
12 Insights on Germany's *Energiewende*

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Agora
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12 Insights on Germany's *Energiewende*

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12 Insights on Germany's Energiewende.

A Discussion Paper Exploring Key Challenges
for the Power Sector

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Introduction

In June 2011 the German Parliament ended a long debate of several decades over the future of the country's energy system with a historical decision. It was historical because of its ambitious goal:

Germany wants to transform its power sector from nuclear and coal to renewables within the next four decades. The decision was also historical because it was an almost unanimous vote, a consensus of ruling and opposition parties.

This transition of Germany's energy system is called *Energiewende*. Germany will phase out nuclear energy; the remaining nuclear power plants will be gradually closed down by the end of 2022. The country's targets to transform its energy system are summarized below.

Since the long-term targets are in place – the big question remaining to be answered is *how* to accomplish these goals. Namely, how to manage the transition from a fossil-nuclear system to a mainly renewable energy system at the lowest possible cost and without compromising the high standard in system reliability? Our attention is focused on the next 10 to 20 years, or the period up to 2030.

We know from numerous studies and scenarios that the power sector will be crucial in this transition. This sector is where key decisions have to be made in coming years – from reforming the energy market design to infrastructure planning. Knowing that the time horizon for implementing such decisions in the energy sector should be contemplated in decades rather than years, the need

Status Quo and Main Targets of the Energiewende					
	2011	2020	2030	2040	2050
Greenhouse Gas Emissions					
GHG (against 1990)	-26.4 %	-40%	-55%	-70%	-80 to -95%
Efficiency					
primary energy use (against 2008)	-6%	-20%	–	–	-50%
electricity demand (against 2008)	-2.1%	-10%	–	–	-25%
heat in residential sector	n.a.	-20%	–	–	–
energy use in transport sector (against 2005)	-0.5%	-10%	–	–	-40%
Renewable Energy					
share in electricity consumption	20.3%	≥ 35%	≥ 50%	≥ 65%	≥ 80%
share in final energy use	12.1%	18%	30%	45%	60%

Introduction

for urgent action is becoming more and more obvious. For these reasons this paper focuses on the power sector.

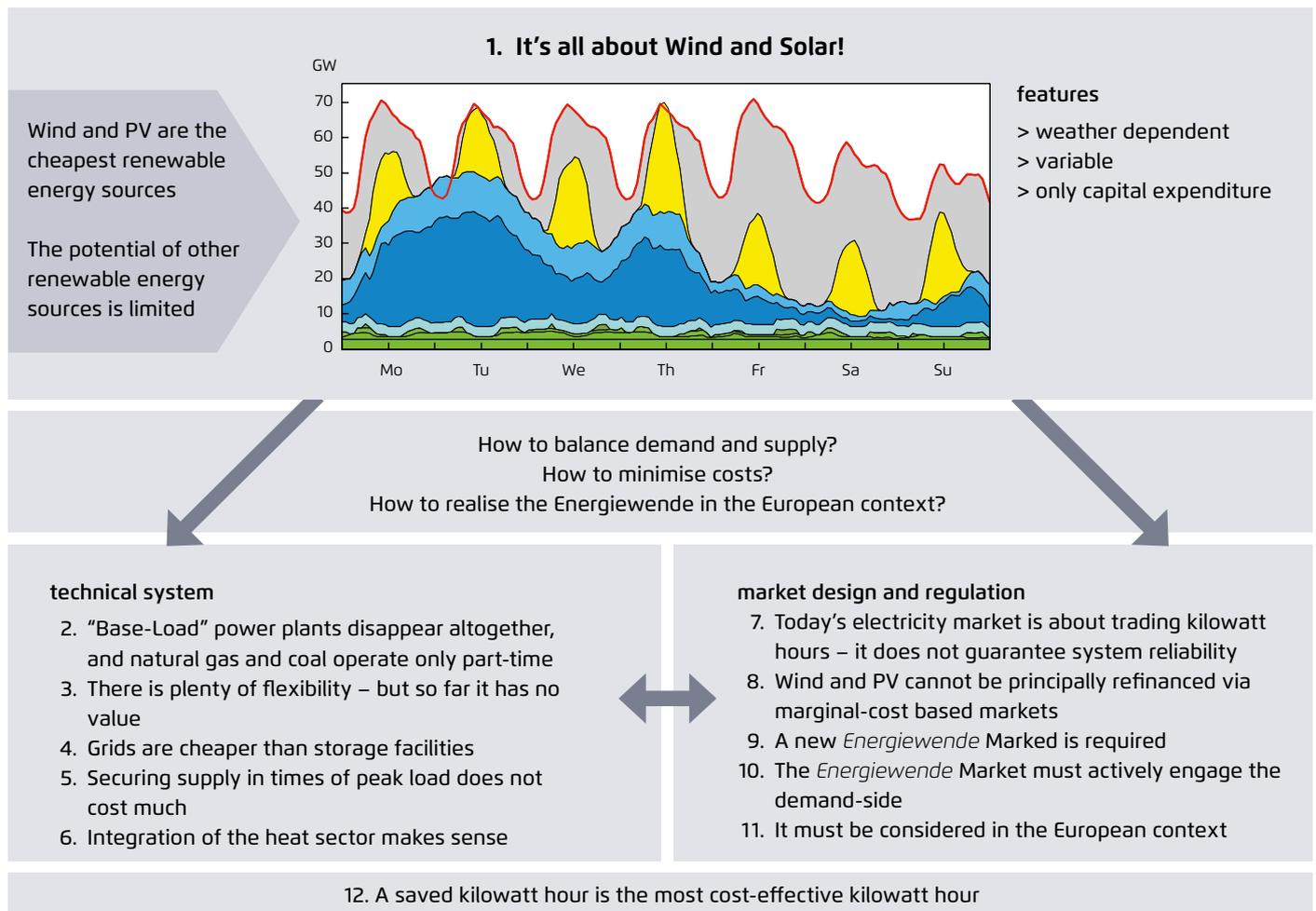
The "12 Insights on Germany's *Energiewende*" specifically describe the German context. However, we strongly believe that many of the developments we currently see in Germany will be highly relevant for other countries and regions as well – certainly, but not only, in Europe where Germany is a key part of the integrated energy system.

Our main insight – entitled "It's all about Wind and Solar" – certainly applies beyond Germany, as wind and solar

are abundantly available in most regions of the world and production costs are going down rapidly.

In many countries, wind power and photovoltaics will form the basis of a future, low-carbon energy system and bring with them similar challenges that Germany is facing today. We leave it to the reader to make up his or her mind on this assertion – and we look forward to any comments and ideas in this regard.

Rainer Baake
and the team of Agora Energiewende



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Insight 1: It's all about wind and solar!

Two winners have emerged from the technology competition initiated by the German Renewable Energy Act – wind power and photovoltaics, the most cost-effective technologies with the greatest potential in the foreseeable future

For the time being, the winners of the technological competition initiated by the German Renewable Energy Act of the year 2000 (Erneuerbare-Energien-Gesetz, EEG) have been determined: the lowest-cost ways to generate electricity from renewable energy are by wind power and photovoltaics (PV). Given the present state of the art, no other renewable energy technology can generate electricity in sufficient quantity at such a low cost. As a result, Germany's *Energiewende* will be based upon these two technologies. Underlying this fact is the enormous decline in cost for the key technologies in wind power and solar energy that has occurred during the past 20 years. For wind, the costs for generated power – despite rising raw material costs for steel – have fallen by about 50% since 1990. For photovoltaics, the change has been even more remarkable. In this sector, systems costs have fallen by 80 to 90% over the same time period. Furthermore, there is no end in sight to this trend toward falling costs for either technology.¹

All other renewable technologies are either significantly more expensive or have limited potential for further expansion (water, biomass/biogas, geothermal energy) and/or are still in the research stage (wave power, energy from osmosis processes, etc.)

Bioenergy's share of German power generation will continue to be limited to less than 10% for the long term (2012:

1 See IPCC (2011) and IRENA (2012a); (2012b). The cost of installing a photovoltaic plant in Germany has since fallen significantly more since the figures cited in these studies.

approx. 6%). The reason is that agricultural and forest acreage is limited in Germany and other countries, and the use of wood and energy crops in the energy system competes directly with many other potential land uses, such as raising food crops, producing raw materials for industry (for example, the paper or chemical industries) and nature conservation. In addition, biomass is a relatively expensive energy source for generating electricity, the costs of which have risen rather than fallen in recent years.² In addition, the quantity of low-cost, sustainably produced wood imports is limited, among other reasons due to the growing demand for food and biomass in developing and emerging countries.³

In addition to wind, PV and biomass, hydropower and geothermal both currently contribute to total power production. However, all forecasts suggest that these sources will not contribute substantially more to power production in the future. Even if some limited potential still exists for expanding hydropower in Germany, it will not play a central role in the electricity supply.⁴ Given the current state of the technology, the cost of power produced from geothermal resources will remain very high over the long term, and for this reason, its current contribution of less than one per thousand is not expected to increase very much in the future.⁵ Other technologies, such as tidal power, wave power and energy from osmosis are still in the research stage and are not nearly ready for large-scale application.⁶

2 In 2002, basic remuneration for small biomass plants was 10.1 ct/kWh, and in 2012 it is 14.3 ct/kWh. On top of this, there are additional bonuses of up to 18 ct/kWh which have been established in recent years. As a result, the average remuneration for electricity from biomass plants today is 19.6 ct/kWh.

3 See, for example DLR/FhG IWES/IfNE (2012); Prognos/EWI/GWS (2010); Prognos/Öko-Institut (2009); SRU (2011); UBA (2010).

4 See Ingenieurbüro Floecksmühle et al. (2010).

5 Thus, for example, the EEG remuneration rate of 9 ct/kWh in 2000 was increased to the current rate of 25 ct/kWh, without bringing about any significant increase in production.

6 More research support for all renewable energy technologies makes

By 2015, the cost for power produced by wind and photovoltaic plants will be 7–10 euro cents per kilowatt-hour – the cost of electricity from a system consisting of wind, PV and backup storage capacity will thus be about the same as electricity generated by new gas and coal-fueled plants

The EEG remunerates onshore wind farms at a current rate of about 7–10 (euro) ct/kWh and PV plants at about 12–18 ct/kWh; both rates dependent on plant size and location, and remuneration is guaranteed for 20 years.⁷ As a result of the decreases in the feed-in tariff established by the EEG and further decreases in the costs of these technologies, it will be possible by 2015 to generate electricity by newly built wind and PV power plants in the range of 7–10 ct/kWh.⁸

Since neither the wind nor the sun is always available, any power system that depends upon these sources must also have supplementary power plants, and for the time being,

sense overall as a way of further reducing costs and, if possible, creating renewable technologies for generating electricity with even more favorable power production costs than wind and PV.

7 See Federal Ministry for the Environment (2012a) and (2012b). Offshore wind power is currently significantly more expensive: The feed-in tariff in the EEG is 15 ct/kWh for at least 12 years, or, in the acceleration model, 19 ct/kWh for at least eight years. After 8 or 12 years, offshore wind facilities receive 3.5 ct/kWh. However, the time for receiving 15 ct/kWh is extended according to the distance of the plant from the coast and the depth of the sea. In addition, the network connection costs are covered through network fees as well as support from the KfW Development Bank's Offshore Guarantee Program.

8 This is generally valid for wind-power plants on land (onshore) as well as for larger PV plants. For offshore wind facilities, future cost trends remains to be seen, as the decline in current remuneration rates is only scheduled to begin in 2018 according to the EEG. Depending on their size, PV plants will be receiving a remuneration of approx. 9–14 ct/kWh as of the end of 2014 if they expand in line with the expansion corridor set in the EEG; if they expand very rapidly, depending on the size of the plant, the remuneration rate will be 6–9 ct/kWh. After this time, even smaller PV rooftop systems in sunnier locations in Germany will be able to produce electricity for 10 ct/kWh, for example, under the following quite realistic conditions: installation costs: €1000 per kWp; electricity yield: 1000 h per year; 25 years working life; operating costs: 1% of installation costs per year; interests costs for capital investment: 5% annually.

these will continue to be primarily dependent on fossil fuels. In the short term, existing power plants will take on this backup function (current electricity prices on the exchange: approx. 5 ct/kWh). In the medium term, investments will be needed for new fossil-fueled power plants to be able to cover the demand even at those times when no electricity can be produced from renewable energies. Given that the costs of generating electricity from new gas or coal power plants is similarly about 7–10 ct/kWh,⁹ and that providing peak power needs is also relatively inexpensive (see Insight 5), then by 2015, it is anticipated that the cost of generating electricity from a system based upon new wind, photovoltaic and flexible fossil fuel power plants will be comparable to that of alternative investment in traditional coal or gas-based power systems.

