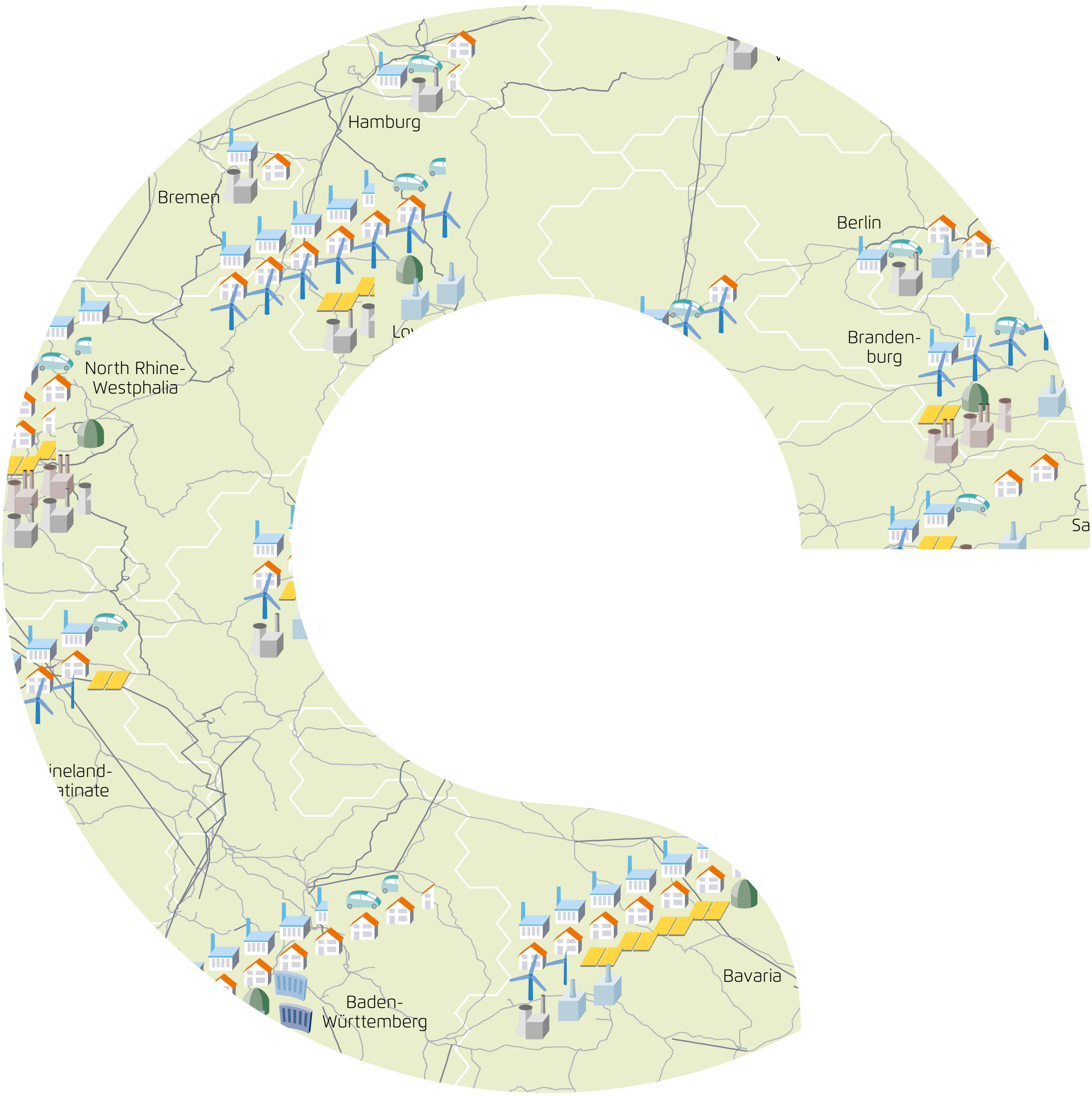
Energiewende 2030: The Big Picture

Megatrends, Targets, Strategies and a 10-Point Agenda for the Second Phase of Germany's Energy Transition

IMPULSE

Agora Energiewende



Power System in 2015

— Existing high-voltage lines

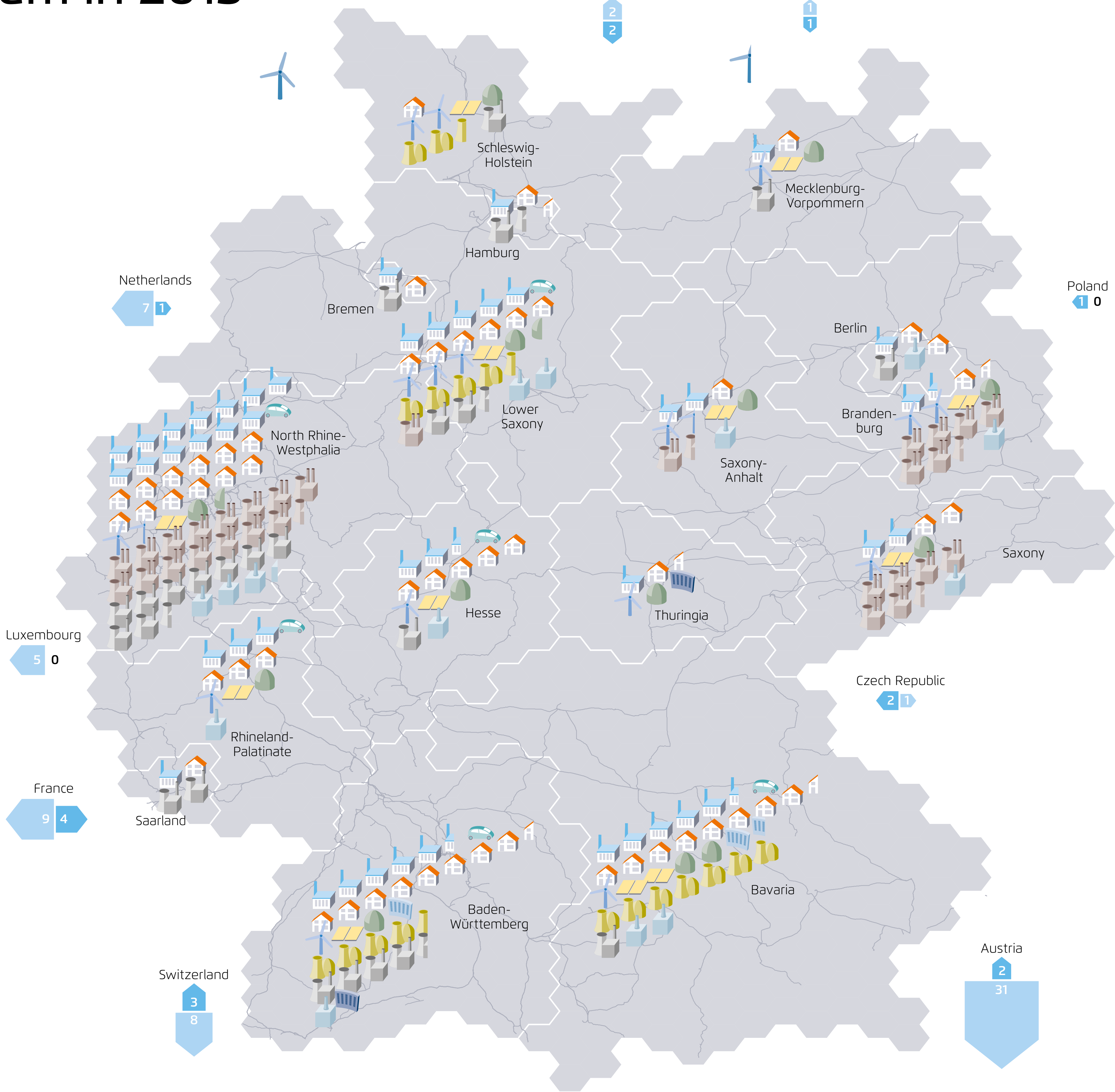
Gross power generation*
- Offshore wind
- Onshore wind
- Photovoltaic
- Biomass
- Hydropower
- Nuclear
- Lignite
- Hard coal
- Natural gas
- Pumped storage

Power demand*
- Industry
- Transport
- Buildings

International electricity trading**
- Power imports (TWh)
- Power exports (TWh)

* Each symbol generally represents 5 terawatt-hours of generation and consumption. In the case of smaller German states, the symbols may represent a little less than this amount for depictive reasons.

** The balance of international electricity trading slightly diverges from the balance of international physical load flows.



Gross power production	TWh
Nuclear	92
Lignite	155
Hard coal	118
Natural gas	62
Pumped storage	9
Misc.	24
Onshore wind	71
Offshore wind	8
Photovoltaic	39
Biomass	50
Hydropower	19
Total	647

Power demand	TWh
Industry	228
Transport	12
Buildings	281
Transformation losses, network losses, etc	74
Total	595

Balance of cross-border physical load flows	52

Source: Authors' calculations

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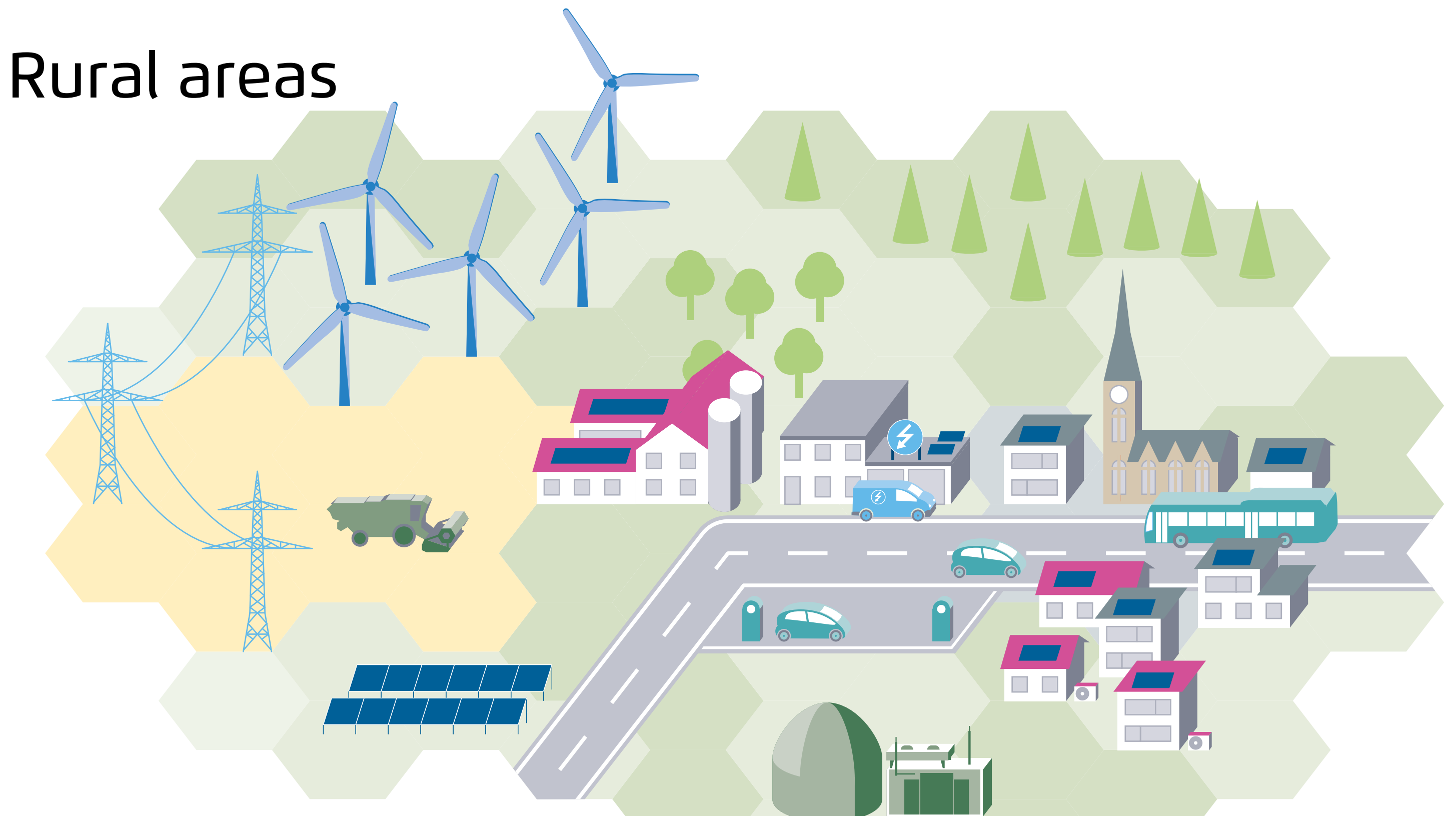
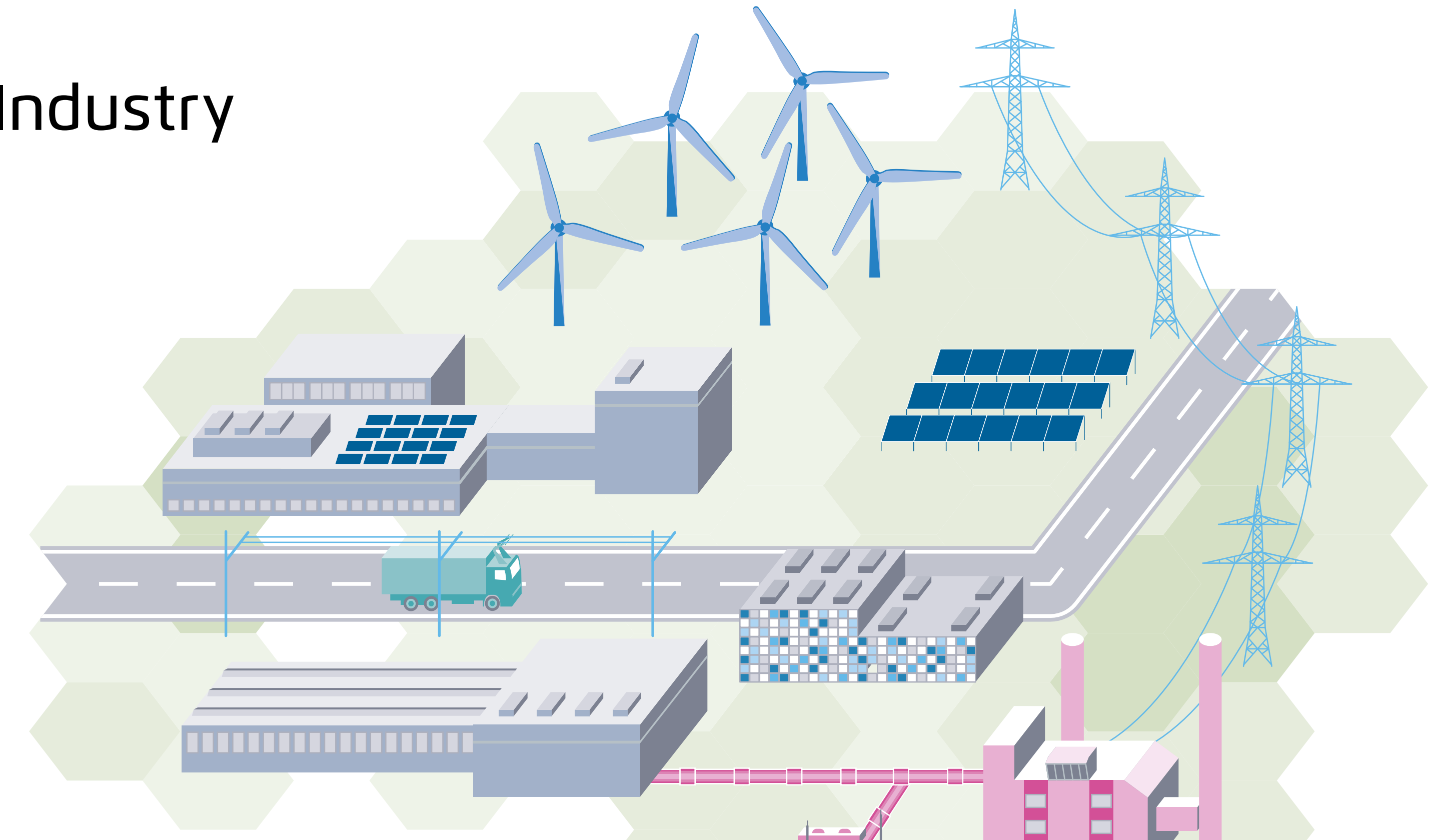
Rural areas



The energy transition will especially benefit the rural areas. Wind and solar power plants will generate revenues for municipal budgets, local firms will benefit by providing operational and maintenance services. Half of all buildings will be heat insulated, many households will generate and/ or consume solar power on-site to power their heat pumps and electric vehicles. However, most cars will still run using conventional combustion engines.

Industry



Industry will benefit from inexpensive solar and wind power, whether generated on-site or procured from the power market. An increasing number of manufacturers will dynamically steer their energy demand based on intermittent power supply levels. Wind and solar electricity will also be used to a greater extent to cover heat demand. In line with the *efficiency first* principle, industrial companies will become ever more efficient.

Power System in 2030

New underground cables and long-distance transmission lines

Existing high-voltage lines

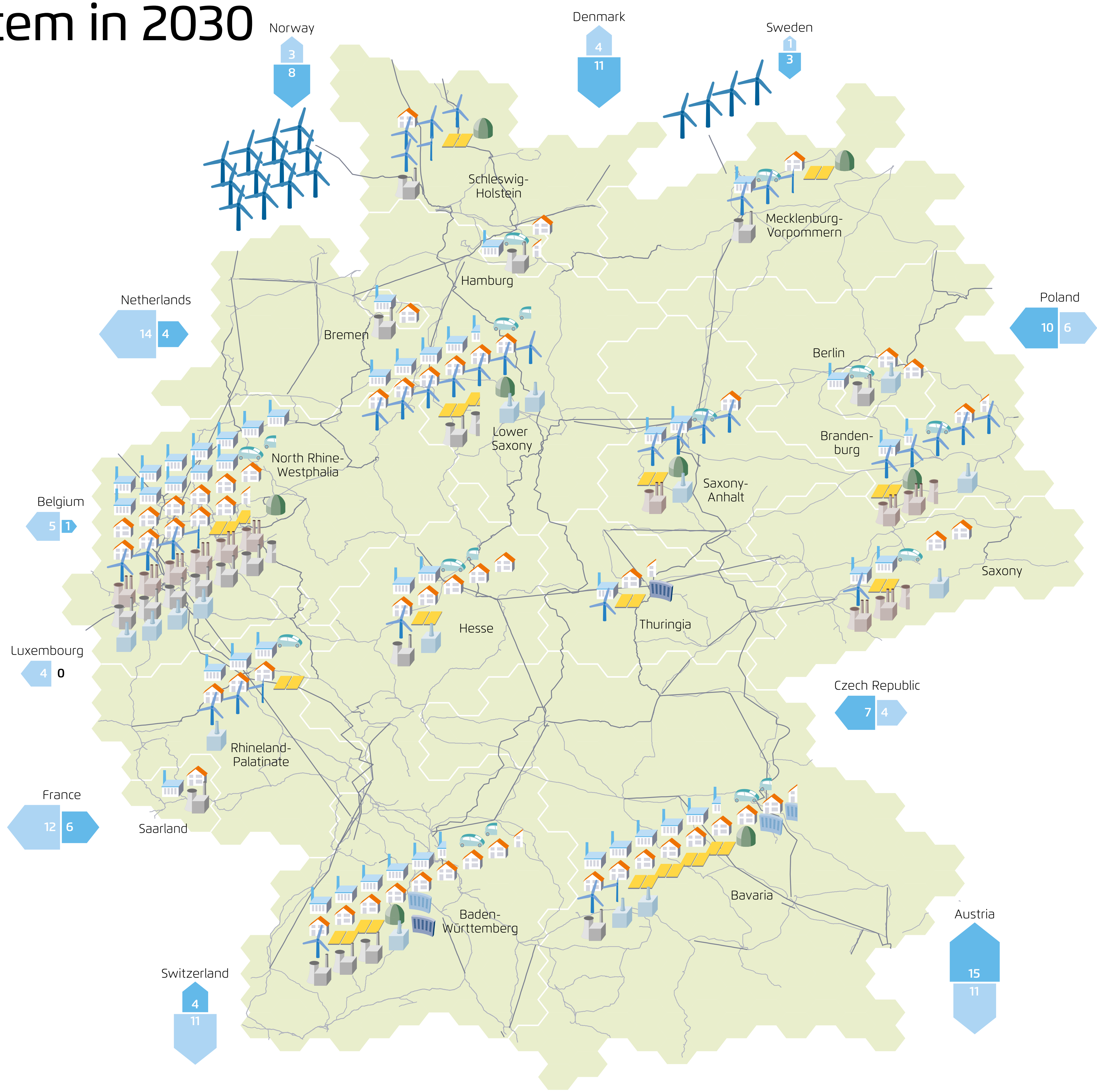
Gross power generation*
- Offshore wind
- Onshore wind
- Photovoltaic
- Biomass
- Hydropower
- Nuclear
- Lignite
- Hard coal
- Natural gas
- Pumped storage

Power demand*
- Industry
- Transport
- Buildings

International electricity trading**
- Power imports (TWh)
- Power exports (TWh)

* Each symbol generally represents 5 terawatt-hours of generation and consumption. In the case of smaller German states, the symbols may represent a little less than this amount for depictive reasons.

