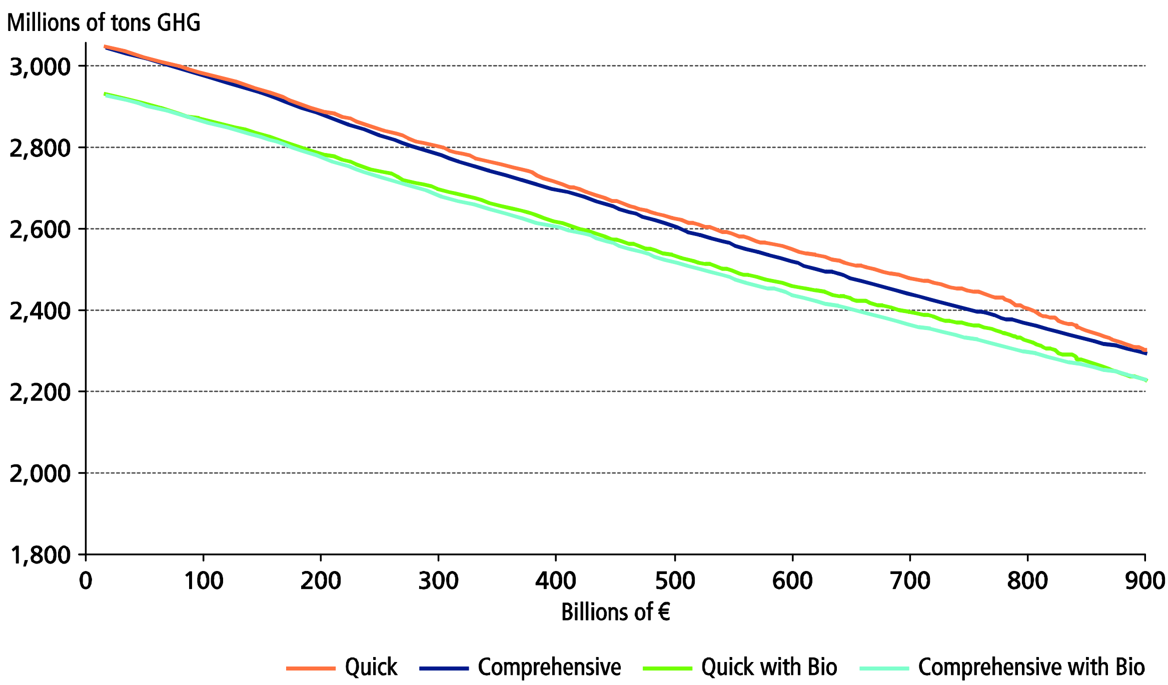
Figure 12 shows the results biofuels have on GHG emissions reductions in 2030 compared to 2008. A significant difference for both options is obvious. Biofuels have an effect of 8 percentage points with no refurbishment and this effect decreases slightly as the share of fossil fuels decreases with increasing refurbishment rates. Since the share of oil and gas is smaller, the effect of biofuels is obviously smaller for Comprehensive than for Quick. It should be noted that we assume no additional costs for biofuels in this figure in order to compare the potential of biofuels.

Figure 12: Comparison of GHG Emissions Reductions (2030–2008) of the Two Options With and Without Biofuels



The same result can be seen for cumulated GHG emissions. There is a small but significant effect of biofuels.

Figure 13: Comparison of Cumulated GHG Emissions of the Two Options With and Without Biofuels



4 Discussion

Since residential building stock is of great importance for achieving the climate protection goals in the European Union and Germany, policymakers have to take appropriate measures in order to increase the refurbishment rate. Given the large amount of investment that is needed, efficiency is essential in this context. Furthermore, habitation is a basic human need and should therefore be affordable. Since refurbishments will lead to higher rents, there is a potential trade-off between social policy and climate policy in the residential building sector. Inefficient funding schemes with distorted effects could worsen this trade-off.

In terms of GHG reductions in the period from 2008 to 2030, our model shows a clear advantage of comprehensive refurbishments compared to partial refurbishments. This outcome applies for any level of investment. Hence, it can be concluded that policymakers should prefer comprehensive refurbishments over partial measures.

However, when placing emphasis on the cumulated GHG emissions, one can come to another conclusion. In the period considered in our model, the advantage of comprehensive refurbishments is recognizable but very small. Since the GHG budget is more important for climate protection policies than GHG reduction at a specific point in time, the advantage of comprehensive refurbishments decreases. On the one hand, one can argue that the small difference in the period considered here is not important, since the advantage of comprehensive refurbishments increases with the period considered and since climate protection policy in the residential building sector is a long-term project. On the other hand, uncertainty also increases with the time period considered and hence makes precise forecasts difficult.

Moreover, being aware of optimal refurbishment options does not necessarily imply being aware of optimal funding schemes. Many papers on house owners' preferences on energy-related refurbishments exist, pointing out different drivers of investment behaviour (see Achtnicht (2011)). As Rehdanz (2007) pointed out, it is obvious that house owners have different investment incentives than landlords, for example.

Another essential point that has to be taken into account is that house owners are often elderly. Hence, the payback period of refurbishment investments might bias investment decisions towards partial refurbishments. A further point that has to be taken into account is that comprehensive measures only brings substantial benefits in terms of energy consumption reduction and changing fuel pattern if significant financial resources support it. Given the current financial situation of EU member states as well as EU citizens, this might be a considerable obstacle. Our results are therefore a first step to frame policy recommendations. Therefore, further research on optimal funding schemes in order to achieve the desired objective is necessary.

In addition, the above-mentioned social aspect of refurbishments is an important issue for policymakers. By raising the energy standard of buildings, the housing price will increase, which is counterproductive from a social perspective. Firstly, rents will increase and secondly, it may reduce the number of people building a detached house. Hence, policymakers will have to face a trade-off between climate protection and social policy. The option of comprehensive or stepwise refurbishments therefore also has a social dimension, since the investment costs per unit of space are very different. For comprehensive refurbishments, few people will face high costs and for stepwise refurbishments, a lot of people will face lower but significantly increasing costs. This situation is complicated for policymakers, because both options could be favourable.

To conclude, we cannot recommend to limit subsidising schemes to comprehensive refurbishment in order to reach the climate protection targets because of the minor advantage of comprehensive refurbishments in terms of cumulated GHG emissions, on the one hand, and because of the uncertainty about optimal funding schemes, on the other hand. The advantage of comprehensive refurbishments is at most 2 %, which is too little given the time period of 23 years considered in our model. Also, optimal measures to promote comprehensive refurbishments have not been identified. In view of the high costs per unit of space, concentrating on comprehensive refurbishments could result in failure to achieve the climate targets, as house owners hesitate to invest in energy-related refurbishments.

5 Conclusion

We analysed different energy-related refurbishment measures that can be taken in order to achieve climate protection targets. Although subsidisation seems to be necessary to increase the refurbishment rate, optimal measures concerning cost effectiveness have not been identified. We used a stylised model of the German residential building stock to analyse different refurbishment measures by simulating every relevant amount of investment until 2030. In particular, we compared two refurbishment options in order to derive policy recommendations: first, we took a look at comprehensive refurbishments that are expensive but achieve the most reductions in energy consumption and GHG emissions and second, we examined partial refurbishments, which include only low-cost improvements but can be achieved on a wide scale.

We found that, at any amount of investment, comprehensive refurbishments provide the highest reductions of GHG emissions and energy consumption in 2030. Also, the advantage increases with the investment level. Hence, partial renovations are never optimal. This result can be explained as follows: typically, it is always efficient to reach a certain energy standard in one big step rather than step by step. Although partial refurbishments have an advantage in the first years, comprehensive refurbishments catch up quickly, since partially refurbished living spaces have to be refurbished again. The same result can be seen when fuel savings and GHG abatement costs are calculated within the time period considered here. However, the share of fuels like biomass and electricity is higher in Comprehensive compared to Quick. Hence, the future price risk of these energy sources is essential for an evaluation of both policy options. To conclude, partial refurbishments are only optimal if the time period is relatively short or, in other words, it's always optimal to apply comprehensive measures if long periods of time are considered.

Furthermore, we analysed the potential of biofuels as an alternative to energy-related refurbishments and found a small but significant impact on GHG emissions reductions. Provided that the production costs of biofuels are lower than refurbishment costs and that biofuels are produced sustainably, this option should not be ignored.

However, when considering cumulated GHG emissions and GHG abatement costs during the entire period, the difference between both options is very small, i.e. less than 2 % for GHG emissions at the highest refurbishment rate. This is completely in line with the explanation above: comprehensive refurbishments make less progress in the first years but catch up quickly. Hence, the advantage of comprehensive refurbishments increases with the refurbishment rate. However, the fact remains that the time period considered is too short to create a significant difference.

Therefore, it may be a mistake for policymakers to limit subsidising schemes to comprehensive refurbishments for two reasons: first, the emission budget, defined as the cumulated emissions, is more important than reductions at a specific point in time. However, the calculated advantage of comprehensive refurbishments seems too small, particularly given the uncertainty caused by the time period considered in our model. Second, even if the reduction at a specific point in time is more important to policy makers, due to the high investment cost per unit of space, landlords and house owners could possibly hesitate to invest in energy-related refurbishments, which may prevent the necessary rate of refurbishment. This hesitation could be essential since comprehensive measures only lead to visible results in terms of energy consumption reduction and changing fuel pattern compared to the quick scenario, if significant financial resources support it. Hence, it could be more sensible to also subsidise stepwise refurbishments in order to increase the rate of refurbishment. Moreover, due to the long-term investments in the residential building sector, reliable policy measures seem to be essential to avoid reluctant investment decisions and therefore may be more important than specific refurbishment options.

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CHAPTER 5

Die deutschen Ausbauziele für erneuerbare Energien: Eine Effizienzanalyse

Sebastian Schröer • Ulrich Zierahn

Abstract

Das Erneuerbare-Energien-Gesetz (EEG) hat sich als sehr erfolgreich beim Aufbau der noch nicht wettbewerbsfähigen erneuerbaren Energien (EE) erwiesen. Nachteilig ist, dass durch die gezielte Auswahl der einzelnen EE und die Festsetzung spezieller Einspeisevergütungen auf einen Wettbewerb der EE untereinander verzichtet wird. Die Bundesregierung gibt in der Leitstudie sowohl allgemeine als auch individuelle Ausbauziele für die einzelnen EE aus, womit implizit die Einspeisevergütungen bestimmt werden. Wir untersuchen die Effizienz dieser Ausbauziele anhand der Kosten der Kapazitätsinstallation und zeigen mit einem einfachen statischen Modell, dass die allgemeinen Ausbauziele für das Jahr 2020 kostengünstiger erreichbar sind.

The German Renewable Energy Law (EEG) has been a very successful instrument in raising the share of the renewable energies that are not yet competitive. However, a detrimental consequence of this policy is that, through specific feed-in tariffs, it hinders the competition among particular renewable energies. Within the framework of the "Lead Study 2008" the German Government set targets both for renewable energies and related technologies and hence affects the particular feed-in tariff. By means of a static model, we analyse in this article the efficiency of the targets for 2020 regarding renewable energies and show that they can be achieved at lower costs.

JEL classification: C60, H30, O33, Q40, Q58

Keywords: climate policy, renewable energies, promotion strategies, policy scenarios

1 Einleitung

Mit den Maßnahmen zur Linderung des Klimawandels steht der Energiesektor derzeit vor großen Herausforderungen. Denn neben der Umweltverträglichkeit muss eine zukünftige Energiepolitik auch die Ziele Versorgungssicherheit und Wirtschaftlichkeit beachten. Alle drei Ziele werden als gleichwertig angesehen und stellen so beträchtliche Ansprüche an die Organisation der Energiemärkte. Hinsichtlich der Energieträger kommt den erneuerbaren Energien (EE) eine besondere Bedeutung zu. Sie müssen außerdem den politisch beschlossenen Kernenergieausstieg kompensieren. Die Bundesregierung hat daher mit den Ende August 2007 veröffentlichten Meseberger Beschlüssen das Ziel ausgegeben, bis zum Jahr 2020 25 % bis 30 % und bis 2050 mindestens die Hälfte der Strombereitstellung aus EE abzudecken.[1] Zudem hat die EU-Kommission unlängst festgelegt, dass Deutschland bis 2020 mindestens 18 % des verbrauchten Stroms mit EE erzeugen und weiterhin seinen CO_2-Ausstoß gegenüber 2005 um mindestens 14 % senken muss.[2]

Jenseits der Frage, ob das Nebeneinander von CO_2-Zertifikate-Handel und direkter EE-Förderung Effizienzkriterien genügt, ist die Umsetzung dieser Kapazitätsziele bedeutsam. Da die meisten EE noch nicht wettbewerbsfähig sind, kann nur ein Subventionsmechanismus sicherstellen, dass die Ziele erreicht werden. Konzeptionell ist das Erneuerbare-Energien-Gesetz (EEG) mit festgeschriebenen und degressiv sinkenden Einspeisevergütungen eine optimale Lösung, um Anreize zur Investition in EE bei gleichzeitiger Kostensenkung zu schaffen. Bei der Ausgestaltung der Einspeisevergütungen steht die Bundesregierung jedoch vor dem Dilemma, dass bei zu niedriger Preissetzung die Ziele nicht erreicht werden und bei zu hoher Preissetzung die Kosten der Zielerreichung steigen. Überdies wurden aufgrund der stark divergierenden Kosten für die unterschiedlichen EE spezielle Einspeisevergütungen festgesetzt, die die ausgewählten Energieträger gleichstellen und einen Wettbewerb der EE untereinander

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1 Vgl. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (2007a).

2 EU-Kommission (2008).

verhindern. Dies ist bedauerlich, da Wettbewerb ein effizientes Mittel ist, um überlegene Technologien auszuwählen und die Ausbauziele kostenminimal zu erreichen.

In diesem Beitrag untersuchen wir anhand der Leitstudie der Bundesregierung, wie effizient der Ausbau der EE im Bereich der Stromerzeugung ist. Mit einem einfachen Modell betrachten wir dabei nur die Kosten der Kapazitätsinstallation. Das Hauptaugenmerk liegt auf der Analyse der einzelnen Energieträger. Konkret stellt sich die Frage, ob die Ausbauziele bis zum Jahr 2020 mit geringeren Kosten zu erreichen sind.

Die Analyse gliedert sich wie folgt: Abschnitt 2 stellt die Förderung der EE in Deutschland sowie seine Begründung dar. Abschnitt 3 betrachtet die in der Leitstudie implizierten Kosten der EE sowie seiner Entwicklung und untersucht die Auswirkungen von Annahmevariationen. In Abschnitt 4 wird anhand verschiedener Szenarien die Effizienz der EE-Förderung überprüft. Abschließend werden in Abschnitt 5 die Ergebnisse diskutiert.

2 Die Förderung der erneuerbaren Energieträger in Deutschland

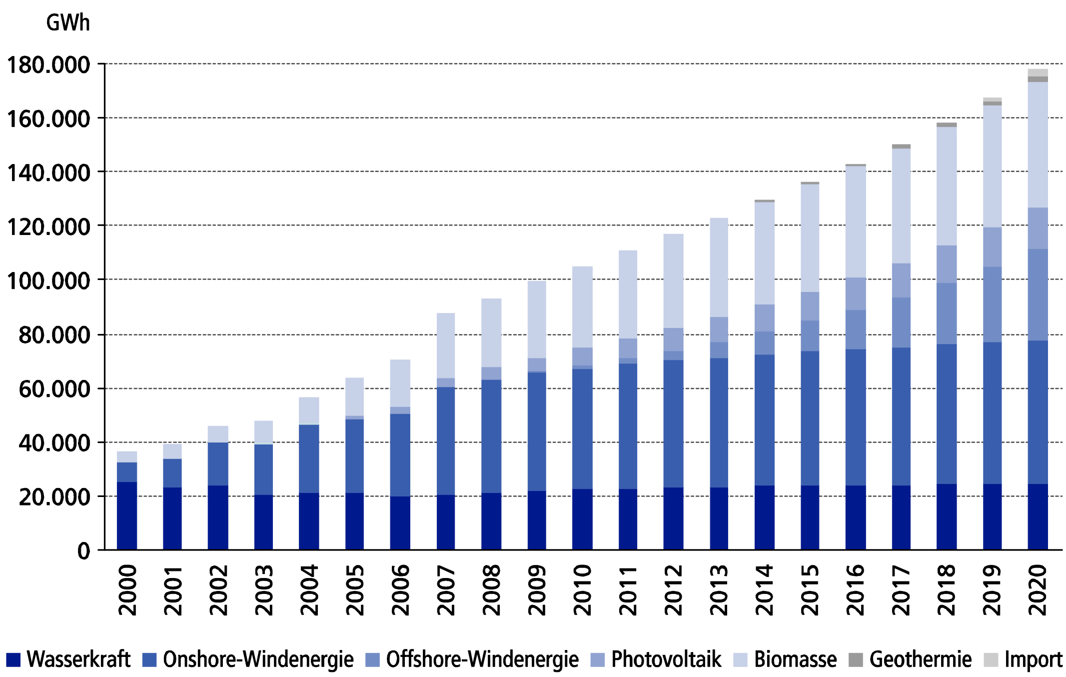
Der Anteil der EE an der Stromerzeugung ist in den letzten Jahren aufgrund der Förderung rasant gewachsen. Im Jahr 2007 wurden bereits 14 % des verbrauchten Stroms durch EE erzeugt, was 86,8 Terawattstunden entsprach.

Entsprechend dem Leitszenario wird sich der Anteil der erneuerbaren Energieträger am gesamten Stromverbrauch bis 2020 auf 30,4 % beziehungsweise 178 Terawattstunden erhöhen. Wie sich in Abbildung 1 erkennen lässt, soll dieses Wachstum im Wesentlichen durch den starken Ausbau der Offshore-Windenergie, der Photovoltaik und der Biomasse getragen werden. Die Energieträger Wasserkraft und Onshore-Windenergie, die Stromerzeugung aus Geothermie sowie der EE-Import können bis 2020 dagegen kaum zulegen.

