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REVIEW

# A review of the German energy transition: taking stock, looking ahead, and drawing conclusions for the Middle East and North Africa

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**Abstract**
This paper reviews the German energy policy framework, commonly known as 'Energiewende', which aims to transform and decarbonise the German energy system. We look at the achievements made over the last 8 years and discuss the implications, e.g., in terms of costs and rents, for consumers and producers of electricity in Germany and beyond. German policy makers have been successful in deploying new technologies, but have so far failed to achieve $CO_2$ emission reductions. Producer rents were significantly cut, while the subsidisation of renewables has led to a sharp increase in end-user prices. The challenge now is to start moving the energy transition beyond power generation and achieve emission savings in the transport, industry, and buildings' sectors.

**Keywords** Energy transition · Germany · Energy policy · Energiewende · Renewables · Fossil fuels

## Introduction

The German energy transition, the so-called 'Energiewende', is one of the world´s most ambitious programmes to decarbonise the entire energy system of a country. The overarching policy goal is a reduction in greenhouse gas emissions by 40% by 2020 and 80% to 95% by 2050, compared with 1990 levels.

After some years of experience, we are in a position to take stock and describe the achievements but also the consequences for suppliers and consumers in Germany and its impact across Europe. The energy transition is gradually becoming a global phenomenon. As such, we also highlight some important lessons learned that can be helpful for policy makers in other countries—in this paper, we specifically draw conclusions for the Middle East and North Africa—when they decide on the market designs and regulatory frameworks that underpin the transition in their countries.

Our analysis shows that the German 'Energiewende' was very successful in delivering a rapid increase in electricity generation from wind and solar PV. The flipside of this development was a substantial increase in end-user electricity prices. Despite significant deployment of renewable energies, $CO_2$ emission reductions were minor over the last 8 years as renewables' growth has, by-and-large, offset the fall in output from nuclear power plants. Based on these conclusions, we look ahead and describe the next steps, but also the challenges that the German energy transition is facing. In the power sector, this implies the actual achievement of $CO_2$ savings, economically efficient deployment of renewables and the introduction of market designs that ensure financial viability of all market participants. However, the real challenge is to move the energy transition beyond the power sector and prepare the ground for a transformation of energy use in transport, industry, and buildings.

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## The point of departure: production, trade, and consumption of energy

The map of Germany shows the centres of domestic energy production. Germany is the largest lignite producer in the world. Lignite, a very low-cost source of primary energy in Germany, is being extracted in ten huge opencast mines spread over three mining areas [1].

Hard coal mining, in contrast, is very costly and its production is subsidised and slated to be phased out this year (there are still two underground mines in operation today). There is only minimal production of natural gas and oil, mostly in the northern part of Germany (Fig. 1).

Germany is highly dependent on energy imports. Some 70% of the country's energy needs have to be met by imports. The vast majority of the consumption of oil, gas, and hard coal comes from sources outside Germany (Fig. 2). In the case of lignite and renewable energy, Germany relies entirely on domestic production. Nuclear is a complicated case: due to international standards, nuclear energy is considered a domestic fuel even if the uranium is being imported [2].

As far as imports of oil, natural gas and coal to Germany are concerned, Russia is the most important single supplier for all of these energy carriers. Western European countries also play an important role as suppliers of oil and gas. The main suppliers of hard coal are—after Russia—the United States, Colombia, Australia, Poland, and South Africa (Fig. 3).

Primary energy consumption in Germany is quite diversified [3]. Oil is still the most important energy source, followed by natural gas, renewable energies, lignite, hard coal,