** International electricity trade flows have been estimated using a scenario that models a European-wide transition to renewables (assumptions: European/national renewable expansion targets are met, share of renewables > 50 %, stable power demand despite integration of energy sectors, expansion of international grid connections).



Gross power production	TWh
Nuclear	0
Lignite	~ 60
Hard coal	~ 80
Natural gas	~ 70
Pumped storage	~ 10
Misc.	~ 20
Onshore wind	~ 170
Offshore wind	~ 80
Photovoltaic	~ 70
Biomass	~ 30
Hydropower	~ 20
Total	~ 610

Power demand	TWh
Industry	~ 210
Transport	~ 60
Buildings	~ 270
Transformation losses, network losses etc.	~ 70
Total	~ 610

Balance of cross-border physical load flows	~ 0

Source: Authors' calculations

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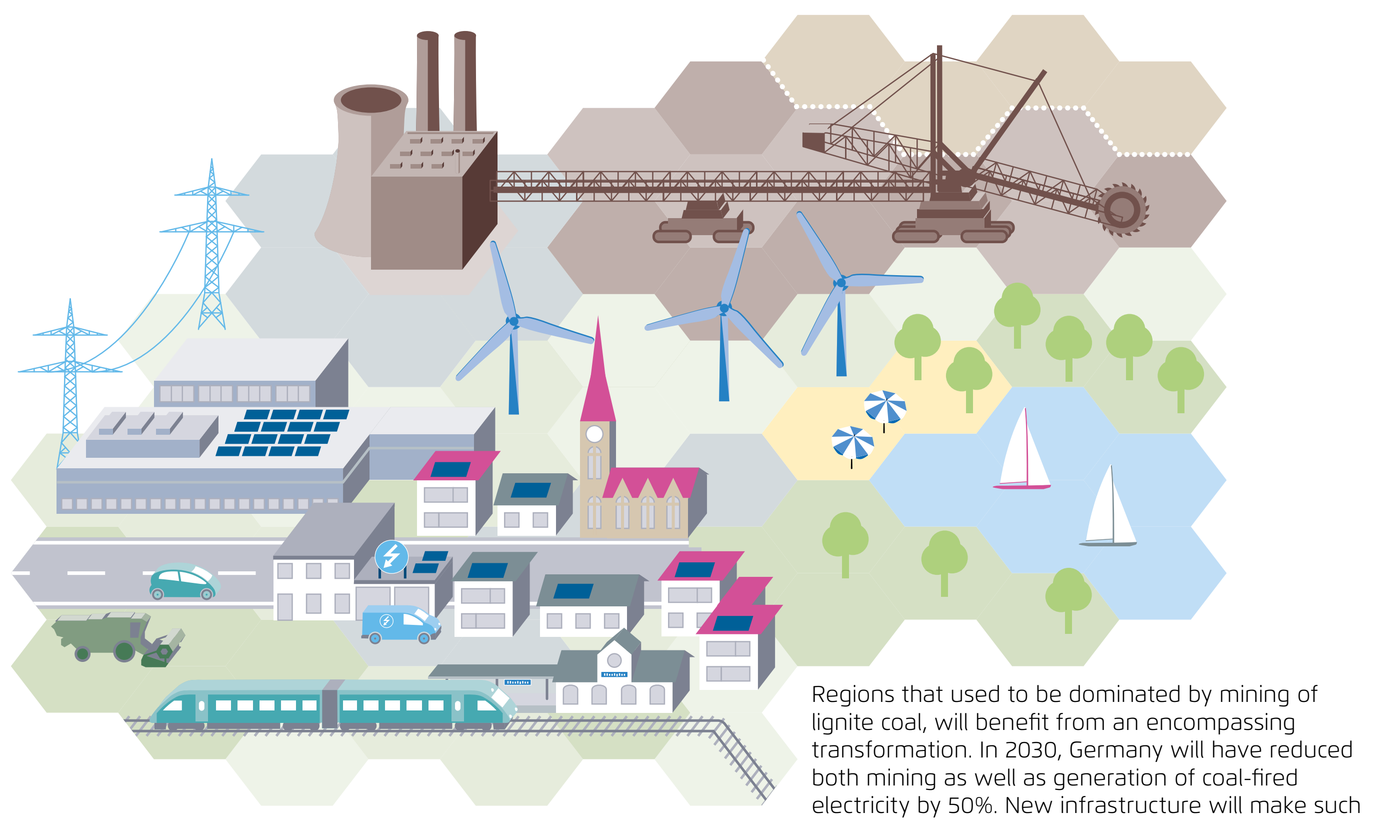
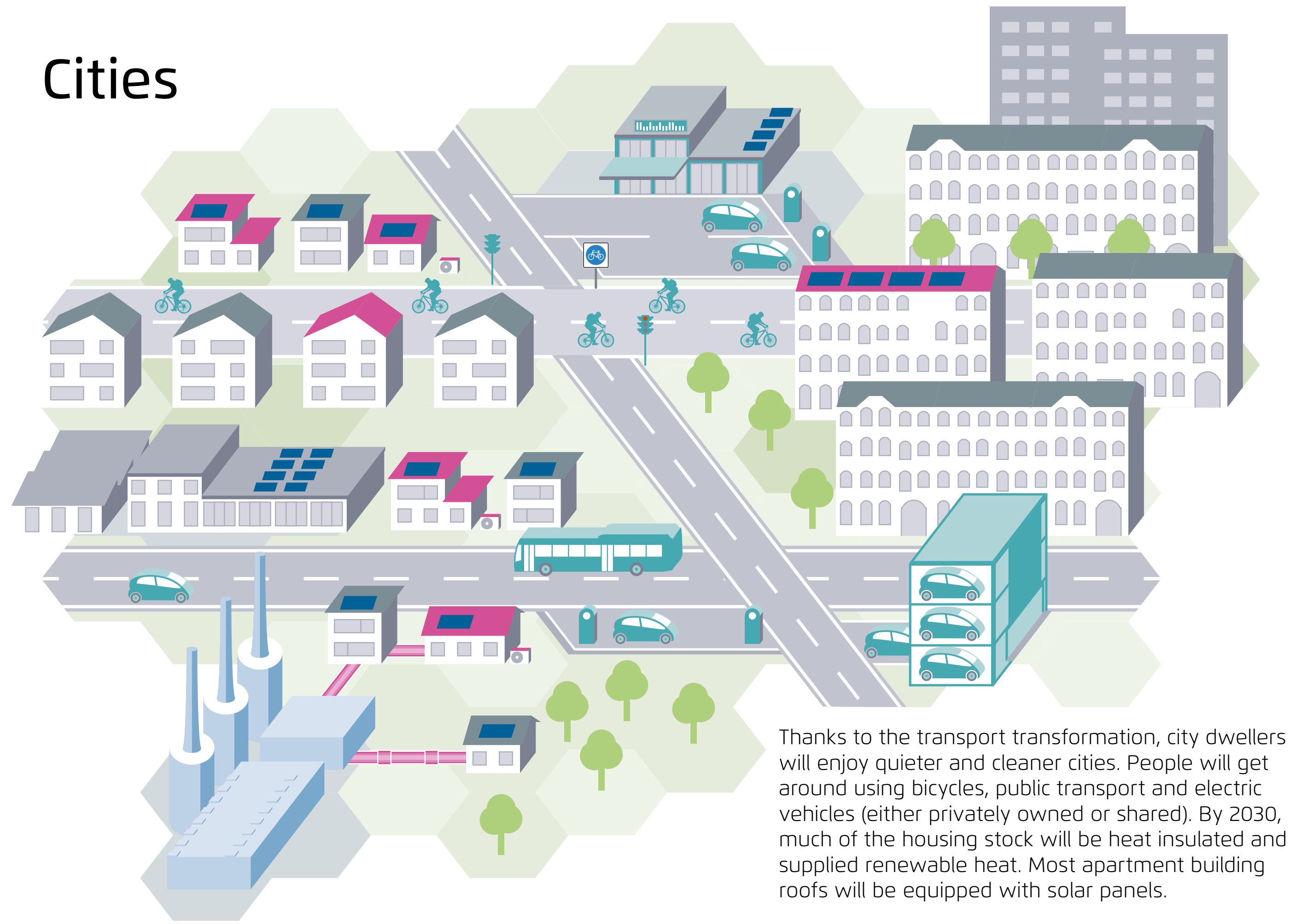
Lignite mining regions



Regions that used to be dominated by mining of lignite coal, will benefit from an encompassing transformation. In 2030, Germany will have reduced both mining as well as generation of coal-fired electricity by 50%. New infrastructure will make such regions attractive for investment. At the same time, renewable energy, efficiency technologies, cutting-edge research and tourism will create jobs and have local economic benefits.

Cities



Thanks to the transport transformation, city dwellers will enjoy quieter and cleaner cities. People will get around using bicycles, public transport and electric vehicles (either privately owned or shared). By 2030, much of the housing stock will be heat insulated and supplied renewable heat. Most apartment building roofs will be equipped with solar panels.

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Germany's Energy Transition

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Preface

Dear readers,

Germany has been an early adopter and significant driver of what has now become a global trend towards energy transitions. Today, international competition and cooperation have drastically driven down the costs of wind turbines, photovoltaics and batteries, kick-starting renewable generation worldwide.

These and other developments are dissolving the longstanding antagonism between economic and climate interests. In every year since 2013, more capacity has been added from renewables than from all other energy sources combined, as investors shift their focus from fossil fuels to renewable energy.

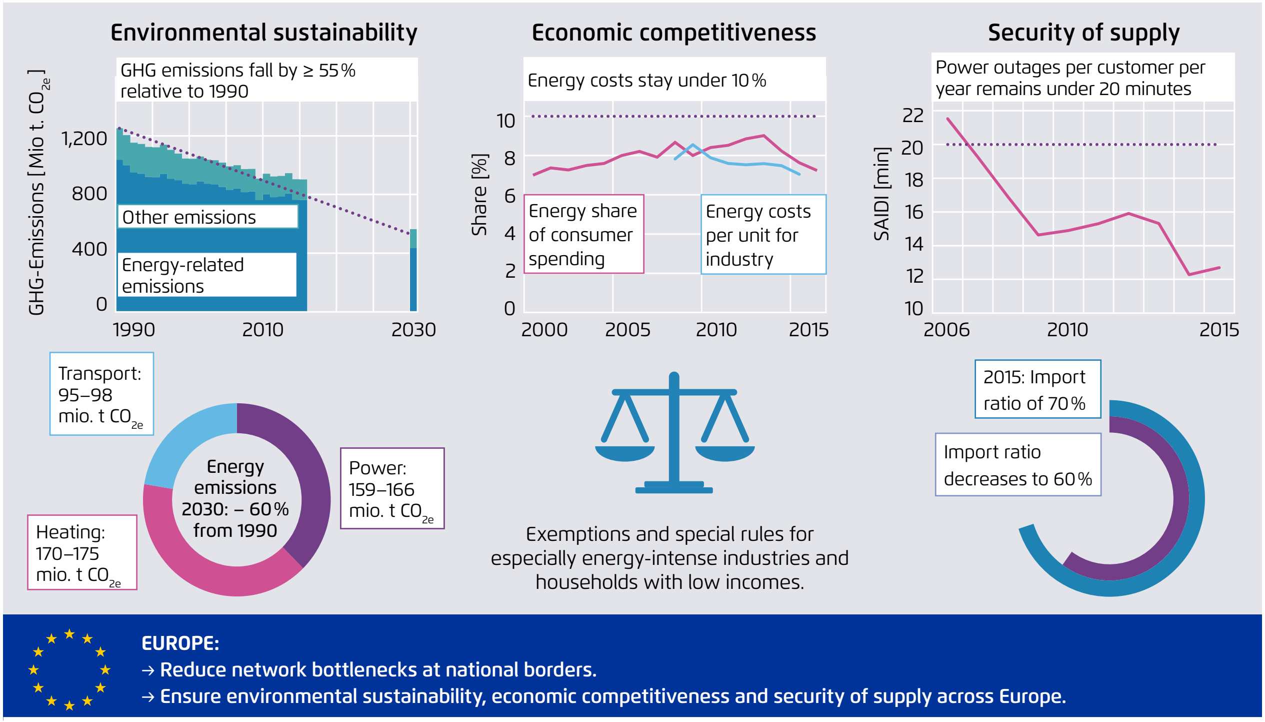
This report proposes specific steps Germany should take to reach its climate target of at least minus 55 % greenhouse gas emissions compared to 1990 levels by 2030, and it describes the challenges and opportunities that this transition holds for the 4th largest economy in the world. While this report is focused on Germany, it also offers insights that stand to benefit the rest of the world: among other things, it spotlights strategies for integrating the power, transport and heating sectors, and illuminates crucial principles that should inform energy policy, such as promoting energy efficiency and creating reliability and predictability through the means of legal frameworks.

Of course, Germany still has much to learn from other countries, too. I therefore encourage you to send us your comments and criticisms so that together we can usher in renewable, affordable and reliable energy systems across the globe.

I wish you an enjoyable read!

Dr. Patrick Graichen
Executive Director of Agora Energiewende

Specifying *Energiewende* targets for 2030: Agora Energiewende's recommendations



Agora Energiewende, based on BMWi (2017), BMUB (2016), Destatis (2016a) and Expertenkommission zum Monitoringbericht "Energie der Zukunft" (2016)

Summary

1. The 7 D's of the Energy Transition: The Trends Shaping Tomorrow's Energy Systems

1. Decrease in costs
Wind power, solar power and batteries are becoming cheaper

2. Decarbonisation
Climate change requires urgent action

3. Deflation of energy prices
Coal, oil and natural gas prices remain inexpensive, but are increasingly volatile

4. Dominance of fixed costs
The energy system of the future will have low operating costs

5. Decentralisation
The new energy system is becoming less centralised

6. Digitalisation
The energy system is becoming smart and better integrated

7. Democratisation
The new energy system affects citizens more

2. Specifying Energy Transition Targets for 2030: Agora Energiewende's recommendations

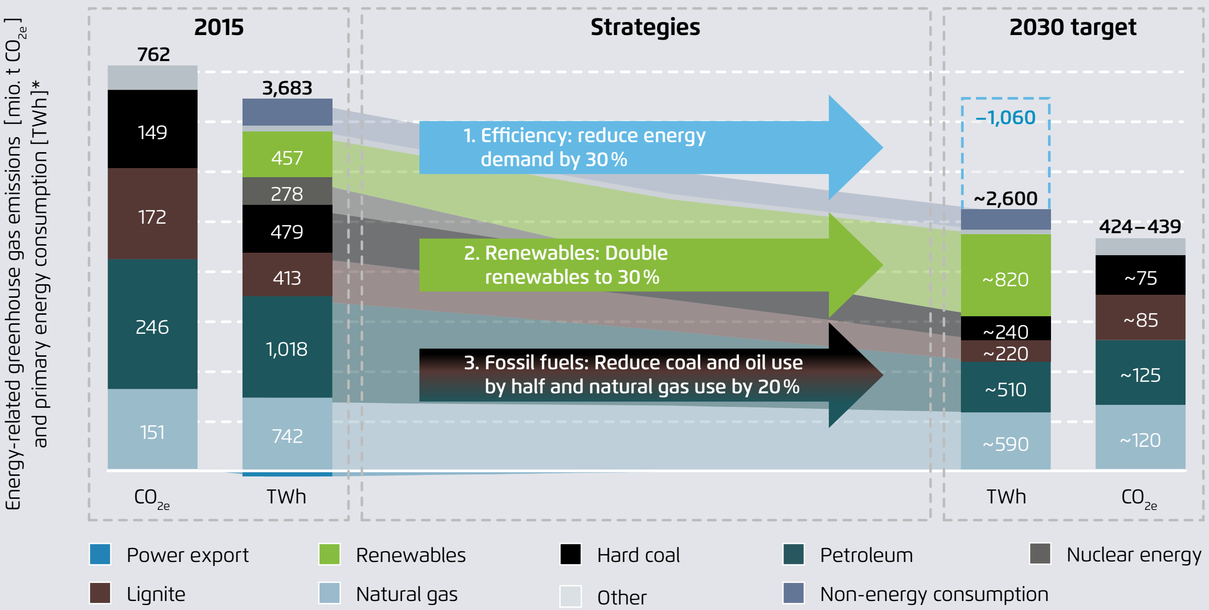
Environmental sustainability
Reduce greenhouse gas emissions in the energy sectors by 60 % relative to 1990 levels by 2030. Adhere to the principles of nature conservation when expanding renewables and repurposing former lignite mines.

Economic competitiveness
Keep energy costs per unit in the industrial sector and energy's share in private consumer spending under 10 %. Give special exemptions to energy-intense industries and private households with low incomes.

Security of supply
Reduce import levels for total primary energy use (coal, oil, natural gas, renewables) below 60 % by 2030. Keep average power outage (SAIDI) permanently under 20 minutes per year.

European integration
Eliminate bottlenecks in power, gas and transport networks at Germany's borders. Create close ties with Germany's neighbours when addressing security of supply, renewable energy expansion and the design of power markets.

3. Strategies for a Cost-Efficient Energy Transition by 2030



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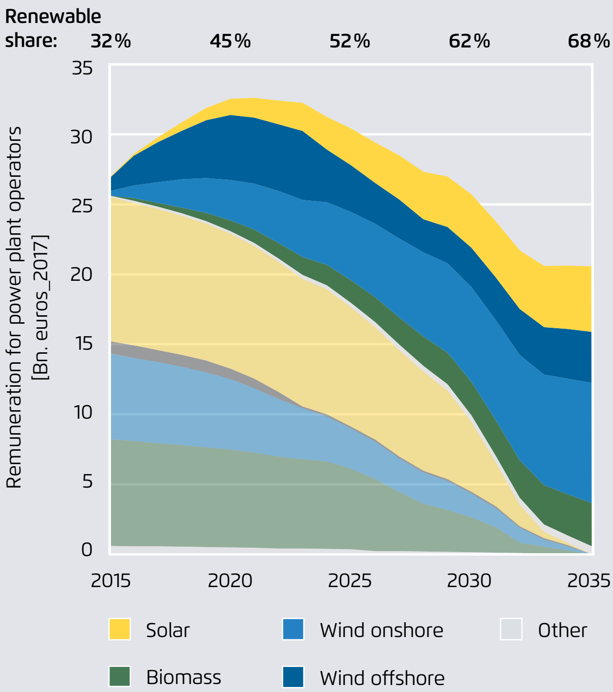
Starting in the early 2020s, costs for expanding renewables in the power sector will drop off noticeably



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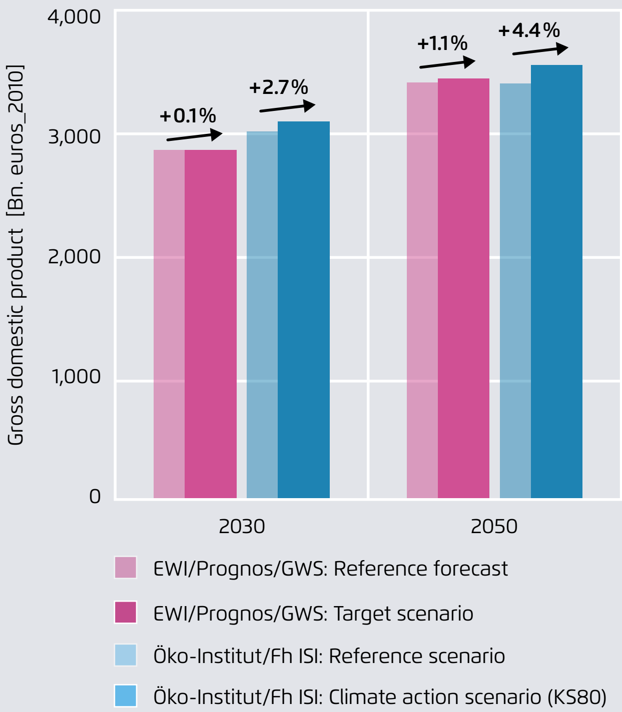
The total economic effects of the energy transition are slightly positive as decreasing imports of coal, oil and natural gas make room for domestic value creation



5. What to Do Now: A Ten-Point Agenda for the Next Phase of the Energy Transition

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Create a legal framework to ensure reliability and predictability

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Support Europe's energy transition; coordinate Germany's efforts within Europe

3. Efficiency
Make *Efficiency First* the guiding principle for planning processes and investment decisions

4. Renewables
Use wind and solar to increase renewables to 60% of the power sector and 30% of primary energy consumption

5. Fossil fuels
Reduce carbon-intense coal and oil by 50%, and introduce carbon-neutral synthetic fuels

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Introduction

The German energy transition – the *Energiewende* – has made major global strides over the past couple of years. In June 2015 government leaders at the G7 summit in Elmau called for the decarbonisation of the global economy by the end of the 21st century. And at the United Nations Climate Change Conference in Paris that December, 197 states signed an agreement setting out a plan to keep the planet from warming well below 2° C above preindustrial levels. Ultimately, this will make the energy industry independent of coal, oil and natural gas and reorient it towards renewable energy and energy efficiency.