Wind and PV power are the two essential pillars of the *Energiewende*

Clearly, Germany's *Energiewende* will be based on wind power and PV. There is no realistic alternative path. By the time renewable energy covers one-half of total power demand, the share of wind (onshore and offshore) and PV will already be 35%. The greater the share of renewable energy, the more important will be the role of wind and PV when compared to other renewable technologies, whose potential for expansion is limited. According to the Federal Network Agency (Bundesnetzagentur) by 2022 wind and PV power will be generating about 70% of the power obtained from renewable energy¹⁰ Subsequently, their share will continue to rise to as high as 80–90%.

Figure 1 illustrates the importance of power generation from wind and PV for Germany's *Energiewende* over the medium term. It presents the findings of model calculations concerning electricity demand and generation in Germany for three different weeks in 2022. The upper red line represents demand in GW, and the different colors represent generation from renewable energy, while the gray area depicts

9 See (EWI) 2011, p. 27–29 and 40 or DLR/IWES/IfnE (2012), p. 217.

10 According to Lead Scenario B for the 2012 Network Development Plan.

Electricity Demand and Generation by Renewable Energy in Three Exemplary Weeks in 2022

1

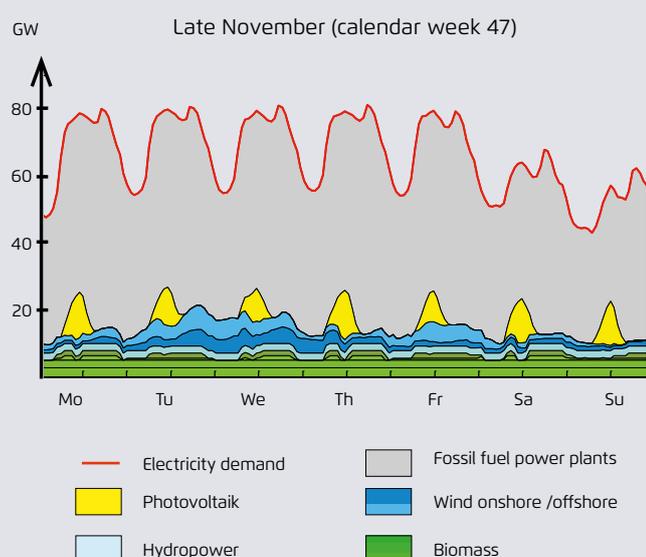
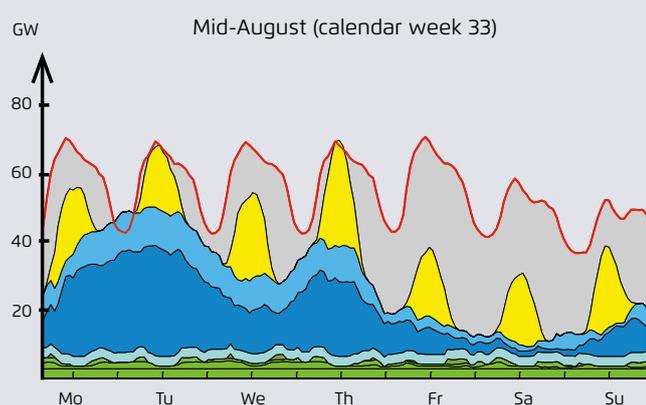
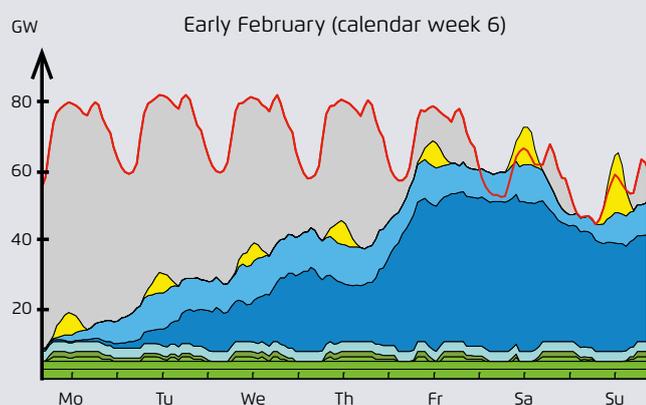


Illustration based on Agora Energiewende (2012a)

residual demand that will still need to be covered by existing fossil fuel power plants. The results show that as early as 2022, there will be about 200 hours during which power production from wind, sun, water and biomass will exceed Germany's total demand for electricity. However, there will also be many hours when renewable energy will only be able to produce a small quantity of electricity. From this analysis, we can identify important challenges, which are described further in this paper.¹¹

At the heart of the challenge for the *Energiewende* will be to continuously balance fluctuating electricity production from wind and solar plants with consumer demand. This will require flexibility – on both the supply side and the demand side.

Wind and solar energy plants have three key characteristics:

→ They dependent upon energy source availability; that is, power production depends upon the weather

Unlike fossil energy sources, the output from wind and PV power plants cannot be controlled in response to either demand for electricity or the price signals on the exchange. These power plants produce energy when the sun shines or when the wind blows.

→ They have high capital costs but (virtually) no operating costs

Running costs (maintenance, operation) for wind and photovoltaic facilities are very low, and represent about 1–3% of capital costs per year.¹² Because there is no need for fuel, the

¹¹ This graph was prepared by Fraunhofer IWES at the request of Agora Energiewende (Agora 2012a). The calculations were based upon what is known as Lead Scenario B from the framework of scenarios for the network development plan authorized by the Federal Network Agency at the end of 2011. Complete data for all 52 weeks can be found at www.agora-energiewende.de/download.

¹² Fixed operating costs of a PV plant are about 1-1.5% of capital costs per year, where the short-term marginal production costs of a functioning facility are zero. For wind power plants, operating costs are about 2 – 4% of capital costs per year, where the operating costs also include wear and tear of materials and as a result, the short-term marginal production costs are a bit greater than zero (see McKinsey (2010), p. 63; DLR/IWES/IfnE (2012),

marginal costs are virtually zero. This means that with wind and solar power, the initial capital investment pays almost completely for the cost of producing electricity over the next 20–30 years.

→ Their production of electricity fluctuates rapidly

As the result of weather variations, such as wind blasts or periods of calm as well as the passage of cloud banks, the power fed into to the system from solar and wind plants sometimes fluctuates widely. This means that the rest of the power system – fossil fuel plants, electricity demand, electrical storage facilities – must be very flexible in order to adjust to the fluctuating input behavior of wind and PV power plants.

These characteristics are fundamentally different from those of coal and natural gas; they profoundly alter the energy system and energy market

Natural gas and coal power plants are controlled according to the market price of electricity on the exchange, and their operating costs (fuel, CO₂ emissions rights) vary greatly. In addition, to date power plants have not been built with the technology to enable them to make rapid adjustments in production. The *Energiewende*, with a growing share of wind and solar power, will fundamentally alter the power system and the power market.

Wind and PV power should be expanded in tandem since they have mutually complementary features; generally speaking, the wind blows when the sun is not shining and vice versa.

Wind power plants are especially good at generating electricity in the winter, and solar plants in the summer. Most sunshine occurs around the middle of the day, whereas wind can happen at any time throughout the day – and often wind is blowing the least at those times when the sun

is shining at its strongest.¹³ Since electricity is relatively expensive to store because of efficiency losses, it makes sense to use less costly options for continuously balancing supply and demand from the perspective of the system as a whole. This includes raising the overall flexibility of the system (see Insight 3).

However, we should also take advantage of the differences in the input behavior of wind and solar power – even if electricity production costs are somewhat lower for wind power than for solar power.

This logic – using asynchronous input behavior as a way to minimize total system costs – also applies to the regional distribution of renewables. Since the wind blows at different times in different regions in Germany, wind power should not be generated exclusively in Northern Germany, and solar power should not be generated only in Southern Germany.

It is true that production costs for wind power are somewhat lower on the coast than in the rest of Germany, and that for solar power they are lower in Bavaria and Baden-Württemberg, but if generation only took place in the most advantageous regions, one could only secure wind or solar power at times when weather conditions in that region permitted. From the perspective of optimizing the system as a whole, it makes sense to take advantage of the differences in weather conditions across Germany in such a way that electricity production from wind and PV is distributed across the greatest possible number of hours in the year, with electricity transmitted between regions using an expanded transmission grid. Little research has been conducted as of yet about the precise times that PV and wind power plants typically produce electricity and which temporal feed-in patterns new facilities should have.

p. 1 of the data appendix; IRENA (2012a); IRENA (2012b).

¹³ See for example, the analyses by Gerlach/Breyer (2012) for central Germany and E.on Bayern (2011) for Lower Bavaria.

Insight 2

“Base-load” power plants disappear altogether, and natural gas and coal operate only part-time

Wind and PV will form the basis of the power supply, with the rest of the power system being optimized around them; most fossil-fueled power plants will be needed only at those times when there is little sun and wind, they will run less hours, and thus their total production will fall: “Base load” power plants will be a thing of the past.

“Base load” is a category of demand for electricity and, in Germany, refers to the 35 to 40 GW that is the minimum consumed at all times over the year. Previously, the base load was supplied through fossil-fueled power plants that ran “24/7,” which led to the misleading term, “base-load power plant.” By guaranteeing priority access to the grid, the

EEG has turned renewables into “base load power by law.” Renewable energy is effectively taking the place of conventional base load power plants. In the future, wind and solar power will cover an ever-growing share of the electricity demand. Already in 2022, total load (base, mid- and peak-load) will be completely covered by renewable energy alone during many hours throughout the year, as shown in Figure 2 below. In the week that is illustrated, a large number of the coal and gas fired power plants remain out of service during the first half of the week, but are needed during the second half. Use of the remaining fossil-fueled power plants must be oriented to demand and the production from renewable energy sources.

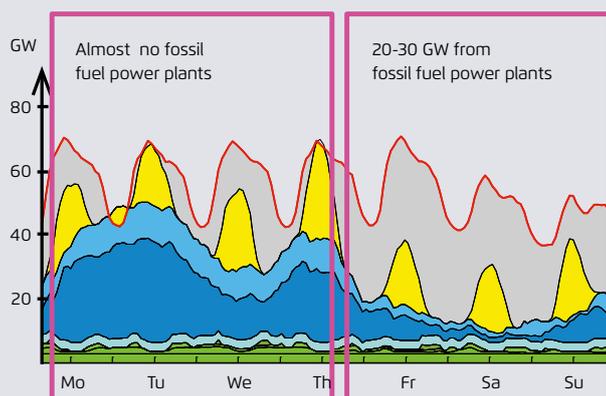
Wind and PV will reduce the total quantity of power produced from fossil fuels, and thus reduce the load factor and number of operating hours. With a 40% share of power coming from renewable energy, only 10 to 25 GW conventional capacity operating between 6000 to 8000 hours per year will still be needed.¹⁴ In ensuing years, this need will decrease even further.

Rapid changes in feed-in from renewables as well as forecasting uncertainties will create new requirements for both short- and long-term flexibility

The fluctuating patterns of generation from wind and solar power will set completely new requirements for the power plants of the future: electricity generation from controllable

Demand for Fossil Fuel Power Plants in 2022:
Example of a Week in August

2



- From Monday to Thursday, wind and solar power cover most of the demand for electricity, fossil fuel power plants are scarcely needed
- Between Thursday afternoon and Sunday morning, 20-30 GW of additional power plant capacity are continuously required

Illustration based on Agora Energiewende (2012a)

¹⁴ See VDE (2012a), p. 43; Consentec/r2b (2010a), p. 51; IWES (2009). For 40% renewables, the VDE (2012a) calculates the need for 10-15 GW of capacity which would be used almost constantly (more than 8000 load hours per year). For 50% renewables, Consentec/r2b (2010a) calculates that 18 GW would be used for more than 6000 load hours, and IWES (2009) calculates a need for 21-26 GW for more than 7000 load hours.

power plants must be rapidly ramped up and down over short periods of time in order to compensate for these fluctuations. As the share of wind and solar power increases, this will also apply to the few remaining "base-load power plants". In the future, all remaining fossil fuel power plants will need to operate on a flexible basis.