Tabelle 1: Stromerzeugung durch erneuerbare Energieträger in Deutschland 2007

	Bruttostromerzeugung (GWh)	Anteil an Stromerzeugung (%)
Wasserkraft	21.249	3,4
Windenergie	39.713	6,4
Photovoltaik	3.075	0,5
Biogene Festbrennstoffe	8.743	1,4
Biogene flüssige Brennstoffe	1.485	0,2
Biogas	6.425	1.0
Klärgas	983	0,2
Deponiegas	1.009	0,2
Biogener Anteil des Abfalls	4.130	0,7
Geothermie	0,4	< 0,1
Σ	86.811	14
Quelle: BMU (Stand: Dezember 2008)		

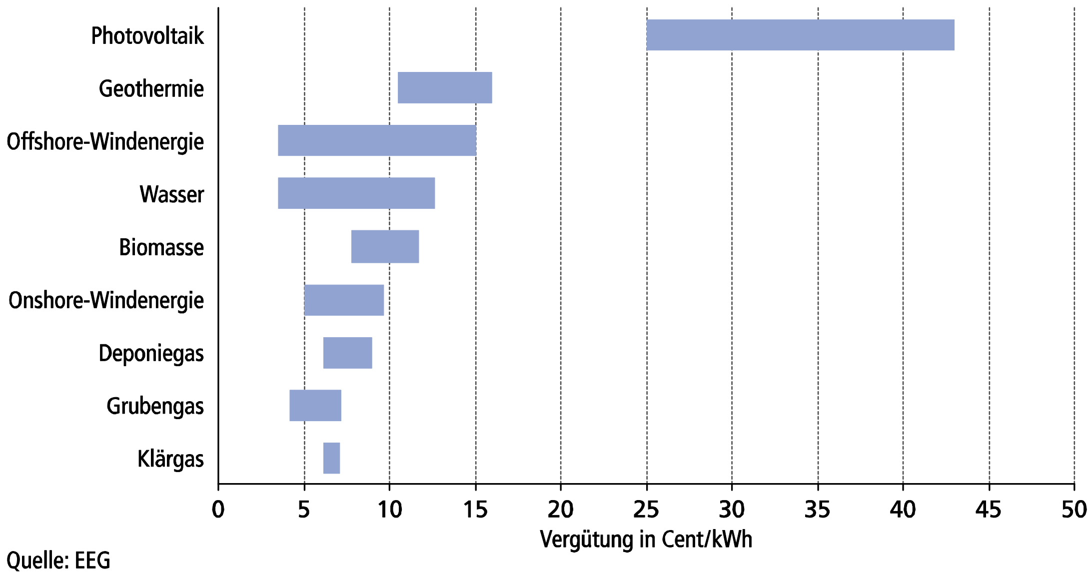
Abbildung 1: Leitszenario 2008: Stromerzeugung aus EE bis 2020



Quelle: BMU (2008)

Um diese Entwicklung sicherzustellen, garantiert das EEG für jeden Energieträger bei Einspeisung in das Stromnetz einen entsprechenden Vergütungssatz (vgl. Abbildung 2), da die EE mehrheitlich noch nicht wettbewerbsfähig sind.[3]

Abbildung 2: Stromeinspeisevergütungen gemäß EEG 2009



Quelle: EEG

Die Förderung der EE wird mit einer Reihe von politischen und ökonomischen Erwägungen begründet:[4] Neben der Reduzierung der Treibhausgasemissionen werden internationale Beschlüsse der EU und UN angeführt. Weiterhin werden die Schaffung von Arbeitsplätzen sowie industriepolitische Gründe genannt. So werde das Wachstum der EE durch die technologischen Innovationen die internationale Wettbewerbsposition Deutschlands stärken. Weiterhin wird darauf hingewiesen, dass die Unabhängigkeit bei der Energieversorgung aus sicherheitspolitischen Erwägungen vorteilhaft sein könne und gleichzeitig als Vorbild für andere Länder zu sehen sei.

Die Auswahl der Energieträger und ihrer Anteile wird im Leitszenario nicht explizit erläutert. Es wird eher implizit unterstellt, dass sich die gegenwärtig vorhandenen und technisch aussichtsreichen Technologien langfristig etablieren und zukünftig ge-

[3] Tatsächlich existiert eine Vielzahl von Einspeisesätzen pro EE, die von der Größe der Anlage, dem Datum der Inbetriebnahme und dem Ort der Aufstellung abhängig sind (siehe EEG).

[4] Vgl. EEG.

genüber den etablierten wettbewerbsfähig sein werden.[5] Dies geht einher mit den Einspeisevergütungen der Energieträger, deren Festlegung sich an den Kosten zu orientieren scheint, offensichtlich jedoch in einem politischen Prozess erfolgt.[6] Exakte Analysen der Kostensituation sind nur schwer ersichtlich. Auch die Festsetzung der Degression scheint eher in einem politischen Prozess stattzufinden als anhand ökonomischer Methoden, wie sie von ähnlichen Problemstellungen, beispielsweise der Zugangsregulierung in Netzindustrien, bekannt sind.[7]

Die ökonomischen Gründe der EE-Förderung werden in der Literatur umfassend diskutiert. Generell können die Investitionen aus zwei Gründen effizient sein: Erstens, wenn nur sie entsprechende technische Entwicklungen garantieren, die wiederum aus unbestimmten Gründen einer langsameren Entwicklung ökonomisch vorzuziehen sind. Zweitens wäre denkbar, dass sich nur hierdurch Exportchancen eröffnen, die die Investitionskosten überkompensieren. Beide Erwägungen sind jedoch problematisch. Die erste Argumentation ist einerseits spekulativ und andererseits wenig plausibel: Spekulativ, weil technische Entwicklung bzw. Anreize zur Investition in Forschung und Entwicklung (F&E) sich nicht zwingend aus Kapazitätsinvestitionen ergeben müssen. Eine direkte F&E-Förderung könnte effizienter sein.[8] Unplausibel ist dies darüber hinaus, weil man impliziert, dass sich diese Technologie am Markt durchsetzen wird, was keinesfalls sicher ist. Die möglichen Gewinne, die sich aus dem Export ergeben, sind ebenso höchst spekulativ. Zwar zeigen sich gegenwärtig Pioniervorteile der Länder, die bereits in EE investiert haben, jedoch ist nicht klar, ob sie andauern und die Anfangskosten überkompensieren können.[9] Eindeutige Aussagen sind insofern erst in einigen Jahren zu treffen, wenn sich die Industrie auch ohne Förderung etabliert hat.

5 Vgl. hierzu auch Neij (1997).

6 Vgl. hierzu BMU (2007b) mit den entsprechenden Empfehlungen.

7 Zur Festsetzung der Windenergieeinspeisesätze vgl. Michaelowa (2005).

8 Unter Umständen wäre es auch möglich, dass durch die hohen garantierten Vergütungen die Anreize zur Investition in F&E sinken.

9 Vgl. Lewis und Wiser (2007), die in ihrer Untersuchung der Windindustrie einen positiven Einfluss des heimischen Marktes auf die Exporttätigkeit feststellen.

Gleichzeitig ist zu bedenken, dass ausländische Unternehmen beim Kapazitätsaufbau in Deutschland teilweise erhebliche Marktanteile besitzen und daher auch potenzielle ausländische Exportindustrien gefördert werden. Aus Wohlfahrtssicht ist dies nicht ungünstig, aber es entspricht nicht dem Ziel der Förderung der deutschen Exportindustrie.

Da sich die ökonomischen Gründe zur EE-Förderung keineswegs als zwingend erweisen, kann gefolgert werden, dass die übrigen Gründe schwerer wiegen. Dies würde auch erklären, warum jenseits der Frage nach dem Sinn der EE-Förderung die Frage nach der Auswahl der einzelnen erneuerbaren Energieträger offenkundig nicht mit Effizienzkriterien begründet wird. Vielmehr werden die EE implizit als eine Gesamtheit betrachtet und angenommen, dass sich alle EE zwangsläufig am Markt durchsetzen werden und daher förderungswürdig sind, wobei die Höhe der Förderung ausschließlich von den technischen Gegebenheiten abhängig ist. Gleichzeitig wird offensichtlich auch angenommen, dass der Nutzen der Förderung in jedem Falle höher ist als deren Kosten. Insofern wird die Entscheidung des Marktes nicht nur hinsichtlich des EE-Sektors, sondern auch für alle seine einzelnen Energieträger vorweggenommen.

Betrachtet man sowohl die Ausbauziele der EE als auch die Auswahl der Energieträger als Datum, sind die volkswirtschaftlichen Kosten hierfür von Interesse. Die direkten Kosten der EE-Förderung ergeben sich einerseits aus den Investitionen zum Aufbau der Kapazität und andererseits aus den garantierten Einspeisevergütungen. Typischerweise benötigen jene Technologien, die hohe Investitionskosten erfordern, auch höhere Einspeisevergütungen, sodass sich intuitiv Einsparpotenziale bei der Zielerreichung ergeben. Dies soll in den nächsten beiden Abschnitten näher untersucht werden.

3 Effizienz- und Sensitivitätsanalyse der EE-Förderung

Da die Leitstudie sowohl die Investitionen in die einzelnen Energieträger als auch die installierte Leistung für die Stromerzeugung betrachtet, unterstellt dies implizit Investitionsmultiplikatoren für die verschiedenen Energieträger. Im Folgenden werden diese Investitionsmultiplikatoren im Rahmen einer Effizienzanalyse genauer untersucht, und es wird diskutiert, welchen Einfluss ein veränderter technischer Fortschritt auf die Installationskosten hätte. Die Analyse beschränkt sich auf die Energieträger Offshore- und Onshore-Windenergie, Photovoltaik und Biomasse, da die sonstigen erneuerbaren Energieträger zumindest im betrachteten Zeitraum bis 2020 von nur geringer Bedeutung sind.

3.1 Methode und Verlauf der Investitionsmultiplikatoren

Die in der Leitstudie implizierten Investitionsmultiplikatoren ergeben sich aus der Relation der Investitionen eines Jahres *t* und der in diesem Jahr aufgebauten Kapazität:

Investitionsmultiplikator (*t*) = Investitionen (*t*) [Mio. €] / aufgebaute Kapazität (*t*) [MW]

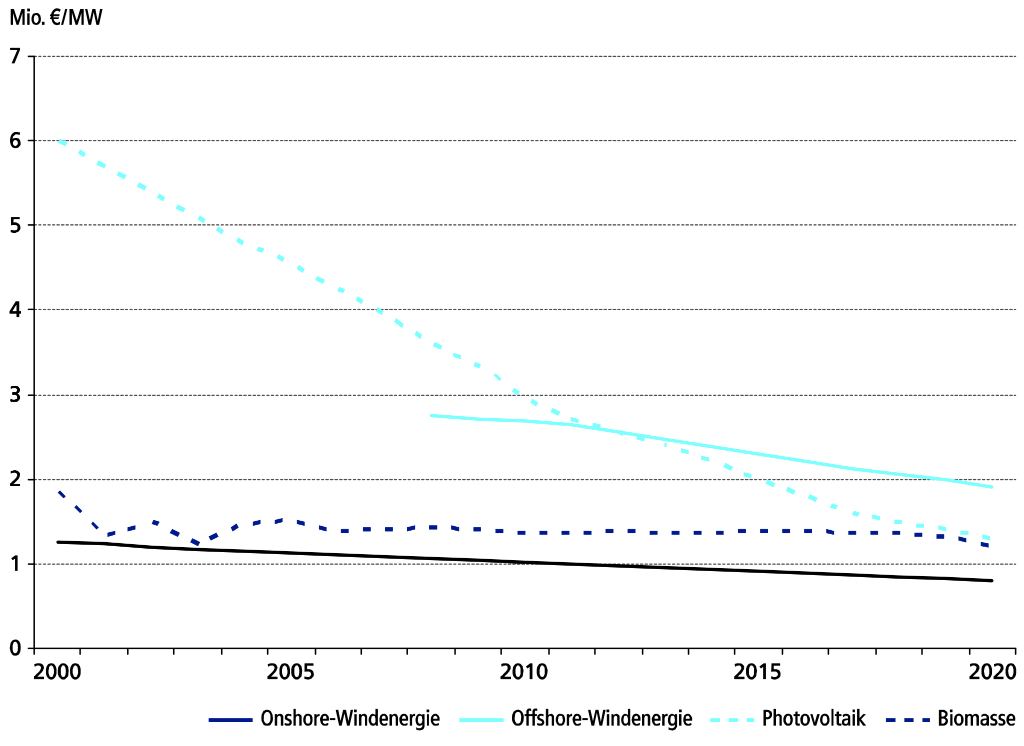
Bei der aufgebauten Kapazität wird jeweils sowohl der Neubau als auch der Erneuerungsbedarf berücksichtigt. Da die Leitstudie die Investitionsdaten für Windenergie nicht nach On- und Offshore unterteilt, wird der Investitionsmultiplikator für Onshore-Windenergie aus dem Verlauf der Investitionen bis 2007 abgeleitet, weil bis 2007 keine Offshore-Windkapazität aufgebaut wurde. Dieser folgt einem sehr deutlichen Trend: Eine einfache Regressionsanalyse[10] des Investitionsmultiplikators für Onshore-Windenergie mit einem exponentiellen Trend über die Zeit ergibt einen Korrelationskoeffizienten von 0,99. Aus dieser Rechnung geht hervor, dass der Investitionsmultiplikator jedes Jahr um 2,2 % abnimmt, woraus sich die Investitionen für Onshore-Windenergie ab 2008 berechnen lassen. Die restlichen Investitionen für Windenergie sind somit der Offshore-Windenergie zuzurechnen. Aufgrund des deutlichen Trends ist der Fehler dieser Zurechnung vergleichsweise gering.

Die Investitionen in Biomasse teilen sich in die Wärme- und Stromerzeugung auf, da Biomasse überwiegend in der Kraft-Wärme-Kopplung (KWK) eingesetzt wird. Da KWK-Anlagen als Einheit zu betrachten sind, ergibt sich für die Analyse das Problem

[10] Wegen der geringen Anzahl an Beobachtungswerten ist hier nur eine einfache Regressionsanalyse möglich.

der Aufteilung der Investitionen, da hier nur die Stromerzeugung betrachtet wird. Als Lösung nehmen wir eine Aufteilung gemäß dem Verhältnis des Stromnutzungsgrades zum Gesamtnutzungsgrad der Anlagen vor. Dieses lag 2005 bei 34,37 %. Entsprechend werden die Investitionen dieses Jahres zu 65,63 % der Wärme- und zu 34,37 % der Stromerzeugung zugerechnet. Dieser Wert ist jedoch nicht konstant, sondern verschiebt sich über die Zeit tendenziell hin zur Stromerzeugung, womit deren Anteil an den Investitionen auch steigt.[11] Diese stark vereinfachte Rechnung soll die Vergleichbarkeit mit den ausschließlich Strom erzeugenden Energieträgern sicherstellen. Gleichzeitig muss bei der Interpretation der Ergebnisse berücksichtigt werden, dass Investitionen in die Stromerzeugung aus Biomasse implizit mit zusätzlichen Investitionen in die Wärmeerzeugung aus Biomasse innerhalb der KWK-Anlagen einhergehen.

Abbildung 3: Verlauf der Investitionsmultiplikatoren

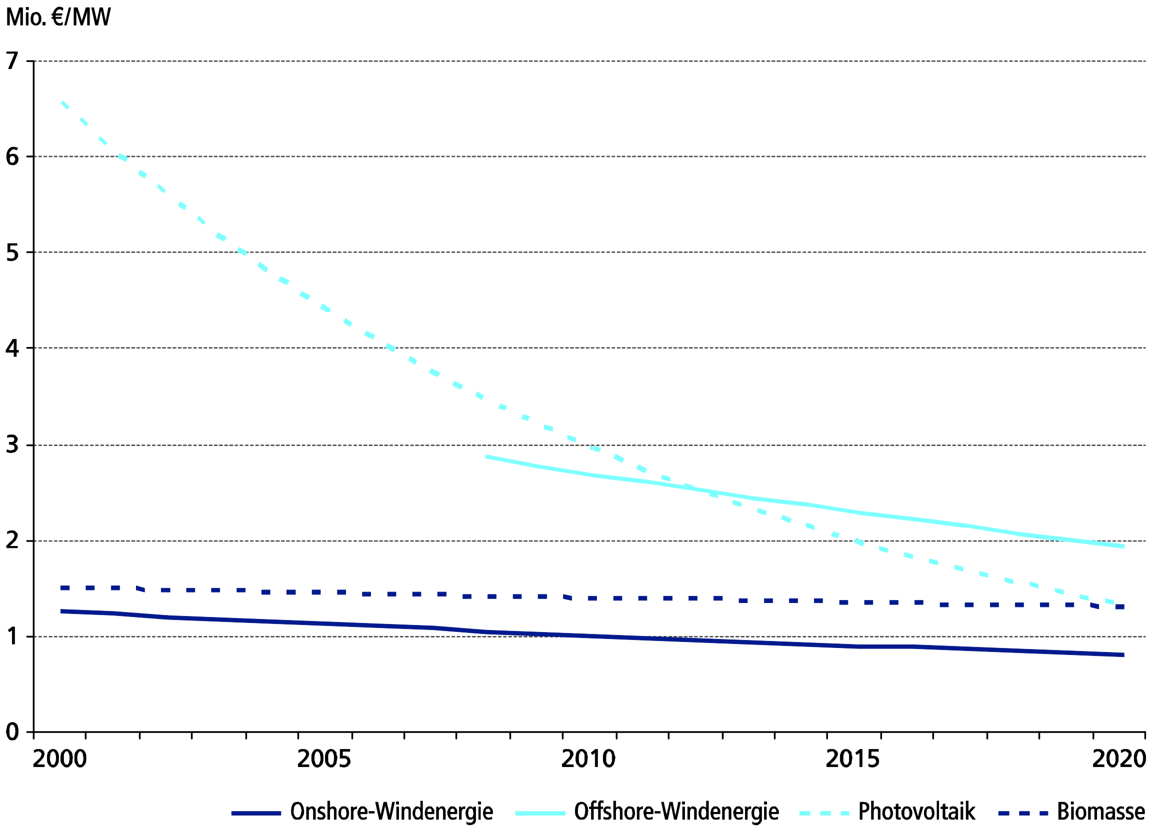


[11] Auf eine Variation des Stromnutzungsgrades über die Zeit wird aus Vereinfachungsgründen verzichtet. Generell erhöht sich der Anteil von Strom an der gesamten Kapazitätsinvestition mit steigendem Stromnutzungsgrad. Erhöht sich zukünftig der Anteil von Strom über den von uns festgelegten Anteil, so werden die Investitionen für Strom aus Biomasse höher bewertet, als sie tatsächlich sind, und vice versa. Da der Trend tatsächlich zu einem erhöhten Stromnutzungsgrad geht, kann von geringeren Investitionskosten als hier berechnet ausgegangen werden. Der Unterschied dürfte jedoch unwesentlich sein, zumindest aber die in Abschnitt 4.2 ohnehin festgestellte Tendenz verstärken.

Abbildung 3 zeigt den Verlauf der berechneten Investitionsmultiplikatoren auf Basis der Leitstudie. Es wird deutlich, dass Onshore-Windenergie mit den geringsten Investitionskosten pro Megawatt einhergeht, während jene von Photovoltaik derzeit die höchsten unter allen geförderten erneuerbaren Energieträgern sind, im Zeitverlauf allerdings auch am stärksten fallen. Auffällig ist, dass die Leitstudie einen jährlich um 8,21 % sinkenden Investitionsmultiplikator ab 2009 für Photovoltaik unterstellt, obwohl er von 2000 bis 2008 jährlich durchschnittlich lediglich um 6,19 % gesunken ist. Insofern wird mit deutlichen Technologieschüben gerechnet, was gleichzeitig einen zukünftig günstigeren Kapazitätsaufbau bedeuten würde. Demgegenüber fällt der Wert für Offshore-Windenergie nur leicht. Der Investitionsmultiplikator für Biomasse hingegen ist vergleichsweise niedrig und schwankt bis 2007 sehr stark, danach sinkt er leicht.

Aus dieser ersten Betrachtung geht hervor, dass momentan insbesondere durch Investitionen in Onshore-Windenergie sehr günstig Stromerzeugungskapazitäten aus erneuerbaren Energieträgern aufgebaut werden können. Die räumlichen Grenzen für diesen Energieträger sprechen hingegen für einen stärkeren Ausbau der Windenergie auf dem Meer (Offshore), die zwar teurer als Onshore-Windenergie, bis 2011 aber günstiger als Photovoltaik ist. Ab etwa 2012 wird dann jedoch Photovoltaik günstiger als Offshore-Windenergie. Biomasse stellt wiederum bis 2017 die günstigste Alternative zur Onshore-Windenergie dar – ab 2018 unterscheiden sich die Investitionskosten von Biomasse und Photovoltaik nur geringfügig.