When the Trump administration announced in May 2017 that the US would withdraw from the Paris Agreement, the initial shock was quickly supplanted by a global movement confirming the necessity of the Paris Agreement, holding that decarbonisation is a must, not an option. Cementing that conviction are not only the dangers of climate change, which are all too real, but also the enormous business opportunities in transitioning to a carbon-neutral world. Thanks to falling technology costs in renewables, wind and solar power are now the most affordable ways to generate electricity in many countries. And the number of renewable energy sector jobs in Europe and the US has already far exceeded jobs for coal, oil and natural gas. These developments signal the beginnings of a seismic shift in thinking about climate and the economy. Where climate policy was once a debate about who should bear the burden of mitigation costs, today it is about which region will have the largest share of the exploding clean-energy market.

Right now, countries are competing with each other to see who can install the most renewable energy capacity in the shortest period of time. Germany wants to achieve an 80 % share of renewables in its power sector by 2050. California, the sixth largest economy in the world, plans to have 100 % of its power from renewable energy by 2045. China installed 65 gigawatts of renewable power in 2017 alone, a feat that Germany took eight years to achieve. India has announced a plan to increase new renewable capacity four-fold by 2022, for a total of 175 gigawatts, and a recent draft bill for a new national electricity plan aims to add another 100 gigawatts by 2027. In Germany's immediate vicinity, Denmark is shooting for a 50 % share of renewables in the power, heating and transport sectors by 2030; Sweden is committed to net zero greenhouse gas emissions by 2045; and the UK and Portugal stated publicly they would stop burning coal for electricity generation by 2025 and 2030, respectively. Finally, the European Union is in the final rounds of negotiating a package of legislation titled Clean Energy for All Europeans, aimed at fulfilling the Paris Agreement. The EU's current 2030 targets for greenhouse gas reductions, energy efficiency and renewable energy will require renewables to account for more than half of all power produced in Europe by 2030. As these examples show, Germany is far from alone in transforming its energy system.

This report takes a comprehensive look at the German energy transition's second phase, which began in 2015 and will end in 2030, the scheduled halfway point in Germany's plan to fully decarbonize its energy system. In doing so, we propose a set of specific targets and measures that would effectively increase Germany's share of renewables in the power sector from 30 % to 60 %. During this second phase, Germany will also need to expand its energy transition beyond the power sector to transport and heating. By 2030, renewable electricity will no long be something merely *added* to existing power supply; it will constitute the backbone of the energy system.

The integration of the power, transport and heating sectors around renewable electricity from wind and solar power will bring fundamental changes to the mechanisms of supply and demand. Power markets will have to become more flexible, more digitalised and more oriented towards short-term trading, while Germany's system of energy taxes, surcharges and levies will need to be reformed to create the proper incentives for market actors. Moreover, energy policy will have to put greater emphasis on efficiency as the energy transition extends to the heating and transport sectors. Last but not least, the scaling up of renewables must be accompanied by the phase-out of fossil fuels, especially coal and oil. This will require industrial and political stakeholders to engage in open, constructive dialogue about the perceived economic trade-offs.

Although this report focuses on Germany, its insights are likely to be pertinent for other countries as well. For every country that seeks to make wind and solar its main source of energy faces the same basic challenge: the weather-dependent nature of the underlying technologies. As a result, the paradigm of the new energy world is flexibility, be it through demand side management, sector coupling, increased energy storage or closer cooperation with neighbouring countries.

Each phase of the energy transition poses different types of questions, and the answers countries find will depend on their particular situation. Island nations, for example, are likely to approach flexibility differently from Germany, and may choose to expand storage options at an earlier stage. Countries that are only now embarking on their own energy transition could leapfrog the first phase and implement energy efficiency, digitalisation and sector coupling right from the start. Countries with a different market design might need to find alternative ways of organising the efficient dispatch of supply and demand. Yet there is one task that all countries share: efficiently using the renewable, affordable electricity that wind and solar energy provide. Germany's lessons and challenges can only benefit other countries regardless of what stage they are at in the energy transition. This, in turn, will aid global efforts to create a greenhouse gas-neutral world.

1 The 7 D's of the energy transition: The trends shaping tomorrow's energy system

Energy supply systems are changing around the globe. Today, the world's biggest markets – the US, China and Europe – are investing more in renewables than in all other power generation technologies combined. In 2015, around 60 % of the world's added power capacity came from renewables. Wind and solar power have supplanted coal, natural gas and nuclear energy as the main energy sources of the future. And they have given a new outlook to developing countries, which have suffered from energy poverty. Within the span of just a few years, the energy transition has become a global phenomenon.

Some big trends are shaping the development of energy systems at the national and international level.

For the most post, these megatrends have emerged independently of national energy policies. Rather, they take their cue from societal circumstances, economic pressures and new technological advances.

But this does not mean that energy policies are for naught. As the world's energy demand increases with its growing population, countries must build their energy policies on and around these megatrends. Indeed, understanding these developments will be crucial for designing an energy supply system that meets the addresses the energy policy triad of economic competitiveness, security of supply and environmental sustainability.

Agora Energiewende has identified seven megatrends in the global energy transition, each beginning with the letter D:

1. **Decrease in costs:** Wind power, solar power and batteries are becoming cheaper.

2. **Decarbonisation:** As climate change accelerates, urgent action is needed.

3. **Deflation of energy prices:** Coal, oil and natural gas prices remain inexpensive, but are increasingly volatile.

4. **Dominance of fixed costs:** The energy system of the future will have low operating costs.

5. **Decentralisation:** The energy system is becoming less centralised.

6. **Digitalisation:** The energy system is becoming smart and better integrated.

7. **Democratisation:** The new energy system affects citizens more.

In the future, unforeseen trends may join the seven D's. But for the coming years at least, these trends will have to be taken into account by any energy policy.

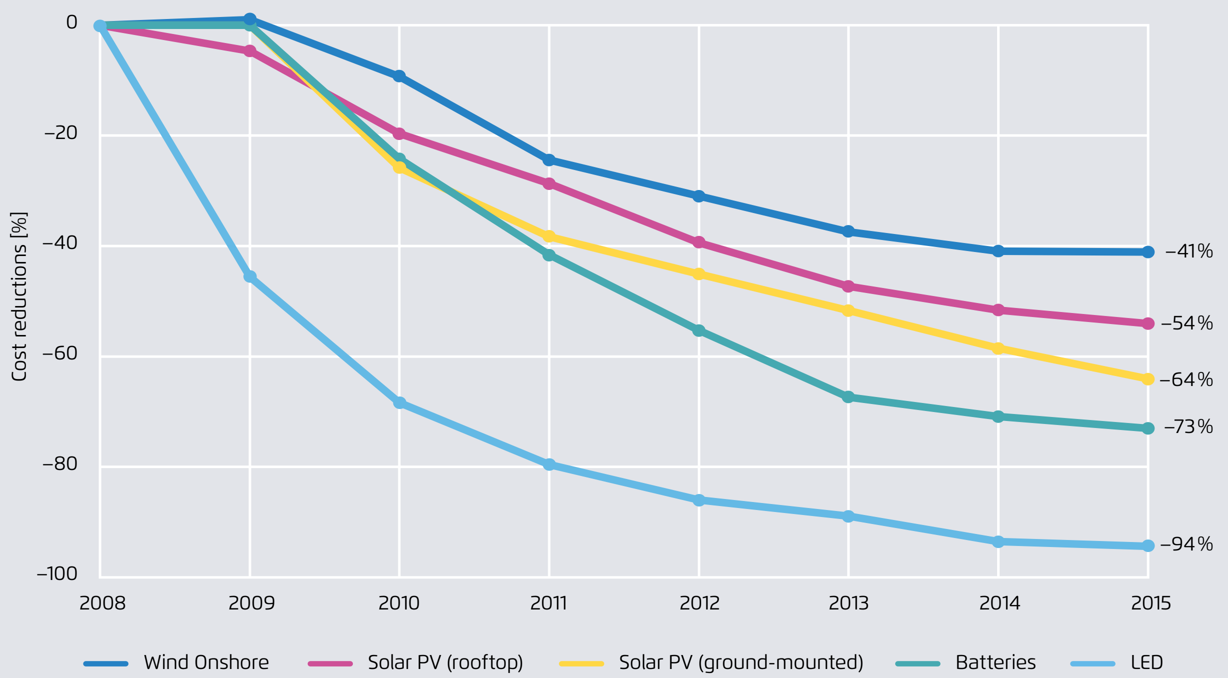
1.1 Decrease in costs: Wind power, solar power and batteries are becoming cheaper

The costs of wind and solar power have drastically decreased over the past years. In more and more regions of the world, wind and solar power costs less than power generated by newly built coal-fired, gas-fired and nuclear power plants. In 2016, renewable energy projects generated power at previously unimaginable costs, and have therefore led to lower prices: 5.0 cents per kilowatt hour for offshore wind in Denmark; 2.7 cents per kilowatt hour for onshore wind in Morocco; and 2.6 cents per kilowatt hour for solar power in Chile. Germany, too, saw record-low prices. At the beginning of 2017, competitive bids for onshore wind, offshore wind and solar energy resulted in prices of only 5 to 6 cents per kilowatt hour.[1] A similar drop in costs has occurred for batteries. In the past six years, the costs of lithium-ion units have fallen by over 70 % to 200 euros per kilowatt hour. As a result, electric vehicles are now ready for the mass market, and solar and wind installations are being combined with energy storage systems.

It can already be anticipated today, that further cost reductions in these key technologies will occur until 2030. This even holds true when the integration costs for grids and the costs for back-up power plants, which come with wind and solar power, are accounted for.[2] An energy system based on wind and solar power is imminent.

Since 2008, the costs of key energy transition technologies have fallen significantly, making wind and solar power competitive

Figure 1



U.S. Department of Energy (2016)

1.2 Decarbonisation: As climate change accelerates, urgent action is needed

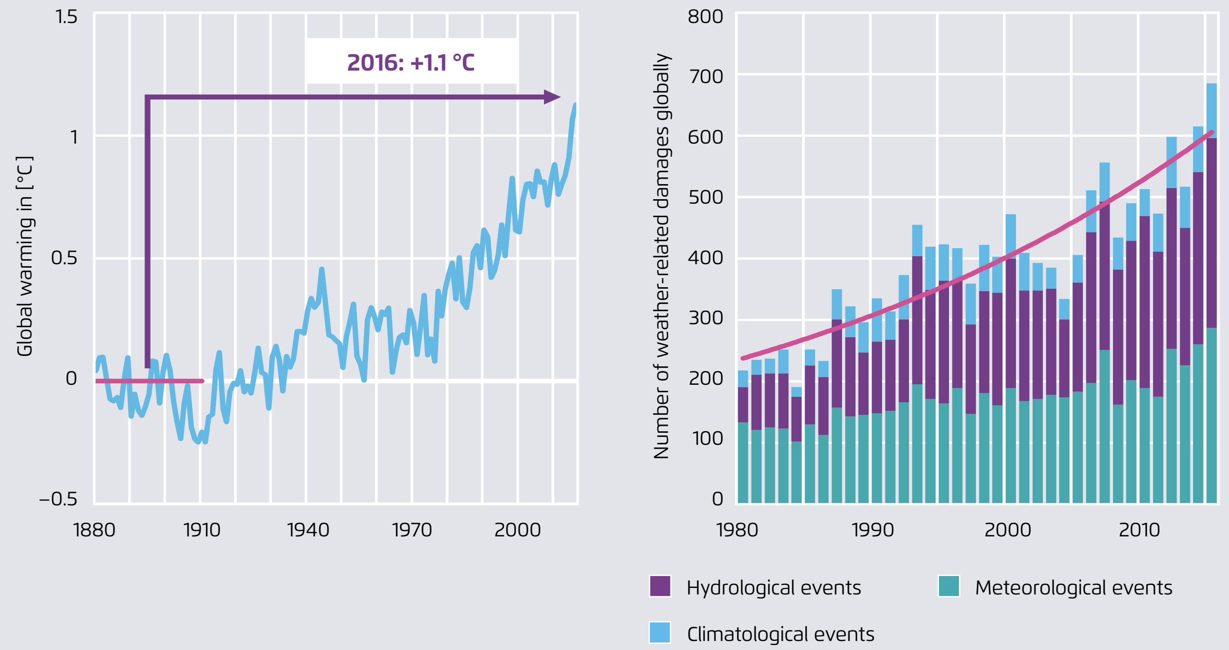
Androgenic climate change is real. 2014, 2015 and 2016 were the warmest years since modern record-keeping began. And 16 of the 17 hottest years have occurred in the new millennium. The planet is now 1.1° C degrees warmer than before industrialisation.[3] The chief cause is the rising concentration of CO_2 in the atmosphere due to the burning of coal, oil and natural gas.

The effects of climate change can already be observed, and are multifaceted: rising ocean levels, more extreme weather, droughts, extinction of animal and plant species, regional food shortages, and, consequently, growing levels of poverty and migration.

These observable phenomena require urgent action. At the 2015 United Nations Climate Change Conference in Paris, the global community agreed to limit the rise in the planet's surface temperature to 2° C above pre-industrial levels. Irrespective of daily politics, when it comes to the implementation of the Paris Agreement, the occurrence of extreme weather events and the subsequent financial loss do help in pushing climate change up on the agenda. For now and for the foreseeable future, energy policy must first and foremost address the challenges of decarbonisation.

Climate change is real: since 1970 the rate of global warming has accelerated, and since 1980 extreme weather events have tripled

Figure 2



Climatological events include hurricanes, thunderstorms and other forms of severe weather; hydrological events describe floods, mud slides, avalanches and rock slides; meteorological events cover droughts and heat waves.
MunichRE (2016) and WMO (2017)

1.3 Deflation of energy prices: Coal, oil and natural gas prices remain inexpensive, but are increasingly volatile

For decades, it was assumed that the price of fossil fuels would be rising continuously as the global reserve depletes. Since 2014, this pattern could not be observed anymore. In 2016, especially oil and gas were traded for much less than during the previous decade. Three factors speak against the return of rising prices for coal, oil and natural gas:

→ Today, the de facto upper price limit for oil and natural gas is no longer set by expensive deep-sea drilling but by the costs of shale oil and gas extraction, which new fracking technologies have reduced considerably.

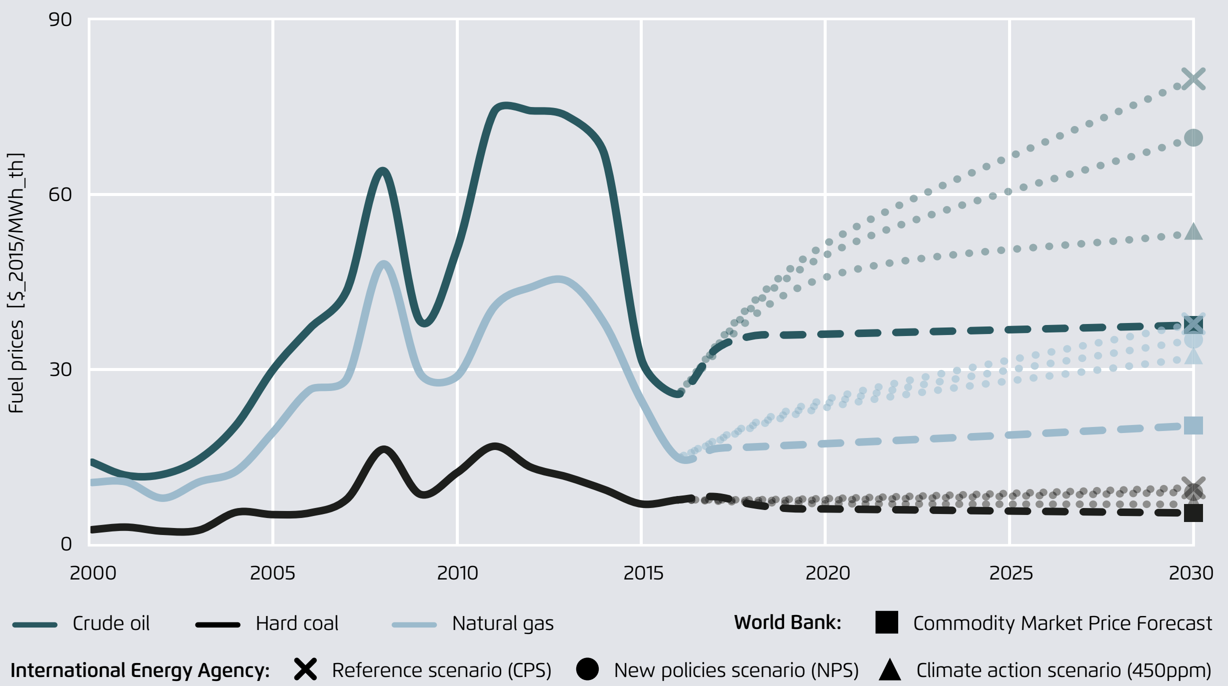
→ The continosly decreasing costs of for wind turbines and PV installations have also created a kind of upper price limit for coal and natural gas, as the operators of coal- and gas-fired power plants seek to keep costs down to compete with renewable energy.

→ There is no shortage of fossil fuels, but an abundance of it. This is because large shares of the planet's remaining reserves of coal (80 %), natural gas (50 %) and oil (30 %) will have to remain underground to meet Paris climate targets.[4]

These general developments may be interrupted by spikes in fossil fuel prices, but whatever spikes occur will be temporary.

Though the IEA projects rising prices for fossil fuels, the World Bank forecast is more likely

Figure 3



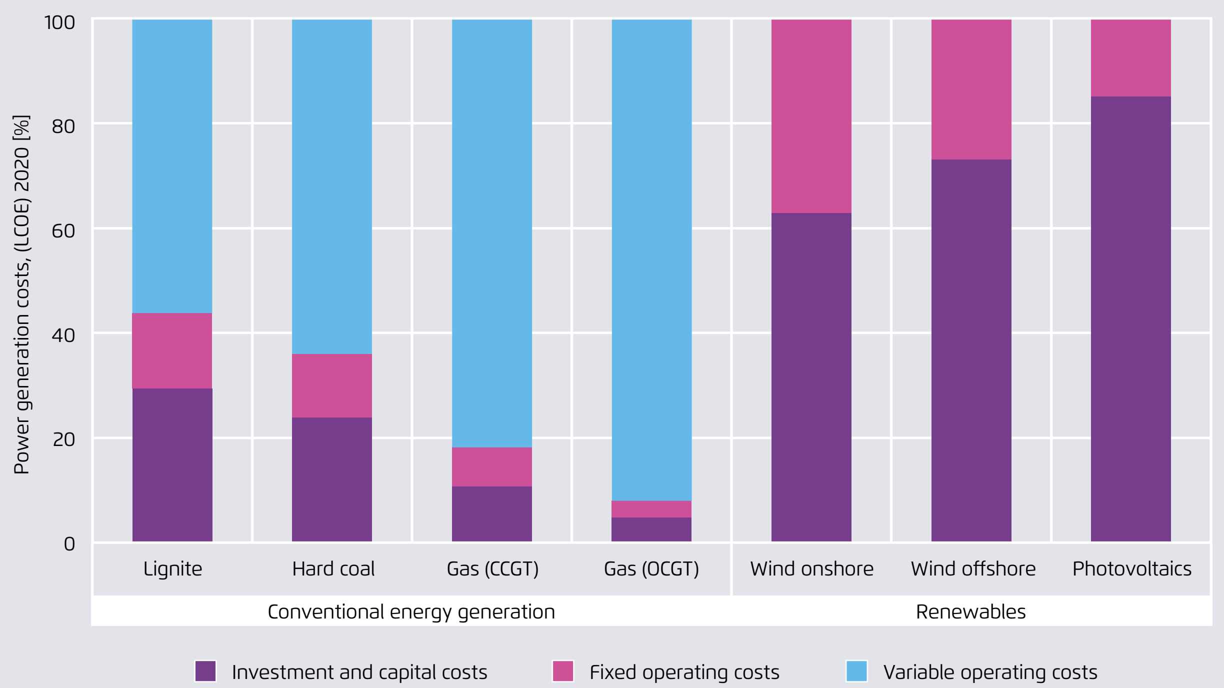
IEA (2016), World Bank (2017a) and World Bank (2017b)

1.4 Dominance of fixed costs: The energy system of the future will have low operating costs

The transition to renewables fundamentally changes the cost structure of the energy system. Electricity from sunlight, wind and hydropower have high fixed costs but low operating costs.[5] The same is true for other core elements of the renewable energy system: storage batteries, efficiency technologies and power grids. These phenomena constitute a profound paradigm shift.