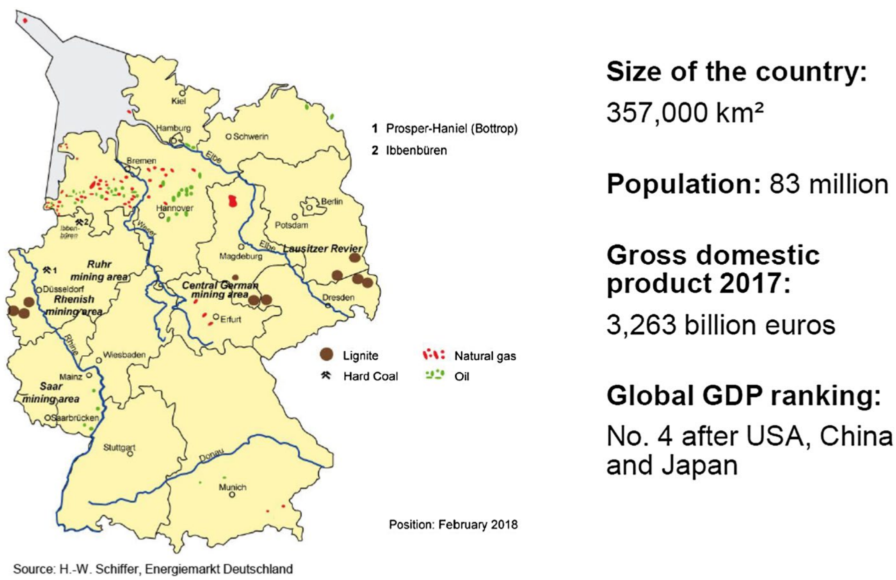



**Fig. 1** Centres of fossil energy production in Germany

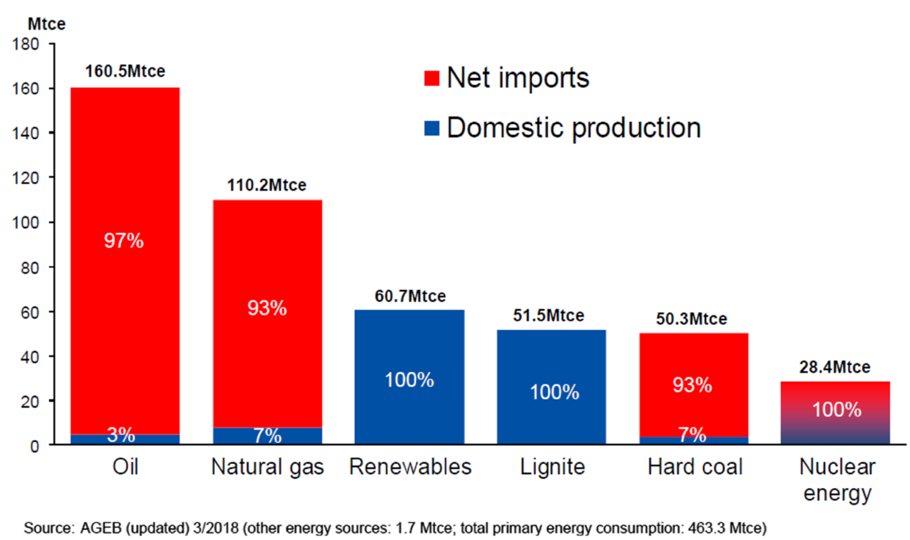



**Fig. 2** Germany's energy import dependency, 2017

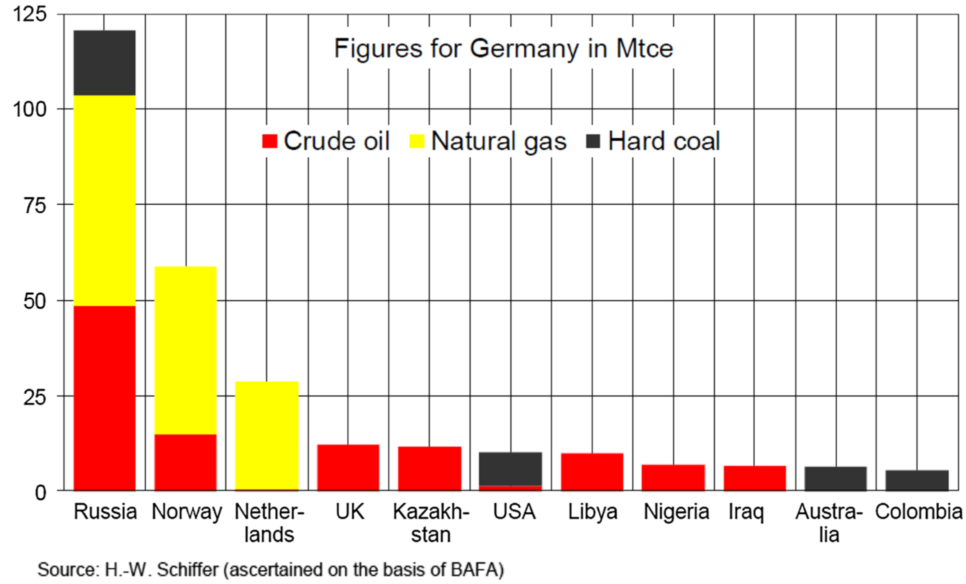



**Fig. 3** Major fossil-fuel suppliers

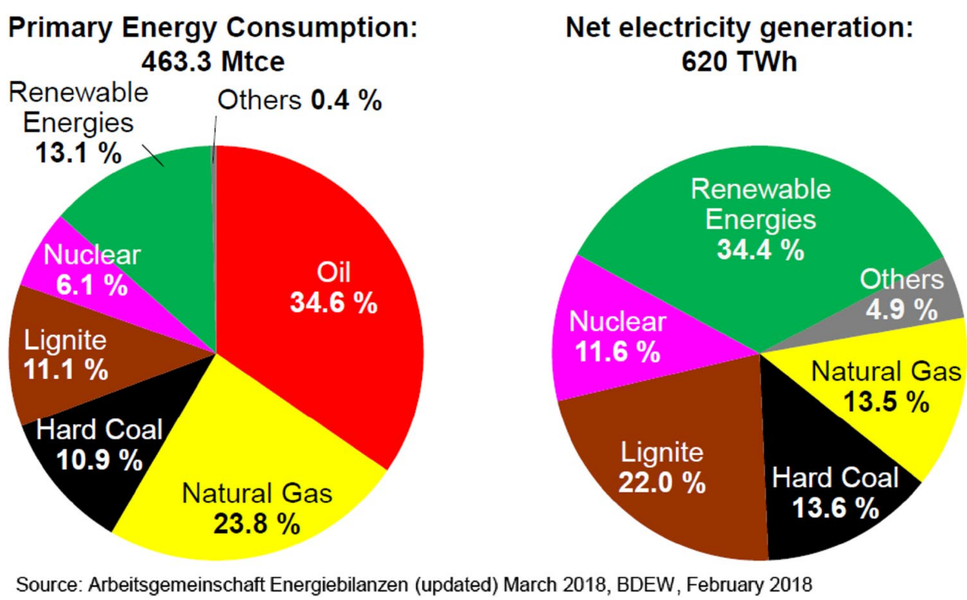



**Fig. 4** Energy mix in Germany, 2017

and nuclear energy. However, when looking at power generation, a different breakdown becomes apparent: lignite still plays a major role, but, in 2017, renewable energies—for the fourth year in a row—were the leading source of power generation (Fig. 4) [4].

While the share of renewables in power generation topped 34% in 2017, their share in total generation capacity reached as much as 52% (Fig. 5).

The reason for this discrepancy is that the output from renewable sources depends on nature, i.e., precipitation determines the availability of hydro power, the generation from solar PV depends on sunshine and that of wind mills on the strength of the winds. This means that in Germany, PV panels produce at full capacity for less than 1000 h per year, while onshore wind plants operate between 1500 and 2000 h per year. This contrasts with today's operating hours of hard

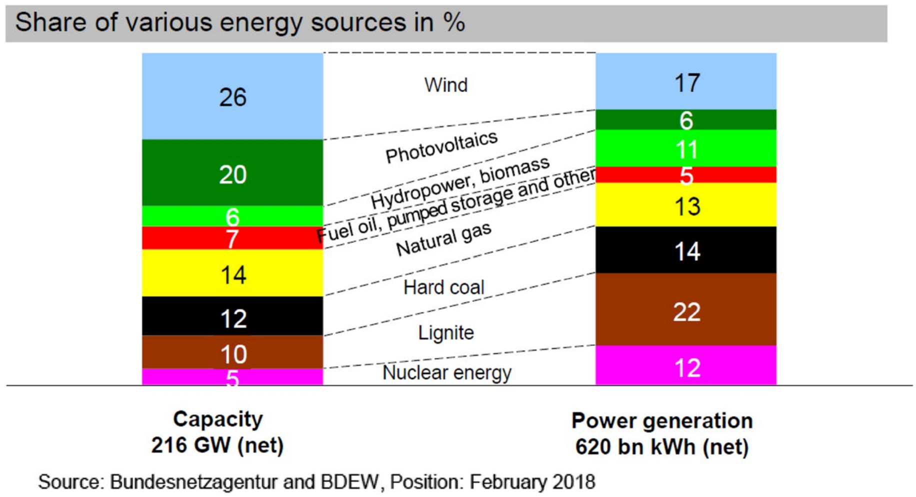



**Fig. 5** Power generation capacity and net electricity generation in Germany, 2017

coal-fired power plants, which exceed 3500 h, of lignite plants at approximately 6500 h and of nuclear plants which run for nearly 7000 h per year.

## The overarching policy framework

The German government's energy policy guidelines have undergone a profound change over the past decades. Until the 1990s, the electricity and gas markets were characterized as regional monopolies and, as such, subject to state regulation. The growing energy demand was covered with nuclear and fossil fuels. In 1998, the deregulation of the power and gas markets began. The liberalisation was largely based on the European Union's regulatory framework.