The quantities of wind and PV can never be accurately predicted in advance. They always entail forecasting uncertainties, which become ever greater the further one looks into the future. The daily and hourly forecasting of wind¹⁵ and PV may improve with more accurate weather forecasting data. With the right regulatory framework, producers can take account of these short-term forecasts when scheduling the operation of their power plants, thereby optimizing generation.

Long-term forecasting for one or more years in advance is even more difficult, and fraught with greater uncertainty. Major fluctuations occur between one year and the next, especially with regard to wind. This was particularly evident in 2010 when power production from wind farms in interior locations in Germany was 25% lower than the average for the previous ten years, and in coastal areas, it lagged by 15%.¹⁶ Since the total installed capacity of non-renewable power plants must be sufficient to accommodate for wind-poor years, they will experience lower load factors during years with ample wind.

Over the medium term, combined heat-and-power as well as biomass plants need to be operated according to the demand for electricity

Today, the operation of combined heat-and-power (CHP) and biomass power plants is not generally dictated by demand for electricity. Instead, CHP facilities are driven by the need for heat, which is to say, when there is a need for

15 For offshore wind and PV, many solutions have already been developed for the challenges that have arisen. Offshore wind is characterized by further challenges resulting from greater and more rapid fluctuations, and until now, there have been fewer measuring points, which may require new technological solutions.

16 See IWR (2012).

heat, the facility runs to produce heat, and merely produces electricity as a by-product. Similarly, most biomass plants run in continuous operating mode, since they are most economical this way as a result of remuneration rules set by the EEG. In the medium to long term, this will have to change. Electricity generation from CHP plants shall increase to 25% by 2020 – according to official government targets. Therefore, over the medium term, these plants will constitute the majority of controllable power generation in Germany.¹⁷ While CHP and biomass power plants only contributed about one-fifth of controllable power generated in 2010, already in 2020 they will produce more than one-third of such power.¹⁸ Therefore, as wind and PV take on a greater proportion of total electricity production, the operation of CHP and biomass plants will have to be geared to the demand for electricity.

Demand side management and storage contribute to maintaining system balance

Flexibility options such as demand side management and pumped storage will help assure the more efficient use of the power plant fleet in the future. Through demand side management, the demand for electricity will be shifted to those times when more wind and sun are available. During periods of high renewable power availability, pumped storage facilities will take in electricity. When there is little wind and the sun is not shining, they release it back into the system. This approach will reduce expensive start-up and shutdown procedures at fossil-fueled power plants, optimize the use of cheaper power plants, and minimize overall costs to the system as a whole.

17 See Cogeneration Protection Law, Paragraph 1.

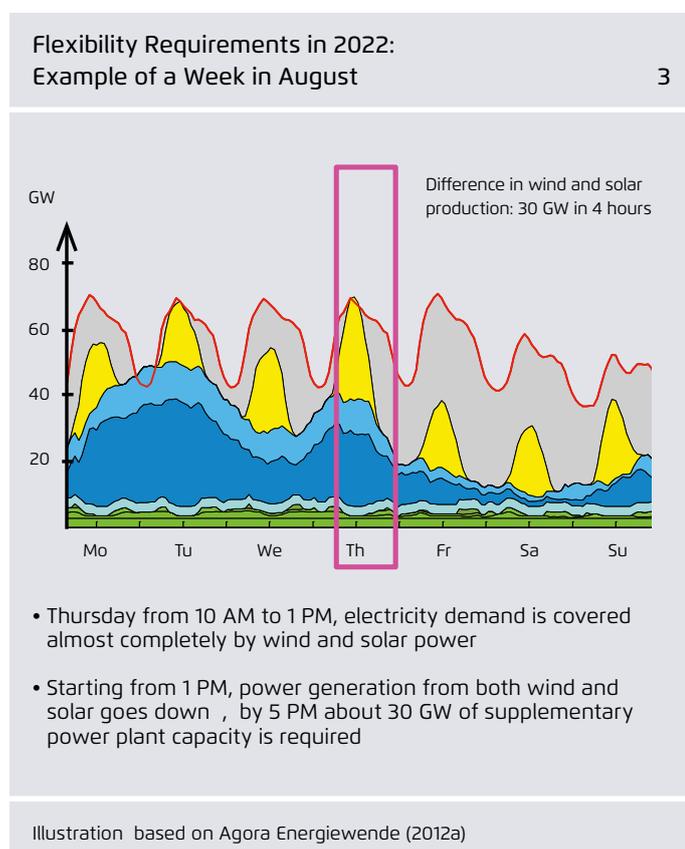
18 See the Federal Environment Ministry's Lead Study Renewable Energies 2011 (DLR/IWES/IFnE (2012)), p. 19; Scenario 2011 A describes a capacity of 22 GW of power produced by CHP and biomass for 2010, and 90 GW from other power plants; the anticipated capacities for 2020 are 31 GW from CHP and biomass and 61 GW from other power plants; for 2040: 30 GW from CHP and biomass and 32 GW from other power sources. The share for biomass in total electricity generation thus remains limited to about 10%, and the power provided from non-biomass plants without CHP to about 3 GW.

Insight 3

There's plenty of flexibility – but so far it has no value

In the future, fluctuations in wind and PV production will demand significantly greater flexibility from the power system

As previously shown in Insight 2, the electrical system will have to respond more flexibly as the share of wind and PV increases. Figure 3 illustrates this need for flexibility. In the case presented, the wind dies down in tandem with a drop in the generation of solar power. As a result, controllable power plants have to cover a major portion of the demand within a few hours. In a worst case scenario, demand might increase at the very same time – for example, if a large part of the population comes home at the time of sunset and turns on electrical appliances, television sets and lights.



At a renewable energy share of 50% in the German power system, one has to anticipate extreme cases in which the load that must be covered by controllable power plants increases by about 40 GW within a span of four hours.¹⁹ This is the equivalent of more than half of today's load in Germany. Within a 15-minute-interval, changes in load of up to 6 GW can be expected. The need for this level of flexibility will create entirely new challenges for power systems in the future.

Technical solutions to provide sufficient flexibility readily exist today

The need for flexibility can be met through various flexibility options on the supply-side, demand-side, through storage and improved grids. With increasing requirements for flexibility, these options should be deployed in the order of their overall economic cost efficiency. In addition to grid expansion (see Insight 4), from today's perspective the most important flexibility options are as follows:

→ Operation of combined heat-and-power and biomass plants according to electricity demand

To achieve flexibility in an efficient way, we first need to avoid unnecessary inflexibilities in the electrical system. Power plants that are readily controllable from a technological perspective should be run to optimally supplement generation from wind and PV plants. As described in Insight 2, this is not the case today for either CHP plants or biomass facilities. In the future, however, such plants will constitute a large percentage of the controllable power generation fleet in Germany. Accordingly, they will need to be operated above all to respond to electricity demand, along with the demand for heat. This form of operation poses no technical

¹⁹ See IAEW/Consentec (2011), p. 17; considering a scenario with 50% renewable energy in 2030.

problems and is associated with relatively low costs. In the case of CHP plants, this merely requires that heat is fed into storage facilities or district heating grids, which can be done for a few hours without major challenges (see Insight 6).²⁰ In the case of new biomass plants, this merely requires an adapted design of the overall facility – for example, with regard to the relationship between fuel storage capacity and generator output.

→ **Improved flexibility of fossil-fueled power plants (minimum output, start-up times)**

Fossil-fueled generators offer very large potentials for improved flexibility. Coal and gas-fired power plants can be made more flexible through technical and organizational modifications. The minimum output rate can be reduced, load gradients increased, and start-up times shortened. The differences between the usual degree of flexibility today and the technical optimization potential are presented in the following table (Figure 4).

For example, an optimized gas and steam turbine could be brought into full service within two hours (today, this takes four hours). Moreover, optimization would allow 10 GW gas and steam turbines that are already running to adjust

²⁰ Upgrading to heat accumulators is subsidized by the 2012 amendment to the Combined Heat and Power Law.

their load by as much as 4 GW within five minutes (today: 1 GW). Similarly, optimization would allow to ramp down generation output from 10 GW hard-coal fired plants under continuous operation to 2GW (today: 4 GW).

Greater flexibility from retrofitted existing power plants and from new plants would also contribute substantially to reducing the minimum feed-in from thermal power plants (the so-called “must-run” level).²¹

→ **Avoid generation peaks from wind and PV or use them for heating**

With very high shares of electricity generated by wind and solar it is likely to make economic sense in the future to limit generation peaks or to use them for producing heat. Yet designing the grid to transport every generated kilowatt-hour would be unacceptably expensive, as the grid would be designed for transport capacity that is only required for a few hours during the year. Wherever possible, electricity that cannot be transported should be used purposefully. One option is to use such power for heating (see Insight 6). Heat production can take place using electrical heating rods in warm water accumulators (1 kWh of electricity generates

²¹ Today, depending on the particular time point, there is still a minimum must-run capacity of up to 25 GW in Germany required for system stability, but it should be possible to reduce this in the long term, see BMU (2012c), p 22.

Flexibility of Fossil Fuel Power Plants						4
Optimization potential (first figure) and typical status today (figure in parentheses) per 1000 MW						
		Hard coal power plant	Lignite coal power plant	Combined cycle power plant	Gas turbines	
Minimum load	MW	200 (400)	400 (600)	300 (500)	200 (500)	
Maximum change in load within 5 minutes	MW	300 (75)	200 (50)	400 (100)	750 (400)	
Start-up time cold start	h	4 (10)	6 (10)	2 (4)	<0.1	

Illustration based on VDE (2102a)

1 kWh of heat) or by using heat pumps (1 kWh of electricity generates about 4 kWh of heat).

→ Load shifting and interruptible loads in industry

Load management is another cost-effective flexibility option with great potential, especially in industry. Industry consumes about 40% of the electricity generated in Germany,²² and a considerable proportion of this consumption takes place in large plants with centrally controlled processes. From a technical point of view, it would be readily possible in many cases to shift demand by several hours by adapting processes and, if necessary, installing storage capacity for intermediate products, for heat, cold or compressed air. The flexibility potential achievable in industry over the medium term is estimated to be about 4.5 GW.²³ Further large and cost effective potentials can be achieved in the area of commerce. Large refrigeration or heating facilities, for example, can be centrally controlled as well as upgraded to store heat or cold for a short time.

The challenge is not about technology and control, but rather about incentives

The flexibility options described here are already technically available today and can be implemented at relatively low cost. Since they primarily involve "large-scale" facilities (CHP plants, biomass facilities, industrial processes, large heat storage), the problem of controlling them is technically easy to solve – in contrast to "small-scale" household facilities such as washing machines or refrigerators. The major challenge in accomplishing this is not about technical implementation, but about providing effective incentives. The goal should be that in each case, the most cost-effective option is used first, and to accomplish this, there needs to be a level playing field for competing flexibilities. Both the supply side and the demand side need to be able to participate in this competition (see also Insight 10). The speed at which flexibility potential can be tapped once the proper incentives are provided was demonstrated by the response to negative prices on electricity markets in Germany. For

example, in 2009, as a result of high feed-in from wind and PV plants in a number of hours with low demand, and because of the lack of flexibility in conventional power plants, in nearly 100 hours a situation occurred in which market participants were paid for accepting electricity. By 2011 the number of hours with negative prices had been reduced by a factor of 10 – despite significant increases in generation from wind and PV.²⁴ Clearly, market participants were able to provide additional flexibility.

Leveraging small-scale flexibility options at the household level by using smart meters is currently too expensive

Seen from today's perspective, "small-scale" flexibility options, which can be leveraged in households by using smart meters, are simply too expensive. It is only in the long term that such options will make an efficient contribution to the overall system. Small-scale options should only be leveraged after all of the more cost-effective options have been exhausted. For example, in order to use a washing machine as a flexibility option it must contain a dedicated control system. The household must have a meter able to measure real-time electrical consumption, and a control signal from the electricity market has to get to the washing machine. The specific expense for implementing such a system is very large in comparison to the specific expenses for the large-scale flexibility options described above. In the long-term perspective, however, especially heat pumps and electrical vehicles will create substantial potential for demand side management at the household level. For this reason, it is important to make sure that in further development of these technologies, consideration be given to their potential contribution to increasing the flexibility of the power system.