Before, the high variable operating costs of fossil fuels shaped the power system. Coal- and gas-fired power plants have variable costs totalling 50 % or more due mostly to fuel costs and carbon credit purchases. Up until now financing structures and electricity markets were based on the fact that the most expensive power plants, the ones that would kick in last and feature very high operating costs, would ensure that other power plants could recover their capital and investment costs as well as their operation and maintenance costs. In the new energy system, the variable costs of a renewable power plant are close to zero after installation. Power prices are determined by the availability of sunlight and wind as well as the cost of investment and capital.

Renewables feature high fixed costs — Figure 4



Variable operating costs consist mostly of costs for fuels and CO_2 emissions; fixed operating costs consist mostly of costs for personnel and maintenance.
Calculations by Agora, based on IEA/NEA (2015).

1.5 Decentralisation: The energy system is becoming less centralised

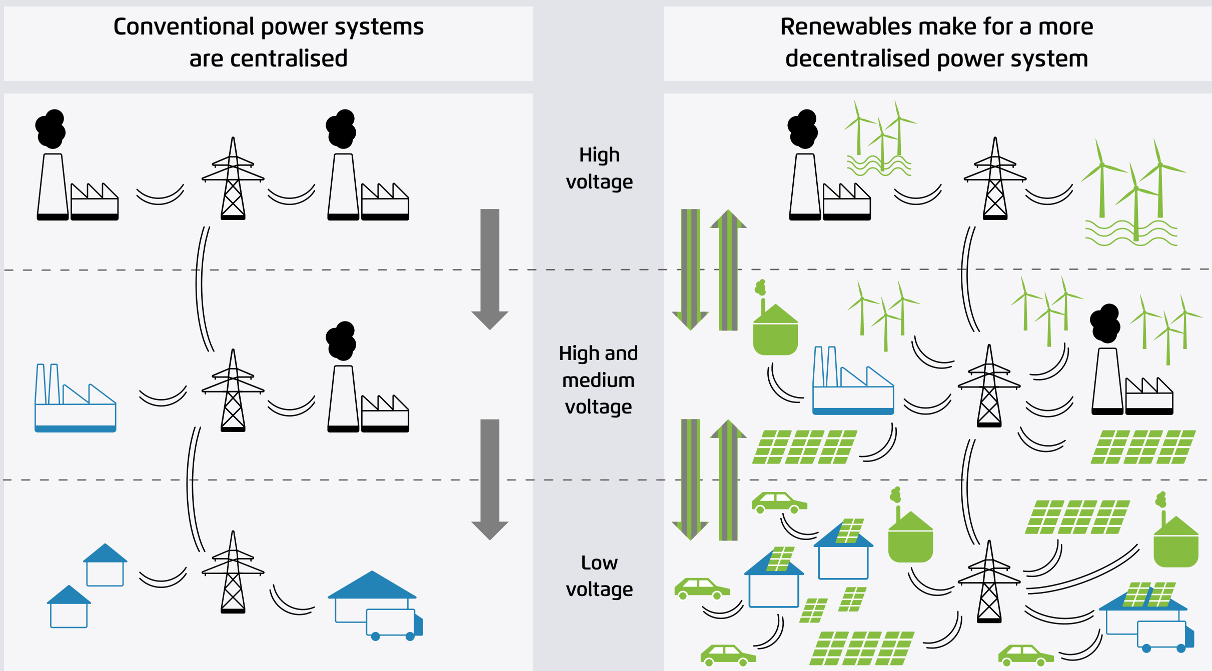
An energy system based on renewables tends to be accompanied by smaller, decentralised structures. The reason is that energy from sunlight and wind is less concentrated than energy from coal, oil and gas. This results in a wider distribution of power generation.[6]

The new technologies have changed the traditional distribution of roles in the energy system. In the old system, a small number of large power plants transported electricity to consumers via transmission and distribution grids. Heating and gas networks also relied on relatively few producers. Today, millions of renewable energy plants, both large and small, generate electricity at every level of the grid, and in the case of prosumers generated energy is directly consumed again by its producers. This decentralised model represents the future of heating and gas networks as well.[7]

The economies of scale created by the old system's large power plant blocks are, are in the new energy system replaced by the mass production of renewable energy plants, energy storage systems and electric vehicles. This fundamental shift in the energy system has produced a variety of new business models and players in the power, heating and transport sectors.

The power system's "one-way street" is replaced by a decentralised, networked structure

Figure 5



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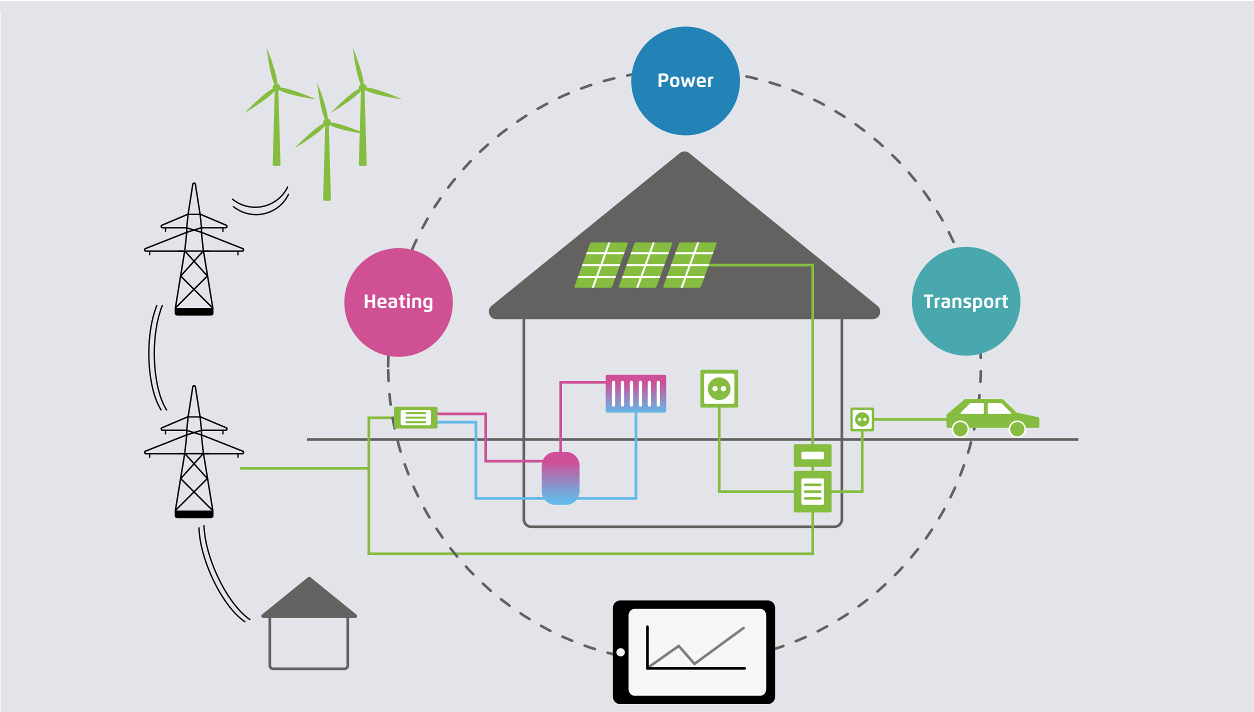
1.6 Digitalisation: Energy will be smart and better integrated

Modern information and communication technologies are revolutionising the energy and transport industries, too. By coordinating energy supply and demand in real time, they are enabling the energy system's transition to variable, small-scale energy generation. Digitalisation in particular has allowed the construction of a reliable, forward-looking energy system dominated by wind and solar power. The ability of digital technology to process massive volumes of data makes the use of electricity, heating and transportation smarter and more flexible. In the future, producers will be able to trade electricity in real time, people will have the option of booking a wide range of transportation services at a moment's notice and heating needs will be flexibly adjusted as required.

The business models that build on digital technology will include the macro-level steerage of numerous producers and consumers and the micro-level optimisation of single-family homes in the use of rooftop solar installations, heating systems, battery storage and electric vehicle charging. In the new energy system, a large part of value creation will come not, as before, from the sale of kilowatt hours or automobiles but from smart markets, smart homes and smart mobility. The protection of personal energy-related data will be an important task in the new system.

Digital technology will integrate the power, heating and transport sectors — Figure 6



Agora Energiewende

1.7 Democratisation: The new energy system affects citizens more

Electricity no longer merely comes *out of* the socket. Technologies such as solar panels, combined heat and power (CHP) plants, batteries and heat storage put electricity *into* the socket, turning millions of individuals into *prosumers*, people who produce large portions of the energy they consume themselves. In more and more regions, municipalities are interested in producing their own electricity, ensuring that added economic value benefits local communities.

At the same time, the energy transition is a comprehensive infrastructure project that affects the lives of many people. Wind turbines, solar farms, new power lines and the rezoning of agricultural land are bringing the energy system closer to where people live and work, especially in rural areas, creating more interaction between population and the power infrastructure.

As a result of the ubiquity of new energy system and thanks to increased political self-confidence, many people are insisting on having their say in the planning and execution of new infrastructure projects. Public protests have become common, while citizens energy companies and local activists are actively shaping the energy system. Energy and transport policies can no longer exclusively be made *top–down*.

Citizens increasingly demand political participation — Figure 7

Bündnis Bürgerenergie e. V. (Jörg Farys), Ende Gelände, Boris Roessler/dpa and Nicolas Armer/dpa

2 Ensuring environmental sustainability, economic competitivness, energy security and European integration: Energy Transition targets 2030

The energy transition is successful when it benefits the environment and the economy while safeguarding security of supply. These make up the classical triangle of priorities in German energy policy. A new, added priority is European integration. Due to its central location, Germany has more power and gas lines connecting it with surrounding countries than any other nation in Europe, closely tying it with the energy policies of its neighbours. From now until 2030, therefore, German legislators must adopt policies for lasting environmental sustainability, economic competitiveness and security of supply within Germany and with its neighbouring countries. And they must do all this with an energy system that is increasingly based on energy efficiency, renewables and flexibility.

The energy transition needs specifying to turn an abstract idea into concrete policies based (wherever possible) on quantifiable indicators. This section proposes specific energy transition targets for 2030.

Specifying Energy Transition targets for 2030: Agora Energiewende's recommendations	
Environmental sustainability	→ Reduce greenhouse gas emissions in the energy sectors by 60 % relative to 1990 levels by 2030. Emissions should total no more than 166 million metric tons in the power sector, 175 million metric tons in the heating sector and 98 million metric tons in the transport sector. → Hew to the principles of nature conservation when expanding renewables and repurposing former lignite mines.
Economic competitiveness	→ Keep per unit energy costs in the industrial sector and energy's share in private consumer spending under 10 %. → Give special exemptions to energy-intense industries and private households with low incomes.
Security of supply	→ Reduce import levels for total primary energy use (coal, oil, natural gas, renewables) below 60 % by 2030. → Average power outage (measured by the SAIDI index) should remain under 20 minutes per year.
European integration	→ Eliminate bottlenecks in power, natural gas and transport networks at Germany's borders. → Create close ties with Germany's neighbours in approaching security of supply, renewable energy expansion and power market design.

An energy transition for 2030 that is environmentally sustainable

To specify the target of an environmentally sustainable energy transition for 2030, the already agreed climate goals of the German government serve as a basis. The German Bundestag and federal government have committed themselves to reducing Germany's greenhouse gas emissions by at least 55 % in 2030, by at least 70 % in 2040 and by 80-95 % in 2050 compared to 1990 levels. To respect the latter range of 80-95 % reduction by 2050 when adopting measures for 2030, it is useful to operate with the average value of 87.5 %. Doing so ensures that based on future needs both the upper and the lower end of the range can be aimed for.

Compared to other sectors, the energy sector's contribution to reaching the climate goals will be above average. This is because the industry and agriculture sectors – Germany's other major sources of GHGs – feature large amounts of process emissions. In the foreseeable future, there will only be limited technical possibilities to avoid these emissions in a cost-efficient way. Based on what is known today, it is ambitious for industry and agriculture to achieve a 60 % reduction of GHG emissions by 2050 against a 1990 baseline.[8] Conversely, this means that Germany's energy-related greenhouse gas emissions must fall by at least 92 % in 2050, with the remaining emissions coming mostly from trash incineration and fugitive emissions.

In real terms, pursuing a median reduction path of 87.5 % by 2050 will require almost the complete decarbonisation of the power, heating and transport sectors. Consequently, energy-related emissions must decrease by around 60 % in 2030 to serve Germany's across-the-boards reduction target of 55 %. This value corresponds with the 2030 sector targets defined in Germany's Climate Action Plan 2050, adopted in November 2016.[9]

Reaching these targets will require a massive expansion of renewables. But the expansion must adhere to the principles of nature conservation if it is to be environmentally sustainable while mitigating climate change. This applies to the planning of onshore and offshore wind farms and especially to the use of biomass, where for biodiversity's sake alternative plants should be cultivated in place of maize monocultures.

The repurposing of abandoned lignite mines will also face environmental challenges. Existing nature conservation legislation provides an adequate framework for these efforts, though details will need hashing out at the local level.

An energy transition for 2030 that ensures economic competitiveness

If the transformation of the energy system is to be acceptable for all users – for private households as well as for the economic sector – it must first and foremost be affordable. And to be affordable, economic optimisation must be one of its central goals. The share of private household income going to energy must remain the same or less, and costs for German industry must be low enough to ensure global competitiveness. In bringing about the energy transition, Germany will remain a nation that derives its economic strength from a technologically advanced industrial sector.

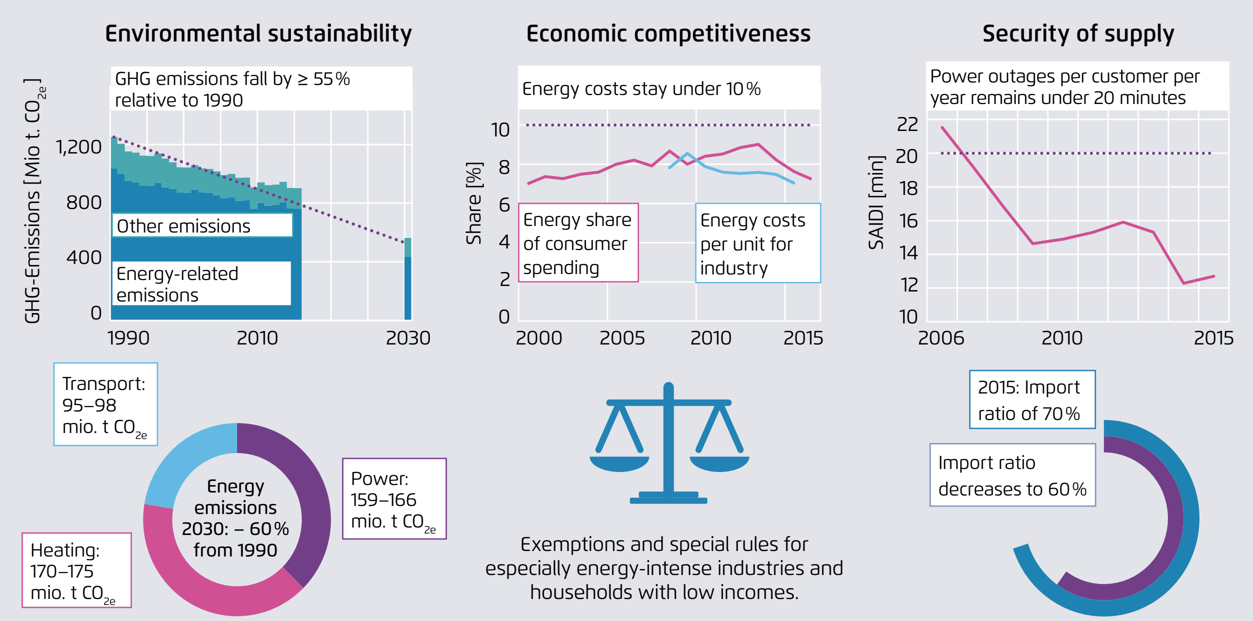
Therefore, competitive, European energy markets are an indispensable element of the energy policy triad. Accordingly, Germany's energy transition must focus on expanding affordable renewables (wind and solar power), introducing free-market auctions for renewables and strengthening the power market. As wind and solar power capacity expands, the need for flexibility within the energy system will continue to rise. In order to achieve flexibility in the most cost-efficient way, open competition between all available flexibility options is needed: power trading with European neighbours, flexible power plants, energy storage, demand side management, power-to-X and the integration of energy sectors. Policies favouring a single technology would be unwise; the market must be allowed to discover the best solutions on its own. The expansion of the power grid, whether nationally or cross-border, is another essential element in the energy market. However, the size of the expansion needs to serve the overall system optimisation and needs to be based on a cost-benefit analysis.

Costs must be minimised gradually over time. Stranded assets such as fossil technology investments, whose amortization periods are incompatible with climate targets (e.g. amortization would be reached past 2050), should be avoided to prevent the risk of economic losses.

Energy costs are the product of energy price and energy use. This is why energy efficiency plays a key role in lowering costs. Advances in energy efficiency not only lower the overall costs of the energy system. They also strengthen the competitiveness of German industry. And with many affordable efficiency options yet to be exploited – especially in the industrial sector – there is great potential to make the energy transition more cost-efficient while ensuring economic competitiveness.

Part of such a transition is to ensure private and industrial users do not spend significantly more on energy than they did in the past. In 2013, 9 % of private consumer spending went for energy. By 2015, the figure had dropped to 7.6 %.[10] A measure of energy spending in the industrial sector is the energy per unit price. This expert index measures the share of energy costs in industrial gross value creation. In past years, the share was approximately 8 %.[11] As a target for 2030, we propose that private households and industrial sector pay less than 10 % of income (or of gross value creation) for energy.

Specifying *Energiewende* targets for 2030: Agora Energiewende's recommendations — Figure 8



EUROPE:
→ Reduce network bottlenecks at national borders.
→ Ensure environmental sustainability, economic competitiveness and security of supply across Europe.

Agora Energiewende, based on BMWi (2017), BMUB (2016), Destatis (2016a) and Expertenkommission zum Monitoringbericht "Energie der Zukunft" (2016)

It is important that this average value be weighed against the specific situations of users. In particular, social policies will be needed in the event of cost increases to compensate low-income households, which already pay an above-average share of their budgets for energy. At the same time, exceptions for some parts of the industry will continue to be necessary and useful to ensure international competitiveness. But it is also vital that such exemptions do not undermine efforts at efficient and flexible energy use in the respective sectors.

An energy transition for 2030 that ensures security of supply

A secure energy supply is of utmost importance for any economy, but especially for a highly industrialised country exposed to global competition. The German energy system has been a world leader in security of supply for decades. Now, as the energy transition moves to its second phase, the task of energy policy must be to preserve Germany's energy security and in some respects, such as dependence on energy imports from crisis areas, even improve it.