As far as renewable energies are concerned, the story started in the early 1990s. At that time, the primary objective was technology demonstration and initial diffusion with subsidies initially paid for capacity rather than output. In the following decade, the objective was to make these technologies mature and bring down costs, underpinned by economies of scale. The instrument of choice was the German Renewable Energy Sources Act, implemented in 2000. This policy truly kick-started renewable energy development based on generous feed-in tariffs and priority infeed rights. The current objective is to integrate the renewable energies into the national and the EU power systems. Key elements of this policy are introduction of market principles in the expansion of renewables (e.g., tenders, market premia, etc.) to make investment more sensitive to system requirements and to better control government targets while reducing excessive rents on the investor side [5, 6].

Concerning nuclear energy, there have been multiple policy turnarounds. In 2001, a nuclear phase-out plan was implemented by law. Then, in 2010, the energy concept of the federal government reconsidered the nuclear phase-out decision from 2001 and allowed for a lifetime extension of the nuclear fleet. The argument was that nuclear energy is a cost-effective and low-carbon bridge to a renewable-based economy. On average, an additional 12 years of lifetime were granted, extending the fleet's operations until the mid-2030s. The Fukushima-Daiichi accident was another turning point: the government decided an accelerated and definitive phase-out of nuclear energy within weeks after the accident—this has become a cornerstone of the so-called 'Energiewende' [7, 8].

The milestones of the implementation of the energy transition with respect to nuclear power are: the immediate closure of 8.5 GW of nuclear capacity in 2011 with the remainder of the fleet (amounting to 12.1 GW) to be decommissioned between 2015 and 2022 (Fig. 6). The decision to phase-out all nuclear plants is without any doubt a definitive one due to public pressure that has accompanied the nuclear debate over the past decades.

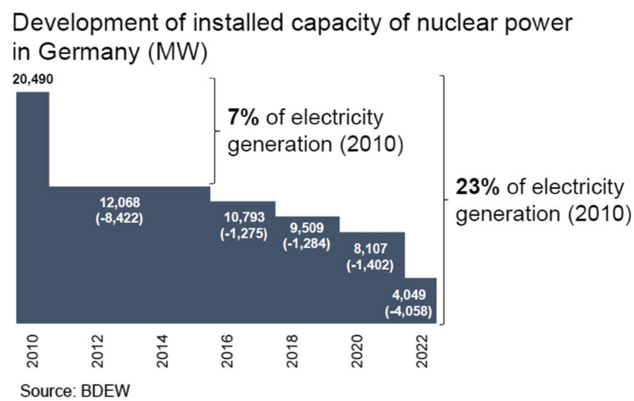



**Fig. 6** Timeline of administered nuclear phase-out in Germany

Other major policy elements are the conversion from a fossil-based to a renewable-based energy system and a concurrent reduction in energy consumption via increased energy efficiency [9]. Three motives underpin this strategy: mitigation of climate change, taking into account the finiteness and the negative external effects of fossil resources and minimising the risks of nuclear energy.

Specifically, the cornerstones of the German 'Energiewende' are [10, 11]:

- a reduction in greenhouse gas emissions by 40% by 2020 and 80%–95% by 2050, compared with 1990 levels;
- an increase in the share of renewable energy in total energy consumption to 30% in 2030 and to 60% in 2050;
- an increase in the share of renewable energy in total power consumption to 80% in 2050;
- a cut in the consumption of primary energy by half by 2050 compared with 2008 levels.

These energy policy guidelines are based on the assumption that a highly industrialised society can be securely and competitively supplied by an energy system based predominantly on renewable energies [12].

## The rapid rise of renewables and its cost

The main instrument to make renewable energy the backbone of power supply is the Renewable Energy Sources Act. This law guarantees renewable energy sources a feed-in tariff for a period of 20 years after the commissioning of the plant. Grid operators are obliged to purchase the renewable electricity and grant priority access to the grid. The trading

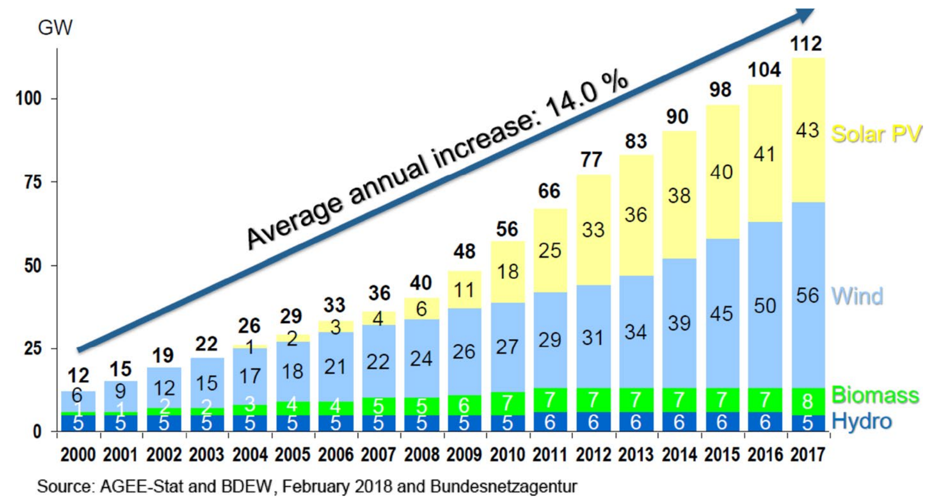



**Fig. 7** Installed renewable power generation capacity in Germany

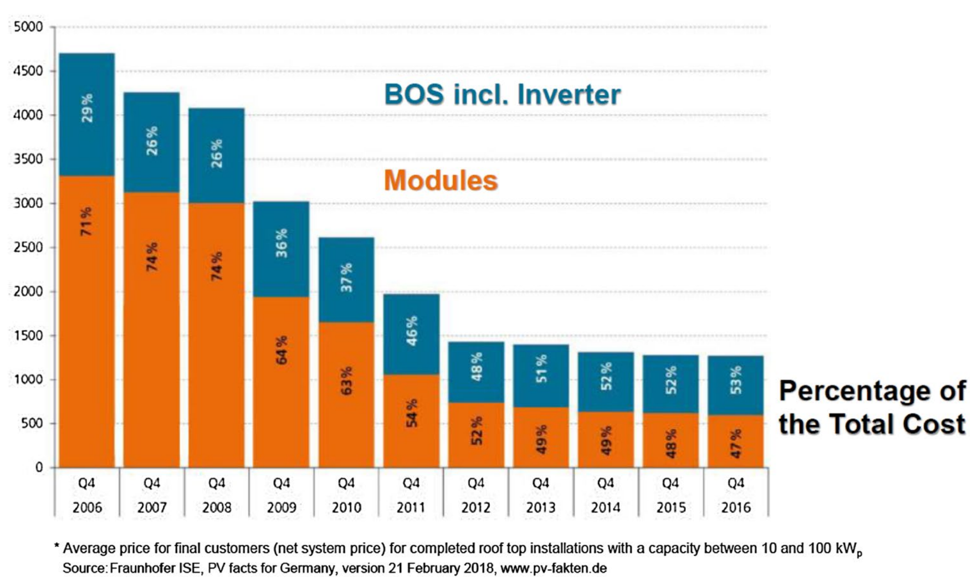



**Fig. 8** Average price for PV rooftop systems in Germany (EUR/kWp)

companies pass on the financial deficit—feed-in tariff minus market price—to end users by imposing a surcharge.