²² See DLR/IWES/IfmE (2012), p. 20; EWI/GWS/Prognos (2011), p. 37.

²³ See VDE (2012b), p. 55.

²⁴ See EnBW (2012), p. 5.

Insight 4

Grids are cheaper than storage facilities

Grids decrease the need for flexibility: fluctuations in generation (wind and PV) and demand are equilibrated across large distances

The larger the area connected by the grid, the greater the extent to which fluctuations in generation and demand can be pooled: while generation by a single wind farm (for example, on the North Sea coast) may vary greatly, the sum of the generation from all wind turbines in Germany (for example, on the North Sea coast, in Thuringia and in Bavaria) is much more balanced. The same is true for demand, where regional fluctuations offset each other as well. More extensive geographical linkage reduces the need for flexibility.

Grids enable access to cost-effective flexibility options in Germany and Europe

Grids also make it possible to take advantage of the cheapest flexibility options over larger distances – in Germany and throughout Europe. For example, at times when there is a large amount of sun and wind, surpluses can be sold to European neighbours instead of having to be stored or cut back.

By 2020, surpluses of up to 22 GW are to be expected during certain hours in Germany, and by 2030, such surpluses could be as great as 41 GW.²⁵ If this demand for flexibility was to be met exclusively through storage facilities, it would be very expensive, since most of these facilities would be used only rarely. Instead, using grid connections to European neighbours, a large portion of the surplus could be sold internationally. During times of little wind and sun in Germany, electrical power could be bought back from neighbouring countries. In this way, a grid connection functions as an "indirect storage facility."²⁶ Expansion of transport capacities to nations with especially cost-effective flexibility options would be most advantageous – for example,

²⁵ IAEW/Consentec (2011), p. 20.

²⁶ See Prognos (2012), p. 17.

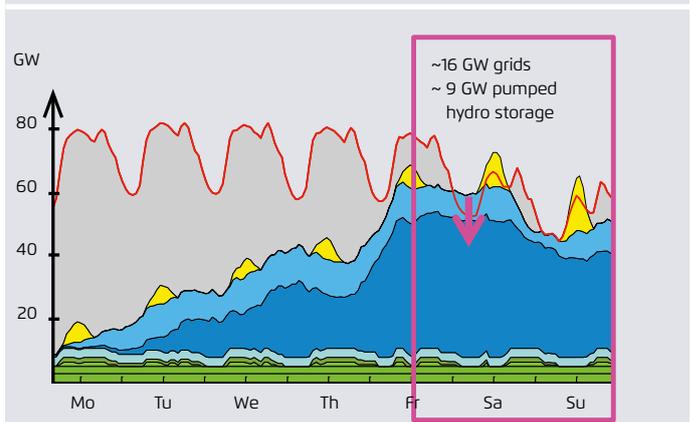
to alpine nations and Scandinavia, with large amounts of hydroelectric and pumped storage facilities. The production of electricity by hydroelectric plants in those nations can be throttled back when cheap electricity is available in Germany. For Germany, it would be more advantageous to sell electricity than to store it. For the opposite case of times with low wind and PV generation in Germany, it may be cheaper to buy electricity abroad than to provide power plants in Germany exclusively for periods of peak demand.

Transmission grids reduce overall system costs with relatively small investment costs

Transmission grids reduce overall system costs since they reduce the need for flexibility and at the same time permit the use of the most cost-effective flexibility options.

Significance of Grids and Pumped Hydro Storage in 2022: Example of a Week in February

5



- In a week in early February there is so much wind that a significant surplus is produced for almost two days
- During this period, about 16 GW can be exported using grids
- An additional 9 GW can be taken up over about five hours in existing pumped storage facilities
- New storage technologies would not be used due to their higher costs (assuming sufficient grid expansion)

Illustration based on Agora Energiewende (2012a) and TAB (2012)

Furthermore, the costs for increased transmission capacity are relative low. Overall, the expansion of transmission grids across Europe will only constitute about 6% of overall costs for the power system in the long term.²⁷

Expanding and upgrading distribution grids is less expensive than local storage facilities as well

The same logic that applies to transmission grids is also true for distribution grids. Local surpluses can be transferred to neighbouring regions or to the transmission grid by expanding distribution grids and upgrading transformers for transferring electricity to high-voltage grids. From today's perspective, new construction and the upgrading of distribution grids is many times more cost effective than local storage using new storage technologies.²⁸

New storage technologies will only become necessary as the share of renewable energy exceeds 70 percent

For quite some time to come, grid expansion will continue to be the cheaper option for integrating renewable energy in the power system in comparison to new storage technologies. From today's perspective, new storage technologies such as batteries, adiabatic compressed air storage, and *power-to-gas* systems should only be deployed in the long term.²⁹ Currently, the costs for these technologies are prohibitively large; and will likely remain high in the medium term as well. To keep overall system costs low, new storage technologies should only be used after the flexibility potentials of other, more cost-effective options have been fully exhausted. Since they are relatively expensive flexibility options, new storage technologies will only contribute to limiting overall system

²⁷ McKinsey (2010), p. 45.

²⁸ Consentec/r2b (2010b), p. 36.

²⁹ This assessment is essentially in agreement with the expert opinion presented in BMU (2012b), but it needs to be qualified by two factors. For one, in the face of long term delayed or limited grid expansion, storage facilities could represent a second-best efficient option, and for another, breakthroughs in the manufacturing costs for new storage technologies could make them more cost-effective in the future.

costs in Germany at the point when renewable energy accounts for about 70% of power generation.³⁰

Local PV- battery systems may provide a business case for individual investors sooner – because of savings in taxes and fees

Battery storage systems combined with PV power units can enable households and firms to use a greater proportion of the decentralized power they generate and to purchase less electricity from the system. The savings in taxes and fees (grid charges, taxes, EEG levies, etc.) incurred can make investments in facilities of this kind attractive from an individual economic perspective in the medium term. This does not by any means imply that decentralized storage facilities will reduce the overall cost of electricity generation in Germany. The main reason for this is that most taxes and fees are calculated per kWh, but overall costs for the system are not reduced proportionately with the reduction of kWh purchased from the grid. For example, increasing private consumption does not reduce the costs for transmission and distribution grids or for assuring system reliability, but merely leads to a different distribution of these costs across the kWh still purchased from the grid. Presumably no private homeowner or firm will chose to be disconnected from the grid. For the design of the grid, however, the most salient factor is not the annual quantity of electricity transported, but instead, the maximum required capacity. Should a breakthrough occur in the costs of battery storage technology (for example, related to the accelerated deployment of electric vehicles and economies of scale for lithium-ion batteries) an accelerated expansion of decentralized storage can be expected – if and as long as the infrastructure costs for the electrical system are apportioned according to kilowatt hours and not according to connected load.

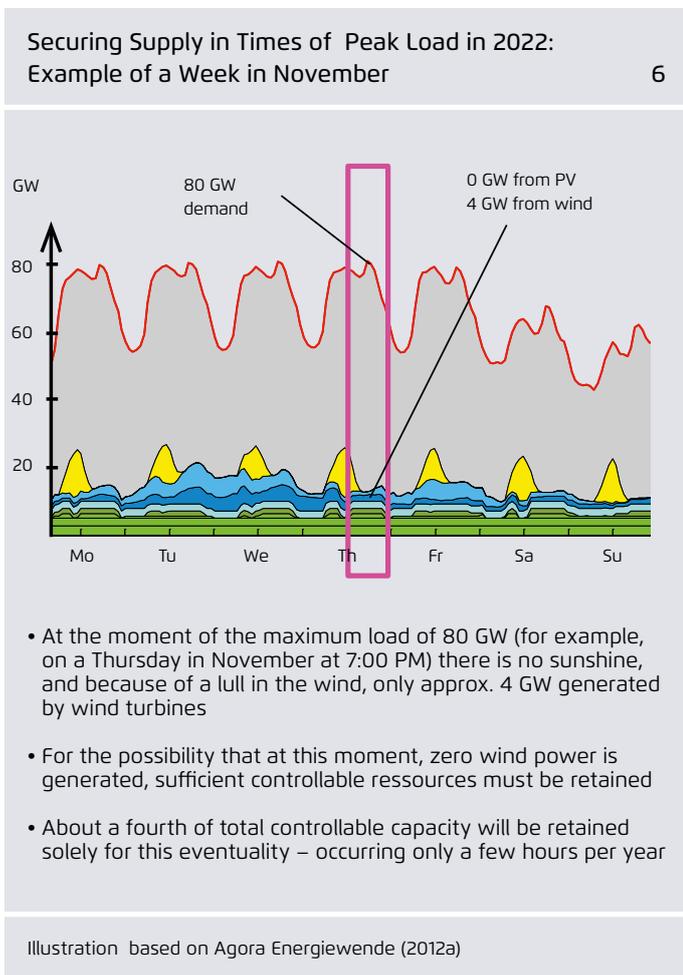
³⁰ 70% is a rough estimate in the case of the German power system. The specific share of renewables, at which new storage technologies will be able to contribute to reducing total system cost depends mainly on the type of renewables (fluctuating vs. controllable), the residual power plant fleet (amount of CHP, flexible generation), the level of interconnection and the future cost of storage technologies. It is likely to be a similar percentage in most other countries which are able to connect to a transmission grid.

Insight 5

Securing supply in times of peak load does not cost much

At certain times (e.g. during windless days in the winter), wind and PV cannot contribute to coverage of peak loads, and, for this reason, controllable resources will be required in the same order of magnitude as today

Power supply must be secured during peak-hours even when there is no wind blowing and the sun does not shine – even if a major power plant goes out of service unexpectedly. Wind and PV, as naturally fluctuating power sources, can only make a small contribution in such moments to assuring system reliability. Figure 6 illustrates such a potential supply and demand situation.



Accordingly, to assure the same level of system reliability in the future, peak demand levels experienced today will need to be covered by resources other than wind and PV. This type of controllable resources can be provided both on the supply-side by power plants, as well as on the demand-side through controllable loads.

Peak-load can be met reliably by firm generation capacity, or be reduced through demand-side measures; almost a quarter of the demand (approx. 15 to 25 GW in Germany) occurs during only very few hours in the year (<200).

A new feature of the "Energiewende world" is that major quantities of controllable resources will be required that will only be used during a few hours of the year or only as a reserve. As can be seen in Figure 7, it is predicted that by 2020 Germany will need about 20 GW of controllable capacity, which will almost never be used or used only for a few hours each year. The graph presents calculations by the VDE [German Electrotechnology Association] based on the assumption of a 40% share of renewable energy in 2020.

On the lower axis, load ranges are presented in GW, and the continuous light blue (2010) and violet colored (2020) lines indicate the number of hours per year that the respective power plant capacity will be required in Germany. According to these calculations, the load ranges between 65 and 85 GW will be used for less than 100 hours per year. These 20 GW make up one fourth of the total required capacity of approximately 80 GW. Many other studies have come to a similar conclusion and determined, depending on the underlying assumptions, that between 14 and 27 GW of gas turbines or other options to provide controllable resources will be needed, and that these resource would be used for only a few hours during the year.³¹

³¹ See Consentec/r2b (2010a), p. 78f; IWES (2010), p. 94; TAB (2012), S. 103; ECF (2010), Appendix Generation, p. 16.