Abbildung 4: Trendkomponente der Investitionsmultiplikatoren

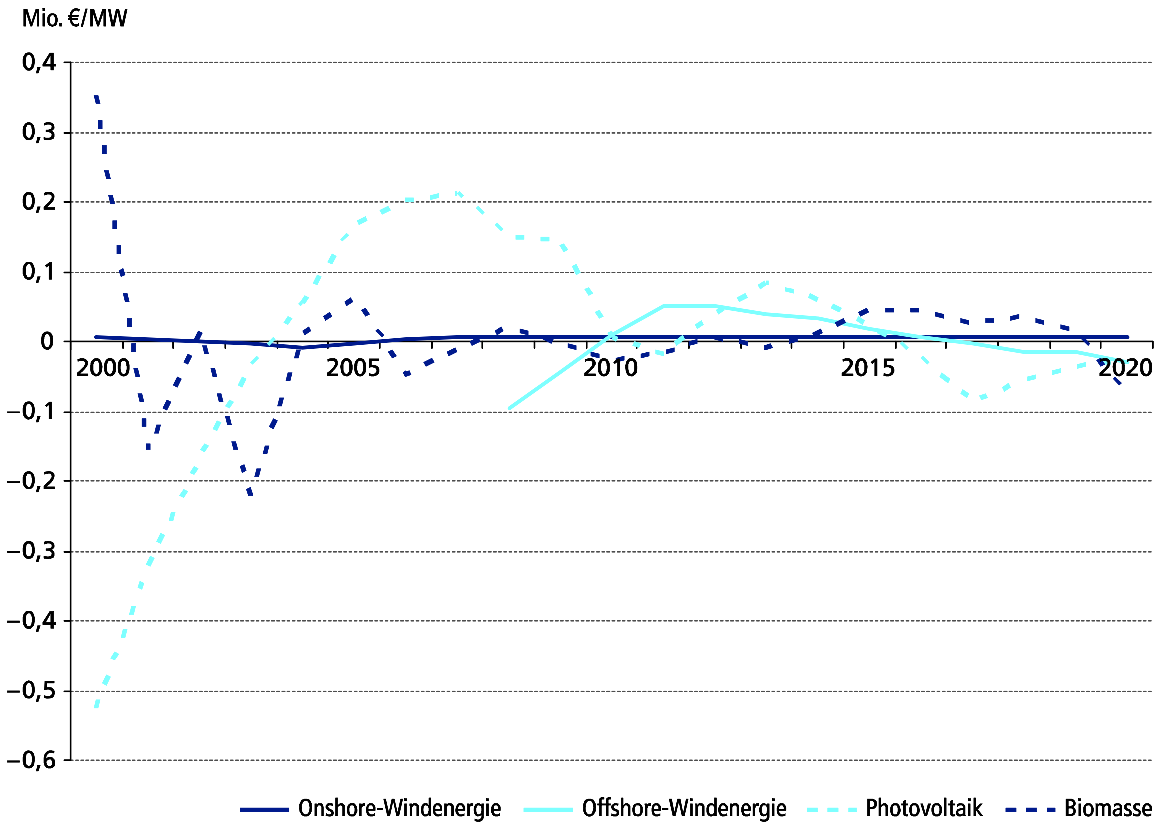


Für die Sensitivitätsanalyse wird die Entwicklung der Investitionsmultiplikatoren in eine Trendkomponente und eine Restkomponente aufgeteilt. Die Trendkomponente spiegelt die trendmäßige Veränderung der Investitionsmultiplikatoren in der Zeit wider und kann als technischer Fortschritt interpretiert werden. Die Restkomponente enthält die zufälligen Schwankungen, die hier aus Vereinfachungsgründen nicht näher analysiert werden. Beide Komponenten werden in unserem Modell additiv verknüpft. Dadurch hat die Restkomponente nur in dem jeweiligen Jahr eine Wirkung auf den Investitionsmultiplikator, eine Folgewirkung wird ausgeschlossen. Dadurch sind die gemessenen Veränderungen tatsächlich nur auf den technischen Fortschritt zurückzuführen. Die zufälligen Einflüsse werden von der Analyse vernachlässigt. Bei der Sensitivitätsanalyse wird unterstellt, dass der technische Fortschritt anders verläuft, sodass der trendmäßige Verlauf der Investitionsmultiplikatoren verändert wird. Die Restkomponente hingegen verändert sich nicht. Sie wird jedoch mit berücksichtigt, damit die Ergebnisse der Analyse nicht nur untereinander, sondern auch direkt mit dem

Ausgangsszenario vergleichbar sind und keine gesonderte Herausrechnung der Restkomponente nötig ist. Die neuen Investitionsmultiplikatoren ergeben sich daher aus der veränderten Trendkomponente und der unveränderten Restkomponente.

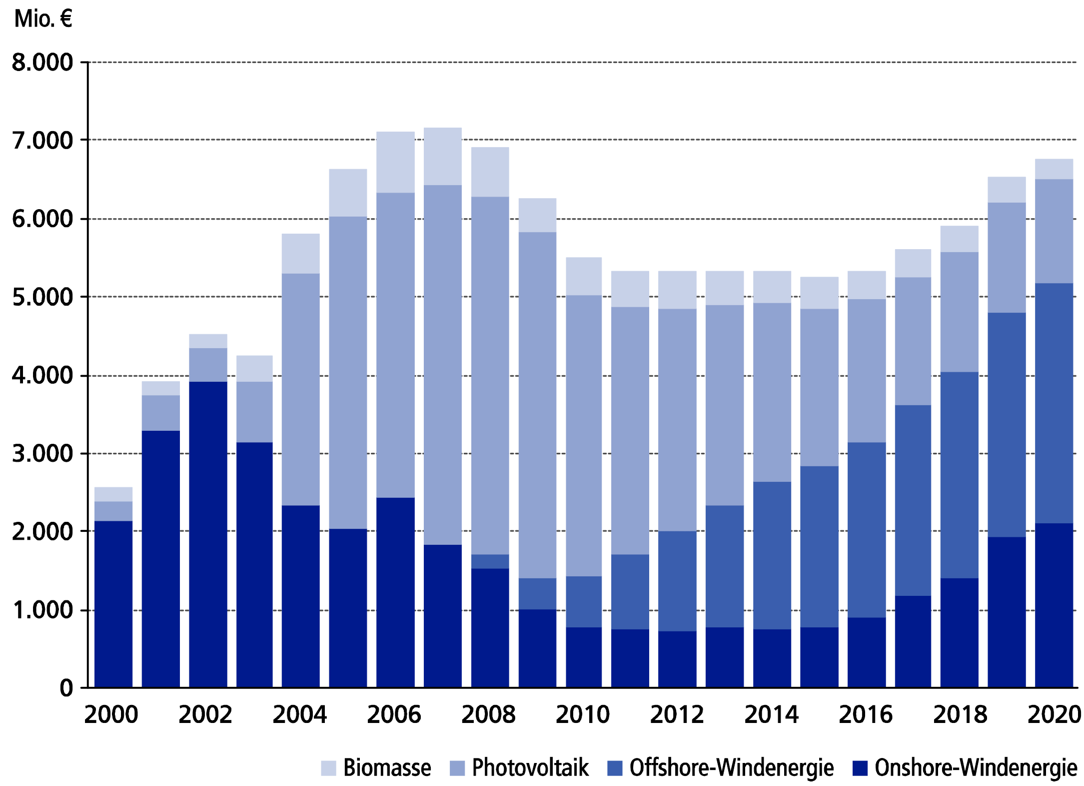
Der Vergleich der Abbildungen 4 und 5 zeigt bereits, dass die Restkomponente bei Photovoltaik ab 2010 und bei Onshore-Windenergie generell keine große Bedeutung, bei Offshore-Windenergie und Biomasse jedoch großen Einfluss auf die Entwicklung des Investitionsmultiplikators hat. Dieser Zusammenhang wird in Abbildung 5 deutlich, in der lediglich die Restkomponente für die Investitionsmultiplikatoren dargestellt ist.

Abbildung 5: Restkomponente der Investitionsmultiplikatoren



Bei reiner Betrachtung der Trendkomponente ergibt sich im gesamten Zeitraum ein Rückgang der Investitionskosten pro Megawatt bei Onshore-Windenergie jährlich um durchschnittlich 2,2 %, bei Offshore-Windenergie um 3,02 %, bei Photovoltaik um 7,36 % und bei Biomasse um 2,06 %. Daraus und aus den in der Leitstudie angenommenen Kapazitätszuwächsen lassen sich die jährlichen Investitionskosten für den Kapazitätsaufbau an Stromerzeugung ableiten (Abbildung 6).

Abbildung 6: Investitionskosten gemäß der Leitstudie

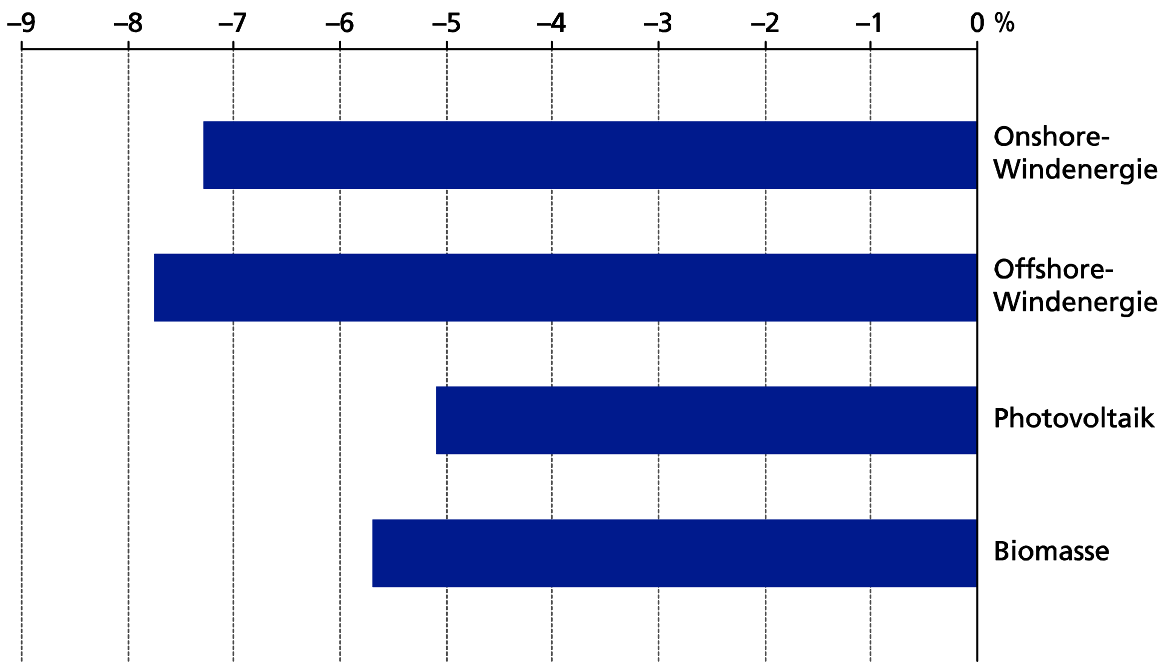


3.2 Sensitivitätsanalyse

Um zu analysieren, welche Bedeutung der technische Fortschritt für die Entwicklung der Investitionskosten für erneuerbare Energieträger hat, wird die in der Leitstudie unterstellte Trendkomponente im Investitionsmultiplikator variiert. Hierdurch soll ein schnellerer oder langsamerer technischer Fortschritt simuliert werden. Beide Fälle sind durch die hohe Dynamik des EE-Sektors denkbar. Neben der unsicheren technischen Entwicklung kann allein der Einfluss der weltweiten Investitionen in EE auf deren technische Entwicklung beträchtlich sein. Beispielsweise kann ein mögliches Folgeabkommen zum Kyoto-Protokoll große positive Auswirkungen auf die technische Entwicklung haben. Andererseits können etwa dauerhaft niedrige Rohölpreise zu geringen Investitionen in EE und damit zu vermindertem technischem Fortschritt führen.

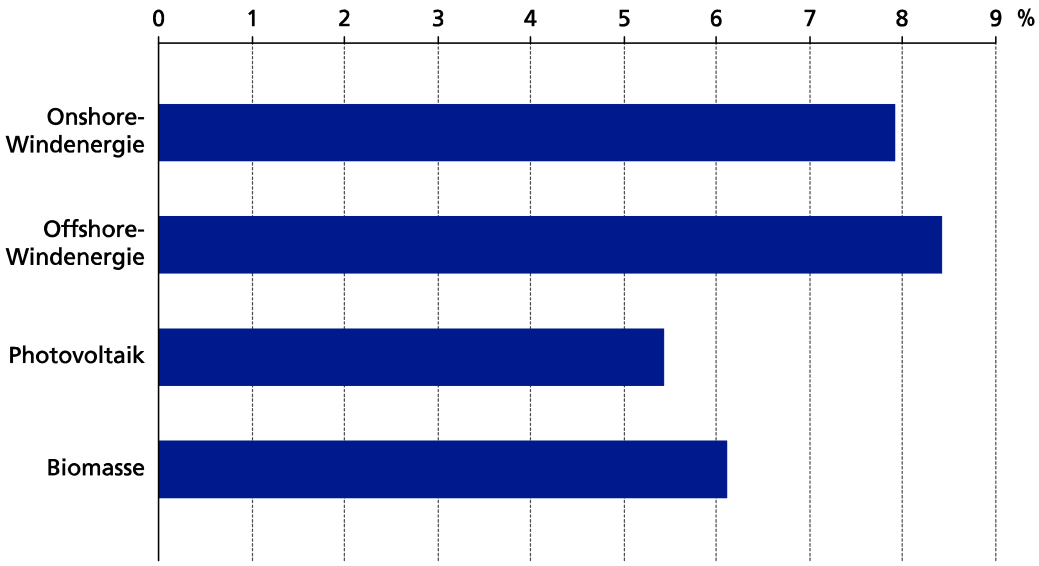
Im ersten Fall eines schnelleren technischen Fortschritts wird angenommen, dass sich die bisherige Trendentwicklung der Investitionsmultiplikatoren verstärkt, der Investitionsmultiplikator also in jedem Jahr um einen Prozentpunkt geringer ausfällt als im Vorjahr. Die Investitionskosten verringern sich für den Zeitraum 2009 bis 2020 dann gegenüber der Ausgangssituation (vgl. Abbildung 7). Bei der Windenergie fällt der Rückgang besonders stark aus, da hier die Investitionen im Zeitverlauf ansteigen und dadurch überwiegend dann stattfinden, wenn sie besonders günstig sind. Dies gilt auch für die Onshore-Windenergieanlagen, da hier hohe Investitionen aufgrund des „Repowerings" stattfinden. Überraschend ist die geringe Bedeutung bei der Photovoltaik. Zwar wird hier am meisten investiert, jedoch gehen die Investitionen im Zeitverlauf stark zurück, weshalb der zusätzliche technische Fortschritt nicht so stark ins Gewicht fällt. Paradoxerweise kann so kaum von den sinkenden Investitionskosten profitiert werden, da der Großteil des Kapazitätsaufbaus bereits stattgefunden hat, als er vergleichsweise teuer war. Der gleiche Zusammenhang ergibt sich für die Biomasse, wenngleich die Investitionskosten hier nur unwesentlich sinken.

Abbildung 7: Rückgang der Investitionskosten infolge eines schnelleren technischen Fortschritts



Das umgekehrte Bild ergibt sich im Fall des langsameren technischen Fortschritts, wenn der Investitionsmultiplikator zusätzlich zur Trendentwicklung jährlich um einen Prozentpunkt höher ausfällt als im Vorjahr.

Abbildung 8: Anstieg der Investitionskosten infolge eines langsameren technischen Fortschritts



4 Szenarien

Wie zuvor dargestellt wurde, sind die in der Leitstudie angenommenen Investitionskosten der Energieträger nicht nur momentan sehr unterschiedlich, sondern entwickeln sich im Zeitverlauf bis 2020 auch ungleich. Wenn die politische Zielvorgabe lautet, bis zum Jahr 2020 einen bestimmten Anteil der Stromerzeugung durch EE zu erzeugen, könnte es aus Effizienzerwägungen daher sinnvoll erscheinen, innerhalb der Energieträger Umschichtungen vorzunehmen. Insbesondere der Kostenverlauf der Photovoltaik lässt erhebliche Einsparungen vermuten. Ob alternative Investitionsverteilungen tatsächlich zu Einsparungen führen und wie hoch diese sind, soll anhand der folgenden Simulationsrechnung mit zwei Szenarien untersucht werden:

- Von 2009 bis 2017 wird anstatt von Photovoltaik Biomasse ausgebaut.
- Von 2009 bis 2011 wird anstatt von Photovoltaik Offshore-Windenergie ausgebaut.

Entsprechend den Investitionsmultiplikatoren wird beim Kapazitätsaufbau die Photovoltaik durch eine günstigere Alternative ersetzt, bis die Photovoltaik günstiger ist (2011 bzw. 2017[12]). Anschließend verläuft der Kapazitätsaufbau wie im Leitszenario. Obwohl die Onshore-Windenergie die günstigste EE ist, wird sie nicht in die Szenarien einbezogen. Da die rentablen Standorte nahezu vollständig besetzt sind, ist ein Wachstum nur noch durch „Repowering" möglich. Das Potenzial dieser Maßnahmen ist jedoch strittig, sie vermögen die Photovoltaik jedenfalls nicht zu ersetzen. Insofern wird Onshore-Windenergie hier als ausgeschöpft betrachtet.

Die Analyse möglicher Einsparungen erfolgt statisch, das heißt es wird jeweils unterstellt, dass einerseits die Entwicklung der Investitionsmultiplikatoren der Energieträger unabhängig von dem Einsatz der jeweiligen Technologien ist und andererseits keinerlei technische oder andere Restriktionen den abrupten Technologiewechsel behindern. Insbesondere erstere Annahme erscheint problematisch, da durch den vermehrten Einsatz einer Technologie Lerneffekte zu vermuten sind. Diese sind jedoch nur sehr schwer zu quantifizieren. Im Übrigen sollen hier nur die Potenziale einer Umschichtung innerhalb der erneuerbaren Energieträger diskutiert werden.

4.1 Technische Entwicklung und Investitionskosten

Wie in Abschnitt 3.2 gezeigt wurde, hat die technische Entwicklung bei den EE einen bedeutenden Einfluss auf die Investitionskosten. Gleichzeitig wurde gezeigt, dass paradoxerweise bei der Photovoltaik, bei der die technische Entwicklung am dynamischsten ist, in Relation nur sehr geringe Einsparungen zu erzielen sind. Dies lässt sich dadurch erklären, dass die Intensität des Kapazitätsaufbaus bei hohen Kosten hoch war und mit sinkenden Kosten ebenso sinkt. Aus Effizienzsicht wäre der umgekehrte Verlauf vorteilhafter. Allerdings stellt sich dann auch die Frage, ob die Kostensenkung vor allem durch den intensiven Kapazitätsaufbau erreicht wurde.