In 2015, Germany drew 70 % of its total primary energy from abroad.[12] The gradual reduction of nuclear energy, coal, oil and gas by means of energy efficiency and renewables decreases Germany's dependence on energy imports from existing or potential crisis zones. Moreover, it will lower the nation's energy bill while shifting value creation to the domestic market.

Today's German power system is characterised by high reliability. Its SAIDI score – a measure of average unplanned outage times in distribution networks per customer[13] – fell during the first phase of the energy transition, and by 2015 had reached 12 minutes per year, a record low.[14] Germany's goal now must be to maintain the same excellent reliability in the future as well, especially when measured against other industrialised nations.[15]

Two actors bear responsibility for this task: transmission grid operators and German legislators. The former are in charge of system security; the later must create legal frameworks that use appropriate measures (capacity reserves, capacity markets, etc.) to ensure around-the-clock security of supply.[16]

As for specific targets, we propose that Germany reduce its dependence on primary energy imports (coal, oil, natural gas, renewables) to below 60 % while keeping its SAIDI score under 20 minutes of outage per user per year.

A European energy transition for 2030

The energy policy triad – environmental sustainability, economic competitiveness, security of supply – can be better and more easily served if Europe's countries cooperate with one another rather than go it alone. A Europe-wide energy transition can better balance weather-dependent wind and solar power production, and the guaranteed capacity that results can be used to ensure energy security across Europe. European cooperation will also enable the expanded use of affordable flexibility options such as pumped-storage plants and demand side management in neighbouring countries. In this way, European cooperation will increase the economic competitiveness of the energy transition while also guaranteeing ensuring energy security.[17]

The advantages of such cooperation will accrue to Germany as well as its neighbouring countries, for by 2030 the energy transition will have become a European project. The EU has already adopted its own climate and energy targets for 2030: at least a 40 % reduction of greenhouse gas emissions by 2030 relative to 1990 levels; at least a 27 % increase in energy efficiency; and at least a 27 % increase in the share of renewables in total energy consumption.[18] Models have projected that these targets will require a 50 % share of renewables in Europe's power market on account of their limited potential in the heating and transport sectors.[19] At the same time, the EU wants to increase Europe's competitiveness and rely on the Energy Union to guarantee a lasting energy security. More energy independence is particularly important considering the risks associated with natural gas imports from Russia.

An effective European energy transition requires an improved integration of energy systems across national borders at three levels:

- → **Better physical integration:** The further increase in interconnector capacity is crucial to facilitate the cross-border flows of energy, people and goods. In order to increase economic competitiveness and security of supply, any bottlenecks at Germany's borders within these three networks should be significantly reduced. We propose that Germany aim for a 25 % increase in the number of electricity interconnectors at its borders by 2030.
- → **Better market integration:** Over the years, the power markets in Europe have become intertwined, though the rules governing intraday and balancing energy markets often vary from place to place.[20] By 2030, these rules should be harmonised to the greatest extent possible.
- → **More political cooperation:** More cross-border cooperation with renewable energy auctions and capacity instruments reduce costs for everyone involved. Furthermore, EU members should seek to coordinate their medium- and long-term energy strategies with their neighbours as part of the EU's 2030 Climate and Energy Policy Framework. Cooperation at the regional level, such as in West Central Europe or the Baltic Sea region, can prepare the way for cooperation between countries.

This European integration of the energy transition does not mean that national policies are no longer needed. National targets and policies for climate protection, economic competitiveness and security of supply continue to be very relevant, especially in the power sector. This is because, in European law, the energy mix falls under the authority of the nation state. Climate and energy policies at the EU level like the EU Emissions Trading System must aim to support national measures and regional cooperation. Governments should strive to create a smart policy mix of mutually reinforcing national and European measures.

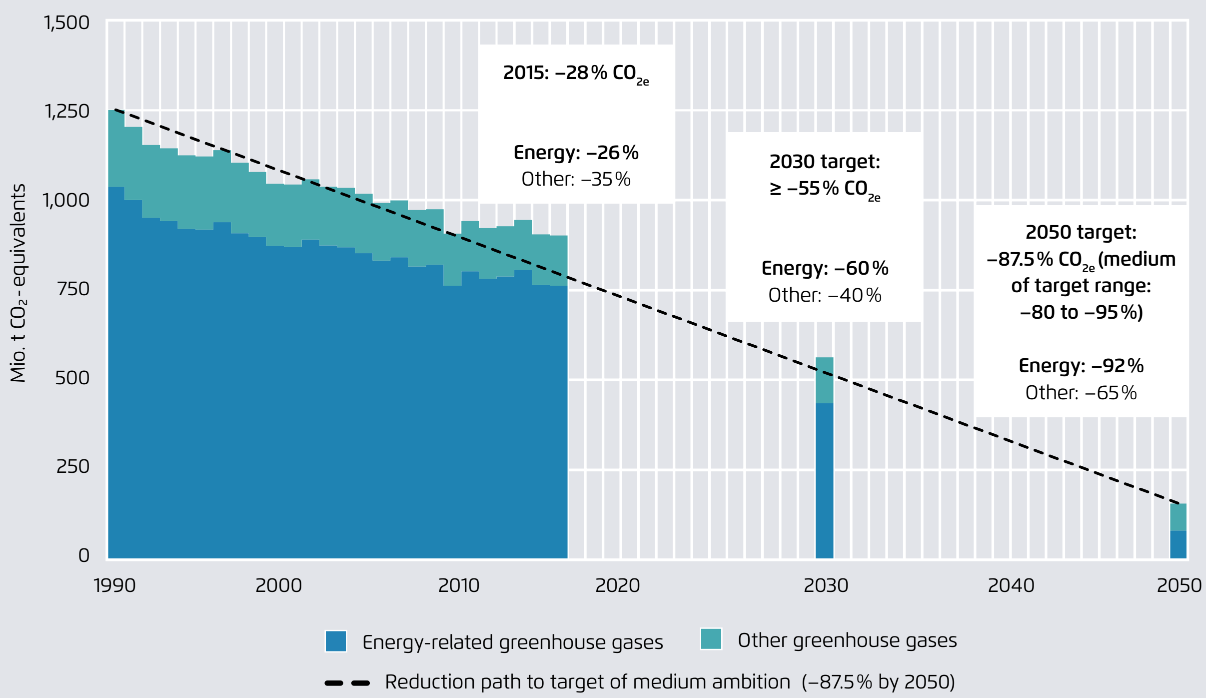
3 *Energiewende* 2030: Redesigning the power, heating and transport sectors

The year 2030 is an important milestone in the German *Energiewende*. It represents the half-way mark on the path to Germany's all-important targets for 2050 - in line with a reduction path of medium ambition - energy-related emissions must be 92 % below their 1990 levels. In 2015, these emissions were down by 26 %. By 2030, they must fall another 34 percentage points. Doing this requires a sweeping transformation, nothing less than a total redesign of the power, heating and transport sectors. The energy system must abandon its previous pillars – nuclear energy, coal, petroleum and natural gas – in favour of energy efficiency and renewables, first and foremost wind and solar power.

In 2030, the energy transition will bring considerable changes without loss of convenience. On the contrary, green retrofits and digital technology will ensure that buildings are warm or cool when they need to be; electric cars and shared mobility will make cities cleaner and quieter; industrial plants will be more efficient and flexible while profiting from low wind and solar power prices. This section describes strategies for realising these technological innovations in a way that benefits the climate, the economy and the consumer.

By 2030 energy-related greenhouse gas emissions must be reduced by 60 % relative to 1990 levels

Figure 9



The baseline year for all the reduction targets is 1990.
UBA (2017); calculations by Agora, based on BMUB (2016) and Öko-Institut/Fraunhofer ISI (2015)

3.1 Strategies for a cost-efficient transformation of the energy sectors by 2030

In 2015, Germany consumed roughly 3,700 terawatt hours' worth of energy. Approximately 93 % of that energy went to power production; the remaining 7 % went into material use.[21] Some 30 % of the energy came from petroleum, 27 % from coal and 22 % from natural gas. Renewable energies supplied 13 %.[22] Gauging by emissions, a different picture emerges. Coal was the main contributor, producing 42 % of Germany's energy-related CO_2 emissions, followed by petroleum (33 %) and natural gas (20 %).[23]

Due to conversion losses, only 72 % of the above 3.700 TWh can be used as final energy.[24] Around one-half of final energy is used for heating, one-third for fuels and one-fifth for electricity.[25] Due to the significant use of coal-fired power generation, the power sector remains the energy sector with the highest emissions.

A three-pronged approach: increase efficiency, expand renewables and initiate the phase-out of coal and oil

Numerous recent studies have investigated the most cost-efficient strategies for achieving the 2030 climate targets.[26] The studies converge on three core findings:

1. Increase energy efficiency
Energy efficiency is the key to success in the power, heating and transport sectors. Reaching Germany's climate targets without massive investment in green retrofitting, in more efficient power use and in transport system efficiency would not only be more expensive; it would run up against the limits of public acceptance in view of the additional efforts needed in renewables expansion and coal reduction. Between 2015 and 2030, Germany must cut final energy consumption by around 22 % and primary energy consumption by 29 % (because of conversion losses).[27]

2. Expand renewables
The expansion of renewables is the second important pillar of the energy transition. By 2030, the share of renewables in Germany's total primary energy consumption needs to increase to around 31 %, somewhat more than double what it is today. The specific share, however, varies by sector. In the power sector, wind and solar energy have great potential for affordable expansion. By contrast, alternative energy sources in the heating sector (solar thermal and geothermal energy, biomass) have only limited potential at this time, while alternative fuels for the transport sector have almost none at all. (The production of first-generation biofuels has stagnated due to sustainability problems, and second-generation fuels have limited potential.) Therefore, renewable energy will be increasingly used in the heating and transport sectors.

3. Focus on reducing coal and oil
The third strategy is to focus on lowering the most carbon-intense energy source in each of the energy sectors, as their reduction does the most to cut CO_2 per kilowatt hour. Consequently, the use of coal and oil in 2030 will be halved compared to 2015 levels. The cleanest burning fossil fuel is natural gas; as such, it will see only a slight reduction by 2030.

Integrating the power, heating and transport sectors on the road to 2030: efficient use of wind and solar power is key

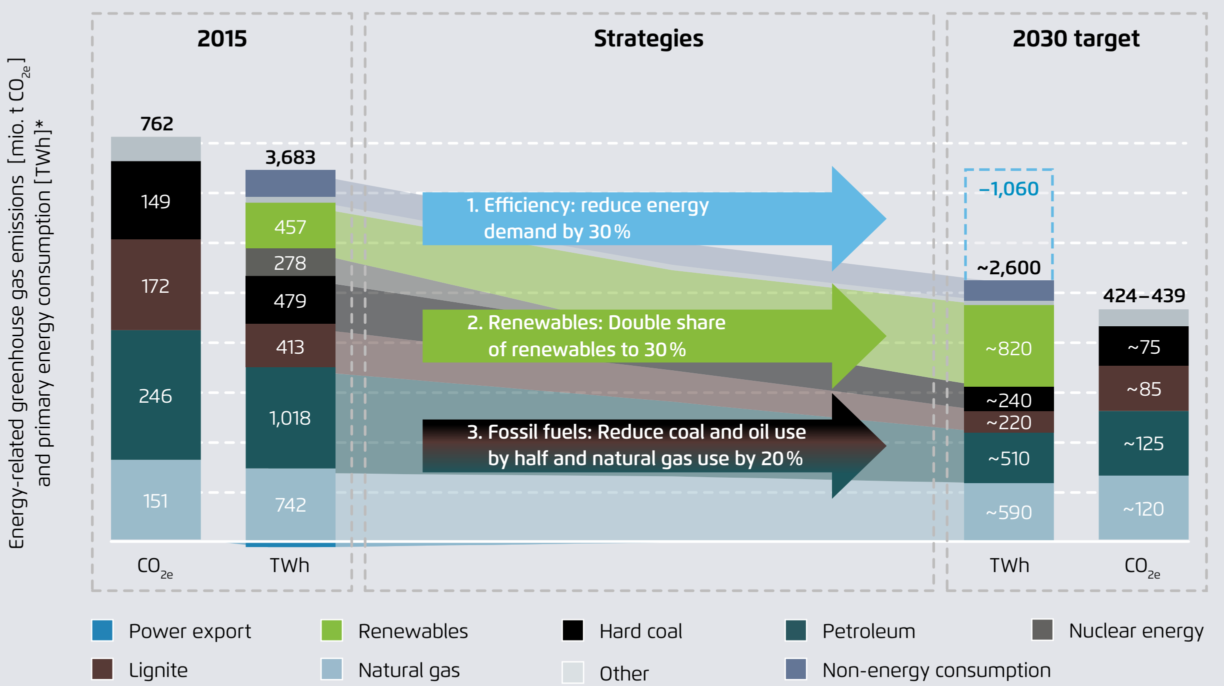
In light of the foregoing strategies, the integration of formerly disparate energy sectors, known in German as "sector coupling" (*Sektorkopplung*), will play an important role. In addition to existing combined heat and power plants and rail transport, more and more renewable energy will be used in the heating and transport sector. This could happen either directly in the form of heat pumps, power-to-heat plants, electric cars, more electricity in the rail system, or indirectly through synthetic fuels produced from renewables such as hydrogen, power-to-gas or power-to-liquid. Direct power better serves efficiency than indirect power does. This is because heat pumps and electric engines, undergo little conversion loss when generating heat and motive power.

But new uses like these will also increase power demand and consumption. As a result, the lines separating the power, heating and transport sectors will begin to fade and eventually disappear. The energy sectors must be regarded as a single system.

As the energy sectors merge and energy efficiency increases and domestic wind and solar power production ramps up, new opportunities for energy companies and energy services providers will emerge on the market, creating value for the German economy. As for climate action, the new power uses will necessitate additional expansion of renewables, because otherwise emissions would only be shifted from one sector to another.

Three strategies for reducing energy-related emissions in line with the 2030 targets

Figure 10



* Coloured energy sources represent CO_2 emissions from primary energy consumption. Source: AGEB (2017a), UBA (2017a); calculations by Agora, based on EWI/Prognos/GWS (2014a)

3.2 Transforming the power sector for 2030

The year 2015 concluded the first phase of the energy transition in the power sector. Between 2000 and 2015, the renewable energy generation increased five-fold, rising to account for a 32 % share of Germany's power consumption. Over the same time span, Germany began its phase-out of nuclear power and by 2015 managed to cut power production from nuclear plants in half. The increase in renewables amounted to twice as much as the decrease in nuclear power, with the latter declining 78 terawatt hours and the former rising 150 terawatt hours. During this process, the security of supply could even be improved. In 2006, average power outages per customer totalled 21.5 minutes; by 2015, it had fallen to 12.7 minutes. Nevertheless, the expansion of renewables between 2000 and 2015 caused considerable added costs for customers, especially due to the initially very high subsidies for new technologies.

The power sector challenge: one-third of electricity comes from renewables, but coal emissions remain high

For all of Germany's success in expanding renewables, the carbon footprint of its power sector is still large. In 2015, the power sector released 312 million tonnes of CO_2, around one-third of Germany's total emissions, and only 4 % less than in 2000. The reason is that lignite and hard-coal use has declined only slightly since 2000 due to the EU's ineffective Emissions Trading System. Today, coal continues to cover 40 % of German power consumption.

In the years leading up to 2030, Germany needs to successfully complete the second phase of the energy transition: 60 % of power from green electricity, the final phase-out of nuclear energy and a 50 % reduction in power emissions.[28] By 2030, wind and solar power will be the leading technologies of the power sector. Between 2020 and 2030, on- and offshore wind farms and ground-mounted PV systems will produce electricity at under 5 cents per kilowatt hour. Roof-top PV systems will be common standard not only for single-family homes but for any building with a suitable roof. The heating and transport sectors will also see increased amounts of renewable power. Moreover, intelligent networks, digitally integrated renewable energy installations, demand side management, energy storage and a stable capacity reserve will ensure that the security of supply remains as high in 2030 as it is today.

Four strategies for 2030: increase efficiency, cut coal use by half, increase renewables to 60 % of power supply, complete the nuclear power phase-out

A cost-efficient energy transition for 2030 must focus on four strategies:

1. *Efficiency First*: keep energy demand stable despite sector coupling

Energy efficiency is an essential part of an affordable energy transition.[29] Traditional energy demand in buildings, industry and transport must fall from 520 terawatt hours today to 470 terawatt hours in 2030. These efforts are all the more important considering that the increasing electrifcation of the heating and transport sector will create an additional 70 terawatt hours of demand. Thanks to efficiency measures, Germany's overall power consumption in 2030 will only be slightly higher than it is today.

2. Reduce coal-fired generation by half

Given the high share of lignite and hard coal in its power mix, Germany must cut coal-fired generation by half if it is to cut energy-related emissions by half. Doing so will also reduce the high levels of coal-based electricity Germany is currently exporting to neighbouring countries. Over the course of the 2020s, old coal-fired power plants will go offline. Those that once produced heat will give way to gas-fired CHP plants, combined with renewable heat sources. Starting in 2025, modular gas-fired motors will be used to guarantee security of supply during peak demand, since coal-fired plants will no longer be around to do the job.

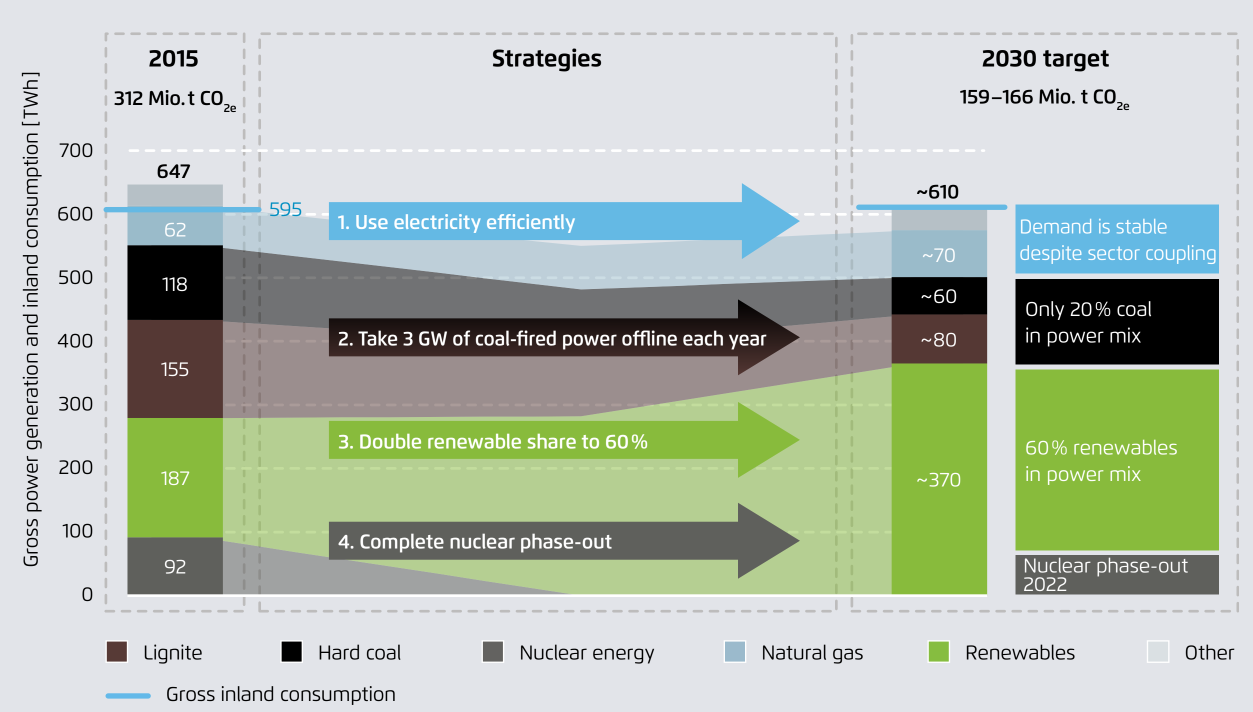
3. Raise renewable share to 60 %

Today, the share of renewables in power generation is 30 %. This share needs to be doubled by 2030 to completely cover the electrification in the heating and transport sectors with renewable energies. In 2015, a total of 42 gigawatts of onshore wind power, 40 gigawatts of PV and 3 gigawatts of offshore wind were installed in Germany. In 2030, a total of 91 gigawatts of onshore wind, 86 gigawatts of PV and 20 gigawatts of offshore is expected. Much of the capacity added between 2018 and 2030 can be achieved with energy costs of under 5 cents per kilowatt hour, so that no additional costs will accrue.