Demand for Controllable Capacity to Cover Maximum Peak Loads

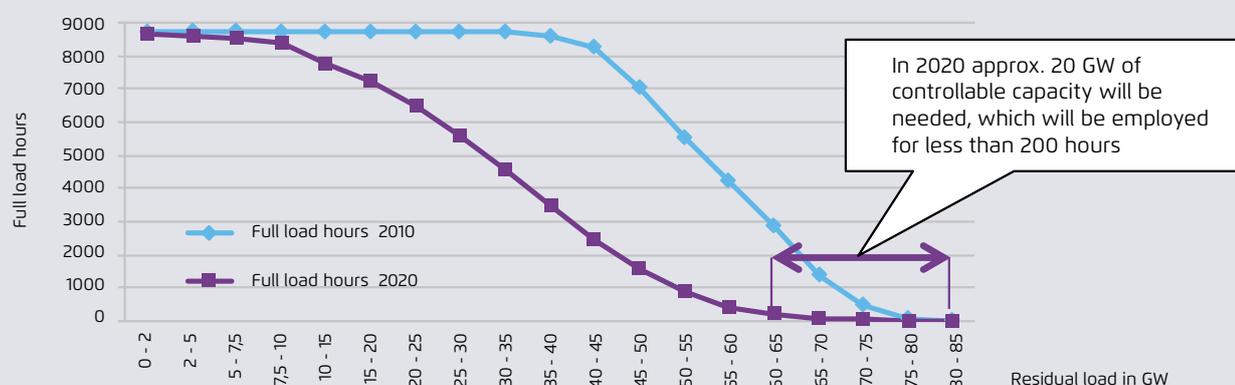


Illustration based upon VDE (2012a)

Gas turbines can meet this demand quite cheaply (35–70 million EUR per year per GW), controllable loads or retired power plants might be even cheaper

The need to cover peak-load in times when high load intersects with minimal feed-in from wind and PV does not need to be met by using expensive, "regular" power plants. Instead, it is possible to use more cost-efficient open cycle gas turbines (OCGTs) for this purpose. OCGTs have been used for generating electricity during peak load periods for many years and are capable of reaching their full capacity in less than ten minutes. Because of their relatively low efficiency – an efficiency factor of about 30% compared to about 60% for combined-cycle gas turbines (CCGTs) – and their associated high fuel costs, OCGTs are not well suited for continuous use in electricity production. However, for the new *Energiewende* world, as a way to cover peak load during only very few hours per year, OCGTs represent a cost-effective option. Their expected costs per GW per year are between 35 and 70 million EUR.³²

In principle, other options can perform this function just as well – as long as they provide the same level of reliability. On the supply-side, such options include the use of older, retired power plants or units as well as smaller diesel and

gas generators, which are often employed for emergency power generation. Experiences in other countries show that the demand side can provide a promising and inexpensive contribution as well – for example, through controllable loads in industry. In the US, this form of controllable capacity has been shown to be a very cost-efficient option (see Insight 10).

European cooperation reduces the cost and simplifies securing supply in times of peak loads

Through the pooling of controllable capacity with other European countries, the cost for securing supply in times of peak-load is reduced even further. For one thing, the combined peak-load across several countries that must be covered without wind or PV is smaller than the sum of the individual peak loads, since these peaks never take place at exactly the same time. The load curves differ significantly and fluctuating production does not reach minimum levels in all countries simultaneously. In addition, neighbouring countries can jointly use the most cost-effective options at any particular moment – regardless whether these are controllable loads, retired power plants or new OCGTs. In this way, costs can be reduced for all participating countries.

³² TAB (2012), p. 114; BMU (2012b), p. 21.

Insight 6

Integration of the heat sector makes sense

The heat sector offers enormous potential for increasing system flexibility

As the power system is adapted to the fluctuating output from wind and PV power, it is important to keep in mind its interaction with other energy sectors. In the future, the heat sector will play a pivotal role in the transition of the power system. There are three reasons for this:

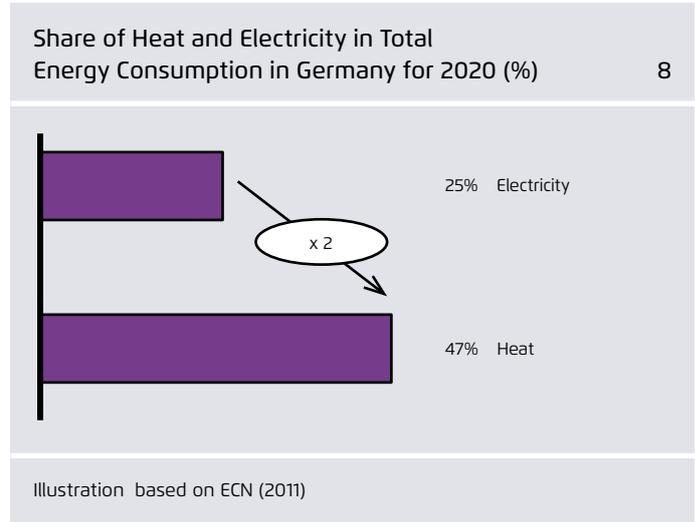
→ **Energy consumption for heating is twice as large as for electricity; gas and oil must (almost) entirely be replaced to achieve emission targets**

Total energy consumption in the heat sector in Germany is twice as large as that in the electricity sector, as the 2020 forecast in Figure 8 exemplifies.³³ To meet Germany's official targets for greenhouse gas reduction – 80% to 95% by 2050 – energy consumption for heating must decrease and renewables must replace oil and gas in heat generation almost entirely. Due to the limitations of biomass (see Insight 1), biogenic fuels are likely to assume only a small share of that burden. In the long run, both the heat sector and the transportation sector must increase their utilization of electricity from wind and PV.

→ **Heat is easy to store – contrary to electricity**

Unlike electricity, heat is easy to store. Heat for homes (warm water and interior heating) can be stored easily in insulated water tanks at private residences, in city-wide district heating systems, or in decentralized local heating networks. Thermal storage systems like these can supply heat for several hours or days at very low cost. Energy losses are far lower than those associated with power storage. The properties of heat also extend to cold, which can be stored for short periods at relatively low cost with relatively low levels of energy loss, for example in commercial refrigeration.

³³ See ECN (2011).



→ **Most heat is needed in winter, when winds are strongest**

Most of Germany's heating needs arise from October to April. These are also the months in which winds – and wind power – are strongest (see Figure 9). This is an advantageous correlation, as electricity from wind is likely to be the least expensive source of energy for Northern Europe.

CHP plants already provide a link between the electricity and heat sectors; in the medium term, dual-mode heating systems, capable of using either fuel or electricity will be deployed; over the longer term, integration will occur by using a common fuel – natural gas, biogas, or power-to-gas

Combined heat and power plants (CHP) produce both heat and power and already provide a link between the electricity and heat sectors. While operation today mostly follows the demand for heat, these facilities can be easily upgraded to be responsive both to demand for electricity as well as demand for heat (Insight 3). This upgrade is done by the addition of a thermal storage system – if there is little demand for heat, but only for power (e.g. in times of

Heating requirement and Wind Power Generation in Germany per Month

9

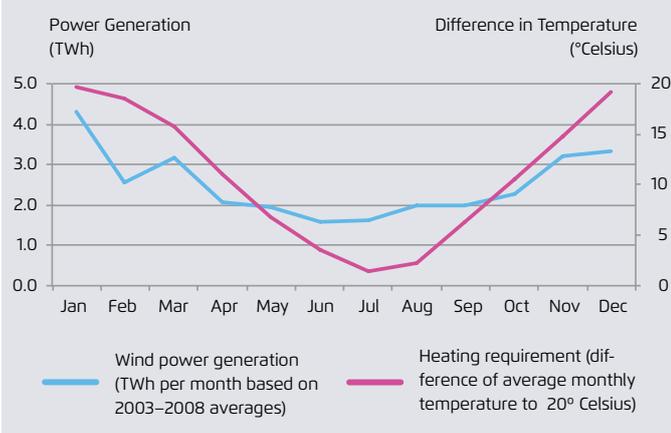


Illustration based on ISI/ISE (2009) and DWD (2012)

little wind) the plant produces power and stores the heat. This approach is already being used by municipal utility companies (Stadtwerke) and other electricity producers. Facilities in Flensburg, Lemgo, and Hamburg are already

considering installation of, or have installed such *power-to-heat* systems.

In the medium term, dual-mode heat systems will be used. Such systems link the power and heat sectors and provide a high degree of flexibility by producing heat either with fossil fuels or with electricity. At times of high power production from wind and sun these systems use electricity to generate heat, taking advantage of the low power prices. When wind and sunlight levels are low, and power prices are high, they use natural gas or oil instead.

Longer-term, both sectors will increasingly be linked by a common and interchangeable gaseous fuel – natural gas, biogas, or *power-to-gas*. This fuel can be used for centralized or decentralized electricity generation, for electricity and heat generation in CHP plants, or in systems used only for generating heat. The advantage of such a gaseous fuel is that it can be stored over long periods, and an extensive storage infrastructure – caverns, pipeline networks – is already in place.



Insight 7

Today's electricity market is about trading kilowatt hours — it does not guarantee system reliability

Today's electricity market handles energy quantities (*Energy-Only*)

Today's electricity market is an energy-only market: suppliers and consumers trade in kilowatt hours, i.e. a specific amount of energy at a specific point in time. The contractual relations between participants do not address system reliability. This is the responsibility of the grid operator, who must maintain the requisite balance between demand and supply in every moment, in order to maintain a stable and reliable system.

The price of electricity is determined in each hour by the operating costs of the most expensive plant running on the system (marginal costs); this mechanism ensures that power plants with the lowest operating costs are run first, followed by those with higher operating costs.

Prices on today's electricity market are determined by what is known as the merit order. Different energy suppliers offer electricity from available power plants to the market at a certain price. Electricity generated from wind and solar energy is cheapest. Next, by order of increasing price, comes electricity from water, electricity from nuclear power, electricity from lignite, and (depending on CO₂ and fuel prices) electricity from hard coal and gas-fired plants (see Figure 10). The cheapest electricity is used first. As consumption increases, more expensive power plants kick in to cover demand. These power stations supply electricity only until demand is met. The most expensive power plant needed to cover demand – the marginal power plant – determines the electricity price on the spot market.³⁴

³⁴ Operators of marginal power plants try not to base their prices on their own variable operating costs. Instead, to

The more electricity generated from wind and solar energy, the lower the operational costs of the plant that serves as the marginal power station, thus prices on the exchange vary in accordance to the levels of wind and sun.

The energy-only market may not provide sufficient incentives for new and existing resources to continuously ensure system reliability.

There is heated debate among economists whether today's energy-only markets can guarantee system reliability. Arguments against are, inter alia, the lack of elasticity in electricity demand, the missing money problem for power plants with few operating hours, and regulatory uncertainty. On the other side it is argued that every demand produces a supply.³⁵ All in all, it is fair to conclude that economic theory cannot answer the question once and for all.

Regulatory agencies in a number of countries with competitive wholesale electricity markets (e.g. United States, Brazil, Spain, United Kingdom, South Korea) have therefore decided to introduce additional measures to ensure the availability of sufficient firm generation capacity. The reason behind this is that system reliability is considered a public good, where there is a high risk that the energy-only markets alone do not deliver at an adequate level.³⁶

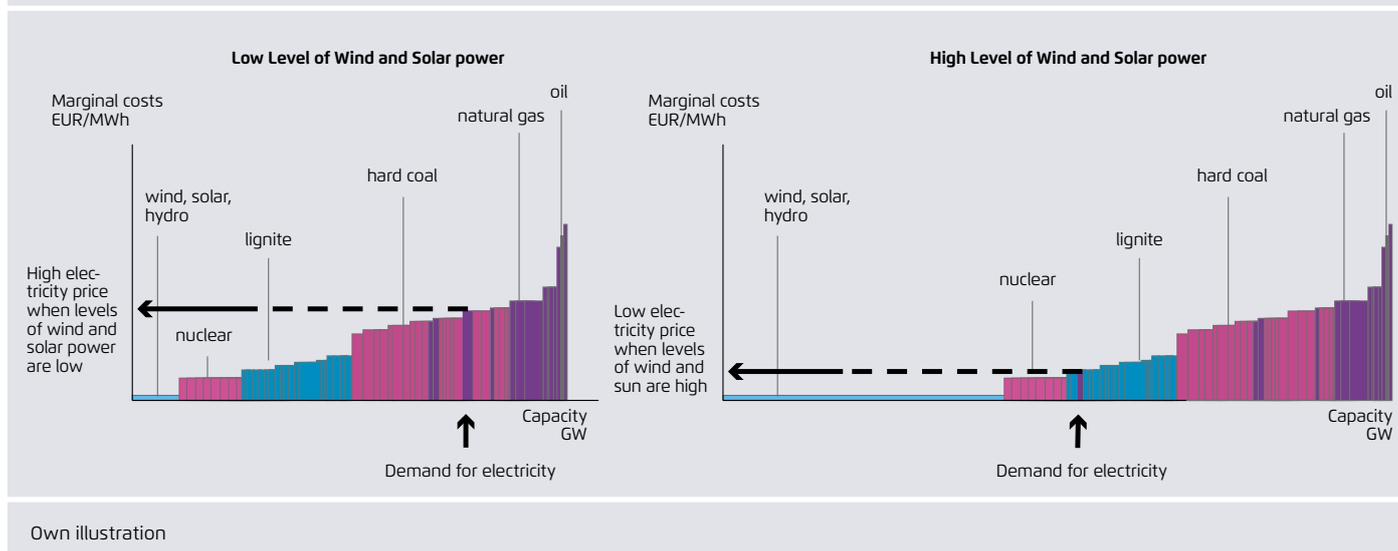
generate additional revenue, they set them just under the variable operating costs of the next power station in the merit order. In markets where the power stations all have similar cost structures, the additional revenues are low, so that station's electricity prices are almost identical to the marginal costs of the last power station in use.