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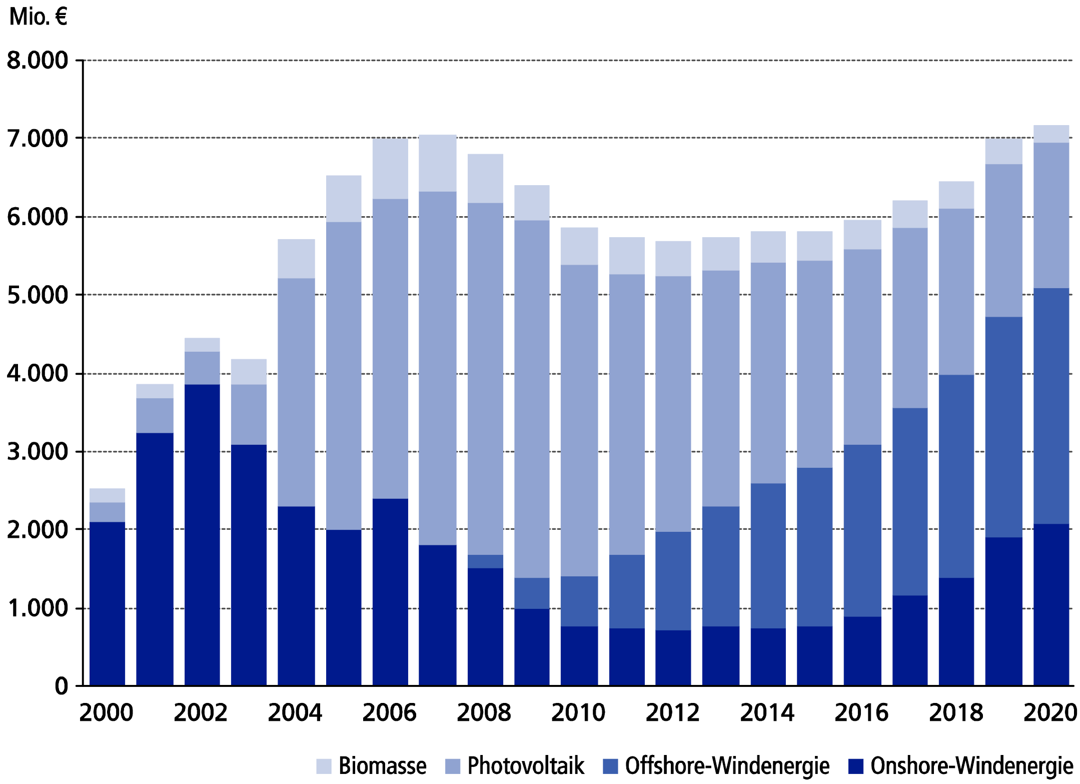
12 Photovoltaik ist ab 2018 zwar nicht günstiger als Biomasse, unterscheidet sich in den Investitionskosten jedoch nur marginal.

Angesichts der in Relation geringen Einsparungen wäre die Schlussfolgerung, dass bei der Photovoltaik die technische Entwicklung generell eine untergeordnete Rolle spielt, jedoch falsch. Tatsächlich ist das Gegenteil der Fall. Da hier die technische Entwicklung am dynamischsten ist, hat die in Abschnitt 3.2 zugrunde gelegte 1-prozentige Variation typischerweise einen verhältnismäßig geringen Einfluss. Dies wird daran deutlich, dass die Leitstudie zwischen 2009 und 2020 von einem jährlich sinkenden Investitionsmultiplikator von 8,21 % ausgeht, wie bereits in Abschnitt 3.1 dargestellt wurde, und nicht von dem beobachteten Wert des Zeitraums 2000 bis 2008 von 6,19 %. Weitet man die Sensitivitätsanalyse aus und geht von diesem Wert auch für den Zeitraum 2009 bis 2020 aus, so erhöhen sich die Investitionskosten für Photovoltaik um 23,11 % und die gesamten Investitionskosten in EE um 9,64 %[13] (siehe Abbildung 9 im Vergleich zu Abbildung 6).

Diese Rechnung macht zwei Dinge deutlich: Erstens hat die technische Entwicklung einen ganz erheblichen Einfluss auf die Investitionskosten, insbesondere bei der Photovoltaik, weshalb Aussagen zu erwarteten Investitionskosten sehr vorsichtig zu begegnen ist. Zweitens wird ersichtlich, dass der Einfluss der Photovoltaik auf die Pläne zur EE-Förderung wesentlich ist. Wie Abbildung 6 zeigt, ist die Photovoltaik die volumenmäßig am stärksten geförderte EE, obwohl sie für den Zeitraum bis 2020 nur sehr wenig Strom erzeugt (vgl. Abbildung 1). Hieraus können sich bedeutende Wirkungen für die gesamte EE-Förderung ergeben. Verläuft die technische Entwicklung weniger optimistisch als angenommen, verteuert sich nicht nur die Photovoltaikförderung, sondern auch die gesamte EE-Förderung beträchtlich.

[13] Bezogen auf den Zeitraum 2009 bis 2020.

Abbildung 9: Investitionskosten im Leitszenario mit neuem Investitionsmultiplikator

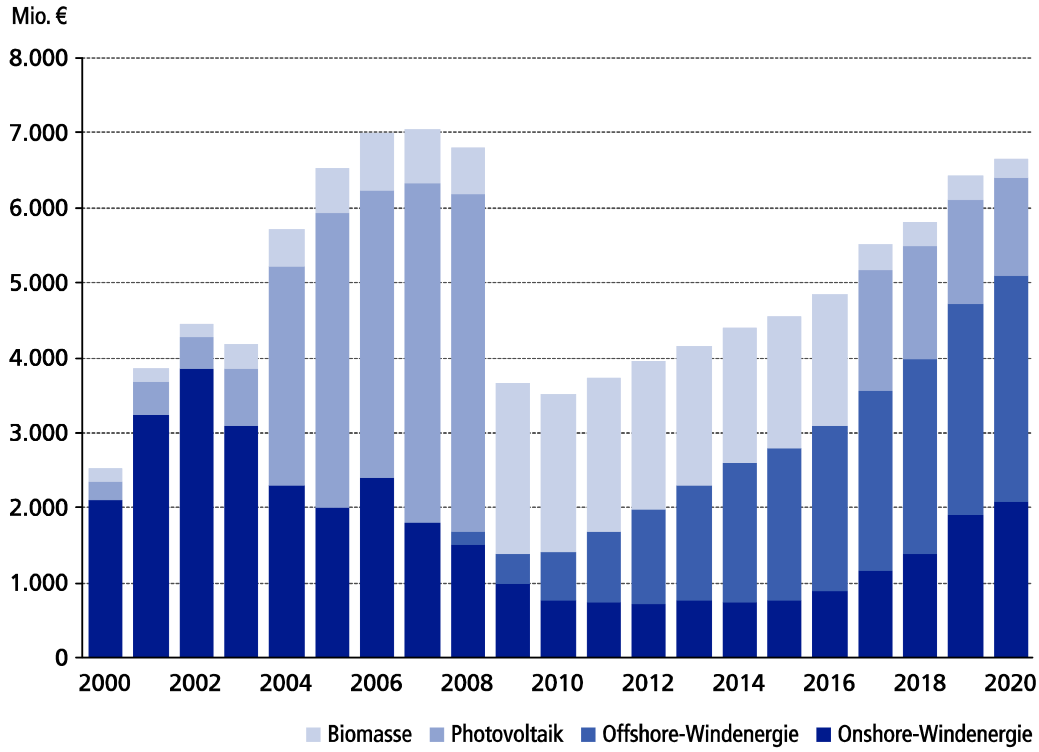


4.2 Szenario A: Biomasse statt Photovoltaik

Ausgehend von der Annahme stark sinkender Investitionsmultiplikatoren kann die Verschiebung des Kapazitätsaufbaus in die Zukunft sinnvoll sein. Daher wird in diesem Szenario die im Leitszenario für Photovoltaik vorgesehene Kapazität für den Zeitraum 2009 bis 2017 durch Biomasse substituiert, während der übrige Zeitraum und die übrigen Energieträger unberührt bleiben. Das Jahr 2017 ergibt sich aus den Investitionsmultiplikatoren unter der Annahme des ersten bzw. zweiten Falles, wie in Abschnitt 3.2 beschrieben.

Ergebnis dieses Szenarios wäre entsprechend den Daten der Leitstudie eine Kostenreduktion in Höhe von 15,08 % beim Ausbau der gesamten Stromerzeugungskapazität für den Zeitraum 2009 bis 2020. Die Mehrinvestitionen in Biomasse würden zwar Mehrinvestitionen in Höhe von 12.176,33 Millionen Euro verursachen, gleichzeitig aber geplante Investitionen in Photovoltaik von 22.346 Millionen Euro einsparen (siehe Abbildung 10).

Abbildung 10: Investitionskosten in Szenario A

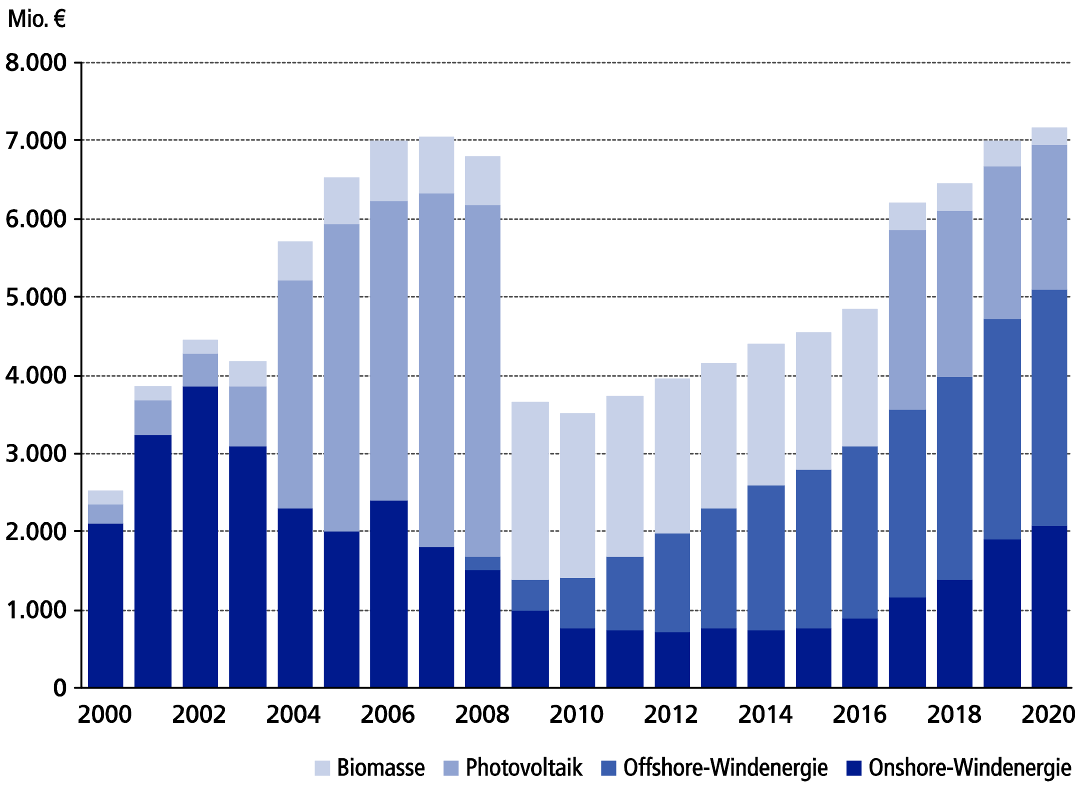


Variiert man darüber hinaus die Annahme über den Verlauf der Investitionsmultiplikatoren für Photovoltaik und geht von einer Entwicklung wie im Zeitraum 2000 bis 2008 aus, erhöhen sich die Investitionskosten gegenüber dem Leitszenario auf 19,25 % (siehe Abbildung 11). Je schwächer die technische Entwicklung bei der Photovoltaik in den nächsten Jahren, desto größer sind die Einsparungen durch das Verschieben von Investitionen.

Selbst wenn sich der technische Fortschritt im EE-Bereich insgesamt schwächer entwickelt, bleibt die Verzögerung des Kapazitätsaufbaus bei der Photovoltaik zugunsten von Biomasse vorteilhaft. Sollten die Investitionsmultiplikatoren für alle erneuerbaren Energieträger, wie in der Sensitivitätsanalyse diskutiert, langsamer sinken als in der Leitstudie angenommen, würden die Investitionskosten für den Zeitraum 2009 bis 2020 bei verzögertem Aufbau von Photovoltaik um 14,58 % geringer ausfallen. In diesem Szenario wäre Biomasse bis 2017 günstiger als Photovoltaik, woraus sich der gewählte Zeitraum für Szenario A ergibt. Ab 2018 wären die Investitionskosten von Photovoltaik und Biomasse vergleichbar.

Auch im ersten Fall des generell schnelleren technischen Fortschritts entsprechend Abschnitt 3.2 ist das Verschieben von Photovoltaikinvestitionen sinnvoll, da die Einsparungen 19,59 % betragen würden. Auch in diesem Fall wäre die Biomasse bis 2017 günstiger als die Photovoltaik und ab 2018 bezogen auf die Investitionskosten vergleichbar mit Photovoltaik.

Abbildung 11: Investitionskosten in Szenario A mit anderem Investitionsmultiplikator als im Zeitraum 2000 bis 2008



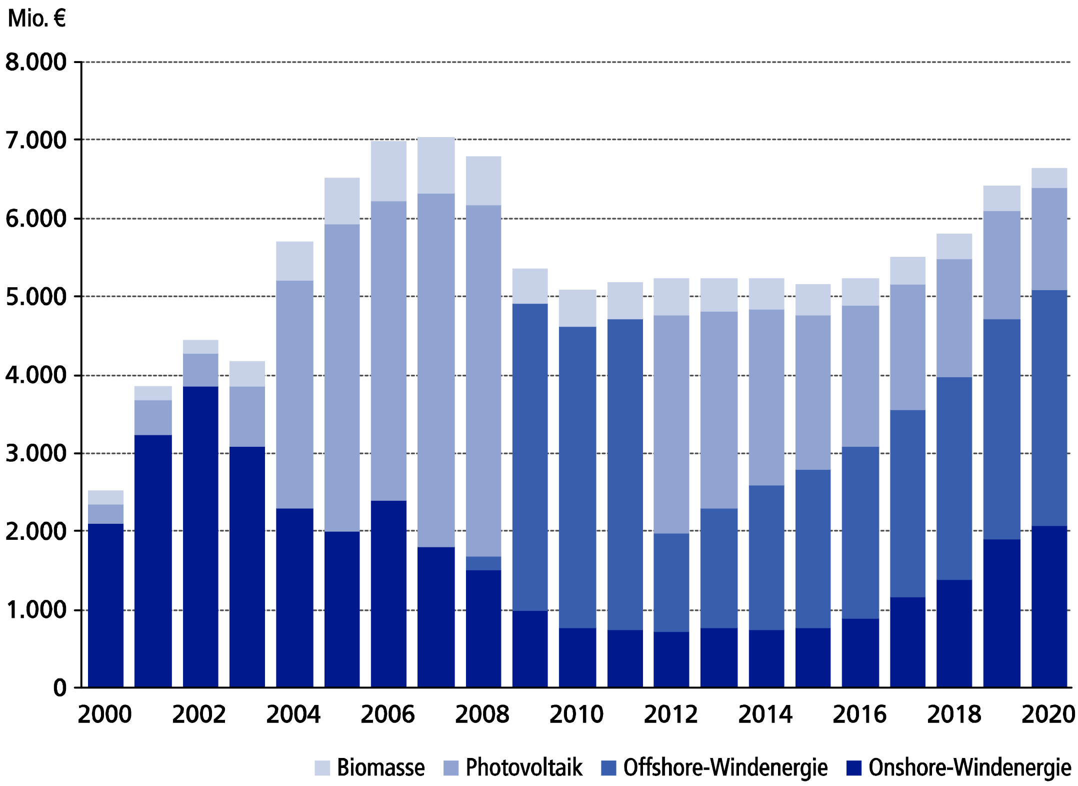
In diesem Szenario ist allerdings zu beachten, dass bei der Biomasse, wie in Abschnitt 3.1 dargestellt, nur die Investitionskosten für Strom berechnet wurden. Insofern sind die Investitionen in Wärme hinzuzurechnen, unabhängig davon, ob die Wärme gebraucht wird.

4.3 Szenario B: Offshore-Windenergie statt Photovoltaik

Im Szenario B sollen nun die Auswirkungen des Ersatzes durch einen weiteren Energieträger untersucht werden. Da die Kapazitätsrestriktionen bei der Onshore-Windenergie am größten sind, kann dies nur die Offshore-Windenergie sein. In Abhängigkeit von den Investitionsmultiplikatoren soll die Photovoltaik daher für den Zeitraum 2009 bis 2011 durch Offshore-Windenergie ersetzt werden. Das Jahr 2011 ergibt sich wieder aus dem Vergleich der Investitionsmultiplikatoren unter der Annahme des ersten und zweiten Falles. Als Besonderheit in diesem Szenario ist die Photovoltaik ab dem Jahr 2011 in jedem Fall günstiger. Für den übrigen Zeitraum und die übrigen Energieträger ändert sich wiederum nichts.

Durch die dreijährige Unterbrechung würden die Gesamtkosten für den Zeitraum 2009 bis 2020 um lediglich 1,76 % sinken, da den eingesparten Photovoltaikkosten in Höhe von 10.977 Millionen Euro Offshore-Windenergiekosten von 9.790,26 Millionen Euro gegenüberstehen.

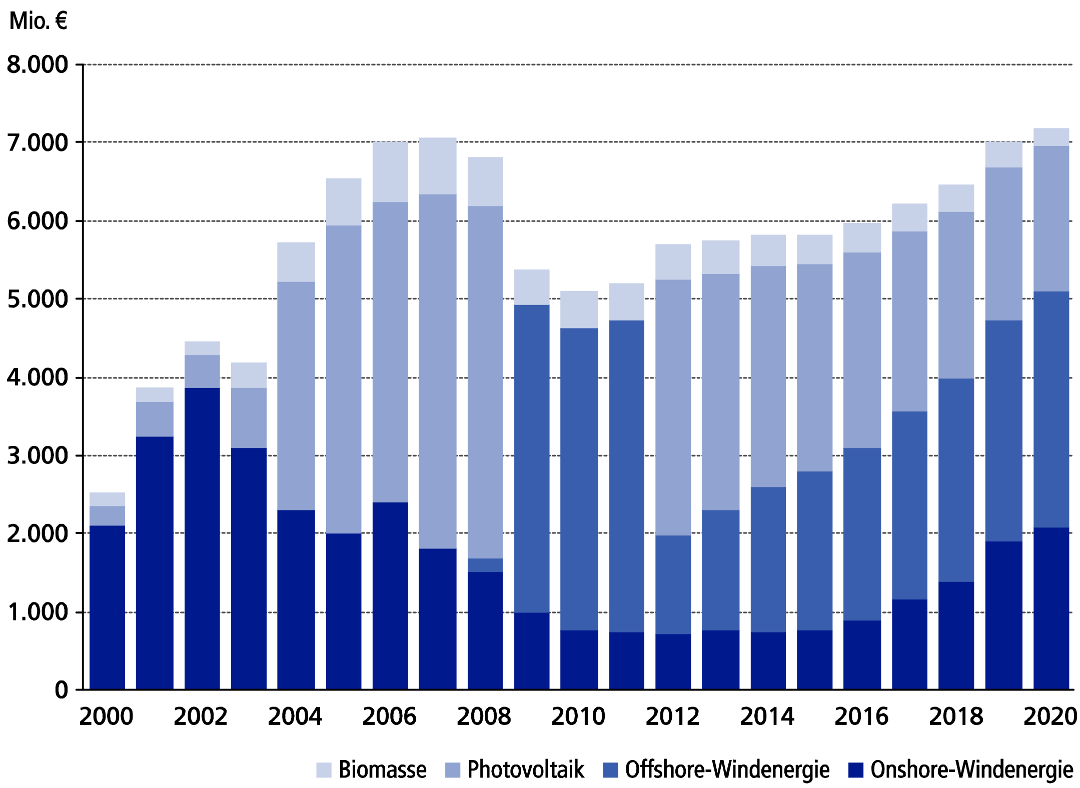
Abbildung 12: Investitionskosten in Szenario B



Der Einfluss verminderter technischer Entwicklung bei der Photovoltaik ist auch in diesem Szenario deutlich. Unter der Annahme der sich wie im Zeitraum 2000 bis 2008 weiterentwickelnden Investitionskosten erhöhen sich die Einsparungen bei den gesamten Investitionskosten auf 3,19 %, verdoppeln sich also nahezu.