Renewable power generation capacity increased from 12 GW in the year 2000 to 36 GW by the end of 2007 and to 112 GW by the end of 2017 (Fig. 7). In particular, the capacity of solar PV soared after 2007, because the costs of the installations were comfortably below the feed-in tariff. Investors could thus be sure to make a guaranteed margin for the next 20 years, which was quite attractive compared with alternative capital investment. Within the last 10 years—between end of 2007 and the end of 2017—the increase was 39 GW for solar PV and 34 GW for wind energy. This means that the funding system for renewable energy sources has been extremely effective in underpinning deployment.

The soaring deployment of solar PV triggered a remarkable learning curve for solar PV. The costs for the installation of PV rooftop systems in Germany decreased by 75% within the last 10 years (Fig. 8). It can be argued that it was primarily the German electricity consumers that paid for this learning curve [13, 14]. The good news is: other countries are now benefitting from it.

The share of renewables in total power demand climbed from less than 7% in 2000 to more than one-third in 2017. However, this development has its price. In Germany, total generation from subsidised renewables amounted to approximately 190 TWh in 2017. The remuneration paid to plant operators and premium payments totalled approximately € 170bn between 2000 and 2017 (Fig. 9).

The subsidies are financed via a surcharge that is paid by electricity consumers through a mark-up on the network tariffs. In 2017, this surcharge increased to € 68.8/MWh. With this, the surcharge reached a level which is more than twice as high as the wholesale price for electricity (Fig. 10).

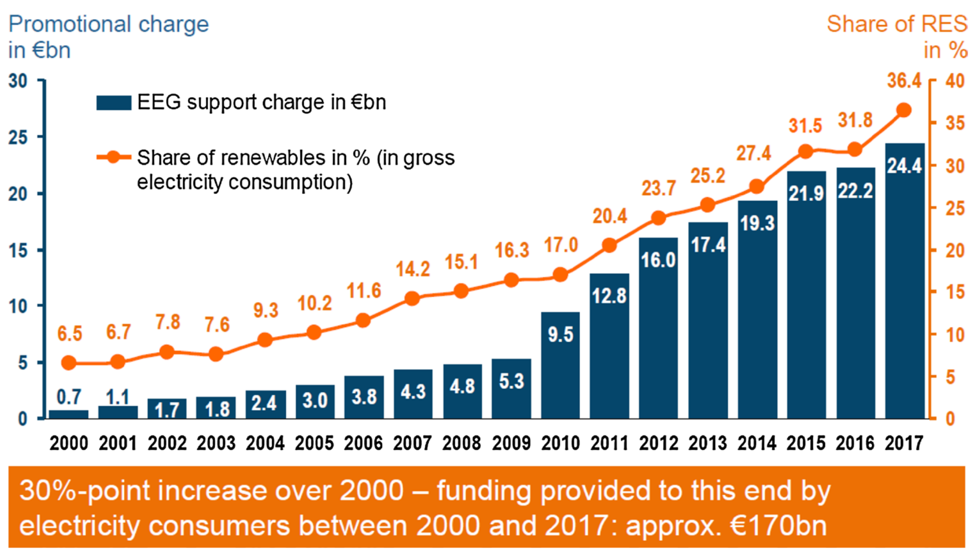



**Fig. 9** Share of renewables in electricity demand and total volume of renewable surcharge

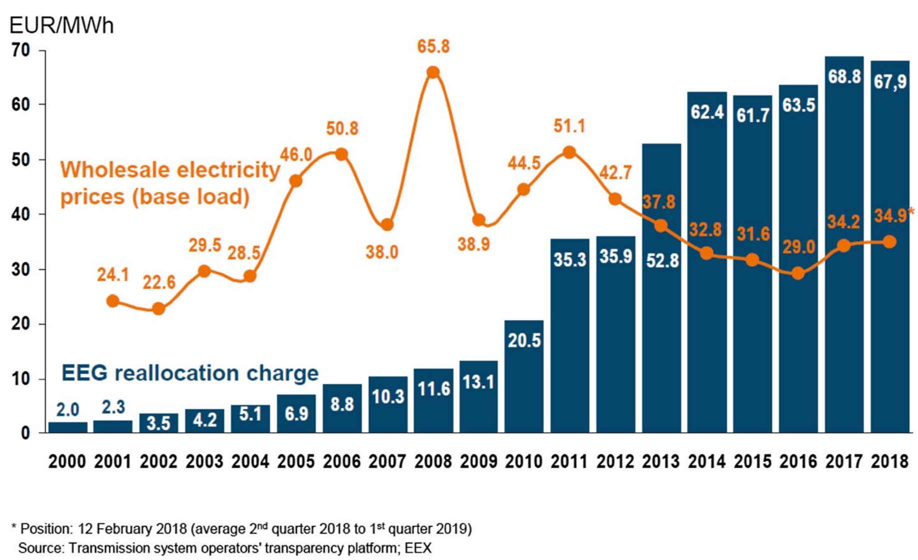



**Fig. 10** Development of wholesale power prices and renewable surcharge

To protect the competitiveness of German companies vis-à-vis their rivals around the world, the domestic industry pays a much lower surcharge (for instance, the energy-intensive industries are almost fully exempted from the surcharge). This implies that households do most of the heavy lifting in terms of financing the rapid deployment of renewables: for an average household with an annual consumption of 3500 kWh, the surcharge—including the value-added tax levied on it—amounts to some € 300 per year. Contrary to solar PV deployment in other countries, in Germany, the vast majority of the expansion in capacity came from small-scale rooftop installations on family homes. This points to an important distributional effect: the subsidisation of solar PV leads to a redistribution of income from low-income households (typically without real estate property) to relatively well-off households that have both the property and the financial means for a rooftop solar PV investment.

## Implications for producers and consumers of electricity

A simple comparison of electricity prices between different countries reveals an important distortion [15]: in Germany, power prices for industry are more or less at the same level as in Japan, but more than twice as high as in countries like the United States. Residential consumers in Germany pay even more for electricity than their counterparts in Japan. The level in Germany is twice as high as that of the OECD average and three times as high as in Norway and the United States (Fig. 11).