³⁵ For an overview of the pro and contra arguments, see Cramton/Ockenfels (2012) and Müsgens/Peek (2011).

³⁶ The capacity markets have a variety of configurations with different degrees of efficiency and effective-

Electricity Prices and the *Merit-Order* Curve

10



In Germany, the issue of back-up capacity needed to ensure system reliability has special relevance: the country's decision to phase out nuclear power will eliminate 4 GW in energy capacity between 2015 and 2019 and another 8 GW between 2020 and 2022.

The *Energiewende* brings this issue to the forefront, because power production from wind and PV will reduce the average market price of electricity and with it the operating times of fossil-fueled power stations

The issue of system reliability in energy-only markets is aggravated by the fact that the *Energiewende* will continue to shrink the market for electricity from fossil-fueled power stations. As the *Energiewende* increases the share of renewables, the operating hours of fossil power plants will decrease, especially those of gas-fired and hard coal power stations that usually find themselves behind the lignite power stations in the merit order. And as the share of renewables with marginal costs close to zero grows, the market price for electricity will fall.

It is doubtful, therefore, whether investors will build new power stations or operate existing ones to an extent that

guarantees system reliability at any one moment in time. Because new OCGTs need two to three years for approval and construction, new CCGTs three to five years, and coal-fired plants longer still, politicians will have to find a regulatory answer to the question of system reliability in the coming legislative period 2013–2017.³⁷

ness. For an overview, see Süßenbacher et al. (2011).

³⁷ For an overview of models currently in discussion on strategic reserves, comprehensive capacity markets, and focused capacity markets, see Agora Energiewende (2012b).

Insight 8

Wind and PV cannot be principally refinanced via marginal-cost based markets

Wind and solar power have operating costs close to zero

Wind and PV are characterized by high investment costs, zero fuel costs, and low operating costs (see Insight 1). Once operational, wind or PV facilities exhibit marginal costs close to zero, that is, the production of an additional kilowatt hour creates essentially no incremental costs - in contrast to coal- or gas-fired plants.

Wind and PV produce electricity when the wind blows and the sun shines, regardless of electricity price

Wind and PV power production is variable depending upon the weather and the time of day. Unlike coal- and gas-fired plants, the electricity output from wind and PV cannot be controlled by plant operators (curtailment is the only exception). Since their marginal operating costs are close to zero, wind and PV will always produce electricity when the wind blows and the sun shines, independent of whether the exchange price for electricity is high or low.³⁸

In times when wind and/or sun is plentiful, wind and PV facilities produce so much electricity that prices decrease on the spot market, thus destroying their own market price

When the wind blows or the sun shines, all wind (or PV) power stations in the same weather zone produce electricity simultaneously. And when there is a significant number of wind and PV power stations in the system, this will have a

price effect in the market: With so much electricity being offered into the market at close to zero price, the market exchange price will decrease. Power plants with more expensive marginal costs will not come on-line and power plants with lower marginal costs determine the exchange price (*Merit-Order Effect*). In Germany, the installed generation capacity of PV and wind is on the order of 30GW each.

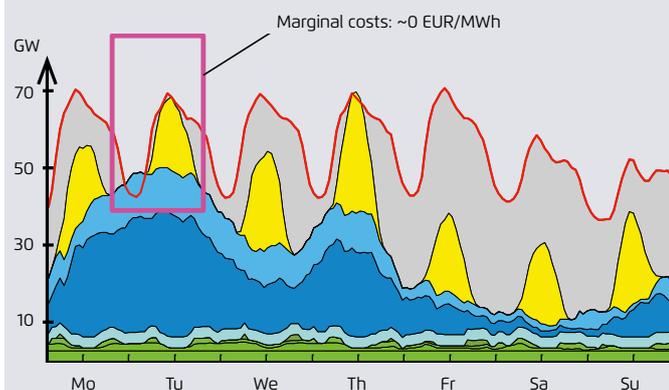
In the sunny month of May 2012, the exchange price during the day was often only 30 €/MWh; the former midday peak in electricity prices due to peak demand does not occur anymore at sunny days. Further evidence for this argument is provided by the forecasts of the grid operators: To estimate the revenues from the sale of EEG electricity, grid operators use so-called "market value factors" for electricity generated from specific renewable energy sources. These factors describe whether the wholesale spot market price at feed-in is above or below the yearly average. The forecasted market value factors for electricity generated by wind and PV are both below 1, i.e. prices are always below average in sunny and/or windy times. Furthermore, these factors are continuously going down.

As a consequence, wind and PV destroy their own prices at the marginal-cost based wholesale spot market. This effect worsens as more wind and PV power plants are built, which then produce electricity concurrently (see Figure 11).

³⁸ One exception is when electricity prices are negative. Operators of wind and PV can turn off their facilities to avoid having to pay out money for their production.

Impact of High Levels of Wind and Solar on Electricity Prices in 2022: Example of Week in August

11



- Between Monday night and Tuesday evening electricity from wind and solar energy (plus small quantities from other renewables) cover total demand for electricity in Germany
- The market price – determined on the basis of marginal costs – would tend to zero EUR/MWh over a period of 18-hours

Illustration based on Agora Energiewende (2012a)

Therefore by principle, wind and PV cannot be refinanced in a marginal-cost based market, even when their total costs are below those of coal and gas.

The fundamental problem is this: Wind and PV cannot earn enough revenues to cover the average cost of their initial investment in the market, because the price will always be lower than the market price average whenever the wind is blowing or the sun shining, which is precisely when electricity can be produced from these weather-dependent technologies. Hence, if the share of wind and PV is high when there are strong winds and/or intensive sunlight, electricity market prices are expected to decrease to minimum levels – from 1 to 2 ct/kWh.³⁹ Simulations with

³⁹ If the electricity price on the market is close to zero or below, new consumers are likely to appear in the electricity market. For instance, by making a small investment, a heating consumer can convert electricity into heat using the immersion heater principle, making the lowest price level on the electricity market 1-2 Cent/kWh – depending

electricity market models have confirmed this effect using Germany's current power mix.⁴⁰

High CO₂ prices do not fundamentally change this effect

Even if the EU Emissions Trading Scheme applies stricter regulations leading to increased CO₂ prices, this problem will not be solved, as high CO₂ prices do not change the fact that wind and PV have marginal costs close to zero. High CO₂ prices cause the costs of electricity generation in coal and gas-fired plants to rise. In times of low wind and sunlight, wind and PV, running at partial capacity, profit from the higher marginal costs of coal and gas-fired plants and receive higher revenues. But these higher revenues cannot compensate for the many hours in which conditions are favorable and wind and PV produce high levels of electricity, lowering market exchange prices.

Hence, the aim to make renewables "market competitive," so that their further development is driven by the electricity market, faces a fundamental problem: Wind and PV cannot be integrated into the existing marginal-cost based market, since these weather-dependent energy sources cannot be re-financed. Thus, without a regulatory instrument governing electricity from renewables, Germany's *Energiewende* will fail.

on gas prices as opportunity costs in the heating market.

⁴⁰ See Kopp et al. (2012).

Insight 9

A new *Energiewende* market is required

The future *Energiewende* market must fulfill two functions:

- Steer the installation of capacity, in order to achieve an efficient balance between demand and supply
- Send investment signals for renewable energy, as well as for conventional facilities and making energy demand and storage (longer term) more flexible.

From Insights 7 and 8 above, we conclude that – in order to succeed – the *Energiewende* requires a new market design (see Figure 12). This market will need to fulfill two basic functions. First, within the realm of energy-only markets, supply and demand will need to be balanced as efficiently as possible based on marginal cost principles – just as in the past. Renewable energy, conventional power plants, and storage will be dispatched in order of increasing marginal costs to meet total demand. Second, the new market must attract the required investment in renewables on the one hand, as well as in conventional power plants, demand-side flexibility and storage technologies. This involves not only ensuring that existing power plants are optimally deployed, but also that the necessary expansion in generation from renewables is assured, while continuing to maintain system reliability. Fossil-fueled power plants, demand-side, and storage systems must compete with one another, in order to deliver the flexibility required to balance the fluctuating output from wind and PV at least cost.

The new market will create two sources of revenue:

- Revenue (as before) from the sale of *electricity quantity (MWh) in the marginal-cost based Energy-Only Market*
- Revenue from a new *Investment Market (MW)*

The new *Energiewende* market will preserve the energy-only market while adding a new market for capacity investment. Operators of renewable energy facilities, fossil-fueled

power plants, and storage systems receive revenues from both markets in order to recover the investment and operating costs of their facilities.

In addition, fossil-fueled power plants, renewable energy, demand-side resources, and storage systems will compete to provide ancillary services (e.g. balancing energy)

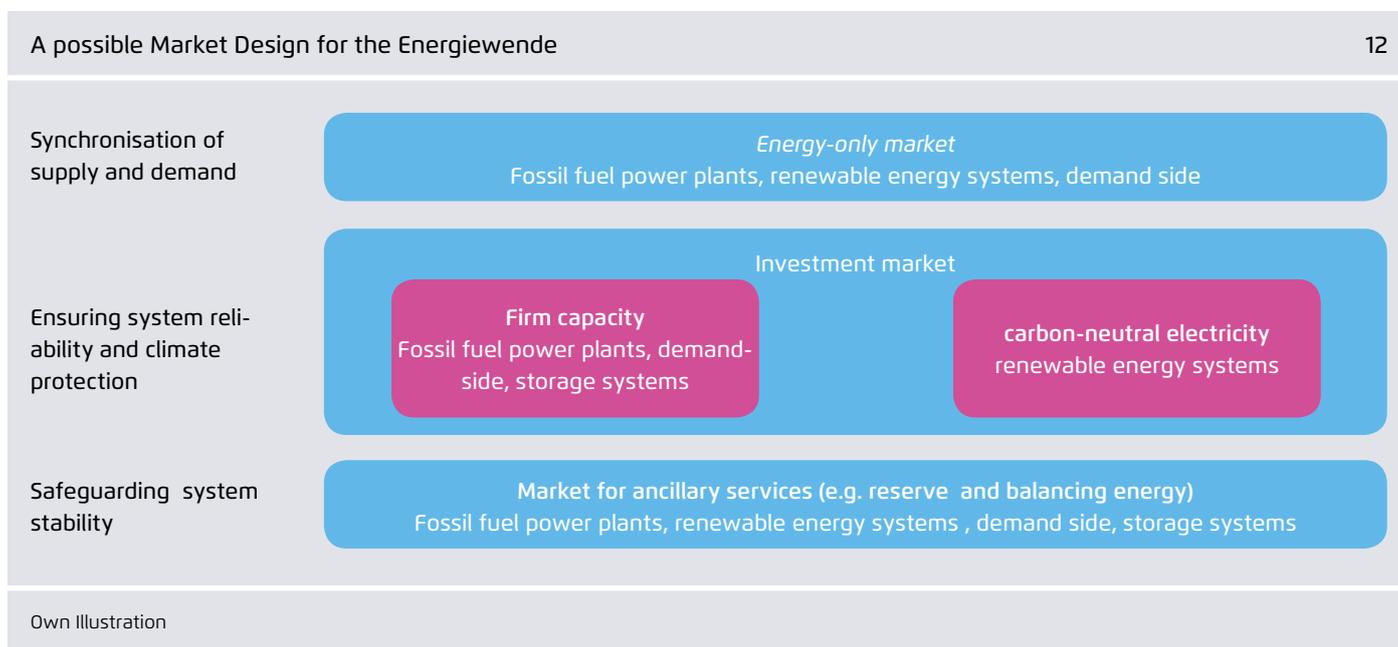
The market for balancing energy as part of the ancillary services market will continue to be necessary for maintaining system stability. But this market also requires modification that allows a greater variety of options for renewables and demand-side resources to participate in the tender process. In addition, these costs should no longer be offset partly by grid tariffs. Instead of socializing up to two-thirds of the system balancing costs – as is the case currently – the entities responsible for balancing should bear them in full. This allows clear assignment of responsibility for next-day electricity production forecasts and demand estimates.