4. Complete the nuclear energy phase-out

Between 2017 and 2022, Germany will shut down its eight remaining nuclear power plants. The phase-out of inflexible nuclear power will create more room for renewables and reduce incidents of excess energy. Since six plants with a capacity of 8 gigawatts are scheduled to go offline between December 2021 and December 2022, policymakers and the Federal Network Agency must act now to ensure security of supply. This might entail temporarily keeping a higher capacity reserve to be prepared for possible power demand peaks in the winters of 2021/22 and 2022/23.

Four strategies to cut power sector emissions by half by 2030 — Figure 11



AGEB (2017a), BMUB (2016); calculations based on Agora Energiewende (2016a), EWI/Prognos/GWS (2014a) and UBA (2017c)

3.3 Transforming the heating sector for 2030

The heating (and cooling) sector[30] consumes more energy than any other segment of Germany's energy system. In 2015, the sector used 1,373 terawatt hours of energy, about as much as the power and transport sectors combined.[31] During the same year, the heating sector released around 290 million tons of CO_2, putting it in second place among the energy sectors. Around 60 % of power went to building heating. The other 40 % was used for industrial process heat.

Between 2000 and 2015, energy for building heating fell 13 % and emissions decreased by 25 %,[32] but climate change mitigation efforts have made few inroads in German industry. Natural gas generates 43 % of heat, followed by petroleum (15 %) and electricity (13 %). The rest is produced in almost equal parts from direct renewables use (10 %),[33] district heating (9 %) and hard coal (8 %).[34] The heating sector has the most durable capital stock of all the energy sectors, with the average German residential buildings being 50 years old.

The heating sector challenge: the largest energy sector also has the most durable capital stocks

In 2030, the heating (and cooling) sector will be cleaner and much more efficient than it is today. Almost half of all buildings are either new constructions or old buildings that have been modernised to meet today's high energy standards. These buildings are good at trapping heat, they use sunlight for indirect heating and they provide comfortable temperatures in winter throughout the whole building.

By 2030, low-emission heating systems such as gas-fired boilers or heat pumps will have mostly replaced oil-fired boilers. In the meantime, many unmodernised or partly modernised buildings will use bivalent heating systems, which combine heat pumps with oil- or gas-fired boilers. These systems will use electricity when the power price is low and oil and gas when it is high, substantially lowering emissions. District heating networks will draw their heat from a variety of sources: gas-fired CHP plants, solar thermal and geothermal energy, biomass, large-scale heat pumps and waste heat. Coal use for district heating and industrial process heat will be cut in half. German industry will rely on efficiency technologies, while renewables or hydrogen produced by renewables will gradually replace natural gas.

Four strategies for 2030: Modernise buildings, cut coal and oil use by half, increase the share of renewables, electrify the heating sector

By 2030, the heating sector must have significantly reduced greenhouse gas emissions from housing and industry – namely, by 40 % over a 2015 baseline.[35] The following four strategies will make this possible:

1. *Efficiency First*: Lower power for building heating by 25 % and for industrial heat by 10 %
To transform the heating sector in a cost-efficient way, energy efficiency must be significantly increased. Specifically, final energy use in buildings must fall 25 % by 2030. To achieve this, 2 % of German buildings must be retrofitted every year. Within the industrial sector, unused potentials need to be tapped to increase efficiency and lower power use by 10 % relative to 2015 levels. All in all, these measures would reduce total power consumption in the heating sector to around 1,100 terawatt hours, roughly half for buildings and half for industrial process heat.

2. Cut coal and oil use by half
Coal and oil are the most carbon-intense forms of energy, hence the need for their dramatic reduction by 2030. Natural gas use will continue and the respective gas infrastructure will be kept for later use with synthetic fuels produced from renewable power.

This means that hybrid heat pump systems or other technologies must replace simple oil-fired boilers in buildings, and that coal use for district heating and industrial process heat will be reduced by half.

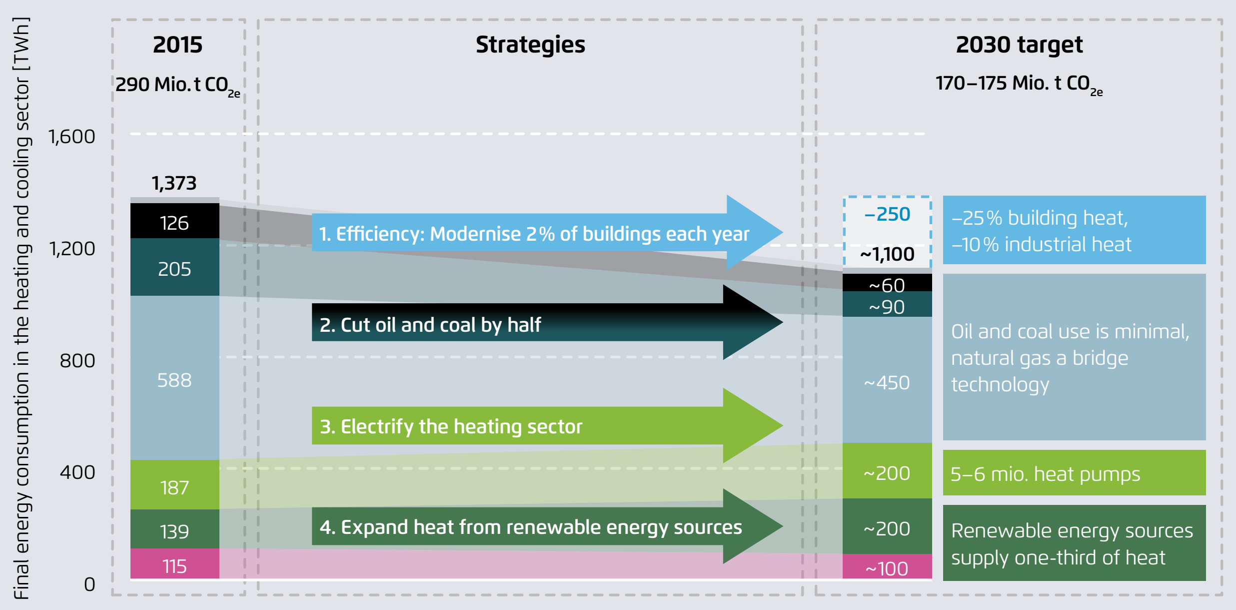
3. Expand the renewable heat supply
There are many options for using renewable heat in buildings, in district heating networks and in industry: solar thermal and geothermal energy, environmental heat and waste biomass. These need rapid implementation so that by 2030 around 200 terawatt hours come directly from renewable heat. This includes the reconfiguring of district heating networks for low-temperature operation.

4. Use heat pumps to electrify the heating sector
Using wind and solar power for power-to-heat and heat pumps is an efficient form of climate charge mitigation in the heating sector. By 2030, 5 to 6 million heat pumps will be installed in Germany, half of which will have back-up gas- or oil-fired boilers. During this time, inefficient electricity-powered night storage heating systems, widely used today, should be replaced, limiting added power demand to around 20 terawatt hours.

If these strategies are not successful, considerable quantities of power-to-gas will be needed to reach sector targets.

Four strategies to reduce emissions in the heating sector by about 40 % by 2030

Figure 12



AGEB (2016a), BMUB (2016), UBA (2017a); calculations by Agora, based on EWI/Prognos/GWS (2014a), Fraunhofer IWES/IBP (2017)

3.4 Transforming the transport sector for 2030

Of all Germany's energy sectors, the energy transition is least advanced in the transport sector. Renewables cover only 5 % of its final energy consumption. Some 93 % of the 727 terawatt hours used in 2015 came from petroleum-based fuels.[36] And rising emissions from roads, rails, ships and air traffic over the past few years has nullified Germany's successes in climate protection in the first decade of the new millennium. With 166 million tons of CO_2 emissions in 2016, transport is the only sector in the German economy to release more carbon today than it did in 1990.[37]

Transport: The only sector with rising CO_2 emissions

Two trends are responsible for this situation:

- **More traffic on the roads:** Between 2000 and 2015, transport of goods increased 25 % to 650 billion tonne-kilometres, and passenger transport by 13 % to 1.180 billion passenger-kilometres. Trucks covered around 80 % of the growth in commercial transport, and cars covered 70 % of the growth in passenger transport.[38]
- **Levels of CO_2 emissions from cars are falling only on paper:** Based on the EU regulation addressing passenger cars' emissions, fossil fuel consumption of cars should be steadily decreasing. Furthermore, the vehicle tax is supposed to benefit low-carbon vehicles. Nevertheless, fuel consumption has barely fallen. One reason is the increasing discrepancy between the fuel economy data car manufacturers publish and the real values. In 2000, the difference for new cars was 9 %; within 15 years, it had climbed to 42 %.[39]

In 2030, CO_2 emissions in the transport sector will have fallen by 95 to 98 million tonnes.[40] In the meantime, the transport sector must undergo a rapid transformation, which Germans call the *Verkehrswende*. The beginnings of this transformation can already be seen today. In urban areas, bicycle use has been increasing, while the number of cars on the roads has remained constant. Moreover, increased digitalisation has given rise to mobile carsharing and attractive public transport services, and the prices of batteries and, by extension, electric cars, have been steadily declining.

The transformation of the transport sector consists of two parts:[41] reducing traffic volume while ensuring mobility (known as the *Mobilitätswende*, or "mobility transition") and bringing an ever-rising share of renewables to the transport sector (the actual energy transition within the transport sector). This transformation will improve the quality of people's lives. Electric cars and new mobility options will make cities quieter and cleaner, reducing noise along with other forms of pollution such as fine particulate matter and nitrogen oxide.

Transforming the transport sector is also crucial for German's automobile industry. As China and California lead a massive global shift towards electric vehicles and mobility services, it is of crucial importance for Germany as an industrialised nation, to keep fostering innovation.

Three strategies for 2030: increase efficiency, advance electric vehicle use, improve rail and bus networks

The following strategies will lead to a 40 % reduction (against a 2015 baseline) of petrol and diesel consumption, along with the emissions they produce, by 2030:

1. *Efficiency First*: reduce energy demand by 30 %
Avoided kilometres are the most cost-efficient way to mitigate climate change. Better urban planning can preserve individual mobility while reducing the distance between work and home. Digital technology can be used to organise transport more efficiently and better integrate private and public forms of transport.

New designs for cars and trucks will ensure that they are truly more fuel efficient than past models. All together, these measures will reduce power consumption in the transport sector by around 30 %.

2. Strengthening the use of railways, busses and shared mobility

Using railways to transport more goods and passengers will reduce road traffic. To achieve this goal, Germany needs a rapid and significant expansion of its rail network. In addition, public transport could win more customers through convenient services, new routes and technological innovation (e.g. shared autonomously driving cabs). This will ensure that most of the increases in goods and passenger transport projected by 2030 can be absorbed by the railways and public transport systems.

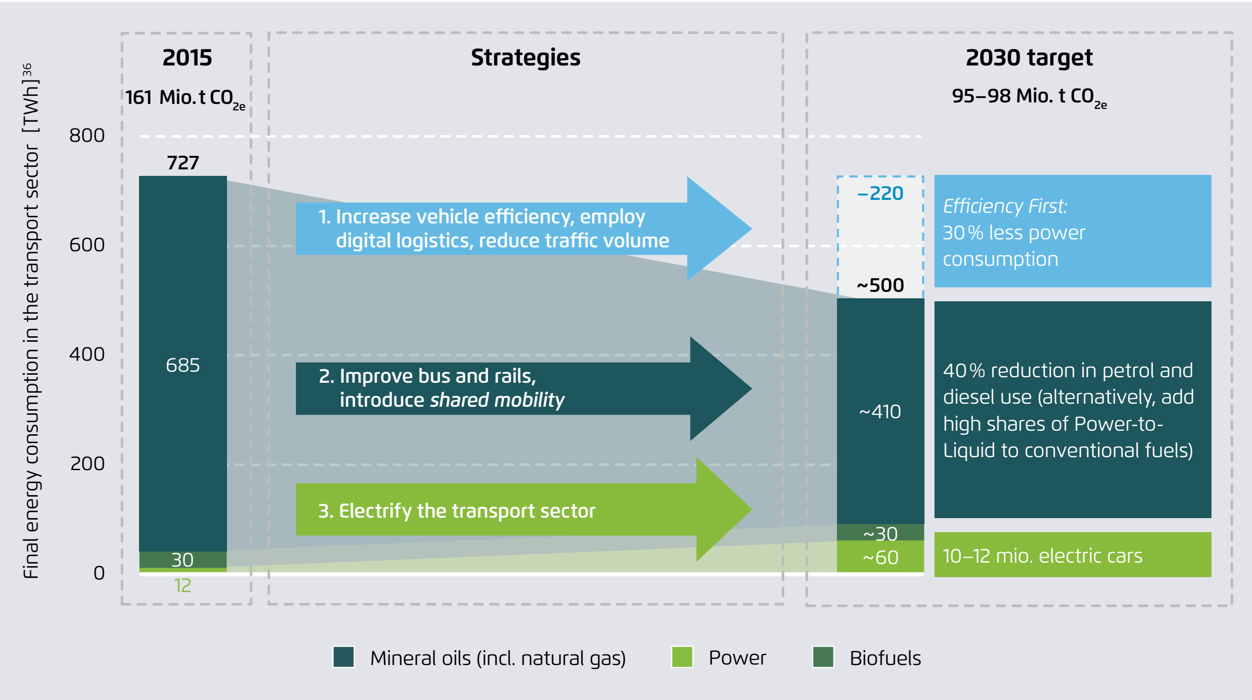
3. Introduce renewable-powered electric cars

With biofuel production stagnating, increases in renewables will have to come from wind and solar power. By 2030, there should be 10 to 12 million electric- and fuel cell-powered vehicles on German streets. Moreover, electrification must spread to 80 % of the rail system, up from 60 % today. To further reduce pollution, overhead lines should be placed along Germany's central motorways to provide hybrid trucks with power for long-haul routes. All in all, these measures will increase power demand in the transport sector by around 50 terawatt hours.

If these strategies fall short of 2030 targets, considerable quantities of power-to-X fuels will be needed. Petrol and diesel would soon have to be mixed with increasing shares of power-to-liquid fuels to reach transport sector targets.

The 2030 strategies for sustainable transport: increase efficiency, improve bus and rails and electrify the sector

Figure 13



AGEB (2016a), BMUB (2016); calculations by Agora, based on EWI/Prognos/GWS (2014a)

3.5 Alternative paths are possible, but more research and development is needed

The measures described so far in this section aim at a cost-efficient transformation of the energy system by 2030. They focus on the most affordable technologies available today for implementing the energy transition. But under certain circumstances, policymakers might consider alternative paths for achieving the energy transition. Here are three such cases:

- **Insufficient energy efficiency:** Increased energy efficiency is a central pillar of the energy transition. Recent experience has shown that green retrofits, reducing traffic volume and increasing power efficiency face a number of hurdles, whose elimination the federal government has yet to prioritise. Should the hurdles remain in place, other measures must be taken to reach Germany's climate targets.
- **Insufficient electrification:** Ideally, Germany should have between 5 to 6 million heat pumps and 10 to 12 million electric vehicles by 2030. But if a lack of incentives or public acceptance prevents these targets from being realised, other options will have to be considered, even though direct power for heating and transport is the most cost-efficient strategy known today.
- **New technological breakthroughs:** On the way to 2030, breakthroughs in other technologies might occur. These breakthroughs could complement the most cost-efficient climate technologies under consideration today (e.g. efficiency measures, wind and solar power, battery storage and heat pumps). Two areas where breakthroughs are most likely are fuel cells and power-based synthetic fuels, both of which have been well researched, and have already found their first fields of application.[42] Though they are still expensive, each has significant potential for reducing costs.[43]

Without energy efficiency or electrification, much more wind and solar power will be needed

Whatever alternative paths are pursued, they cannot get around the central climate goal of the energy transition, namely restricting the use of coal, petroleum and natural gas. Since biomass's potential is extremely limited, all three sets of circumstances would require installing a great deal more wind and solar power by 2030. For instance, if efficiency efforts in the heating and transport sectors miss their targets by 50 %, power-based synthetic fuels will need to make up the difference – in this case, around 470 terawatt hours.[44]

Generating more power from renewables also generates more costs, for building additional wind and solar power installations and for creating added back-up power plants and power grids. These additional wind and solar power plants are likely to encounter public resistance as they could be avoided if e.g. efficiency goals in the transport sector were reached, or electric vehicles were used instead of energy-intensive power-to-liquid fuels. This extra electricity will probably have to be produced abroad, some possible candidates being the North Sea region, North Africa and the Middle East. The need for power-to-liquid technology is likely to be greater for the period post-2030 - and the corresponding climate protection goals - than for the period leading up to 2030. At this point, however, power-to-gas and power-to-liquid technologies are not expected to play a central role in the energy transition before 2030.

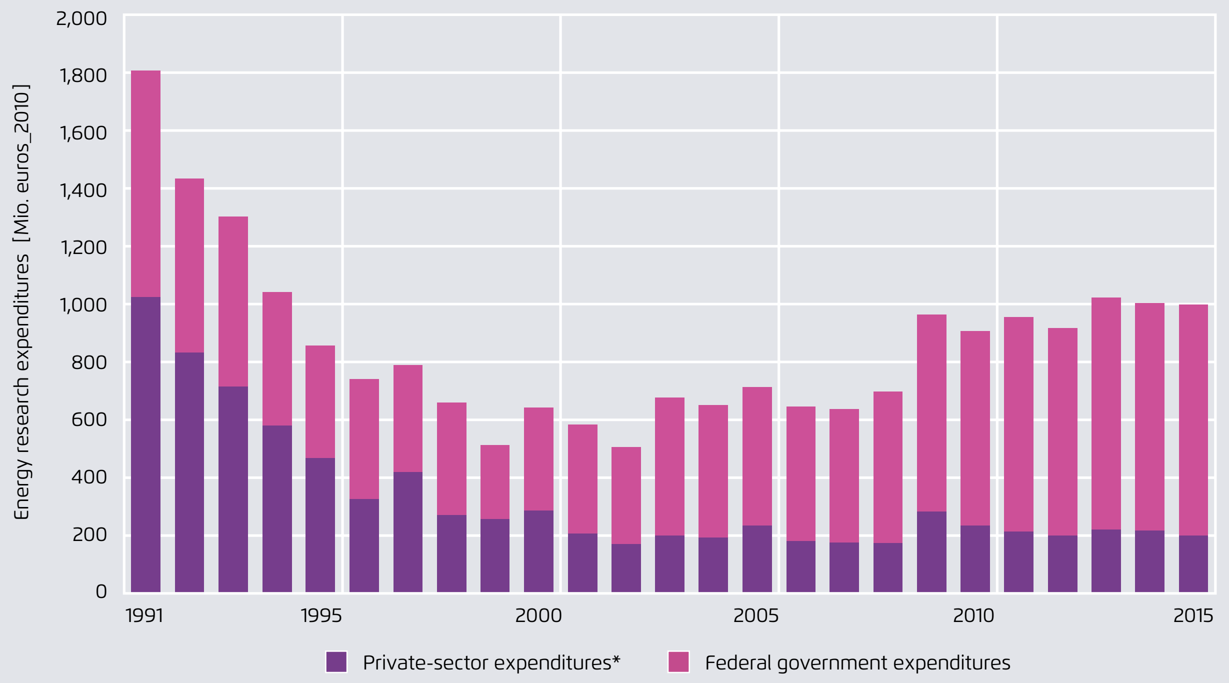
Power-to-X will be key to the energy transition after 2030, and needs to become market-ready

Nevertheless, power-to-gas and power-to-liquid – as well as other power-to-X technologies – will contribute to the long-term success of climate change mitigation and the energy transition. Power-to-heat is already a proven technology, but open-minded research and testing is required if other important power-to-x options are to become viable.
For instance, power-to-liquid, power-to-gas and power-to-chemicals can serve as long-term storage mediums for wind and solar power and are the key for reducing carbon emissions in air traffic, ship transport and trucking. They can also supply carbon-neutral power for energy-intense processes in the industrial sectors and climate-friendly precursors for the chemicals industry.

It is therefore crucial that power-to-x technologies, including carbon capture, quickly become market-ready for the period after 2030. While the cornerstones have already been laid for many technologies, R&D is still needed for others. Countries must devise a joint international strategy for producing and transporting power-based synthetic fuels and chemicals. To these ends, the German federal government and Germany's industries ought to concentrate their energy research efforts in a "Future Pact for Energy Transition and Industrial Policy" pact, agree on a research and testing agenda and combine this agenda with a market-launch programme, most usefully with a focus on grid bottlenecks where renewable power would otherwise be curtailed.