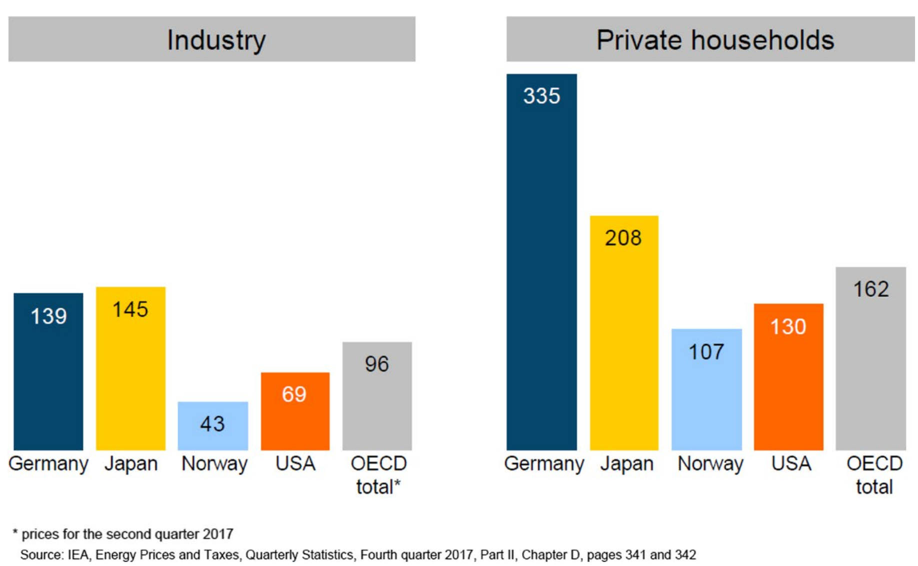
Power producers, too, are facing new challenges. These include:

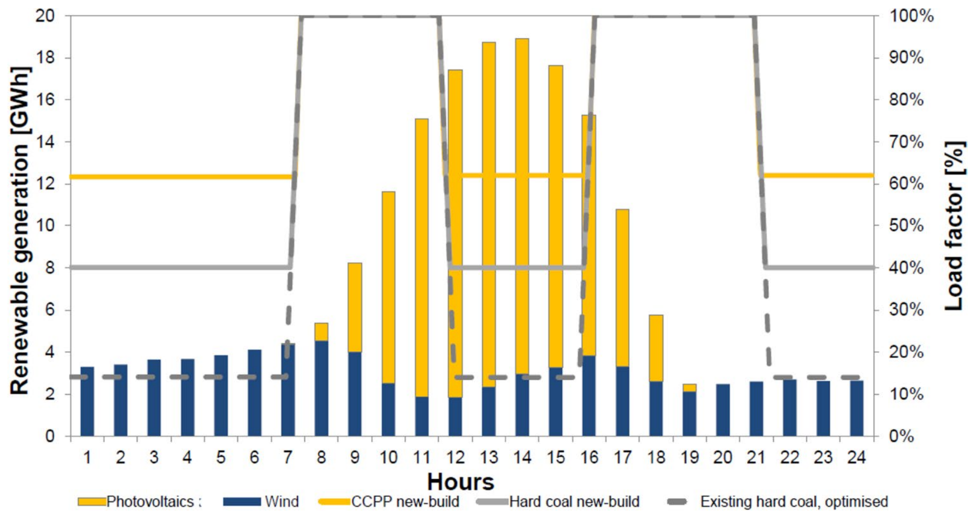
- dropping utilisation rates of thermal power plants;
- falling electricity prices on the wholesale market [16, 17];
- retrofitting power plants for growing flexibility needs to balance fluctuating generation from variable renewables.

As power demand in Germany has essentially been flat since 2000, the increasing generation from renewables led to a decrease in the operating hours of other power plants. This occurred in connection with falling wholesale prices for power. Compared with the peak in electricity wholesale prices, which occured in 2008, wholesale power prices fell by two-thirds. This trend can be explained by falling fuel prices (all energy commodity prices were at historic highs in 2008), slack in the EU emission trading scheme resulting in lower $CO_2$ prices and the so-called merit-order effect of renewable energies. The merit-order effect describes the phenomenon of sources with very low-variable costs (i.e., renewables like wind and solar PV) entering the electricity supply curve on the low-cost end of the curve and thus having an impact on the marginal (i.e., price setting) power plant. With a growing number of low-variable cost plants entering the market, previously, marginal power plants become extramarginal, while previously, intramarginal plants become marginal. In practise, this means that the previously price-setting gas-fired power plants now are too costly to be dispatched, while hard coal-fired power stations now often set the price. This has resulted in a substantial drop of the utilisation rate of gas plants in particular. Before a recent comeback of gas-fired generation in 2016 and also 2017, gas plants that were originally designed for mid-load operation were often confined to meeting peaks.

The electricity price pattern on a sunny day is an illustrative example: over the course of such a day, the electricity price curve takes the shape of an M, i.e., output from solar PV ramps up between 8 am and 1 pm leading to a drop in the

**Fig. 11** Electricity prices for industry and households in 2017 (USD/MWh)






* Regular operation of two gas turbines and one steam turbine
Source: http://www.transparency.eex.com

**Fig. 12** Electricity prices for industry and households in 2017 (USD/MWh)

electricity price; over the course of the afternoon, solar PV plants gradually generate less power leading to an increase in electricity prices. However, the timing of the increase in solar radiation in the morning does not coincide with the increase in power consumption. While electricity demand increases between 4 am and 8 am, the increase in solar PV output occurs later. Similarly, solar PV output decreases in the evening, a few hours before the decline in power consumption. This implies that thermal plants have to meet two distinct and relatively short peaks—in the morning and in the evening. To integrate the high output from solar PV at midday, while remaining available to ramp up in the evening the coal- and gas-fired power plants are running in part-load operation (Fig. 12). This effect is obviously strongest in summer, but can also be observed on sunny days during other seasons.

## Integration of renewables and flexibility of thermal plant

Power producers have to get used to different operational patterns. The routine of the past was to offset different load levels between night and day, workdays and weekends, summer and winter. While all of these tasks remain relevant, the variability of renewable energy sources is complicating system operation significantly. The challenge for operators of thermal plant is not only a technical one but also an economic one: remuneration needs to reflect the higher cost of flexible operation and cover the investment expenditure for retrofits that make existing plants technically capable of handling rapid load swings. New coal- and gas-fired power

**Fig. 13** Indicative flexibility parameters for coal- and gas-fired power plants

| Parameter | Unit | Natural gas CCPP new-build1) | Hard coal New-build | Lignite New-build | Hard coal Exist. plant (optimised) |
|---|---|---|---|---|---|
| Capacity | MW | 800 | 800 | 1,100 | 300 |
| Minimum-load point/ rated-load point ($P_{Min}/P_{Rated}$) | % | ~ 60 | ~ 25 to 40 | ~ 25[2)] to 40 | ~ 20 |
| Mean load change rate[4)] | %/min. | ~ 3.5 | ~ 3[3)] | ~ 3 | ~ 3 |

1) Regular operation of two gas turbines and one steam turbine
2) Thanks to the "BoA-Plus" design (lignite-fired power plant with optimised plant technology plus upstream coal drying) a minimum-load point of 25% is possible today but has not been implemented yet
3) In the lower load range (25 to 40%) the operating gradient differs from this value
4) With respect to rated load

station designs thus already feature the necessary technical elements for operational flexibility. Existing plants have by-and-large been retrofitted (or closed), so that pure base-load power plants without flexible operation hardly exist any more in the German market (Fig. 13).