The new investment market will reward

- reliable, flexible resources (both supply and demand-side) to guarantee system reliability
- CO₂-free electricity, to ensure the transition to renewables

A new market for investments must take into account supply as well as demand if system reliability is to be secured. The products on this market must be defined in a way that enables controllable power stations, flexible demand, and energy storage systems to participate. Due to the increasing share of wind and PV, power stations and load displacement must become very flexible, with quick ramp-up and ramp-down times.

For the renewables sector, a market must be designed that attracts new investments so that the *Energiewende*-targets can be reached and total system costs kept to a minimum.



The exact configuration of the new market requires further study; many options are possible (premiums/bonuses, tenders, certificates)

There are many options for incentivizing investment:

- bonuses on top of the prices on the energy-only market (bonus or premium model)
- a central agency (e.g. the transmission system operator or Germany's Federal Network Agency) that organizes tenders and contracts the most cost-efficient provider (tender or auction model)
- obligations for electricity distributors to hold a certain amount of renewable electricity respectively supply guarantee certificates (certificate or quota model)

The advantages and disadvantages of these models for the expansion of renewables have been discussed many times.⁴¹ For ensuring system reliability, the main candidates under consideration have been the second and third options, in addition to the creation of a strategic reserve.⁴²

⁴¹ For a current overall, see Verbruggen/Lauber (2012) and Fraunhofer ISI et al. (2012).

⁴² For a current overall, see Agora Energiewende (2012b) and Dena (2012). On the recommendations now being discussed in Germany,

It is important to analyze these options anew in the specific context of the *Energiewende*. Crucially, the costs for the technologies to be rewarded – be they wind or PV, capacities for system reliability, or – in the longer term – energy storage systems – arise almost entirely with the initial investment, while operating costs are negligible or – in the case of fossil fuel capacities for system reliability such as gas turbines – yield insufficient return on investment due to the limited extent of their operating hours.

Installing a new mechanism instead of the current feed-in tariffs for renewables is only justified if it brings increased efficiency

The creation of a market for renewables has no inherent value in itself. Rather, the new market design must allow us to expect greater efficiency for consumers and society than that offered by the existing feed-in tariff system.

The problem with feed-in tariffs for renewables is that legislators can err when setting the level of remuneration, or they can be prone to influence from interest groups. When

see Consentec (2012), EWI (2012), and Öko-Institut et al. (2012).

transitioning to a new mechanism three considerations should be kept in mind:

- Once a new wind or PV facility is built, there are few options for modifying it. The crucial step, therefore, is the initial investment. Given the various, location-dependent feed-in profiles of wind and PV, it is important that a new market for investments provides the correct incentives for building facilities in a way that is efficient for the total system.
- Wind and PV facilities are costly investments, and hence seem risky to investors if future revenues are uncertain. Currently, the system of feed-in tariffs is neutralizing this price risk through fixed 20-year guarantees. A market model that gives too little attention to the risks of high-capital investments may drive up costs for consumers.
- In the past, the expansion of renewables has been financed through citizens as well as small and medium enterprises (SMEs). This has created widespread support in the population for the *Energiewende*. A market design that no longer permits the participation of citizens and SMEs would endanger the future of the *Energiewende*.

For these reasons, it is vital that the alternatives to the existing feed-in tariff system be studied carefully. How, exactly, will they affect a power system dominated by wind and PV? A hasty transition to a new mechanism may give rise to a system that is both less efficient than the current one and unnecessarily driving up the cost of the *Energiewende*.

Insight 10

The *Energiewende* market must actively engage the demand-side

Greater demand-side flexibility is fundamental to increasing the use of wind and PV

Shifting demand from periods of low levels of sun and wind to those with high levels increases the ability of the power system to integrate a growing level of wind and PV, without relying on expensive storage (see Figure 13). Historically, electricity demand has been very inflexible to changes in electricity prices over the course of a day. Currently, about 2 to 3% of demand is flexible (around 1.5 GW in total load of 50 to 80 GW). The technological potential is markedly higher, however. In the long term, over 50% of today's demand could be able to respond to the available supply from

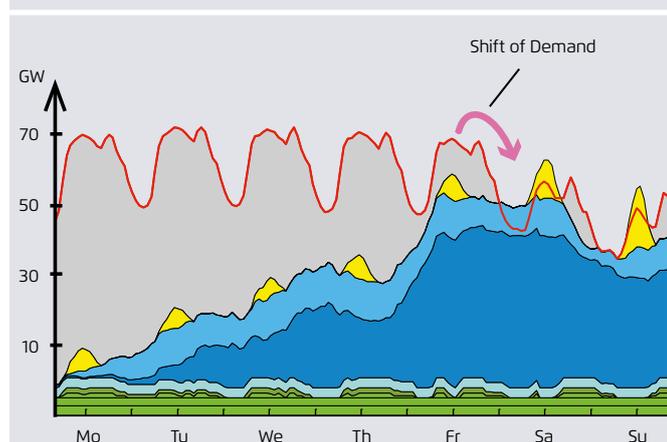
wind and PV.⁴³ There are two reasons for the lack of demand responsiveness in Germany: Firstly, the price fluctuations during the day are not very large, so that load shifts generate little additional value. Secondly, Germany's system contains counterproductive incentives – especially with respect to grid tariffs – that further inhibit demand-side responsiveness to price changes.

Demand response is usually cheaper than electricity storage or supply-side options

In most cases, demand-response is the cheapest flexibility option. For instance, with little investment refrigeration facilities can be cooled to below minus 18° Celsius when winds are strong and then do without some electricity when winds are weak. In the industrial sector, electricity demand can be temporarily shifted without additional investment, and in many cases affordable thermal storage systems or storage for intermediate products such as chemicals can be introduced. Experience in the United States shows that the costs of increased demand flexibility are often substantially below those of supply-side solutions. Following the introduction of a capacity market in the eastern United States, demand-side offers have won an impressive share of auctions. 11 GW of demand-side resources (primarily demand response) was added in delivery year 2012–13, with consumer savings of more than one billion U.S. dollars.⁴⁴

Current regulations for grid tariffs and ancillary services often work at cross purposes with demand response, and should therefore be reformed

Contribution of Demand-Side Measures to Flexibility in 2022: Example of a Week in February 13



- From Friday night to Saturday morning, excess electricity is available; during Friday noon and afternoon, around 20 GW of fossil power are needed
- Industries and other electricity users can shift their demand from Friday afternoon to Friday night or Saturday.

Illustration based on Agora Energiewende (2012a)

43 See Bundesumweltministerium (2012b), p. 24–28.

44 See Gottstein (2012).



Regulations governing grid tariffs are often at odds with the flexibility requirements of the energy transition. With many industrial customers, grid tariffs are calculated at least in part using the energy prices that result from individual maximum load. As a consequence, industrial customers are at a disadvantage when their yearly maximum loads increase due to demand response measures even if, seen from the whole, this would be beneficial in times when e.g. wind power is plentiful.

Current grid tariffs exemptions for facilities with utilization hours of 7,000 or more are also counterproductive: For as long as these exemptions offer greater economic incentive than demand response, the energy-intensive industries have no reason to modify their demand, for doing so could lower their utilization hours below the 7,000-hour mark and disqualify them from exemption. Moreover, companies that operate close to the threshold have an incentive to use more electricity to ensure they reap the exemption benefits. The fee exemption program, therefore, provides perverse incentives in terms of making the system as a whole more efficient and flexible.

The regulations governing interruptible demand currently under consideration should therefore address the flexibility

that the demand-side can offer to the entire system, and not just focus on the rare instances when load reductions are required for grid stability.

The demand side can also take part in ancillary services markets, such as the market for balancing energy, by bidding negative load. Current prequalification requirements, however, are in some respects so onerous, that many potential industrial customers are not able to participate.

The new market for investments in firm capacity must be designed such that demand-side resources able to shift loads can actively participate

Products for the capacity market (securing load change for a specific duration at a certain speed) should be specified so that they can be delivered, not only by generators, but also by demand-side changes in load. For example, most industrial companies as a rule cannot sign multi-year load management contracts, since their load management potential depends on their core business orders. Accordingly, at least some of the products for tender must be short term (e.g., one year) and take into consideration the unique demand-side conditions.

Insight 11

The *Energiewende* market must be considered in the European context

The ongoing integration of the German power system into the European system makes the *Energiewende* simpler and more affordable because:

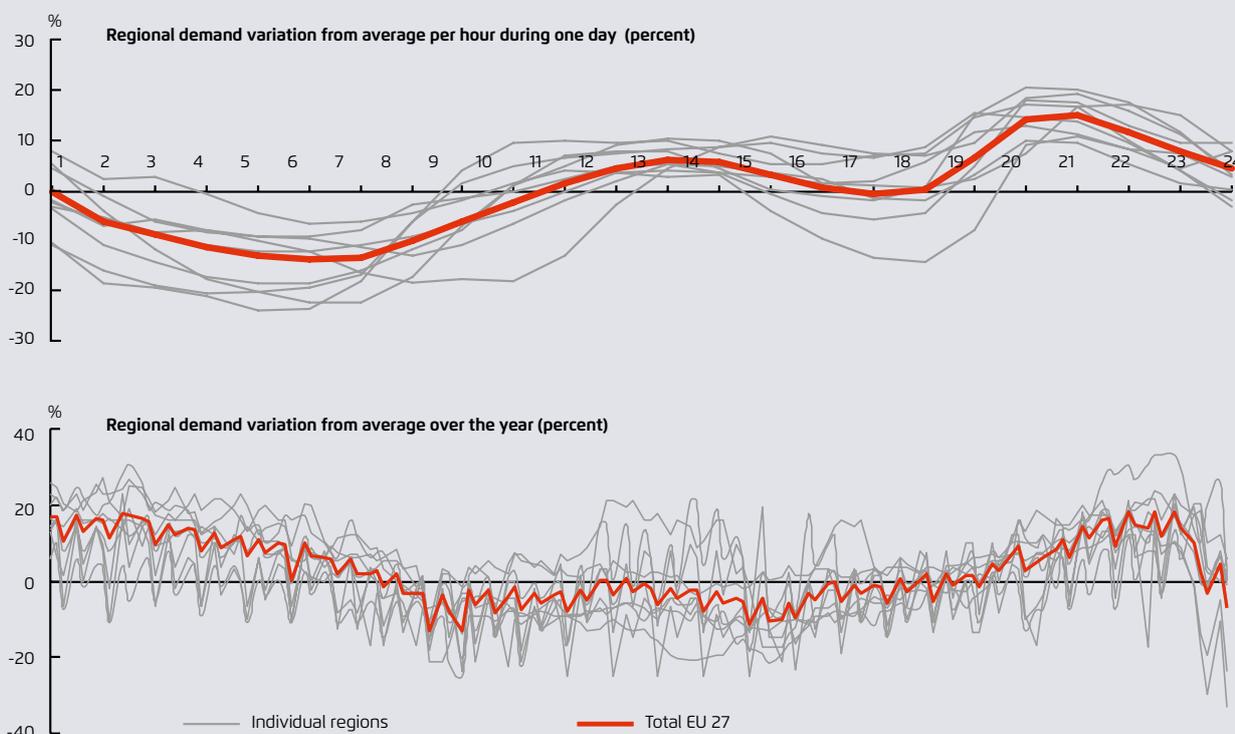
- the fluctuations of wind and PV energy production becomes less pronounced over a larger geographic region
- firm capacity can be collectively shared
- low-cost flexibility options in Europe can be more fully utilized (e.g. energy storage resources in Scandinavia and Alpine countries)

Germany's electricity market is already strongly interconnected with neighbouring markets. With some 17 GW of interconnector capacity, the coupled markets with western neighbours as well as the regulatory framework for the EU internal market, it is absurd to take on a purely national perspective. And all indications point to further market integration in the coming years.