Auch bei insgesamt verminderter technischer Entwicklung im EE-Bereich bleibt die zeitweise Substitution von Photovoltaik zugunsten von Offshore-Windenergie vorteilhaft. Entsprechend dem zweiten Fall aus Abschnitt 3.2 würden die gesamten Investitionskosten für den Zeitraum 2009 bis 2020 in Szenario B um 1,67 % sinken, da Offshore-Windenergie bis 2011 günstiger wäre als Photovoltaik. Im ersten Fall würden die Einsparungen 1,83 % betragen, da auch hier die Offshore-Windenergie bis 2011 vorteilhafter wäre.

Abbildung 13: Investitionskosten in Szenario B mit anderem Investitionsmultiplikator als im Zeitraum 2000 bis 2008



Daran wird ersichtlich, dass die möglichen Einsparungen durch Biomasse größer sind als durch Offshore-Windenergie. Die Schlussfolgerung der generellen Überlegenheit von Biomasse gegenüber Offshore-Windenergie innerhalb der nächsten Jahre wäre jedoch unzulässig. Wesentlicher Unsicherheitsfaktor in dieser Analyse bleibt die Zuordnung des Wärmeanteils von Biomasse. Insofern muss bei einer Entscheidung zwischen beiden Energieträgern abgewogen werden, ob der Bedarf an Fernwärme vorhanden ist und sich hieraus Synergieeffekte ergeben. Andererseits ist die Offshore-Windenergie in Deutschland gegenwärtig weitgehend noch in der Planungsphase, woraus sich erhebliche Unsicherheiten ergeben. Nicht zuletzt sind die Kosten hier auch wesentlich von den politischen Rahmenvorgaben abhängig. Insbesondere die gewünschten großen Entfernungen der Windparks von den Küsten sind ein wesentlicher Kostenfaktor.

5 Diskussion

Die vorangegangene Analyse hat gezeigt, dass die Umsetzung der Ausbauziele der EE zur Stromerzeugung ineffizient ist. Durch eine alternative Auswahl der kostenmäßig sehr unterschiedlichen erneuerbaren Energieträger könnten die Ausbauziele zu erheblich niedrigeren Kosten erreicht werden.

Derzeit und auch in absehbarer Zeit wird Onshore-Windenergie der im Kapazitätsaufbau günstigste erneuerbare Energieträger für die Stromerzeugung sein, während Photovoltaik gegenwärtig der teuerste ist. Entsprechend den bisherigen Erfahrungen wird bei der Photovoltaik zukünftig von starken Kostenrückgängen ausgegangen, wodurch diese etwa ab 2012 günstiger als Offshore-Windenergie und etwa um das Jahr 2020 günstiger als Biomasse sein wird. Gleichzeitig wird jedoch geplant, den Kapazitätsaufbau von Photovoltaik im Zeitverlauf zu reduzieren, obwohl durch eine Verschiebung erhebliche Kosten eingespart werden könnten. Hieraus ergibt sich auch eine in Relation zu den übrigen Energieträgern geringe Auswirkung verminderten technischen Fortschritts: Da die Investitionen zurückgehen, wirkt sich dieser nicht so stark aus wie bei der Windenergie. Sowohl bei der Onshore- als auch bei der Offshore-Windenergie steigt der Kapazitätsaufbau, während die Investitionskosten sinken. Insofern würde sich eine veränderte technische Entwicklung stärker auswirken.

Lohnend wäre jedoch nicht nur eine Verschiebung von Investitionen in Photovoltaik. Auch eine zeitweise Umschichtung zugunsten der übrigen Energieträger, insbesondere Biomasse bzw. Offshore-Windenergie, würde sich bei allen Annahmen zur technischen Entwicklung lohnen. Diese Umschichtung ist umso vorteilhafter, je weniger optimistisch die Erwartungen für den Verlauf der Investitionskosten von Photovoltaik sind. Zwar sind die Einsparungen relativ geringer als bei den übrigen Energieträgern, absolut jedoch bei Weitem höher. Da die Leitstudie Kosteneinsparungen im Bereich der Photovoltaik erwartet, die deutlich über den beobachteten des Zeitraums 2000 bis 2008 liegen, ist eine verminderte Entwicklung durchaus nicht unplausibel. Eine pauschale Empfehlung für einen alternativen Energieträger ist jedoch nur schwer zu tätigen, da dies insbesondere vom Bedarf an zusätzlichen Kapazitäten zur Wärmeerzeugung abhängt, wodurch die Attraktivität von Biomasse variiert.

Insgesamt lässt sich festhalten, dass die gegenwärtigen Investitionen in Photovoltaik in hohem Maße ineffizient sind. Photovoltaik verursacht gegenwärtig die höchsten Investitionskosten pro Megawatt Kapazität und hat auch absolut den höchsten Anteil an den Kapazitätsinvestitionen für EE, obwohl die Bedeutung von Photovoltaik für die gesamte erneuerbare Energieerzeugung bis 2020 und damit die CO_2-Vermeidungskosten sehr gering sind. Weiterhin ist zu beachten, dass hier nur die Fixkosten des Kapazitätsaufbaus betrachtet wurden. Die sich aus den garantierten Einspeisevergütungen des EEG ergebenden Ausgaben müssen zur Berechnung der Kosten der EE-Förderung hinzugerechnet werden. Auch die Einspeisevergütungen sind im Vergleich zu den übrigen EE deutlich höher. Frondel et al. (2008) bieten hierzu anhand verschiedener Szenarien eine Untersuchung der variablen Kosten der Photovoltaik, die sich aus dem EEG ergeben.

Grundsätzlich kann die Umverteilung der Investitionen in EE auch lediglich ein zeitlicher Aufschub sein, wenn unterstellt wird, dass der wesentliche Kostentreiber nicht F&E, sondern Massenvorteile sind. Gemäß dieser Annahme müssten die hohen Investitionen in jedem Fall getätigt werden. Da die Investitionen jedoch jetzt und im weltweiten Kontext im hohen Maße von Deutschland getragen werden, könnte sich für andere Länder der Anreiz ergeben, Investitionen zurückzuhalten und von den positiven Externalitäten zu profitieren. Eines der erklärten Ziele der EE-Förderung ist nationale Industriepolitik. Das EEG jedoch ist unabhängig von der Herkunft der Herstellerunternehmen. Daher könnte es zukünftig schwierig sein, die Auswirkungen der Investitionen zu internalisieren, vorausgesetzt, die jeweiligen EE, insbesondere die Photovoltaik, haben zukünftig tatsächlich die erhoffte Bedeutung.

Hinsichtlich der Emissionsminderung ist die Förderung der EE bei gleichzeitigem Emissionshandel konzeptionell ineffizient, solange beide Maßnahmen perfekt funktionieren.[14] Wenn dies der Fall ist, besteht die Gefahr der vollständigen Kompensation der CO_2-Einsparungen durch die EE.[15] Neben dieser Problematik kann sich auch eine Reihe von unerwünschten Effekten ergeben. Durch die Fokussierung auf die EE-Förderung sowohl in finanzieller Hinsicht als auch in der öffentlichen Wahrnehmung können beispielsweise andere Maßnahmen zur CO_2-Minderung verdrängt werden. Durch die verminderte Diversifizierung bei innovativen Technologien ergeben sich auch Risiken für die wachsende Umweltindustrie und daher auch für deren potenzielle Exporterfolge. Auch innovative Politikmaßnahmen erscheinen sinnvoll, wie zum Beispiel ein zwischenstaatlicher Handel mit Herkunftsnachweisen zur Erreichung der EU-Ziele, um regionale Kostenvorteile innerhalb der EU auszunutzen. Ragwitz et al. (2009) analysieren ein solches Handelssystem auf Regierungsebene. In diesem Zusammenhang ist auch die Ausgestaltung des EEG durch die sinkenden Einspeisegebühren ambivalent: Obwohl sie Anreize für Kostensenkungen geben, entsteht gleichzeitig bei ohnehin hoher technischer Entwicklung ein Anreiz, möglichst schnell zu investieren, um hohe Einspeisevergütungen sicherzustellen. Dadurch werden die Investitionen eben dann getätigt, wenn sie teuer sind. Auch hieraus lässt sich schlussfolgern, dass nicht

[14] Zur Diskussion der Koexistenz von EE-Förderung und Emissionszertifikatehandel siehe u. a. Diekmann und Kemfert (2009) und Blankart et al. (2008).

[15] Vgl. hierzu Sinn (2008).

der Kapazitätsaufbau, sondern die Forschung subventioniert werden sollte, um die Technologie dadurch wettbewerbsfähig zu machen.

Letztlich ist bei der Bewertung der Klimapolitik das Effizienzkriterium nur eines unter vielen. Aus politischer Sicht kann das in der Öffentlichkeit oft angeführte Argument der Vorbild- oder Vorreiterfunktion durchaus seine Berechtigung haben, wenn es darum geht, die internationale gesellschaftliche Position zum Klimawandel zu beeinflussen. Insofern mögen hierfür eine gewisse Überbetonung in der anfänglichen Umsetzung einer neuen Politik und entsprechend auch die damit verbundenen Mehrkosten gesellschaftliche Akzeptanz finden.

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Tabellen

Tabelle 1: Investitionskosten der Szenarien (2009–2020)

	Onshore-Wind-energie	Offshore-Wind-energie	Photo-voltaik	Biomasse	Insgesamt	Einsparung an Investitionskosten gegenüber dem Leitszenario (bei identischer Entwicklung des technischen Fortschritts)
Leitszenario	12.916,2	21.775,8	28.146,0	4.598,5	67.436,5	
Leitszenario und langsamerer technischer Fortschritt für Photovoltaik	12.916,2	21.775,8	34.649,4	4.598,5	73.939,9	
Grenzeffekt (schnellerer technischer Fortschritt)	11.975,6	20.086,1	26.714,6	4.336,3	63.112,5	
Grenzeffekt (langsamerer technischer Fortschritt)	13.939,1	23.610,1	29.672,7	4.879,2	72.101,1	
Biomasse statt Photovoltaik	12.916,2	21.775,8	5.800,0	16.774,8	57.266,8	−15,08 %
Biomasse statt Photovoltaik und langsamerer technischer Fortschritt für Photovoltaik	12.916,2	21.775,8	8.239,4	16.774,8	59.706,2	−19,25 %
Biomasse statt Photovoltaik und insgesamt schnellerer technischer Fortschritt	11.975,6	20.086,1	5.204,2	16.007,0	53.272,9	−15,59 %
Biomasse statt Photovoltaik und insgesamt langsamerer technischer Fortschritt	13.939,1	23.610,1	6.455,3	17.584,5	61.589,0	−14,58 %
Offshore statt Photovoltaik	12.916,2	31.566,1	17.169,0	4.598,5	66.249,8	−1,76 %
Offshore statt Photovoltaik und langsamerer technischer Fortschritt für Photovoltaik	12.916,2	31.566,1	22.501,3	4.598,5	71.582,0	−3,19 %
Offshore statt Photovoltaik und insgesamt schnellerer technischer Fortschritt	11.975,6	29.688,1	15.942,1	4.336,3	61.942,1	−1,85 %
Offshore statt Photovoltaik und insgesamt langsamerer technischer Fortschritt	13.939,1	33.591,0	18.488,7	4.879,2	70.898,0	−1,67 %

Tabelle 2: Kapazitätszuwächse der Szenarien (2009–2020) (MW, brutto)

	Onshore-Windenergie	Offshore-Windenergie	Photo-voltaik	Biomasse
Leitszenario	14.547	9.940	12.819	3.372
Leitszenario und langsamerer technischer Fortschritt für Photovoltaik	14.547	9.940	12.819	3.372
Grenzeffekt (schnellerer technischer Fortschritt)	14.547	9.940	12.819	3.372
Grenzeffekt (langsamerer technischer Fortschritt)	14.547	9.940	12.819	3.372
Biomasse statt Photovoltaik	14.547	9.940	4.000	12.191
Biomasse statt Photovoltaik und langsamerer technischer Fortschritt für Photovoltaik	14.547	9.940	4.000	12.191
Biomasse statt Photovoltaik und insgesamt schnellerer technischer Fortschritt	14.547	9.940	4.000	12.191
Biomasse statt Photovoltaik und insgesamt langsamerer technischer Fortschritt	14.547	9.940	4.000	12.191
Offshore statt Photovoltaik	14.547	13.589	9.170	3.372
Offshore statt Photovoltaik und langsamerer technischer Fortschritt für Photovoltaik	14.547	13.589	9.170	3.372
Offshore statt Photovoltaik und insgesamt schnellerer technischer Fortschritt	14.547	13.589	9.170	3.372
Offshore statt Photovoltaik und insgesamt langsamerer technischer Fortschritt	14.547	13.589	9.170	3.372

Tabelle 3: Investitionsmultiplikatoren (€/MW) des Leitszenarios

Jahr	Onshore-Windenergie	Offshore-Windenergie	Photovoltaik	Biomasse
2000	1,26		6,00	1,85
2001	1,23		5,71	1,33
2002	1,20		5,40	1,49
2003	1,17		5,10	1,25
2004	1,14		4,80	1,47
2005	1,12		4,55	1,51
2006	1,10		4,25	1,39
2007	1,08		3,95	1,41
2008	1,06	2,76	3,60	1,44
2009	1,03	2,72	3,33	1,40
2010	1,01	2,68	2,95	1,37
2011	0,99	2,64	2,70	1,37
2012	0,97	2,56	2,55	1,38
2013	0,94	2,47	2,40	1,36
2014	0,92	2,39	2,20	1,37
2015	0,90	2,30	2,00	1,39
2016	0,88	2,21	1,80	1,39
2017	0,86	2,13	1,60	1,36
2018	0,85	2,05	1,50	1,36
2019	0,83	1,99	1,40	1,33
2020	0,81	1,91	1,30	1,22

CHAPTER 6

CO_2-Einsparpotenziale des Energieträgers Erdgas

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Abstract

Angesichts der staatlichen Klimaschutzziele stellt sich die Frage, wie diese mit möglichst geringer Beeinträchtigung einer sicheren Versorgung zu günstigen Preisen erreichbar sind. Erdgas, das im Vergleich zu anderen fossilen Energieträgern deutlich kohlenstoffärmer ist und zudem bei der Verbrennung auch keine weiteren Schadstoffe emittiert, kann hier einen Beitrag leisten. Gegenwärtig hat Erdgas für die Versorgung mit Wärme sowie bei der Erzeugung von Strom eine erhebliche Bedeutung, die zukünftig weiter wachsen wird. Anhand verschiedener Szenarien werden Prognosen zur weiteren Entwicklung von Erdgas und zu den Auswirkungen auf die CO_2-Emissionen angestellt. Es zeigt sich, dass der Anteil von Erdgas im Bereich der Wärmeversorgung von 46 % auf 56 % steigen wird. Durch Änderung des Energiemix und Effizienzsteigerungen kann der CO_2-Ausstoß für Raumwärme daher bis 2020 um 8,3 % gesenkt werden. Für die Stromerzeugung werden alternative Szenarien berechnet. Beim derzeitigen Energiemix käme es zu einer jährlichen Steigerung des CO_2-Ausstoßes um 0,8 %. Würde Kohle komplett durch Gas ersetzt, könnte der CO_2-Ausstoß jährlich um 1,9 % gesenkt werden.

Given the governmental climate targets, the question arises how these targets can be achieved without affecting a secure and cheap energy supply. As natural gas causes less carbon emissions than any other fossil fuel it might be able to make a contribution in this regard. Currently, in the generation of heat and power natural gas plays a significant role, which will further increase in the future. Using several scenarios, we predict the development of the importance of natural gas and the consequences for carbon emissions. The calculations show that the share of natural gas for the supply of heat will increase from 46 % to 56 %. Efficiency increases together with changes in the structure of power generation can reduce heating-related carbon emissions by 8.3 % until 2020. For power generation, we calculate alternative scenarios. If the current structure of power generation is held constant, carbon emissions will increase by 0.8 % per year. If instead natural gas completely replaces coal and lignite, the carbon emissions will be reduced by 1.9 % per year.

JEL classification: C60, H30, O33, Q40, Q58

Keywords: climate policy, GHG emissions, policy scenarios

1 Einleitung

Energie- und Klimapolitik sind in der öffentlichen und wirtschaftspolitischen Diskussion immer weniger voneinander zu trennen. Dabei stehen sich energie- und klimapolitische Zielsetzungen gegenüber, die in einer ökonomisch und ökologisch sinnvollen Weise in Übereinstimmung gebracht werden müssen. Diese Ziele umfassen einerseits Versorgungssicherheit von Haushalten und Industrie mit Energie sowie andererseits Einsparziele bei den CO_2-Emissionen. Bis zu einem gewissen Grad unterliegen energie- und umweltpolitische Aufgaben dabei einem Zielkonflikt. Maßnahmen zur Erhöhung der Energieeffizienz unterstützen zwar beide Ziele, jenseits unausgeschöpfter Effizienzpotenziale stellt sich jedoch die Frage, durch welchen Energiemix die klimapolitischen Ziele, die verbindlich vereinbart und daher als politisches Datum anzusehen sind, ökonomisch und energiewirtschaftlich effizient erfüllt werden können. Diese Diskussion ist insbesondere unter dem Aspekt zu führen, welche langfristigen volkswirtschaftlichen Vermeidungs- und Folgekosten durch den Klimawandel entstehen, unter welchen Szenarien diese Kosten minimiert werden und welchen Beitrag die verschiedenen Energieträger hierzu leisten können.

Im Folgenden wird untersucht, welche Bedeutung Erdgas für die Erreichung der klimapolitischen Zielvorgaben der Bundesregierung zukommt. Nach einer kurzen Darstellung der klimapolitischen Rahmenbedingungen wird zunächst die aktuelle Relevanz von Erdgas in den Bereichen Wärme, Strom und Verkehr beschrieben. Es ist zu erwarten, dass sich diese zumindest in den Bereichen Wärme und Strom in Zukunft stark erhöht. Das sich daraus ergebende CO_2-Minderungspotenzial wird anhand verschiedener Szenarien prognostiziert.