In 1991, expenditures for energy research were almost twice as high as today, with the private-sector's share declining considerably

Figure 14



*selected key branches, estimates (see original source)
BMWi (2017), Destatis (2017)

3.6 Grid infrastructure in 2030

Energy transition is not only about fundamentally changing how energy is generated and consumed. It is also about adapting the power, heating, gas and transport infrastructure to the changes in the system. The longevity of this infrastructure requires long-term planning. Indeed, we need to train our sights on 2050, when infrastructure will need to support a nearly carbon-free energy system.

Defining grid targets and advancing innovation for 2030

The advances of the energy transition have necessitated major expansion and restructuring of Germany's transmission and distribution grids. But this work, especially transmission line expansion, has encountered strong resistance from local residents, with the result that only 850 of the planned 7,700 kilometres of additional power lines have been built.

The energy transition relies on the expansion of wind and solar power. In Germany, the latter is available in plentiful quantities primarily in the summer; the former, in the winter. Ideally, wind and solar power installation would be distributed evenly throughout Germany. But the reality is that more than 75 % of wind power capacity is located in northern Germany and offshore. This has resulted in a considerable transmission demand for moving power south. If the transmission network expansion does not take place, then around 75 % of new wind turbines will need to be built in central and southern Germany. But so far, there's been no sign that Germany's states have the political will to tackle such an undertaking.

This is why it's important that the planned expansions to the transmission lines provided for in the 2016 Power Line Development Act (EnLAG) and the Federal Requirement Plan Act (BBPG) get underway quickly. In 2030, when renewables make up 60 % of the power sector, these lines will be responsible for balancing power generation and consumption across regions in Germany. Even if the grid expansion is one of the more affordable measures for integrating renewables, it still carries a hefty price tag: by 2030, the investment will total some 50 billion euros, which translates into an annual grid-fee increase of 3.5 billion euros.[45]

Yet in view of the costs, the future need for technological innovation and the question of public acceptance, further grid expansions need a fundamental re-examination. We propose the planning of a target grid for 2050 based on power lines that the government has already planned. After 2030, additional transmission demand should primarily be covered by expanding capacity of existing power lines, new digital technologies in grid management, and regulatory changes. For instance, smart markets will send price signal for regional power use and thereby reduce transmission demand. The distribution networks also require major investment to link up with new wind and solar farms and to integrate heat pumps and electric vehicles. Here, too, the need for grid expansion can be reduced by introducing intelligent management systems, integrating new users into smart markets and bundling new generation facilities with existing ones, such as the construction of PV installations in existing wind farms so they can use the same grid connection.

Modernising heating and gas networks for 2030

District and local heating systems are central features of climate action in the heating sector. In cities large and small, they enable a low-carbon heat supply. To reach 2030 targets, existing heating networks must be reconfigured for falling heat demand. As it stands now, networks are geared towards transporting heat from central generation facilities to poorly heat-insulated buildings.

In the future, numerous low-carbon heat sources – biomass plants, geothermal and solar thermal energy, large-scale heat pumps, power-to-heat plants, industrial waste heat – will be incorporated into heating networks. This will gradually reduce the share of fossil fuels in the heating sector. At the same time, improved heat insulation of buildings will reduce heat demand. Existing networks, in addition to being reconfigured for low temperatures, must be equipped with hydraulic mechanisms that allow the feed-in of various, decentralised heat sources.

The significance of gas networks for the energy transition remains unclear at this time. By 2030, natural gas use will have dropped only slightly, the primary focus being on reducing coal and petroleum, far more carbon-intense energy sources. Only after 2030 will natural gas use decline; by 2050 it will have vanished almost entirely.

The central question for the future of gas networks is the extent of power-to-gas deployment. Synthetic, carbon-neutral gases such as hydrogen or methane can be used for heating, as fuels, as industrial precursors and as long-term storage mediums for wind and solar power. The downside is the cost of their production. Based on what is known today, direct power and energy efficiency will remain more affordable measures than synthetic gases. It is likely, therefore, that gas networks in 2050 will be smaller than they are today, while distribution networks in rural areas will become less and less profitable. By contrast, gas networks in industrial regions and as supply systems for back-up power plants are likely to remain important.

Which heating and gas networks are deployed in the long run, and where, are questions that can only be answered case by case depending on local potentials for carbon-free heat generation and the availability of heat sinks. Therefore, it is of crucial importance to firstly, develop municipal heating concepts until 2030. Those concepts should map out how a carbon-neutral heat supply system could look like and predict the needed infrastructure. Secondly, those concepts need to be implemented.

Transport networks in 2030: furthering the electrification of traffic routes

As a central strategy for decarbonising the transport sector, we need electrification in addition to increased efficiency. But the transport sector is far from being prepared for across-the-boards electrification. Massive investment is necessary, and must focus on three areas:

- → **Expanding and further electrifying the rail system:** A rapid rail expansion is needed to shift more transport from roads to rails and a rapid electrification is needed for the parts of the railway system that continue to use diesel locomotives, so that by 2030 as many as 80 % of trains are electric.
- → **Creating a charging infrastructure for electric vehicles:** The 10 to 12 million electric vehicles on German roads in 2030 requires a charging infrastructure, both for highways and rural roads as well as in cities and at commercial properties.
- → **Overhead lines along the autobahns:** Overhead power lines for trucks is one way to electrify nationwide goods transport. With them, hybrid trucks can complete part of their routes powered by electricity. After the current pilot project is over, Germany should proceed with the installation of overhead power lines along its central motorways.

The current Federal Transport Plan was decided before the Climate Action Plan 2050 and thus does not mention these necessary investments. The Federal Transport Plan must be thoroughly revised as soon as Germany devises a strategy to transform the transport sector for 2030.

4 What will the energy transition cost?

The price tag of the energy transition has been a contentious issue. On the one side, detractors claim that it will be prohibitively expensive and a danger for the Germany economy; on the other, supporters praise it a cost-efficient investment in the future.

The true price of the energy transition results from a comparison with the costs of not having an energy transition

Any serious attempt to calculate the cost of the energy transition must take into account two essential considerations. First, there is a difference between the costs that have accrued so far and those still to come. For while costs for renewables were at times quite high during the first 15 years of the EEG, especially for PV and biogas installations, this is no longer the case for new investments in renewables. The problem is that previous commitments for existing installations have packed quite a financial wallop. With terms of 20 years, the financial commitments won't begin to dry up until 2023 and won't disappear entirely until 2033. But these past outlays shouldn't warp our view of the future investment trajectory.

The second important point to consider when figuring out the cost of the energy transition is that expenditures don't reveal the whole picture. For even without the energy transition, new power plants would have to be built; buildings modernised; fuels purchased; cars ordered; and power grids renewed. Not the total costs of the energy transition are decisive, but the difference between this scenario and the counterfactual of not pursuing the energy transition. It is furthermore important how investments in each scenario – one with the energy transition, one without – affect growth, employment and the overall economy. This can only be calculated using theoretical models. The chosen underlying assumptions will determine whether and when the energy transition will deliver additional *costs* or additional *benefits* for the economy and for society.

Currents costs and benefits of the energy transition

In 2015, the total energy costs for end consumers in Germany (including taxes, levies and surcharges but excluding VAT) amounted to around 193 billion euros.[46] Of that amount, 72 billion was spent on fuels, 69 billion on electricity and 52 billion on heating. Energy spending has remained fairly constant over the past few years, and, if anything, has fallen somewhat, totalling 204 billion euros in 2011 and 219 billion euros in 2013. What has changed is where the money is being spent. Expenditures for fuels and heating energy have decreased, while those for electricity have increased. The reasons for these changes are falling global prices for oil and natural gas and rising costs for the expansion of renewables in the power sector.

In 2015, Germany's households bore 60 % of total energy costs, or around 117 billion euros. This is roughly the same as the 115 billion euros spent in 2010 and is significantly lower than the 132 billion euros spent in 2013.[47] The share of household energy expenditures in overall consumer spending has remained remarkably constant over the past decades. In 1991, the money spent on power, heating and fuels totalled 7.3 % of consumer spending. In 2015, the total was 7.6 %.[48]

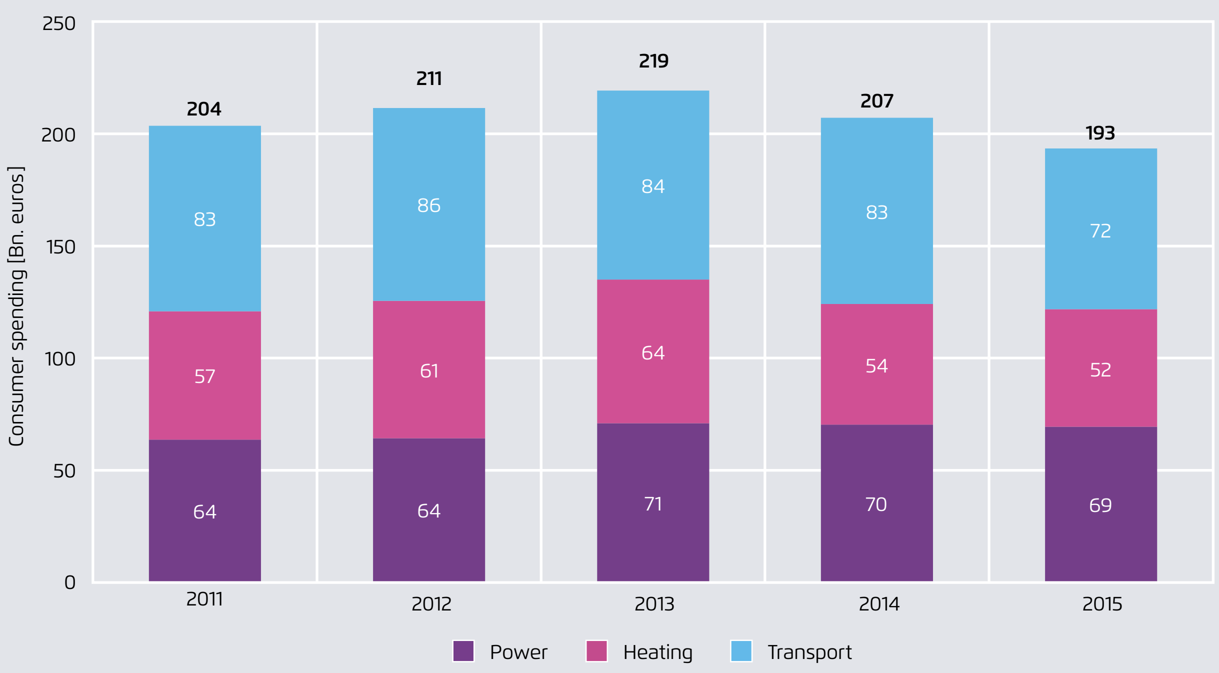
The remaining 40 % of expenditures for energy in 2015, roughly 75 billion euros, were borne by industry and commerce. The energy per unit costs in Germany industry – the share of energy costs in gross value added – are slightly below the European average and amounted to 7 % in 2015.[49] Since 2008, the share has fallen 10 %, most strongly in energy-intensive industries. Price declines in wholesale markets and wide-ranging tax, levy and surcharge exemptions for energy-intensive industries are responsible for this trend. These developments have helped to ensure the global competitiveness of German industry:

Between 2000-2015, Germany's gross domestic product increased by 43 % and industrial production rose by 25 %.

Of the 193 billion euros spent on energy in 2015, roughly 20 billion was used for the energy transition in the power sector.[50] A large portion of this money went to fund previous financial commitments, described above. The remunerations for renewable energy installations would amount to 10 billion euros instead of 24 billion euros if those 32 % of renewable energy were financed under today's conditions for wind and solar tariffs.[51] Expenditures in 2015 for the energy transition also included 2 billion euros' worth[52] of state subsidy programmes in the heating and transport sectors, for a grand total of 22 billion euros.

The extra costs of the energy transition have also brought extra benefits, bringing economic stimulus to the areas of construction, skilled labour and technical services. To measure those benefits, EWI, Prognos & GWS have created several models that compare the total economic effects of investments in the energy transition from 2010 to 2013 with the counterfactual of not pursuing the energy transition.[53] Their models come to a number of important findings. In 2013, inflation was 0.25 % higher than it would have been without the energy transition on account of higher power costs. At the same time, the additional investment boosted economic growth, leading to a 0.4 % increase in Germany's gross domestic product in the period 2010–2013, creating an average of 70,000 new jobs each year.

Consumer spending on energy, 2011–2015 — Figure 15



Expert commission for the monitoring process "Energy of the Future" (2016)

The costs and benefits of the energy transition in 2030 and 2050

So far, five comprehensive studies have been published on the added costs of the energy transition.[54] Each has compared the costs of the business-as-usual scenario (i.e. without the energy transition) with the costs of the energy transition. Some have also tried to quantify the total economic effects for each scenario.

These studies draw different conclusions about whether the energy transition will bring added costs or added benefits for the economy and for Germany society in general. Indeed, some come to completely opposing views. According to our analysis, the findings of these studies crucially depend on two sets of assumptions:

→ **Cost assumptions for fuels, technologies and capital:** The energy transition uses new technology to reduce the consumption of coal, oil and natural gas. Hence, price assumptions for fossil fuels and for future renewable-energy technologies such as wind and solar power, energy storage, electricity networks and synthetic, power-based fuels are key. The expected capital costs for financing new investment also play an important role.

→ **Cost assumptions for CO_2:** What is the value of each avoided tonne of CO_2? This assumption is decisive in determining whether the energy transition is estimated to produce added costs, and if so, how much. The lower the value assigned to an avoided tonne of CO_2, the better the business-as-usual scenario looks.

Despite the different assumptions made in these studies, six common positions emerge when comparing them:

1. The energy transition will require considerable added investment, but the costs will be manageable

The total added annual investment required by the energy transition varies between the studies, ranging from 15 to 40 billion euros. To put this in context: Germany's gross fixed capital formation in 2015 amounted to 600 billion euros. The average projected annual investment in the energy transition would require a 5 % increase over the status quo.

2. If climate-related damage is valued at 50 to 60 euros per ton of CO_2 or if the price of raw materials for fossil fuels increases, then the energy transition will be the cheaper option

In scenarios where prices for coal, oil and natural gas are high, the additional investments required do not produce added costs, but added benefits, as expensive fuel imports are avoided. In the scenarios where they remain the same, the question comes down to CO_2 price. Fraunhofer ISE estimates that, were the CO_2 price set to zero, the energy transition would cost 30 billion euros in added expenses per year. If the CO_2 price is set between 50 to 60 euros per tonne, however, most scenarios project that the energy transition will produce no added costs, only added benefits.[55] These costs seem manageable.

3. Overall, the energy transition has a slightly positive effect on the economy, mainly thanks to efficiency measures decreasing the import of coal, oil and gas

The analysed scenarios reflect a slightly positive effect on the gross domestic product stimulated by the additional investments of the energy transition. The main driver for this is the value provided by green building retrofits, which reduce fossil fuel imports and the associated costs. The effect on growth is larger in scenarios that project rising prices for coal, oil and natural gas. For instance, EWI, Prognos & GWS estimate that if fossil fuels prices remain constant, the energy transition will lead to a 0.1 % increase of Germany's gross national product by 2030 and a 1.0 % increase by 2050.[56] The Öko-Institut & Fraunhofer ISI, which expect fossil fuels prices to increase, project a 2.5 % growth in GDP by 2030 and a 4.4 % growth by 2050 (figure 16).[57]

4. None of the studies considers the additional effects caused by rising exports of energy technologies

Curiously, the studies make no allowance for the possibility that the energy transition will improve Germany's export position as a pioneer in technologies for mitigating climate change. If this happened and Germany were to become a major player on the emerging markets embarking on their own energy transition, there would be additional effects to be considered (figure 16).

5. Capital costs have a massive effect on the total expense of the energy transition

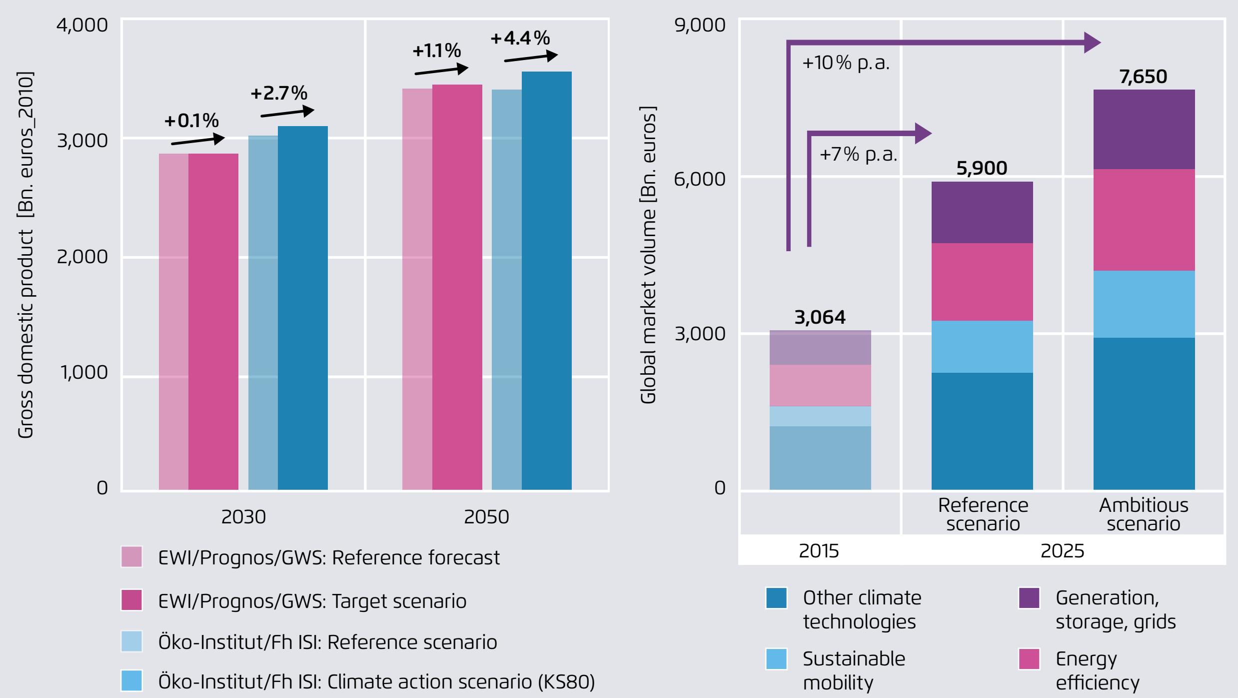
The financing conditions of the energy transition play a central role in the total added costs of the transition. The scenarios projected by Fraunhofer ISE and Fraunhofer IWES clearly indicate that the rate of return decides whether the energy transition will be more expensive or less expensive than the business-as-usual approach. The reason: technologies used in the energy transition have low operating costs but high investment costs. (For more on this difference, see Megatrend 6.)

6. Previous financial commitments from launching renewables will put a strain on consumers until 2021–2023

The market launch of PV, biogas and wind offshore installations brought with it a period of high costs, and the 20-year financial commitments that made the launch possible will only gradually run their course, reaching their peak somewhere between 2021 and 2023. Afterward, renewable energy costs will begin to sink and by 2030 the sum of the wholesale price and the EEG surcharge will fall below 2015 levels even though the share of renewables in every kilowatt hour of electricity will have doubled by then

The energy transition will have a slightly positive effect on the economy; rising exports would create additional positive effects

Figure 16



Agora Energiewende based on EWI/Prognos/GWS (2014a), Öko-Institut/Fraunhofer ISI (2015) and Roland Berger (2017) (figure 17). Prices will continue to fall through 2035, as EEG subsidies for PV installations run out in the period 2030-2034.

Summary: the energy transition will bring affordable climate change mitigation, if it's approached the right way

The following six conclusions can be drawn from the above analysis and that of the previous section:

1. Neither doom nor salvation: the total economic effects of the energy transition in Germany are limited

If energy prices remain stable (see Megatrend 3), the energy transition will lead to some minor added costs or some minor added benefits, depending on the estimated CO_2 price. Either way, the macroeconomic effects for the German economy are likely to be positive, since the energy transition will reduce the need for imported coal, petroleum and natural gas and improve national value creation. But in all the studies, the effects are not projected to be very large because the percentage of energy transition investment in Germany's gross fixed capital formation is in the single digits. Ultimately, the energy transition can be seen as insurance for the event that the prices of fossil fuels increase significantly.