This is advantageous for Germany's *Energiewende*. Improved interconnection of power systems across Europe, or at least across sub-regions of Europe, are projected to yield considerable savings in comparison with an isolated

Fluctuation of Electricity Demand across Europe

14



Adopted from ECF (2010)

national solution.⁴⁵ The reason is that differences on the supply- as well as the demand-side between regions become advantageous with broader geographic diversification of the system. On the demand side, the marked (daily and seasonal) load curve differences between individual member states and regions can result in a lower total average peak load (see Figure 14). On the supply side, regional differences in levels of wind and sun can balance out fluctuating energy production. Furthermore, geological differences can be partly equalized, for example, by expanding the limited potential for low-cost pumped storage in Germany with reservoir power stations in Scandinavia or in Alpine countries, provided the necessary grids are in place. All in all, less peaking power plants and balancing energy would be needed.

European electricity trading stabilizes market prices

Although other European member states are pursuing somewhat ambitious expansions of renewables, Germany clearly stands out when it comes to the absolute level of production from variable renewables. By 2020, Germany will produce about twice the amount of electricity from wind and sun as the rest of the EU.⁴⁶ Since wind and PV have near-zero marginal costs, the market price for electricity will decrease – an effect that we see today mostly at noontime (see Insight 8). When this happens, demand from surrounding countries can act to stabilize prices. Conversely, in times when wind or PV production levels in Germany are low, energy from neighbouring states can flow into Germany and dampen high market prices in Germany. Naturally the same effects can be observed – in reverse – in these neighbouring countries.

In the long run, there will be total market integration in Europe

Electricity market integration in Europe began two decades ago. Many steps have already been taken, including the unbundling of production and grid operations. In coming years, energy-only markets and ancillary services will merge more and more. According to the current schedule, the EU Third Energy Package, which contains regulations on market coupling and network codes, will be fully implemented by 2015.

In contrast, current discussions related to system reliability – such as capacity markets or strategic reserves of various designs – are exclusively being debated on the national level. As discussed above, however, separate systems for ensuring system reliability in an interconnected European market are not efficient. The debate should therefore be raised to European level discussions very soon. How national capacity markets can and should be harmonized is still an open issue. Regional markets would be a conceivable intermediate step before long-term expansion of interconnector capacity and a uniform European solution can be achieved.

⁴⁵ See ECF (2010), p. 59ff. Calculations from KEMA und Oxford Economics predict savings of up to 40% should the electric grid be made Europe-wide.

⁴⁶ According to the recent numbers of National Renewable Energy Action Plan, Germany will produce around 24% of its energy from variable sources (with 35% electricity from renewables in total) by 2020. The rest of Europe is projected to produce 13%. See European Environmental Agency (2011).

Insight 12

Efficiency: A saved kilowatt hour is the most cost-effective kilowatt hour

Energy efficiency decreases total costs; increased energy productivity enables the decoupling of economic growth from energy consumption

Realising the *Energiewende* requires not only meeting targets for renewable energy production, but also targets for improved energy efficiency, among others. Accordingly, the German federal government aims at reducing electricity consumption below 2008 levels by 10% by 2020 and by 25% by 2050. In particular, improved electricity efficiency will play a critical role in meeting Germany's emission reduction goals, for without greater efficiency measures, a significantly greater expansion of renewable energy installations will be needed to achieve an equivalent reduction of greenhouse gases.

Energy efficiency means that the same level of goods and services can be produced with less energy input. This, in turn, means that economic growth and energy consumption can be decoupled, and greater prosperity no longer relies on a higher consumption of resources.

Every kilowatt saved means

- less burning of natural gas and coal
- fewer investments in new power plants, fossil and renewable

Numerous studies have demonstrated that improved electricity efficiency is not only advantageous for the economy, but also benefits individual businesses and private households. This is because many efficiency measures pay off: With today's available technology, internal rates of return of over 30% (which corresponds to a 3 year pay-back period) can be achieved, especially in the industrial sector.⁴⁷ This is

⁴⁷ See, for instance, McKinsey (2007); Roland Berger (2011); Prognos et al (2009); ZVEI (2008).

also beneficial to the economy, as the less electricity consumed, the less gas and coal must be imported. Moreover, fewer investments in renewable and fossil-fueled power stations must be made. The net result from improved energy efficiency is increased domestic product and employment.⁴⁸

The challenge lies less in technology and more in creating the right incentives

Market-ready technologies for efficiency exist on both the supply side and the demand side. Nevertheless, relatively few measures have been implemented primarily due to insufficient incentives. In many companies, management's attention is not focused on energy efficiency because it is not the most pressing investment decision to make and, despite the savings that efficiency offers, energy may only comprise a small fraction of total costs. The situation is similar for households. For most people, electricity consumption is a side issue: the share of electricity in total consumer expenditures is, on average, only 2.3%. As a result, quite profitable efficiency potential – from, for example, replacing heat pumps or refrigerators – is not realized.

Implementation of the EU energy efficiency directive gives the opportunity to create a new incentive system for electricity efficiency. It is critical that policy makers take advantage of this opportunity, most importantly, by clearly organizing the demand for energy efficiency and activating market forces for delivering efficiency services. Energy efficiency must become a viable business model. To this end, the markets for energy efficiency in other countries can serve as role models for accessing Germany's large and unrealized energy efficiency potential.

⁴⁸ See, for instance, Prognos et al (2009).

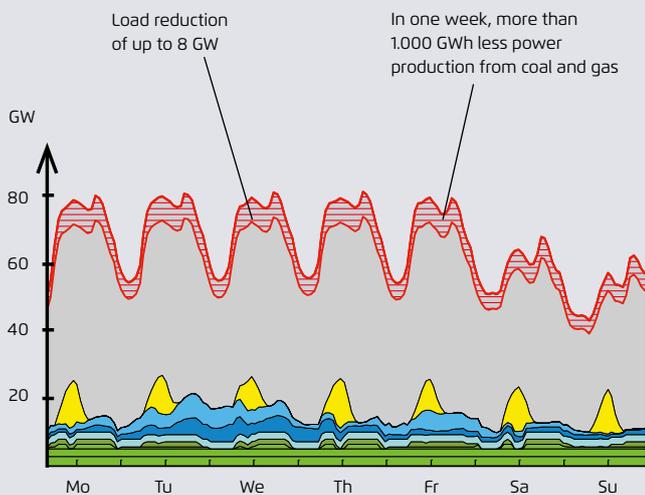
Comprehensive consideration of electricity, heat, and transport sectors is required: heat pumps and electric vehicles may increase electricity demand but they are not at odds with efficiency

Especially where energy efficiency is concerned, we need to look beyond the boundaries of the electricity sector. As more electricity is used for heating and electric mobility, demand for electricity may increase. But this does not pose a contradiction with respect to energy efficiency. The use of wind and PV power for heating or electric vehicles will displace demand for oil and natural gas in the heating and

transport sectors, thereby reducing consumption of these resources. Moreover, the building and transportation sectors offer the largest economic potential for energy efficiency, specifically, in building insulation improvements and better propulsion technologies.

Over the medium term, increased use of electricity in the heating and transport sectors, together with emerging hydrogen and *power-to-gas* technologies, will lead to stronger integration of the electricity, heating, and transport sectors, and is thus intensifying the need for coordination among these different sectors in the future.

Effects of efficiency in the year 2022 in an exemplary week in November



- The aim of the German government is to reduce power demand in 2020 by 10 per cent (against 2008); this equals a 60 TWh reduction of gross demand
- Lower electricity demand reduces power production from coal and gas fueled plants
- In addition, the need of firm capacity is reduced – in this November week, up to 8 GW less firm capacity or load shifting is needed to ensure system reliability

Illustration based on Agora Energiewende (2012a)

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Publications by Agora Energiewende

12 Thesen zur Energiewende

Ein Diskussionsbeitrag zu den wichtigsten Herausforderungen im Strommarkt
(Lang- und Kurzfassung)

Brauchen wir einen Kapazitätsmarkt?

Dokumentation der Stellungnahmen der Referenten der Diskussionsveranstaltung am
24. August 2012 in Berlin

Die Zukunft des EEG – Evolution oder Systemwechsel?

Dokumentation der Stellungnahmen der Referenten der Diskussionsveranstaltung am
13. Februar 2013 in Berlin

Erneuerbare Energien und Stromnachfrage im Jahr 2022

Illustration der anstehenden Herausforderungen der Energiewende in Deutschland.
Analyse auf Basis von Berechnungen von Fraunhofer IWES

Kapazitätsmarkt oder strategische Reserve?

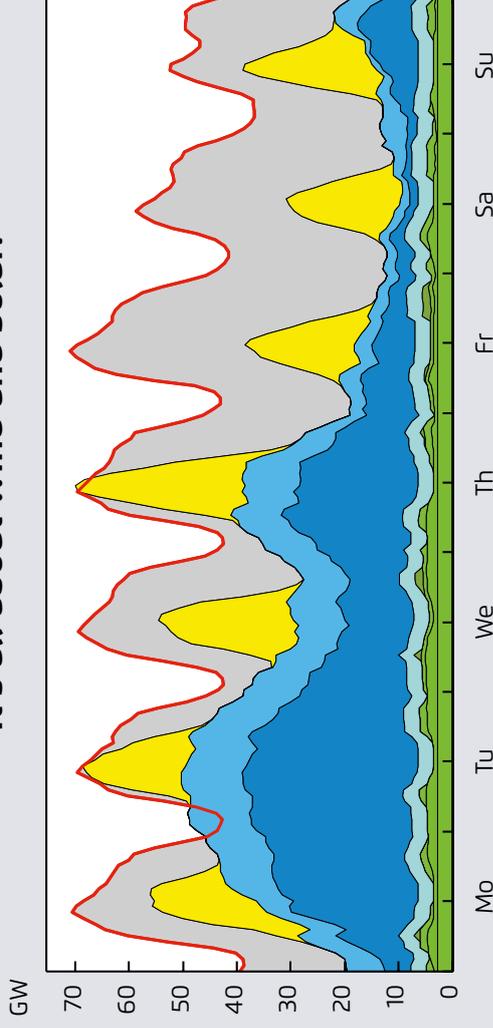
Ein Überblick über die in der Diskussion befindlichen Modelle zur Gewährleistung der
Versorgungssicherheit in Deutschland

Steigende EEG-Umlage: Unerwünschte Verteilungseffekte können vermindert werden

Analyse des Deutschen Instituts für Wirtschaftsforschung (DIW)

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It's all about Wind and Solar!



features

- > weather dependent
- > variable
- > only capital expenditure

Wind and PV are the cheapest renewable energy sources

The potential of other renewable energy sources is limited

How to balance demand and supply?

How to minimise costs?

How to realise the Energiewende in the European context?

technical system

2. "Base-Load" power plants disappear altogether, and natural gas and coal operate only part-time
3. There is plenty of flexibility – but so far it has no value
4. Grids are cheaper than storage facilities
5. Securing supply in times of peak load does not cost much
6. Integration of the heat sector makes sense

market design and regulation

7. Today's electricity market is about trading kilowatt hours – it does not guarantee system reliability
8. Wind and PV cannot be principally refinanced via marginal-cost based markets
9. A new *Energiewende* Market is required
10. The *Energiewende* Market must actively engage the demand-side
11. It must be considered in the European context

12. A saved kilowatt hour is the most cost-effective kilowatt hour

How can Germany realise its *Energie-wende*? What concrete legislation, initiatives or measures are required to make the Energiewende a success? Agora Energiewende lays the groundwork to ensure that Germany makes the decisions required to set the course towards full decarbonisation of the power sector. We are a „think-and-do tank“, working to enhance a fuller understanding of the Energiewende and facilitate a convergence of views among relevant stakeholders.



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