2 Klimapolitische Rahmenbedingungen

Im jüngsten Report des Intergovernmental Panel on Climate Change (IPCC) der Vereinten Nationen wird festgestellt, dass ohne massive Gegenmaßnahmen der Klimawandel kaum noch zu verhindern sei und dieser gravierende Folgen für die gesamte Welt haben würde.[1] Zunehmende Überschwemmungen, Dürreperioden und Wirbelstürme würden nicht nur direkte Kosten verursachen, sondern auch weltweite Migrationsströme infolge von Wasserknappheit und Hungersnöten auslösen. Zu einem ähnlichen Ergebnis kommt auch der Stern-Report, der rechtzeitiges und entschiedenes Handeln anmahnt, da die Vermeidungskosten des Klimawandels deutlich geringer wären als dessen Folgekosten.[2] Eine Erwärmung von durchschnittlich 3 °C hätte bereits massive Folgen; bei Projektion der derzeitigen Emissionen würde es in knapp 100 Jahren jedoch schon zu einer globalen Erwärmung von 4 °C bis 6 °C kommen.

Als Handlungsoptionen können grundsätzlich Maßnahmen zur Begrenzung des Klimawandels ergriffen werden oder aber es sind Anpassungen an die Folgen des Klimawandels nötig. Doch neben den klimapolitischen Zielen gilt es, auch die Versorgungssicherheit mit Energie zu gewährleisten. Sowohl die Energieversorgung als auch der Klimaschutz erfordert Nachhaltigkeit. Um die klimapolitischen Ziele zu erreichen und gleichzeitig energiepolitisch Versorgungssicherheit zu gewährleisten, ist ein optimaler Energiemix notwendig. Die maßgeblichen Kriterien für den optimalen Energiemix sind – gemäß den angestrebten Zielen – der CO_2-Gehalt der verschiedenen Energieträger, deren spezifische Energieeffizienz und Effizienzpotenziale sowie die geologische und technologische Verfügbarkeit von Energie. Schließlich sollten die klima- und energiepolitischen Ziele zu den geringstmöglichen volkswirtschaftlichen Kosten erreicht werden. So müssen etwa den CO_2-Vermeidungskosten, die bei der Umstellung des Energiemix entstehen, die dadurch vermiedenen Folgekosten des Klimawandels gegenübergestellt werden. Die globalen Kosten des Klimawandels werden bei Fortschreibung der Emissionen bis zum Jahr 2050 auf bis zu 2 Billionen US-Dollar pro Jahr geschätzt.[3] Allein auf Deutschland entfielen davon ca. 137 Milliarden US-Dollar. Im Jahr 2002 hat das „Jahrhunderthochwasser“ in Deutschland allein einen Versiche-

[1] Vgl. IPCC (2007).

[2] Vgl. Stern (2007).

[3] Vgl. Kemfert (2002), DIW (2004).

rungsschaden in Höhe von 9,2 Milliarden Euro verursacht.[4] Die Eintrittswahrscheinlichkeiten solcher Naturkatastrophen werden infolge des Klimawandels deutlich ansteigen und mit ihnen auch die volkswirtschaftlichen Kosten. Ein weiterer Anstieg der Oberflächentemperatur um 1 C würde diesen Schätzungen zufolge in einem Zeitraum von 50 Jahren Schäden bis zu 214 Billionen US-Dollar verursachen. Die Vermeidungskosten, also Aufwendungen für Investitionen und Maßnahmen gegen den Klimawandel, würden sich laut Angaben des IPCC bis zum Jahr 2050 auf 305 Milliarden bis zu 1 Billion US-Dollar belaufen; dies wäre mindestens eine Halbierung der Kosten, die bei „ungebremstem" Eintritt des Klimawandels entstünden. Nach derzeitigem Stand müsste Deutschland demnach heute ca. 1 % des BIP aufwenden, um in Zukunft eine Reduzierung des BIP um 5 % infolge von Klimaschäden zu vermeiden.

Im Kyoto-Protokoll der UN Framework Convention on Climate Change (UNFCCC) von 1997 wurde ein durchschnittliches Absenken der CO_2-Emissionen um 5 % bis 2012 bezogen auf den Stand von 1990 vereinbart. Die EU hatte sich verpflichtet, die Emission von Treibhausgasen um 8 % zu senken.[5] Verbindliche Vereinbarungen für die Zeit nach 2012 existieren derzeit noch nicht.[6] Im März 2007 hat der EU-Rat jedoch sein eigenes Ziel aus dem Kyoto-Protokoll von 1997 einseitig revidiert. So wollen die EU-Staaten bis 2020 gemeinschaftlich die Emissionen um mindestens 20 % gegenüber dem Stand von 1990 reduzieren und sogar um bis zu 30 %, falls sich die übrigen Industrieländer in einem Nachfolgeabkommen ab 2012 zu vergleichbaren Zielen verpflichten. Zur Demonstration einer Vorreiterrolle hat die Bundesregierung darüber hinaus angekündigt, dass Deutschland im Falle einer Reduktion um 30 % durch die EU-Staaten seinerseits die Treibhausgasemissionen um 40 % reduzieren wird.

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4 Vgl. Münchner Rück (2002).

5 Das EU-Ziel von 8 % wurde auf die Mitgliedsländer umgelegt (gemeinschaftliche Erfüllung). So hat Deutschland sich zu einer Reduzierung der CO_2-Emissionen um 21 % gegenüber dem Stand von 1990 bis 2012 verpflichtet.

6 Auf der Klimakonferenz von Bali haben sich 186 Staaten darauf geeinigt, bis 2009 ein Klimaschutzabkommen zu beschließen, welches das Kyoto-Protokoll ersetzen soll.

Gleichzeitig wurde beschlossen, bis 2020 den Anteil der erneuerbaren Energien am Primärenergieverbrauch auf mindestens 20 % zu erhöhen. Der Anteil der erneuerbaren Energien an der Stromerzeugung soll mindestens 27 % betragen. Darüber hinaus soll durch Erhöhung der Energieeffizienz um 20 % der Energieverbrauch gegenüber dem „Business as usual“-Fall gesenkt werden.[7]

Um eine ökonomisch effiziente und ökologisch wirksame Reduzierung der CO_2-Emissionen zu erreichen, sind grundsätzlich drei Schritte erforderlich:

1. Die vorhandenen Potenziale bei der Energieeffizienz müssen ausgeschöpft werden.
2. Es muss in den Bereichen Wärme, Strom und Verkehr ein jeweils optimaler Energiemix gefunden werden.
3. Gemäß Grenzvermeidungskosten müssen in den genannten Bereichen Einsparungen im Verbrauch erreicht werden.

Sind in einem ersten Schritt die Potenziale zur Erhöhung der Energieeffizienz ausgeschöpft worden, muss in den Bereichen Wärme, Strom und Verkehr der optimale Energiemix unter Berücksichtigung der teilweise konkurrierenden Ziele der CO_2-Reduktion und der Versorgungssicherheit bestimmt werden.

Der CO_2-Gehalt der verschiedenen Primärenergieträger spielt dabei für den jeweils optimalen Energiemix eine zentrale Rolle. Es zeigt sich, dass Erdgas unter den fossilen Energieträgern den geringsten CO_2-Gehalt aufweist (vgl. Abbildung 1). Die sich insgesamt im Jahr 2006 ergebenden Anteile am Primärenergieverbrauch und an den CO_2-Emissionen werden in Abbildung 2 dargestellt.

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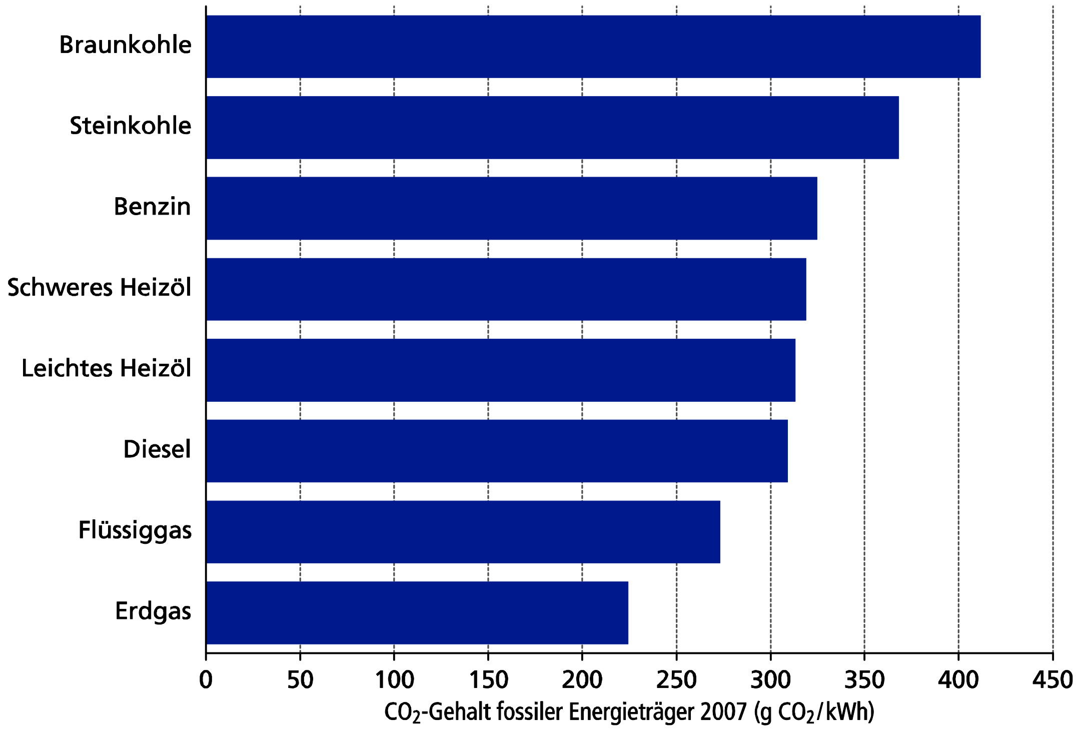
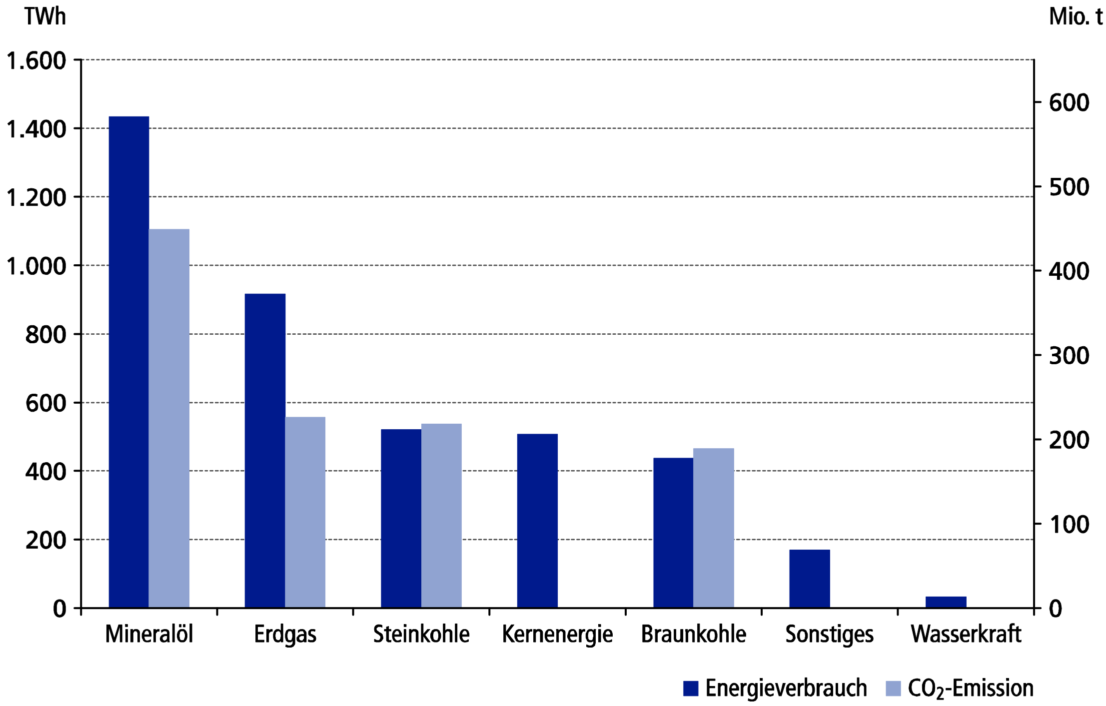
[7] Council of the EU, Presidency Conclusions, 7224/07. Zu konkreten energiepolitischen Handlungsoptionen siehe BMU (2007), Regierungserklärung von Sigmar Gabriel am 26.04.07 vor dem Deutschen Bundestag.

Abbildung 1: CO_2-Gehalt fossiler Energieträger 2007



Quellen: Fritsche (2007), Gloor Engineering, AG Energiebilanzen

Abbildung 2: Primärenergieverbrauch und CO_2-Emissionen nach Energieträgern 2006



Quellen: Fritsche (2007), Gloor Engineering, AG Energiebilanzen, eigene Berechnungen; die CO_2-Faktoren wurden als Mittelwerte der Faktoren der verschiedenen Erdgas-, Mineralöl- bzw. Kohleprodukte berechnet

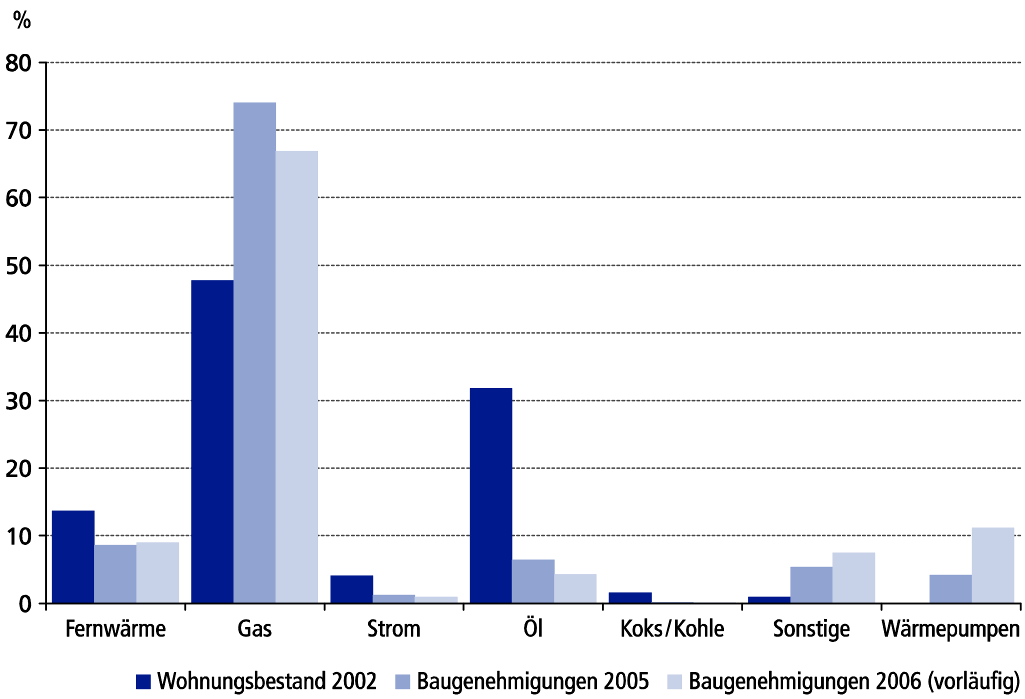
In den Bereichen Wärme, Strom und Verkehr gibt es jedoch jeweils technische Besonderheiten, wie etwa unterschiedliche Substitutionsmöglichkeiten oder Wirkungsgrade der Energieträger, die jeweils einen spezifischen Energiemix erfordern, welcher Umweltverträglichkeit und Wirtschaftlichkeit in effizienter Weise verbindet.

3 Energiebereiche

3.1 Wärme

Mit einem Anteil von 77 % am Energieverbrauch im Haushaltsbereich (2004) ist die Erzeugung von Raumwärme der hauptsächliche Anwendungsbereich, gefolgt von Warmwasser mit 11 %. Im Wesentlichen wird die Raumwärme durch Erdgas[8] (46 % im Jahr 2002), Öl (32 %) und Fernwärme (14 %) bereitgestellt. Strom (4 %), Kohle (2 %), übrige Gase (2 %) und sonstige Energieträger[9] (1 %) sind kaum von Bedeutung.

Abbildung 3: Anteil der Heizarten am Wohnungsbestand und an den Baugenehmigungen in Deutschland



Quelle: Statistisches Bundesamt

8 Sowie zu geringen Anteilen Erdölgas und Grubengas.

9 Unter anderem Brennholz, Brenntorf, Klärschlamm, Müll.

Abbildung 3 zeigt den Anteil der Heizungsarten am Wohnungsbestand bzw. an den Baugenehmigungen. Der hohe Anteil der Gasheizungen an den Baugenehmigungen (ca. 74 % im Jahr 2005) lässt eine weiter steigende Bedeutung von Gas als Heizträger erwarten. Dieser Zuwachs an Gasheizungen geht zulasten von Ölheizungen, welche zwar im Bestand mit knapp 32 % (2002) an zweiter Stelle stehen, jedoch bei den Baugenehmigungen lediglich ca. 6 % aller Heizungen stellen. Der Anteil sonstiger Heizarten am Wohnungsbestand ist zwar bisher noch gering, jedoch spielen diese in den Baugenehmigungen mit über 5 % bereits eine nicht zu vernachlässigende Rolle. Hier zeigt sich eine besondere Bedeutung von Wärmepumpen, die ca. 4,2 % (2005) ausmachen. Die Bedeutung der Wärmepumpen für den CO_2-Ausstoß hängt dabei wesentlich vom zukünftigen Strommix ab, sodass diese bei einer günstigen Entwicklung einen besseren CO_2-Ausstoß aufweisen könnten als mit Gas betriebene Brennstoffzellen.[10] Die Effekte der Verschiebung der Heizungsarten sind jedoch lediglich langfristig spürbar, da der Anteil der Baugenehmigungen am Wohnungsbestand nur 0,6 % beträgt (2005) und es somit lange dauert, bis sich die Heizstruktur der Wohnungen angepasst hat. Daher werden sich auch in Zukunft die Anteile der Energieträger am Energieverbrauch der Haushalte für die Erzeugung von Raumwärme nur langsam verschieben. Das bedeutet jedoch auch, dass Energiepolitik langfristig angelegt sein sollte.

Diese Verschiebung zwischen den Heizungsarten wirkt sich ebenso auf den zukünftigen Energieverbrauch für Raumwärme aus wie der Trend zu kleineren Haushaltsgrößen (bezogen auf die Personenzahl), die steigende Wohnfläche pro Haushalt und die im Trend steigende Energieeffizienz[11]; dieses führt zu einem geringeren Ener-

10 Wuppertal Institut für Klima, Umwelt, Energie, Deutsches Luft- und Raumfahrtzentrum – Institut für Thermodynamik (2002).