In the typical configuration of two gas turbines and one steam turbine, the minimum load of a new natural gas combined-cycle plant is typically around 60% of its installed capacity. Lower levels of minimum load are possible by either running only one gas turbine in combined-cycle mode or running one or two gas turbines in open cycle mode (this has the advantage of very short start-up times), but this means that the power plant operator needs to accept a substantial loss in efficiency. By contrast, a new coal-fired power plant has a lower minimum load of approximately 40%, with further potential to reduce this to 20–25%. It was possible to reduce the minimum load at existing power plants in Germany by optimizing the boiler–turbine system using modern control systems. Certain optimized power plants are now able to achieve a part-load level of less than 20% [18].

The change between part load and full load in power plants involves ramping rates of approximately three percentage points per minute; the change in operating mode can, therefore, be achieved at all plants in less than half an hour. Note that rapid ramping is only possible for plants that are already running. Starting up a power plant is a time-consuming and costly procedure (a cold start of a coal plant can take several hours).

## Reliability, financial viability, and new market designs

There are times when wind and solar power meet up to three quarters of electricity demand, while at other times, there is nearly no output from these sources available (Figs. 14, 15) and the thermal plant fleet needs to run hard to ensure

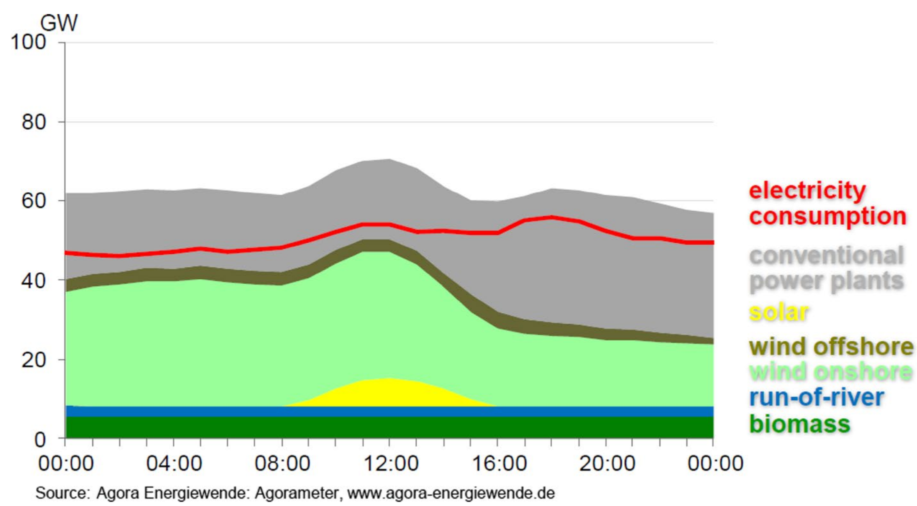



**Fig. 14** Electricity generation and load on 1 January 2018

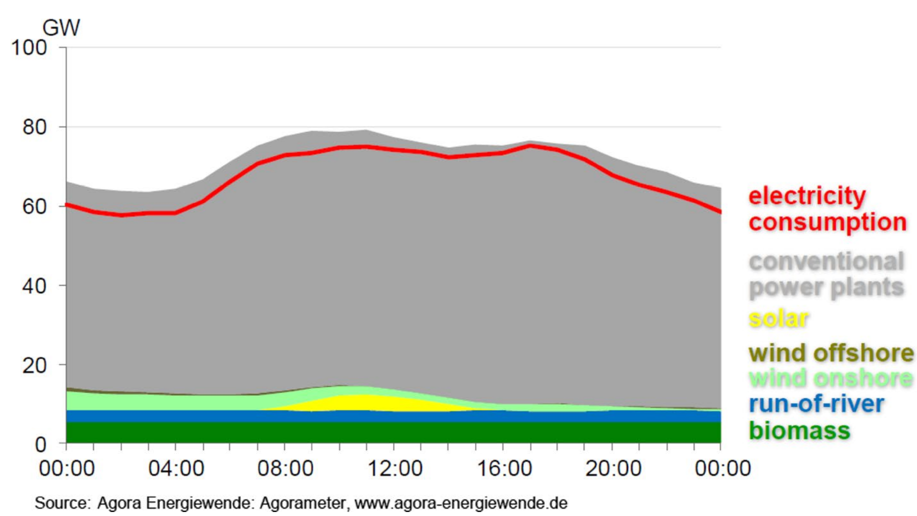



**Fig. 15** Electricity generation and load on 8 November 2017

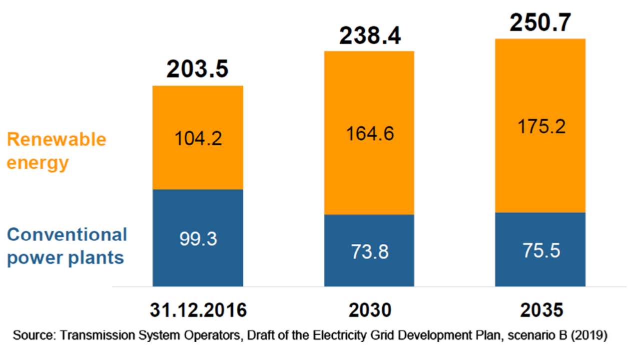



**Fig. 16** Power generation capacity (net), 2016, 2030, and 2035 in Germany

reliability of supply [19]. Further increases in the installed capacity of renewable energy are expected, mainly on the basis of PV and wind. By 2035, renewable capacity could be twice as high as peak load (i.e., the maximum annual load). Given the variability of wind and solar PV, significant amounts of thermal power plant capacity will continue to be needed in the years to come to cover electricity demand at times when the sun does not shine and the wind does not blow (Fig. 16).

The economic challenge is to ensure the financial viability of these plants that run less and less often, but remain indispensable at certain times. Given recent trends in the profitability of thermal plants, it is questionable whether the remuneration they can get from selling electricity will be sufficient to cover their full costs in the medium-to-long terms. The introduction of a capacity market, which remunerates the reliability of power plant, is a good complement to the revenues earned from electricity sales. This is the mechanism of choice to guarantee reliability of electricity supply in a number of countries and a proposal for a decentralised market of firm capacity put forth by German energy utilities points in the same direction. The appropriate market design for a capacity mechanism depends on the specifics of the power system in question [20, 21].

## Networks bottlenecks make the integration of renewables costly

Despite the rapid closure of nuclear power plants, there has been no shortage of power generation capacity in Germany. However, the decommissioning of nuclear capacity seriously affects the industrialised south of Germany, while wind power capacity has been growing primarily in the rural north (offshore and onshore). This requires a substantial expansion of the transmission grid. In practise, the extension of the grids—this also applies to the necessary expansion of the distribution networks—is not keeping pace with the increase in the power generation capacity of wind and PV systems. The reasons for this include long approval procedures, some of which are prolonged further by local resistance and by financing problems [22–24].