11 Um die Effizienz von Energieträgern weiter zu verbessern, stehen laut Umweltbundesamt (www.bmu.de) im Rahmen des CO_2-Gebäudesanierungsprogramms im Zeitraum 2006 bis 2009 jährlich Mittel von rund 1,4 Milliarden Euro zur Verfügung, was eine Vervierfachung der Mittel gegenüber dem Jahr 2005 bedeutet. Besonderes Einsparpotenzial erwartet das Umweltbundesamt (www.bmu.de) dabei in der Raumwärme, etwa durch bessere Dämmung und effizientere Heizungsanlagen. So wird davon ausgegangen, dass sich etwa der Energiebedarf bei Altbauten in Einzelfällen um bis zu 90 % und im Durchschnitt um 50 % verringern lässt. In dieser Prognose werden allerdings deutlich moderatere Werte verwendet, schon allein da der Neu- und Umbau viel Zeit in Anspruch nimmt.

gieverbrauch pro Quadratmeter. Der Trend zu kleineren Haushaltsgrößen spiegelt sich in einer Zunahme der 1- und 2-Personen-Haushalte um 6,5 % bzw. 11,3 % bis 2020 gegenüber 2005 wider, während 3- und 4-Personen-Haushalte um 6 % bzw. 14,1 % zurückgehen. Die durchschnittliche Wohnfläche aller Haushaltstypen ist zudem von 1995 bis 2004 um 6,9 % gestiegen, diejenige bei 2-Personen-Haushalten sogar um 9,8 %. Das Umweltbundesamt geht davon aus, dass die Wohnfläche je Haushalt bis 2050 von heute 38,5 m^2 auf 58,6 m^2 zunehmen wird, was einer jährlichen Steigerung von ca. 0,9 % entspricht. In dieser Studie dagegen wird von einer Sättigung ausgegangen, sodass die jährliche Steigerung im Durchschnitt lediglich 0,2 % beträgt.[12] Die Zunahme der durchschnittlichen Wohnfläche führt tendenziell zu einem steigenden Energieverbrauch. Dem steht die steigende Energieeffizienz gegenüber – so wird beispielsweise der Energieverbrauch zum Heizen eines Quadratmeters mit Gas im Zeitraum 2004 bis 2020 trendmäßig um voraussichtlich ca. 0,5 % pro Jahr zurückgehen.

Diese Entwicklungen werden in der Prognose berücksichtigt. Grundlage der Prognose ist der Energieverbrauch für Raumwärme pro m^2 je Haushalt, aufgegliedert nach Energieträgern. Dieser wurde auf Basis der (bisherigen) Haushaltszahlen gemäß der Raumordnungsprognose[13], der Entwicklung der Anteile der Haushalte nach Heizart[14] und dem Energieverbrauch der privaten Haushalte nach Energieträgern sowie der durchschnittlichen Wohnfläche[15] ermittelt und für die Zukunft geschätzt. Zusammen mit den Daten über die durchschnittliche Wohnfläche und deren Trend, den zukünftigen Haushaltszahlen[16] sowie dem Trend der Anteile der Heizarten ergibt sich somit aus dem geschätzten zukünftigen Energieverbrauch pro m^2 der prognostizierte Verbrauch für Raumwärme, aufgegliedert nach Haushaltsgrößen und Energieträgern.

12 Wuppertal Institut für Klima, Umwelt, Energie, Deutsches Luft- und Raumfahrtzentrum – Institut für Thermodynamik (2002).

13 Bundesamt für Bauwesen und Raumordnung (Hrsg.) (2006).

14 Auf Basis von Mikrozensusdaten über den Wohnungsbestand und Neubau des Statistischen Bundesamtes.

15 Beides Statistisches Bundesamt (2006).

16 Bundesamt für Bauwesen und Raumordnung (Hrsg.) (2006).

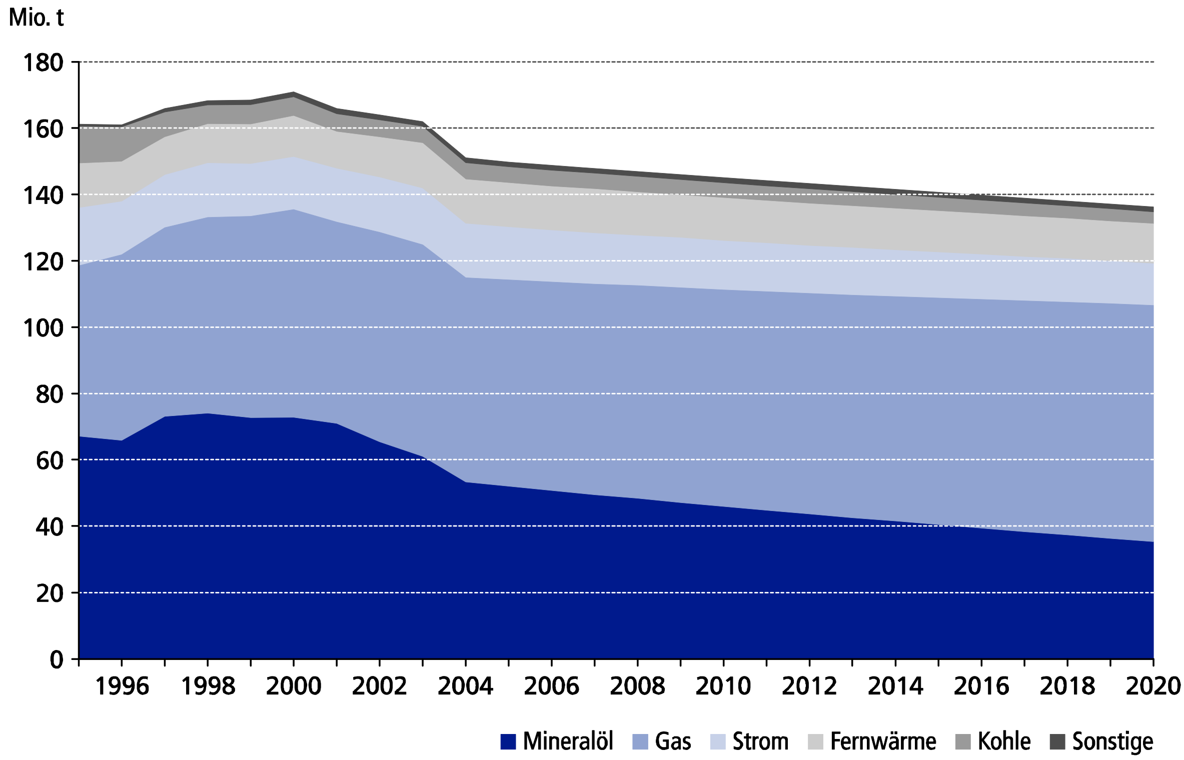
Im Ergebnis der Prognose wird der Energiebedarf in den nächsten Jahren tendenziell sinken, allerdings mit starken Verschiebungen zwischen den Energieträgern. So ging der Anteil von Mineralöl von rund 37,9 % im Jahr 1995 bis 2004 bereits auf 29,3 % zurück und wird bis 2020 auf rund 20 % sinken. Dieser Rückgang wird durch eine zunehmende Bedeutung von Erdgas kompensiert. Der Anteil von Erdgas lag 2004 bei bereits 46 % (gegenüber 39,5 % im Jahr 1995) und wird bis 2020 auf etwa 56 % steigen. Strom sowie Kohle bleiben weiterhin unbedeutend, während sich auch der Anteil von Fernwärme mit ca. 7 % im Jahr 2020 praktisch nicht verändert.

Der Rückgang des Energieverbrauchs spiegelt sich im CO_2-Ausstoß wider, welcher somit ebenfalls bis 2020 zurückgehen wird. Dabei unterstützt der Trend zu mehr Gas (Gas nimmt im Verbrauch als einziger Energieträger absolut zu) den Rückgang im CO_2-Ausstoß. Dieser Verbrauchsanstieg wird jedoch durch die steigende Effizienz von Gas im Wärmebereich kompensiert, wenn auch nicht gänzlich aufgefangen.

Der gesamte CO_2-Ausstoß wird von 2005 bis 2020 um etwa 0,6 % pro Jahr zurückgehen, jedoch durch die Verschiebungen zwischen den Energieträgern mit großen Unterschieden zwischen den Energieträgern: So wird beispielsweise der CO_2-Ausstoß durch Mineralöl in diesem Zeitraum um etwa 2,6 % pro Jahr zurückgehen, während der Rückgang bei Fernwärme etwa 0,8 % beträgt.

Abbildung 4 zeigt die Entwicklung des CO_2-Ausstoßes für die Bereitstellung von Raumwärme im Haushaltsbereich, aufgegliedert nach Energieträgern. Hier wird nochmals der starke Rückgang von ca. 0,6 % pro Jahr deutlich. Der CO_2-Ausstoß wurde dabei durch den CO_2-Gehalt der Energieträger ermittelt, wobei für Strom das Szenario „Status quo" des folgenden Abschnitts unterstellt wurde und für Fernwärme Daten zum CO_2-Gehalt zugrunde liegen, die das Institut Wohnen und Umwelt ermittelt hat.

Abbildung 4: CO_2-Ausstoß der Haushalte für Raumwärme nach Energieträgern von 1995 bis 2020 (ab 2004: Prognosewerte)



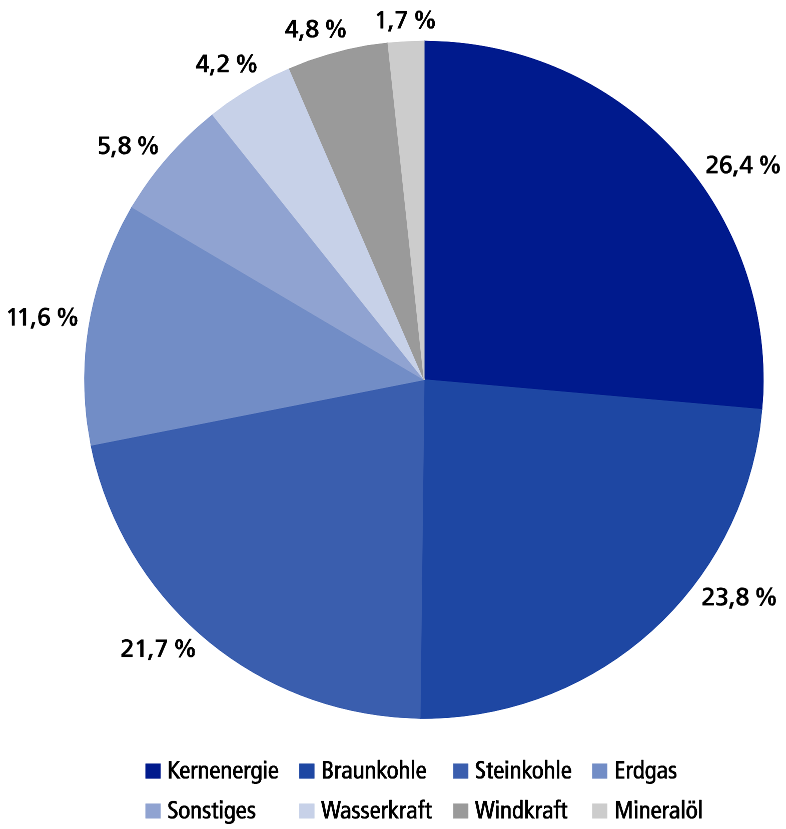
Quellen: eigene Berechnungen, Statistisches Bundesamt (2006), Bundesamt für Bauwesen und Raumordnung (Hrsg.) (2006), Umweltbundesamt (2007), Verband der Elektrizitätswirtschaft, Institut Wohnen und Umwelt (2007), AG Energiebilanzen

3.2 Strom

3.2.1 Stromerzeugung mit Erdgas

Gegenwärtig hat Erdgas in Deutschland einen Anteil von ca. 11 % am erzeugten Strom und ist damit nach der Kernenergie, Braun- und Steinkohle der wichtigste Primärenergieträger für die Stromerzeugung. Obwohl Erdgas im ausschließlich Strom erzeugenden Kraftwerkseinsatz momentan überwiegend Kostennachteile gegenüber den übrigen fossilen Energieträgern und der Kernkraft hat, eignen sich Gasturbinenkraftwerke aufgrund ihrer Schnellstarteigenschaften insbesondere für die Bedarfsdeckung im Spitzenlastbereich. Abbildung 5 stellt den Anteil der Primärenergieträger an der Bruttostromerzeugung in Deutschland im Jahr 2006 dar.

Abbildung 5: Anteile der Energieträger an der Bruttostromerzeugung 2006



Quelle: AG Energiebilanzen

Die ehrgeizigen Klimaschutzziele einerseits und die Sicherstellung wettbewerbsfähiger Energiepreise andererseits deuten darauf hin, dass sich der Anteil von Erdgas an der Stromerzeugung mittelfristig ausweiten wird: Neben dem Ausbau des Anteils regenerativer Energiequellen werden große Anstrengungen für effizienzsteigernde Maßnahmen unternommen. Beispielsweise wird es zu einer massiven Zunahme der gekoppelten Erzeugung von Strom und Wärme (KWK) bei gleichzeitiger Reduzierung ausschließlich Strom erzeugender und mit fossilen Brennstoffen betriebener Kraftwerke kommen. Weiterhin wird sich die Stromerzeugung dezentralisieren, und zwar einerseits zur Verringerung der Transport- und Verteilungsverluste und andererseits um den Anforderungen der zunehmend wettbewerblich organisierten Strommärkte Rechnung zu tragen.

Bei diesen Entwicklungen kommt Erdgas eine große Bedeutung zu. Erdgas ist deutlich kohlenstoffärmer als Kohle und hat auch im Bereich der übrigen Emissionen klare Vorteile. Darüber hinaus eignen sich Erdgaskraftwerke auch aufgrund ihrer geringen Fixkosten besonders für den dezentralen Einsatz. Gasbefeuerte KWK-Anlagen sowie mit Gas- und Dampfturbinen (GuD) produzierende Kraftwerke, die Schnellstarteigenschaften und geringe CO_2-Emissionen vereinen, leisten daher einen kostengünstigen Beitrag zur Erreichung der Klimaschutzziele und wettbewerbsfähiger Energiepreise. Die momentanen Nachteile von Erdgas im Kraftwerkseinsatz durch die vergleichsweise hohen variablen Kosten werden durch die hohen Wirkungsgrade moderner Anlagen kompensiert, sodass die Klimaschutzziele bis zur vollständigen Substitution durch regenerative Energiequellen mit Erdgas effizient erreicht werden können. Um Anreize für Investitionen in Effizienzsteigerungen zu setzen, werden seit 2002 KWK-Anlagen durch das KWK-Gesetz, aber auch GuD-Kraftwerke bei entsprechendem Wirkungsgrad und Verfügbarkeit des Kraftwerks steuerlich gefördert.

3.2.2 Annahmen und Szenarien der Prognose

Wie sich die Bedeutung von Erdgas in der Stromerzeugung in Zukunft entwickeln wird, hängt wesentlich von politischen Entscheidungen ab. Daher werden hier vier Szenarien miteinander verglichen, um die Folgen politischer Entscheidungen für den Energieverbrauch zur Stromerzeugung und den resultierenden CO_2-Ausstoß zu zeigen.[17]

Das 1. Szenario – „Status quo" – dient dabei als Referenz und unterstellt, dass die Aufteilung der Energieträger in der Stromerzeugung von 2005 gleich bleibt (dadurch wird der bisherige Trend der Abkehr von im Vergleich weniger effizienten Kohlekraftwerken ausgeschaltet, welcher sich tendenziell dämpfend auf den Verbrauch auswirkt[18]).

Im 2. Szenario – „Ausstieg aus der Kernenergie" – wird dagegen untersucht, wie sich eine Abkehr von der Kernkraft bis 2020 auswirken würde, sofern die durch den

[17] Generell wird von der Einführung einer CO_2-Abscheidetechnologie abstrahiert, da die Einführung bis 2020 zwar denkbar, deren Umfang und Zeitpunkt jedoch mit gewissen Unsicherheiten behaftet sind.

[18] Diese Annahme wurde getroffen, da der zukünftige Energiemix wesentlich von politischen Entscheidungen abhängt und daher der Trend der letzten Jahre keine sichere Grundlage für eine Prognose darstellt.

Wegfall der Kernkraftwerke zu ersetzende Energie auf die übrigen Energieträger gemäß deren aktueller Gewichtung verteilt würde.

Im 3. Szenario – „Ausstieg aus Kohle" – werden die Auswirkungen einer Abkehr von Kohlekraftwerken zugunsten von Gaskraftwerken ermittelt.

Im 4. Szenario – „20 % erneuerbare Energien" – wird schließlich untersucht, wie sich der Energieverbrauch sowie der CO_2-Ausstoß ändern, sofern das anvisierte Ziel von 20 % erneuerbaren Energien in der Stromerzeugung bis 2020 erreicht würde.

Dies geschieht alles vor dem Hintergrund eines steigenden Stromverbrauchs. Im Zeitraum 2005 bis 2020 wird der Stromverbrauch um jährlich knapp 1 % zunehmen, nachdem er von 1995 bis 2005 um ca. 1,5 % pro Jahr gestiegen ist.[19]

Auf der Basis des Stromverbrauchs wird in den Szenarien jeweils der zur Stromerzeugung nötige Energieverbrauch unter Berücksichtigung des Eigenverbrauchs der Kraftwerke sowie der Netzverluste[20] ermittelt. Dazu werden die Anteile der Energieträger[21] sowie deren Effizienz[22] in der Stromerzeugung jeweils im Zeitablauf betrachtet (insbesondere die Gaskraftwerke steigern hier durch den Einsatz von modernen GuD-Kraftwerken ihre Effizienz), wobei jedoch aufgrund der unzureichenden Datenlage eine Zuteilung des Energieaufwandes der KWK-Anlagen auf Strom und Fernwärme nicht möglich ist. Der Einfachheit halber wird daher der gesamte Energieverbrauch der KWK-Anlagen Strom zugeschrieben. Daraus wird schließlich anhand des CO_2-Gehalts der Energieträger[23] der CO_2-Ausstoß geschätzt.

Ziel dieser Szenarienanalyse ist es, die Wirkungen von Veränderungen in den Rahmenbedingungen aufzuzeigen. Die Wirkung des im Trend steigenden Stromver-

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19 Diese Daten stammen aus separaten Prognosen über den Energieverbrauch der Haushalte, der Industrie, des Sektors Gewerbe, Handel und Dienstleistungen und des Verkehrs.

20 Auf Basis von Daten des Umweltbundesamtes.

21 Auf Basis von Daten des Verbands der Elektrizitätswirtschaft (VDEW) e. V.

22 Beruhend auf Berechnungen des Umweltbundesamtes.

23 Dabei werden nur die direkten Emissionen betrachtet, indirekte Emissionen durch vorgelagerte Erzeugungsstufen (Brennstoffgewinnung, -transport) werden nicht betrachtet. Somit entstehen beispielsweise durch Kernkraft keinerlei Emissionen. Die Werte beruhen auf Daten des Umweltbundesamtes.

brauchs auf den Energieverbrauch zur Stromerzeugung und den resultierenden CO_2-Ausstoß wird dabei durch die steigende Energieeffizienz zum Teil aufgefangen.

3.2.3 Ergebnisse und Fazit

Tabelle 3.1 zeigt die wesentlichen Ergebnisse der vier Szenarien im Vergleich zu den Daten von 2006.

Tabelle 3.1: Ergebnisse der Prognose im Überblick

	2006	2020			
		Status quo	Ausstieg aus der Kernenergie	Ausstieg aus Kohle	20 % erneuerbare Energien
	Anteile der Energieträger an der Stromerzeugung (%)				
Öl	1,7	1,7	2,2	1,7	1,6
Gas	11,6	11,6	15,7	56,9	10,9
Kohle	45,3	45,3	61,5	0,0	42,7
Kernkraft	26,3	26,3	0,0	26,3	24,8
Wasserkraft/Windkraft	9,2	9,2	12,5	9,2	11,6
Übrige Energieträger	6,0	6,0	8,1	6,0	8,4
	Anteile der Energieträger am Energieverbrauch zur Stromerzeugung (%)				
Öl	1,6	1,6	2,3	1,7	1,5
Gas	11,3	10,7	15,8	54,9	10,3
Kohle	46,0	46,1	68,0	0,0	44,3
Kernkraft	31,7	32,2	0,0	33,6	30,9
Wasserkraft/Windkraft	3,6	3,7	5,5	3,9	4,8
Übrige Energieträger	5,8	5,7	8,4	6,0	8,2
	CO_2-Ausstoß der Energieträger zur Stromerzeugung (Mio. Tonnen)				
Öl	7,6	8,4	11,4	8,4	7,9
Gas	36,8	39,0	52,9	191,7	36,7
Kohle	233,2	260,3	353,4	0,0	245,5
Übrige Energieträger	13,3	14,7	20,0	14,7	20,7
Insgesamt	290,9	322,4	437,7	214,8	310,8

Im Szenario „Ausstieg aus der Kernenergie“ wird Kernkraft ab 2007 bis 2020 schrittweise durch die verbleibenden Energieträger (gemäß deren vorheriger Gewichtung) ersetzt. Es ergibt sich so zunächst ein geringerer Energiebedarf zur Stromerzeugung gegenüber dem Szenario „Status quo“: So wird der gesamte Energieverbrauch von 2005 bis 2020 um jährlich ca. 0,3 % steigen, während er im Szenario „Status quo“ um ca. 0,9 % steigt. Das liegt jedoch vor allem an der vergleichsweise geringen Effizienz von Kernkraftwerken.[24] Für den CO_2-Ausstoß ergibt sich dagegen beim Ausstieg aus der Kernenergie im gleichen Zeitraum eine Steigerung von jährlich ca. 2,8 % auf 437,7 Millionen Tonnen gegenüber 0,9 % im Referenzszenario, was vor allem am steigenden Anteil der Kohlekraftwerke von 45,3 % (2006) auf 61,5 % (2020) liegt. Der Anteil von Gaskraftwerken an der Stromproduktion wird dabei voraussichtlich um jährlich 2,1 % auf 15,7 % im Jahr 2020 steigen, um den Wegfall von Strom aus Kernenergie zu kompensieren. Der Anteil von Erdgas am CO_2-Ausstoß bleibt mit ca. 12 % im Jahr 2020 gegenüber 2006 annähernd konstant; der Anteil von Kohle am CO_2-Ausstoß steigt mit einem Anteil von 80,7 % (2020) gegenüber 80,1 % (2006) nur leicht.

Das Szenario „Ausstieg aus Kohle“ dagegen unterstellt, dass die Kohlekraftwerke ab 2007 bis 2020 durch Gaskraftwerke ersetzt werden, während die übrigen Kraftwerke ihren Anteil an der Stromproduktion behalten. Dabei wurde die Effizienz von Gas aus dem bisherigen Verlauf geschätzt – tatsächlich aber müsste die Effizienz von Gas noch stärker zunehmen, da vorwiegend GuD-Kraftwerke mit einer hohen Effizienz als Ersatz für die Kohlekraftwerken gebaut würden.

Unter diesen Voraussetzungen würde es zu einer jährlichen Steigerung des Energieverbrauchs zur Stromerzeugung von ca. 0,6 % von 2005 bis 2020 kommen (gegenüber 0,9 % im Referenzszenario). Dabei würde sich der CO_2-Ausstoß um jährlich ca. 1,9 % verringern (gegenüber einer Zunahme von 0,8 % im Referenzszenario). Hier kommt zum Tragen, dass Gas einen geringeren CO_2-Gehalt besitzt und dass Gaskraftwerke (insbesondere durch moderne GuD-Kraftwerke) einen höheren Wirkungsgrad besitzen, weshalb weniger fossile Energieträger verbrannt werden. Dieser hohe Rückgang von CO_2 trotz des steigenden Stromverbrauchs ergibt sich jedoch auch daraus, dass hier unterstellt wird, dass alle Kohlekraftwerke ersetzt werden, während in dem

[24] Diese wurde wie in den Energiebilanzen der AG-Energiebilanzen mit 33 % angenommen.

Szenario „20 % erneuerbare Energien" Kohlekraftwerke etwa 42,7 % (2020) der Stromerzeugung ausmachen. Dieses Szenario verdeutlicht aber, dass Gas als Brückentechnologie dazu geeignet ist, in einer Übergangsphase andere fossile Energieträger in der Stromproduktion (teilweise) zu ersetzen und dadurch gleichzeitig den CO_2-Ausstoß zu senken.

Im letzten Szenario wird angenommen, dass die erneuerbaren Energieträger in der Stromproduktion bis 2020 einen Anteil von 20 % erreichen. Dabei wird unterstellt, dass der noch fehlende Teil ab 2007 schrittweise jeweils zu 50 % von Wasser- und Windkraftanlagen und den sonstigen erneuerbaren Energieträgern erbracht wird. Um dies zu erreichen, müsste der Anteil von Wasser- und Windkraftanlagen an der Stromproduktion von 2005 bis 2020 jährlich um 1,9 % (auf 11,6 % im Jahr 2020 gegenüber 9,2 % im Jahr 2006) und der Anteil der sonstigen erneuerbaren Energien um jährlich 3,3 % (auf 8,4 % gegenüber 6 % im Jahr 2006) steigen, während der Anteil von Gaskraftwerken um ca. 0,3 % pro Jahr zurückgehen würde. Der Energieverbrauch zur Stromerzeugung würde dabei um etwa 0,8 % zunehmen. In diesem Szenario steigt der CO_2-Ausstoß von 2005 bis 2020 jährlich um ca. 0,5 % auf 310,8 Millionen Tonnen) gegenüber ca. 0,8 % (322,4 Millionen Tonnen) im Referenzszenario. Dies liegt unter anderem daran, dass bei den sonstigen erneuerbaren Energien auch Müll mit einfließt, bei dessen Verbrennung CO_2 entsteht.[25] Zudem wird in diesem Szenario unterstellt, dass auch gegenüber Kohlekraftwerken CO_2-ärmere Kraftwerke eingesetzt werden. Zusammen mit dem steigenden Strombedarf führt dies schließlich zu einem wenn auch nur schwach steigenden CO_2-Ausstoß – auch wenn die mit erneuerbaren Energien produzierenden Kraftwerke einen wesentlich geringeren CO_2-Ausstoß besitzen als die übrigen Kraftwerke (Kernkraftwerke ausgenommen). Beim Vergleich dieses Szenarios mit dem Szenario „Ausstieg aus Kohle" sollte daher beachtet werden, dass in letzterem Kohle völlig ersetzt wurde, während hier alle Kraftwerke zum Teil durch solche ersetzt werden, die mit erneuerbaren Energieträgern produzieren.

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[25] Dabei wurde ein Anteil des Mülls an den sonstigen Energieträgern von 50 % unterstellt.

Vor dem Hintergrund des geplanten Ausstiegs aus der Kernenergie bleibt festzuhalten, dass Gaskraftwerke eine sowohl effiziente als auch vergleichsweise CO_2-arme Brückentechnologie darstellen, um die Kernkraft zu ersetzen, bis erneuerbare Energieträger weit genug ausgebaut wurden. Soll tatsächlich die Kernkraft bis 2020 abgeschafft werden, so muss deren Anteil von 26,3 % (2006) ersetzt werden – dies ist allein durch erneuerbare Energieträger in diesem Zeitraum unrealistisch[26] und würde zudem die Energiekosten wie auch die Versorgungssicherheit negativ beeinflussen. Wird dagegen vermehrt Kohle als Ersatz eingesetzt, so würde dies zu einem starken Zuwachs des CO2-Ausstoßes führen. Gas stellt somit – insbesondere durch die GuD-Technologie – eine Alternative dar. Der gegenwärtig zu beobachtende Trend zu einem vermehrten internationalen Wettbewerb auf den Gasmärkten und die daraus resultierenden geringeren Gaspreise erhöhen die Wettbewerbsfähigkeit der derzeit noch mit hohen variablen Kosten verbundenen Gaskraftwerke zusätzlich zur Steigerung der Wettbewerbsfähigkeit durch Effizienzgewinne.

3.3 Verkehr

Im Verkehrssektor werden gegenwärtig fast ausschließlich Mineralölprodukte (Ottokraftstoffe, Dieselkraftstoffe und Flugbenzin) als Energieträger verwendet. Dies führt einerseits zu einer starken Abhängigkeit von den Erdöl exportierenden Ländern und andererseits zu hohen Umweltbelastungen. So sind ca. 28 % aller Treibhausgasemissionen auf den Energieverbrauch im gesamten Verkehrssektor zurückzuführen. Die EU-Kommission hat 2001 in ihrem Grünbuch (2001a) geschätzt, dass sich im Verkehrssektor die CO_2-Emissionen zwischen 1990 und 2010 um 50 % auf 1.113 Milliarden Tonnen steigern werden, sollten keine Reduktionsmaßnahmen ergriffen werden. Aus ökologischer Sicht wurde daher geschlussfolgert, dass sowohl die Verwendung alternativer Kraftstoffe als auch die Energieeffizienz der Verkehrsträger erhöht werden müssen. Dies würde gleichzeitig auch die Erdölabhängigkeit senken. Hierbei sei insbeson-

[26] Vgl. Bräuninger et al. (2007).

dere der Straßenverkehr zu beachten, da dieser für 84 % der verkehrsbedingten CO_2-Emissionen verantwortlich sei.[27] Als erste Maßnahme hat die Kommission festgelegt, dass bis 2020 der Anteil alternativer Kraftstoffe am gesamten Kraftstoffverbrauch insgesamt 20 % und der von Erdgas 10 % betragen soll.[28] Weiterhin wurde Ende 2007 von der EU-Kommission beschlossen, dass bis 2012 der Durchschnitt aller Neuwagen in Europa nicht mehr als 120 Gramm CO_2 pro gefahrenen Kilometer ausstoßen soll.[29]

Eine wesentliche Reduktion von Treibhausgasemissionen durch die Einführung vollständig neuer Antriebsarten ist auf absehbare Zeit technisch und auch aus Kostengesichtspunkten unwahrscheinlich.[30] Die momentan als langfristige Lösung der Klimaschutzvorgaben diskutierte Brennstoffzellentechnologie kann in der Gesamtbilanz auch nur dann klimafreundlich sein, wenn der benötigte Wasserstoff durch erneuerbare Energieträger erzeugt wird, was auf absehbare Zeit unwahrscheinlich ist. Auch die Entwicklung von synthetischen und Biokraftstoffen allein kann eine klimaneutrale Energieversorgung im Verkehrssektor nicht sicherstellen. Daher werden auch in absehbarer Zukunft Otto- und Dieselmotoren in Verbindung mit Mineralölkraftstoffen die vorherrschende Technologie sein. Eine nachhaltige Energieversorgung im Verkehrssektor kann demnach nur durch eine Reihe von Einzelmaßnahmen erreicht werden, bis eine hinreichend effiziente regenerative Primärenergiegewinnung zur Verfügung steht. Erdgas hat im Rahmen dieser Maßnahmen eine wichtige Bedeutung.

Der Vorteil von Erdgas als Kraftstoff gegenüber den Mineralölprodukten liegt in der deutlich geringeren Emission von CO_2. Ein weiterer Vorteil gegenüber Benzin und Diesel ist die nahezu vollständige Vermeidung des Ausstoßes weiterer Schadstoffe wie Schwefeldioxid, Ruß und anderer Partikel. Daher mindert Erdgas nicht nur die Treib-

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[27] Vgl. Europäische Kommission (2001b).

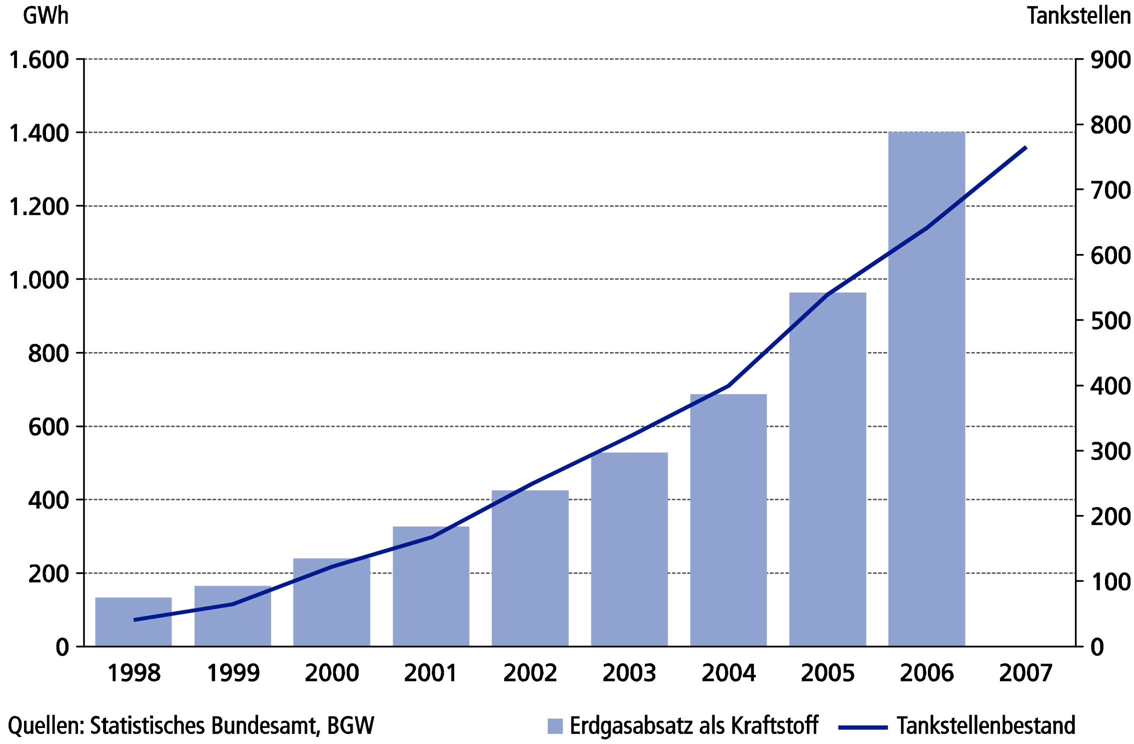
[28] Vgl. Europäische Kommission (2001a).

[29] Vgl. Europäische Kommission (2007).

[30] Vgl. hierzu und insbesondere zur Rolle von Erdgas in einer nachhaltigen Energieversorgung Wuppertal Institut für Klima, Umwelt, Energie (2003).

hausgasemissionen, sondern leistet auch einen Beitrag zur Erhöhung der lokalen Luftqualität.

Abbildung 6: Kraftstoffbedingter Erdgasabsatz und Tankstellenbestand von 1998 bis 2007



Der Anteil von Erdgas betriebenen Fahrzeugen in Deutschland ist gegenwärtig zwar sehr gering (ca. 0,5 % im Jahr 2006), in den vergangenen Jahren hat er jedoch deutlich zugenommen. Zudem hat sich auch das Angebot an Erdgasfahrzeugen erhöht. Um das Ziel von 10 % Erdgasanteil am gesamten Kraftstoffverbrauch bis zum Jahr 2020 zu erreichen, unterstützt die Politik die Verbreitung von Erdgasfahrzeugen durch Steuervergünstigungen, die bis zum Jahr 2018 gelten. Da Erdgas als Kraftstoff über einen Netzwerkcharakter verfügt, ist die Höhe des Fahrzeugbestandes wesentlich von der Dichte des Erdgastankstellennetzes abhängig. Die Errichtung von Erdgastankstellen ist umgekehrt nur bei einer entsprechenden Anzahl an Fahrzeugen profitabel. Somit sind vorausgehende Investitionen in ein flächendeckendes Netz von Tankstellen notwendig, um die Kaufentscheidung zugunsten von Erdgasfahrzeugen zu beeinflussen. Ab einem kritischen Bestand an Tankstellen und Fahrzeugen sind dann die Möglichkeiten für ein überproportionales Wachstum gegeben. Nach Angaben der erdgas mobil GmbH war geplant, noch im Jahr 2007 in Städten alle 5 Kilometer, in Mischgebieten alle 10 bis 15 Kilometer und in ländlichen Gebieten alle 20 bis 25 Kilometer eine Erdgastankstelle zu errichten, um damit ca. 1 Million Fahrzeuge versorgen zu können. Zusätzlich sollen bis Ende 2008 entlang des Autobahnnetzes 150 weitere Tankstellen gebaut werden.[31]

Im Rahmen der Einzelmaßnahmen stellt Erdgas demnach eine vielversprechende Brückentechnologie dar, um die gesteckten Klimaschutzziele im Verkehrssektor kostengünstig zu realisieren.

4 Zusammenfassung

Energie- und Klimapolitik bewegen sich in einem Spannungsfeld zwischen Versorgungssicherheit, Preisgünstigkeit und Umweltverträglichkeit. Zu fragen ist hierbei, wie die staatlichen Klimaschutzziele ohne signifikante Beeinträchtigung einer sicheren Versorgung zu günstigen Preisen erreichbar sind. Die Verwendung von Erdgas als Energieträger kann hier einen Beitrag leisten, da Erdgas im Vergleich zu anderen fossilen Energieträgern deutlich kohlenstoffärmer ist und darüber hinaus bei der Verbrennung auch keine weiteren Schadstoffe emittiert. Bereits heute hat Erdgas eine erhebliche Bedeutung für die Versorgung mit Wärme sowie bei der Erzeugung von Strom. Diese Bedeutung wird zukünftig weiter wachsen, was aus klimapolitischer Sicht zu begrüßen ist. Im Wärmebereich hat sich Erdgas aus Sicht der Konsumenten im Vergleich zu den übrigen Energieträgern als bequem und kostengünstig erwiesen. Im Stromerzeugungsbereich ist das Wachstum von Erdgas insbesondere durch die steigende Bedeutung kleiner und dezentraler (KWK-)Kraftwerke getrieben, für die Erdgas als Brennstoff besonders geeignet ist. Zusätzlich ergeben sich durch den Ausstieg aus der Kernenergie in den nächsten Jahrzehnten zusätzliche Anforderungen an neue Kraftwerke.

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31 www.erdgasfahrzeuge.de.

Welche Auswirkungen auf den CO_2-Ausstoß der vermehrte Einsatz von Erdgas hat, wurde in verschiedenen Szenarien gezeigt. Hier zeigten sich erhebliche Minderungspotenziale. Im Bereich der Wärmeversorgung wird der Anteil von Erdgas von 46 % auf 56 % steigen. Durch die Änderung des Energiemix und die Effizienzsteigerung kann der CO_2-Ausstoß für Raumwärme bis 2020 um 8,3 % gesenkt werden. Für die Stromerzeugung wurden alternative Szenarien berechnet. Sofern der derzeitige Energiemix beibehalten würde, käme es zu einer jährlichen Steigerung des CO_2-Ausstoßes um 0,8 %. Im Vergleich dazu könnte der CO_2-Ausstoß jährlich um 1,9 % gesenkt werden, wenn Kohle komplett durch Gas ersetzt würde.

Da es für die Wettbewerbsfähigkeit der deutschen Wirtschaft notwendig ist, die Kosten für Energie weiterhin gering zu halten, ist ein vermehrter Einsatz von Erdgas zu begrüßen, solange Erdgas günstiger ist als die Verwendung regenerativer Energieträger und die Preisrelationen zu den übrigen Energieträgern gewahrt bleiben. Beim Übergang zu regenerativen Energieträgern kann Erdgas als „Brückentechnologie" demnach zur Erreichung von Klimaschutzzielen bedeutsam sein.

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