The network bottleneck between the north and the south of Germany is causing a number of problems. Since Germany has—for many reasons a uniform electricity price—congestion on the transmission network requires costly re-dispatch measures. However, the expansion of renewables and the congestion on the domestic transmission network result in unscheduled electricity flows from Germany's north to the south via the electricity grids of neighbouring countries (so-called loop flows). Polish and Czech grid operators in particular have raised concerns with respect to such flows. They have begun to install phase shifters on German borders that enable TSOs to physically push back electricity flows if necessary. This approach contradicts the principle of the European internal energy market. Moreover, the expansion of renewables in Germany also impacts the wholesale electricity prices, the producer, and the consumer rents in other European countries. Simply speaking, the merit-order effect reduces the profitability of electricity producers in other European countries, but also lowers the electricity price for consumers in other countries that do not contribute to the financing of German renewables via the surcharge. This effect is considerable as German electricity exports continue to grow. In 2017, Germany achieved a new record of 83 TWh in power exports (net exports standing at 55 TWh).

## A sketch of the energy policy guidelines for the upcoming years

After months of negotiations since the general election in Germany on 24 September 2017, a final agreement has been reached between Chancellor Merkel's conservatives (CDU/CSU) and the Social Democrats (SPD). The full 177-page coalition agreement "A new awakening for Europe—A new dynamic for Germany—A new cohesion for our country", dated 12 March 2018, sketches the policy agenda for the next 4 years and contains the following targets concerning climate and energy [25].

GHG (greenhouse gas) emissions (Fig. 17): commit to national, EU and UN Paris Agreement targets for 2020, 2030, and 2050. Work towards becomes GHG neutral no later than the second half of the century. The national target of reducing emissions by 40% by 2020 compared with 1990 is toned down to lowering emissions "as far as possible", whereas the national target of 55% by 2030 is to be reached "using all means", but taking into account the triangular goal of secure, clean and affordable energy, as well as structural

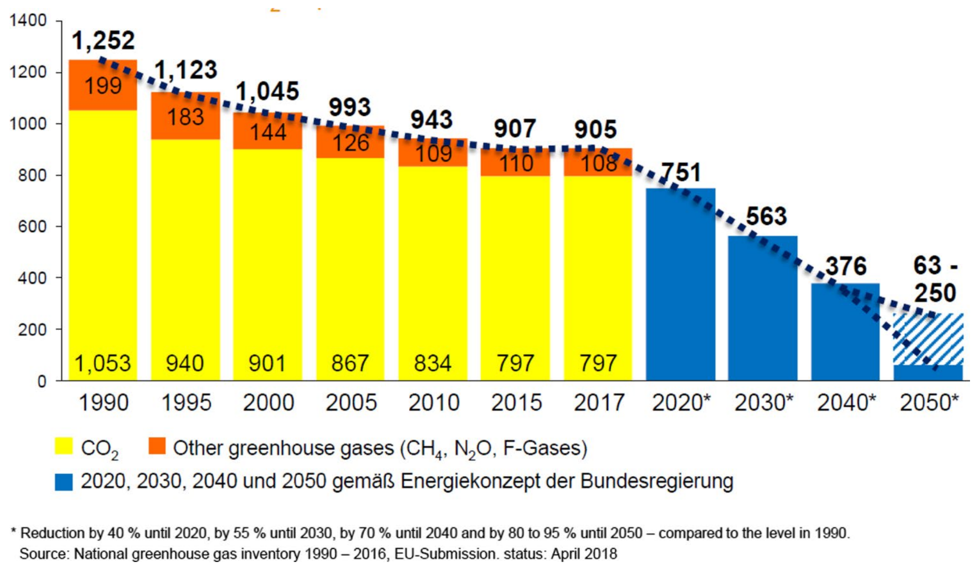



**Fig. 17** Greenhouse gas emissions in Germany 1990–2017 and targets until 2050

dislocations and the need for a science-based, technology-open and efficient climate policy.

Coal phase out [26, 27]: establish a special commission on “Growth, Structural Change and Employment”, bringing together policymakers, industrialists, NGOs, trade unions, and regional stakeholders, to draft an action plan by the end of 2018, which should include:

- measures to close the 2020 target gap “as far as possible” and to reliably reach the 2030 energy-sector target;
- a plan “for the gradual reduction and phase out of coal-fired power generation, including an end date, and the necessary accompanying legal, economic, social and structural policy measures”;
- financial support from the federal budget for the necessary structural changes in affected regions.

The commission’s findings will feed into a law on climate protection promised in 2019. This new law will ensure compliance with the 2030 targets found in the ‘Klimaschutzplan 2050’ (Climate Action Plan 2050). At the same time, a similar process is planned for the transport and buildings sectors.

EU Emission Trading System (ETS): strengthen the EU-ETS as the primary mechanism to price $CO_2$ emissions as part of a global system that includes at least the G20 countries.

Climate finance: recognise Germany’s responsibility for international climate protection by increasing foreign development aid.

Industry and commerce: guarantee the international competitiveness of energy-intensive industries by maintaining integrated value chains and preventing carbon leakage while bolstering Germany’s leading position in the energy transition, including through bilateral energy partnerships that advance the global energy transition. Provide R&D funds for low-carbon industrial processes and the closed-carbon-cycle economy. Establish a support programme for the decarbonisation of industry to secure Germany’s position as an industrial location with modern products and processes, to strengthen its international competitiveness and to secure future-proof jobs in Germany.

Renewables: target-oriented expansion to 65% in total power consumption by 2030 (instead of 2040), with “special auctions” in 2018 and 2019 for 4 GW of onshore wind (balancing public interests), 4 GW of solar PV and one offshore wind farm, but moving towards market mechanisms and giving opportunities for citizen ownership.

Grid: optimise existing grid (through digitalisation) and accelerate expansion using underground cables where needed and perhaps profit sharing with landowners.

Efficiency: reduce energy consumption by 50% by 2050 (e.g., tax breaks for retrofit of buildings).

Costs: reform grid fees to reflect costs on a “causal principle”.

Storage: facilitate the electrification of the heating, mobility, and electricity sectors (sectoral coupling) in combination with storage technology (e.g., large-scale thermal storage at old power plants).

Gas: make Germany a location for LNG infrastructure.

Nuclear: reaffirmed phase out by 2022. No EU support or state aid for new nuclear power plants anywhere. Safety reviews of neighbouring nuclear plants and restrictions on fuel supply to nuclear plants outside Germany, where safety is in doubt, all within legal frameworks that may require amendments to the EURATOM Treaty.

## Conclusion: continued success of the 'Energiewende' requires focus on costs when moving beyond the power sector

German energy policy has successfully underpinned a rapid expansion of renewable energies in the power sector while managing the phase out of nuclear energy. Replacing a carbon-free source of electricity (nuclear) with another carbon-free source of electricity (renewables) implies, however, that the impact on overall $CO_2$ emissions from power generation has been modest since 2010. The fact that Germany is unlikely to achieve its 2020 targets is a reflection of the difficulty of achieving multiple targets at the same time. (The rapid cost decreases achieved in the past years, especially for solar PV, have had positive spill-over effects for renewable energy deployment around the world and helping to curb $CO_2$ emissions elsewhere.) [28–40].

Now that the nuclear phase out is well underway, and the new government's focus is moving on to phasing out coal. In the beginning of April 2018, the new minister of economic affairs and energy, Peter Altmeier, announced a target of cutting coal-fired power generation in half, by 2030. A roadmap for the coal phase out will be determined over the course of the year 2018. Chances are that the coal phase out will be nationally administered, resulting in negotiations between the government and the plant owners and potentially through litigation. Bypassing the EU-ETS, however, risks a drop in $CO_2$ prices, incentivising coal-fired power plant operators outside Germany to produce more electricity and potentially offsetting some of the $CO_2$ savings from the coal phase out in Germany (especially if less efficient plants fill the gap).

However, the real challenge of the next decade is to move the energy transition beyond the power sector. Heat production—in industry and in buildings—is a major source of $CO_2$ emissions today. Certainly, efficiency improvements, renewable sources (geothermal or solar thermal), or decarbonised electricity (for example, for heat pumps or resistance heaters) can play an important role, but they all hit constraints at a certain point in time. For example, based on what we can see today, large-scale seasonal electricity storage for heating purposes is unlikely to become economically feasible. Other problems arise in industry, where it is not evident how to substitute high-temperature process heat (today mostly provided by natural gas) with decarbonised electricity.

In the transport sector—another major source of $CO_2$ emissions (169 Mt in 2017)—the energy transition has not yet gained any momentum either. France and the UK have pledged to ban the sales of conventional vehicles from 2040 onwards (The Netherlands even from 2030)—although the issue came up in the German election campaign nothing came out of it. A conscious policy decision to support another technology would be an alternative to bans, but this has not yet happened either.

There is no lack of alternative technologies to kick off the energy transition in other sectors. For instance, hydrogen is a particularly promising candidate to decarbonise the energy that is currently provided by natural gas (hydrogen could either be produced through electrolysis using decarbonised electricity or from natural gas in combination with carbon capture and storage). Some also argue that hydrogen could be the solution for the decarbonisation of the transport sector, but here, electric vehicles are the front runner in terms of global policy momentum and technology development [41]. For either of those, the focal point is infrastructure development and this is where government intervention is needed to overcome the chicken and egg problem.

Independent of which technologies the German government decides to support (or to ban), the national strategy to achieve the energy transition needs to be aligned and ideally embedded in a European strategy. Coordination helps keep the costs in check. The power sector is a case in point: a common European renewable energy strategy in combination with network expansion would enable the best sites for renewables to be used, independent of the national energy needs, while an expanded and strengthened grid would allow for balancing over a wider geographic area and thus keep the balancing cost low [42–44].

Finally, it must not be forgotten that the energy transition is a global effort for a sustainable energy future. Developing countries often have other priorities (access to energy, industrialisation) than Germany and that one tonne of $CO_2$ saved in Germany has the same effect for the climate as a tonne of $CO_2$ saved in India. International cooperation is thus a long-term imperative for a successful energy transition [45].

The energy transition is not a zero-sum game, it comes with loads of business opportunities, but to harvest these, a reliable and transparent policy framework is needed. The new coalition agreement shows an awareness for most of these aspects but what is needed now is a clear vision on how to achieve the long-term goals of the 'Energiewende'.

## What the Middle East and North Africa can learn from the German experience

What can the Middle East and North Africa (MENA region) learn from the German experience? The countries of the MENA region have committed themselves to the achievement of the Paris agreement and, as such, need to transform their energy systems away from hydrocarbons towards low-carbon technologies [46, 47]. Contrary to Germany, this needs to happen against a backdrop of rapid energy demand growth (the IEA's World Energy Outlook projects annual energy demand growth of 2.1% for the Middle East in the period to 2040 [48]) and lower income levels (for 2017, the IMF estimates GDP per capita in Germany at US$ 45 thousand versus US$ 6 thousand in the MENA region [49]).

This implies two major policy guidelines that differ from the initial approach in Germany: first, the region needs to mobilise various sources of low-carbon energy to satisfy runaway energy demand growth, i.e., technology neutrality for new technologies is paramount, and most importantly, no technology should be excluded upfront. Second, the region needs to bring low-carbon energy to its consumers in the least costly way possible, i.e., market-based mechanisms should be given priority when planning regulation for the deployment of low-carbon technologies.

Putting a price on $CO_2$—either via an emission trading system or via a tax—would be the first best solution from economic point of view. In practise, pricing $CO_2$ often faces political headwinds. Nevertheless, when second best solutions are the only viable alternative, the design of support schemes should be market-based (e.g., tender systems for the optimal allocation of renewable capacities or market premia for the remuneration of low-carbon technologies). A renewable energy support system, which is based on 'produce and forget', with long-term guaranteed margins for investors, is not a sustainable solution in the long run. In the German case, it was only appropriate in the very early stages of the 'Energiewende'.

Subsidising fossil-fuel consumption—not an issue in Germany but common in the countries of the Middle East and North Africa—underpins wasteful use of energy and is, similar to feed-in tariffs for electricity, leading to economic distortions. Phasing out such subsidies is thus an important step towards creating a level playing field between the different technologies and fuels and in fostering improvement of energy efficiency.

The MENA region has excellent potential for solar energy and, in some cases, also wind energy. Globally, the capital cost of new solar PV installations fell by 70% between 2010 and 2016 and those of new wind projects by 25% [48] with further drops in costs since then. As an early mover, Germany, or more precisely German electricity consumers made substantial contributions to bringing these costs down. Some solar projects recently realised in the Middle East are already among the least cost of their kind in the world, suggesting that the time is ready to step up investment in the region.

Germany, being at the heart of the European electricity system, has benefitted from interconnections with its neighbours and would probably not have been able to smoothly integrate rapidly growing amounts of variable renewable energy into the system without the flexibility provided by its neighbours. Despite some noteworthy cooperative approaches, the MENA region lacks the overarching regulatory structure of the European Union that actively pushes for market integration. Without market integration, the energy transition risks being constrained and unnecessarily costly.

Finally, policy makers in the region are advised to not only focus on the decarbonisation of electricity generation but instead to pursue a holistic approach that includes pathways to decarbonise other sectors in parallel. The MENA region, as a major producer of oil and gas and a hub for the petrochemical industry, would be a good candidate for large-scale deployment of carbon capture and storage technologies (CCS) [50]. The availability of relatively pure streams of $CO_2$ from industry in combination with ample geological storage potential within easy reach and the possibility to use the $CO_2$ for enhanced oil recovery are ideal pre-conditions for the viability of the CCS technology.



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