2. Safeguard Germany's strong position on global clean-energy markets

Germany can benefit from additional economic effects if it secures and expands its position as a technological pioneer on global clean-energy markets. By 2025, the value of this market will roughly double, increasing by 6 to 7.5 billion euros. To benefit from this development, however, Germany needs a targeted energy transition industry policy.

3. CO_2 requires adequate pricing

As soon as the climate-related damage caused by burning coal, natural gas and oil is at least partially internalized, the energy transition pays off financially. The most efficient measure for climate change mitigation would be the quick introduction of adequate CO_2 pricing. The current price per tonne of CO_2 in the EU Emissions Trading System – 5 euros – by no means reflects the true cost of climate change. In the non-ETS sectors, the effects of the 1999–2003 eco-tax reforms have fizzled out. Falling fossil fuel prices have made adequate CO_2 pricing all the more urgent, but the conditions are favourable considering the significant drop in consumer spending in energy over the past few years.

4. Power costs and previous financial commitments must be untangled

The past costs of the EEG continue to be a considerable strain on power consumers, and the EEG surcharge will rise through 2023 before starting to decline (figure 17). Moreover, these costs have produced high power prices, while the prices for heating oil, natural gas, petrol and diesel have fallen to 2005 levels on account of persistently low fossil fuel prices. Since the electrification of the heating and transport sectors are important climate change mitigation strategies (section 3), the current price structure sends the wrong signals. A reform of the taxes on power, heating and fuels is needed to correct these skewed prices.

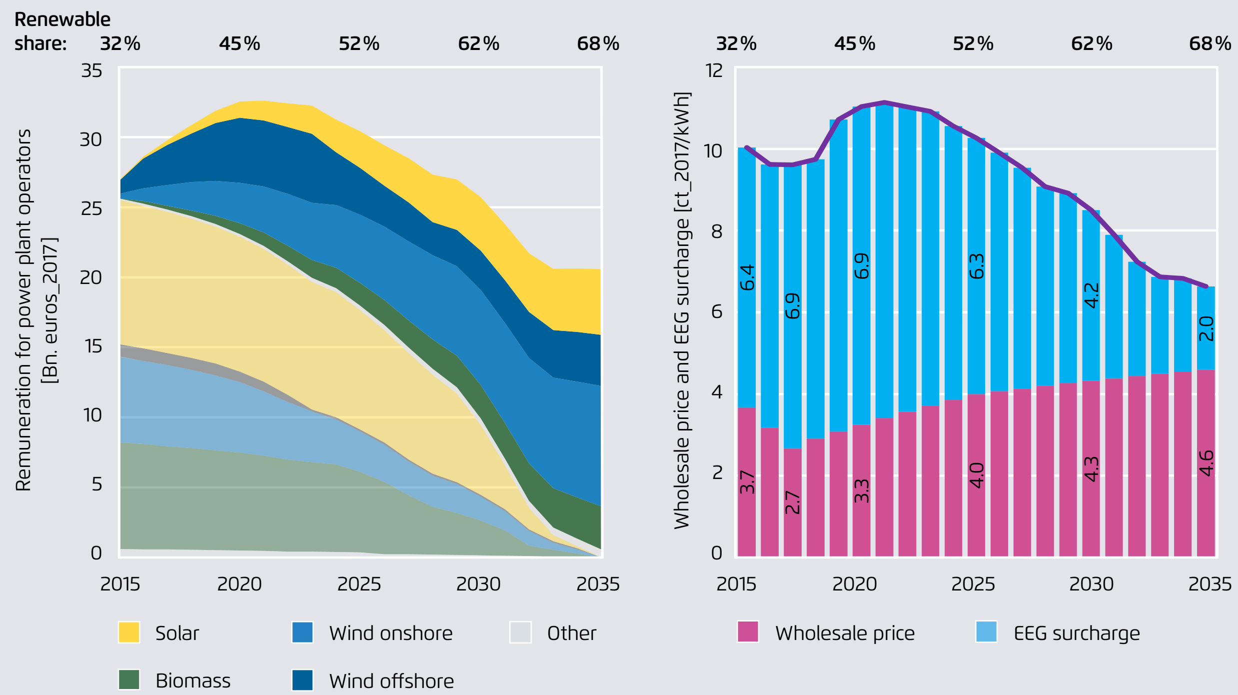
5. Exemptions are needed for energy-intense industries and low-income households

The energy costs for power, heating and transport are, on average, at acceptable levels for industry and households. This is set to continue in the coming years on account of the low additional costs needed for renewables. Nevertheless, price breaks are needed for two particular groups: energy-intense industries trying to compete globally and whose energy per unit costs are significantly more than 10 %; and low-income households, where the share of energy costs in private consumer spending is also significantly more than 10 %. The EEG exemptions already provide price breaks to the industrial sector, but low-income households have yet to see any similar types of exemptions.

6. The implementation of the energy transition must be strictly geared towards cost-efficiency

All the studies we reviewed assume that the energy transition will be guided in a cost-efficient manner. This means that the energy transition will continue to develop along the lines described in section 3, with a clear focus on the most affordable technologies: efficiency, wind and solar power, heat pumps and electric vehicles. If the government deviates from this strategy, the energy transition stands to become considerably more expensive. To ensure that the energy transition brings added benefits and not added costs to the Germany economy, policy must be strictly geared towards cost-efficiency. Moreover, clear and reliable frameworks must ensure that capitals costs for investments remain low.

Costs for increasing the capacity of renewables in the power sector will rise until 2021–2023 and then fall noticeably through 2035 — Figure 17



Note on left chart: Transparent areas show existing power plants, filled areas show new power plants
Note on right chart: The wholesale price in 2035 has a real value of 4.6 ct/kWh but a nominal value of 6.0 ct/kwh.
Calculations by Agora, based on Öko-Institut (2017a)

5 What to Do Now: A ten-point agenda for the next phase of the energy transition

The complete transformation of Germany's energy system will not happen overnight but over many years. The decisions taken in the next couple of years will set the course for the state of the energy transition in 2030. The following suggests a ten-point agenda for achieving the 2030 goals.

The megatrends discussed in section 1 will shape the energy world of tomorrow, which is why they mark the starting point of our agenda. Let us recall the 7 D's: decreasing costs of wind turbines, photovoltaics and batteries; decarbonisation; deflating fossil fuel prices; the dominance of fixed costs; decentralisation; digitalisation; and democratisation.

Against the backdrop of these megatrends, policy needs to address the energy policy triad of environmental sustainability, economic competitiveness and security of supply. Our ten-point agenda brings together the Energiewende targets for 2030 specified in section 2: reduce emissions in the energy sectors by some 60 % below 1990 levels by 2030; limit energy costs for industries and private households to below 10 %; reduce energy imports to under 60 %; and restrict average power outage per customer to under 20 minutes a year.

Germany can best reach these targets if it coordinates its efforts with those of neighbouring countries and the EU in general (section 2). In addition, Germany needs a cost-efficient energy strategy based on the core elements spelled out in section 3:

- → Substantially increase efficiency: Each energy sector (power, heating, transport) holds great potential for low-cost energy savings. Energy efficiency will thus play a key role in the targeted 30 % reduction of Germany's primary energy consumption targeted for 2030.
- → Expand renewable energies: The expansion of renewables is the second important pillar of the energy transition. By 2030, the share of renewables in primary energy consumption should be at least 30 %, more than double of what it is today. The focus should be on expanding wind and solar power – the least expensive renewables by far – and on boosting their deployment in the heating and transport sectors.
- → Phase out coal and oil: For the greatest reduction of CO_2 emissions per kilowatt hour, policymakers should begin by eliminating the most carbon-intense energy source in each energy sector. Consumption of coal and oil must therefore be cut by half in 2030, while natural gas consumption should decline by 20 %.

Our 10-point agenda defines the steps for a energy transition that maximises economic benefits and minimises economic costs (section 4). Each agenda item will include specific policy recommendations to make the transition a success.

5.1 *Energiewende* Framework 2030: Reliability and predictability

1) Provide reliability and predictability by creating a legal framework	
Where we are today	→ Germany's energy transition continues to be based on the federal government's 2010 Energy Concept and several other pieces of legislation. → Unlike many German states, the federal level lacks an institutional and procedural framework to achieve the three central goals of the energy transition: environmental sustainability, economic competitiveness and security of supply.
Where we want to be in 2030	→ The energy transition, as a task that is shared by generations to come, is based on a legally binding framework that ensures steady goals while providing flexibility in implementation. → Adequate reliability and investment security is provided to stakeholders of the power, heating and transport sector transformation. → The framework includes regular monitoring and revision of single measures and laws and provides for active participation of stakeholders.
How we get there	→ Adopt a legal framework for the energy transition with broad parliamentary support. → The framework must define quantitative targets for 2030, 2040 and 2050 relating to the environment, economic competitiveness and security of supply. Moreover, it should specify processes for adopting new climate actions plans and revising existing ones with input from stakeholders, and it should convene an independent commission for monitoring and evaluating the energy transition.

Where we are today

The energy transition involves nothing less than the complete re-engineering of a complex, energy-independent industrial society towards sustainability within the span of a generation. But there is a blatant disparity between the enormity of this undertaking and its legislative foundations, which consist of an energy plan introduced by the federal government in 2010 and a renewed commitment to the phase-out of nuclear power in the wake of the 2011 Fukushima disaster. Though the federal government and the *Bundestag* have reaffirmed the climate and energy targets contained in this legislation multiple times – most recently in the 2050 Climate Action Plan – their efforts are far from enough. In the absence of a proper legal framework, companies and households have so far failed to make the investments needed for transforming the power, heating and transport sector. Given these conditions, missing the targets is inevitable.

Where we want to be in 2030

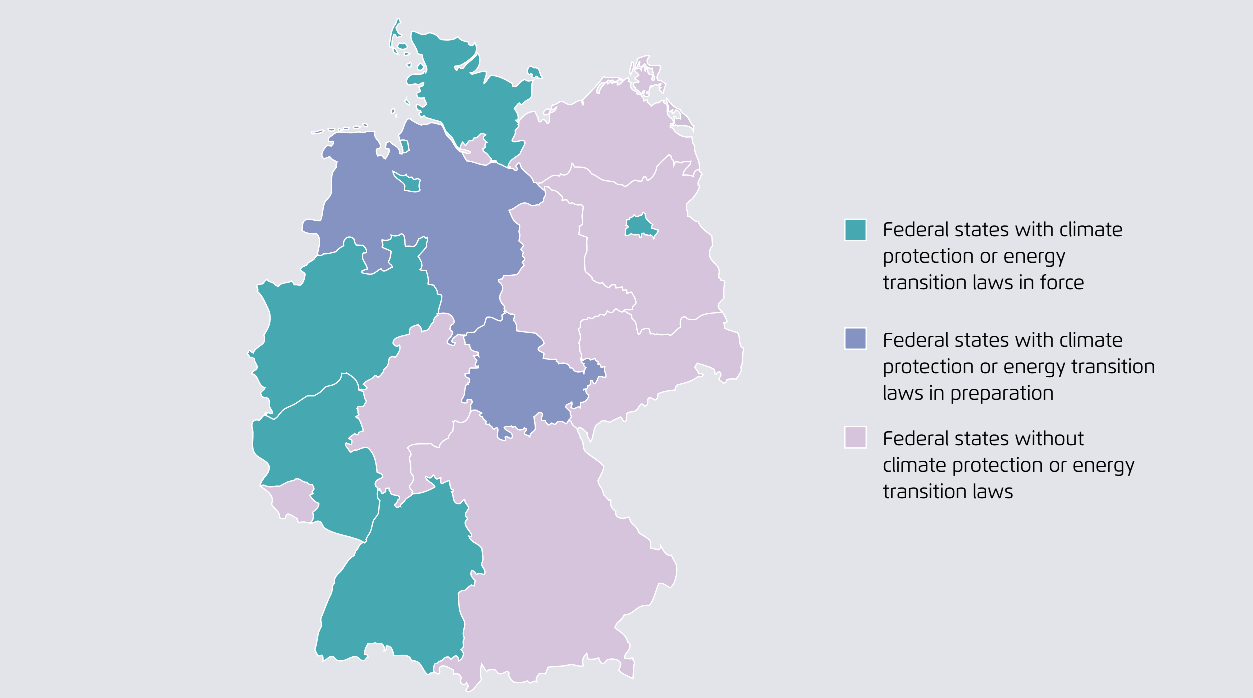
We need a cross-party legal framework in proportion to the size of the challenge posed by the energy transition. Such a framework will ensure that Germany reaches its targets in environmental sustainability, economic competitiveness and security of supply while furnishing it with enduring management structures and processes. Importantly, the framework needs to provide enough flexibility to take into account technological and societal developments. The strategies for implementing the energy transition must be as flexible as its targets must be robust. A legal framework that preserves both will provide predictability and reliability for everyone affected in society and economy.

How we get there

Germany needs a national legal framework for climate action and the energy transition much like the one that already exists in the U.K. or the one that will come into effect in Sweden next year. Many German federal states have or are planning similar frameworks or laws. This national legal framework would not contain specific measures. Based on a broad parliamentary consensus, it would define an institutional structure that would persist beyond any single legislative period.

At the core of the framework would be the quantified goals of the energy policy triad (environmental sustainability, economic competitiveness and security of supply) and the European integration thereof. The framework would oblige government administration to meet these targets, and define the responsibilities, management procedures and monitoring processes needed to achieve them. At the beginning of every legislative period the government should specify the measures to be enacted over the next four years. It is also important that suitable forms of participation are in place so that all stakeholders, in the economy and in society at large, can provide input before measures are passed. Germany would be well advised to introduce a national forum for each sector affected by the energy transition – power, heating and transport – that brings together all the central players to discuss medium- and long-term goals and options for action.

Half of the federal German states have legal frameworks for climate protection or energy transition either already in force or in preparation — Figure 18



Agora Energiewende

5.2 Europe 2030: A European energy transition

2) Support Europe's energy transition; coordinate German efforts within Europe

Where we are today	→ In 2015, the EU's greenhouse gas emissions were 24 % less than in 1990, and in the past few years security of supply remained fairly constant. Competitiveness varies greatly between member states. → In 2014, the EU set itself new climate targets, to be achieved by 2030: at least a 40 % reduction of greenhouse gas emissions by 2030 relative to 1990 levels, at least a 27 % increase in energy efficiency relative to 1990s levels and at least a share of 27 % renewables covering power demand and better integration of Europe's energy markets. → But so far Europe lacks a clear legal framework to support member states in reaching the 2030 targets.
Where we want to be in 2030	→ A 50 % reduction of Europe's greenhouse gases relative to 1990 levels, coupled with a 30 % increase in energy efficiency and a 30 % share of renewables in final energy consumption. → A Europe with improved competitiveness and security of supply and a Europe in which member states lend one another mutual support for better energy security. → Integrated power and natural gas markets in Europe, and a significant expansion of trans-European networks for power, natural gas and rail
How we get there	→ Enact a stable EU 2030 framework for renewables, energy efficiency, market design, emissions trading and a socially responsible transition in coal-mining regions. → Set a Europe-wide CO_2 price, both within the Emission Trading Scheme and outside of it, to steer emissions trading and shape government policy. → Implement a low-emissions mobility strategy for reaching the 2030 climate targets in the transport sector. The strategy must include the reform of CO_2 regulation for cars and trucks.

Where we are today

Germany is not the only country that is undertaking an energy transition. Greenhouse gas emissions, energy efficiency and renewables have followed similar trends throughout Europe. Between 2005 and 2015, the share of renewables in EU power consumption rose from 15 % to 29 %, analogous to development in Germany. At the same time, emissions have been rising in the European transport sector.

German's energy system is already closely tied with the energy systems of its neighbours thanks to their highly interconnected power and natural gas markets. This has produced a flourishing energy trade. In 2014, the EU set itself three targets for the energy union 2030: better integrated energy systems between member states, increased energy efficiency and a greater share of renewables. All three serve the goal of strengthening climate change mitigation, security of supply and economic competitiveness in Europe. The package of laws proposed in November 2016 under the name Clean Energy for All Europeans is slated for adoption by the end of 2018.

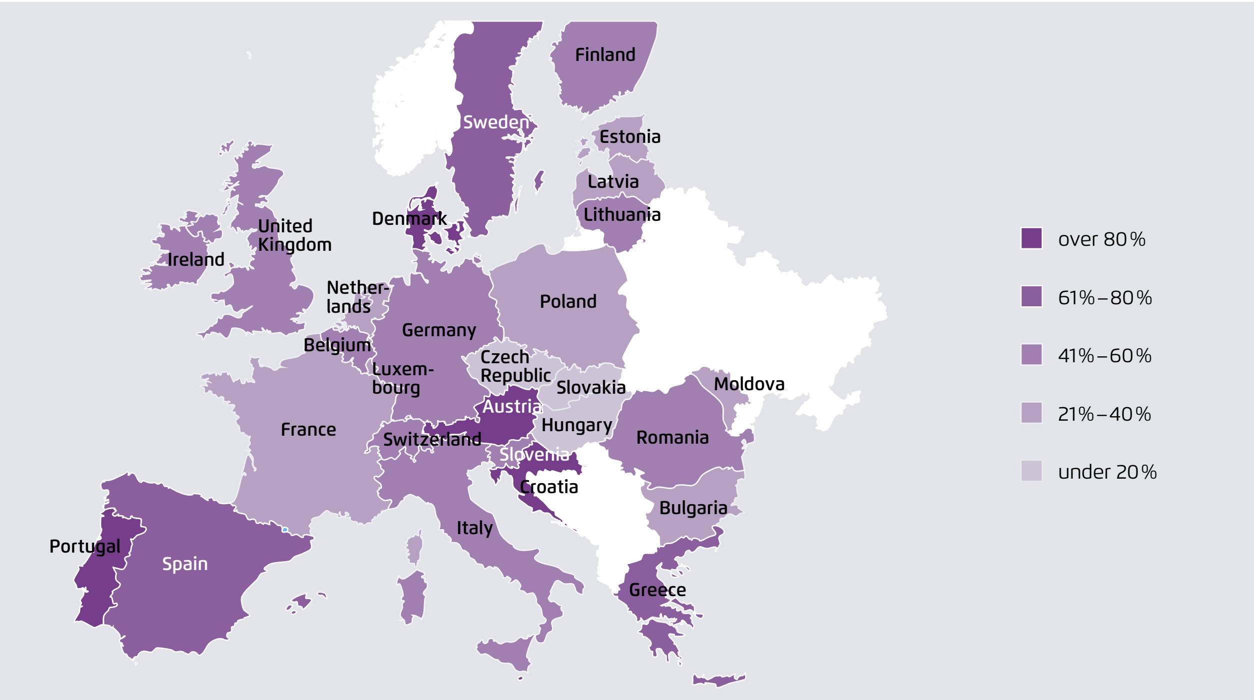
Where we want to be in 2030

By 2030, Europe must reduce its greenhouse gas emissions 50 % relative to 1990 levels. This will require a 3-percentage point increase in its 2030 efficiency and renewable targets, from 27 % to 30 %.[58] In view of the drastically falling prices for renewables (section 1) and the value of energy efficiency (section 3), these targets will also serve economic competitiveness and security of supply. The EU transport sector must drastically increase energy efficiency by 2030, and around one-fourth of the vehicles on the road must be electric. Moreover, an effective energy transition in Europe demands better integration of its member states' energy systems on three levels: physically, through the further expansion of Europe's infrastructure, particularly its power grid and railways; economically, through the improved integration of its power and gas markets; politically, through the coordination of each member state's 2030 energy and climate strategies with its neighbours.

How we get there

The measures proposed in the EU Commission's Clean Energy for All Europeans package are supposed to be adopted by the end of 2018. But these alone will not suffice. Especially in the area of renewables, clear targets and reliable frameworks must be introduced. Other important measures include the institution of an effective minimum CO_2 price across Europe and further efforts to incentivise efficient climate action in the transport, building and agricultural sectors. The introduction of an effective CO_2 price within or in addition to the Emission Trading Scheme would be a suitable instrument. Moreover, amendments to Europe's CO_2 directives for cars and trucks are crucial for mitigating climate change and increasing energy efficiency in the transport sector. Revised CO_2 directives can create a domestic market that makes Europe's electric car manufacturers globally competitive. Finally, structural assistance is needed for Europe's coal-mining regions as they prepare for structural changes to their local economies.

The energy transition is not only happening in Germany: by 2030, renewables will make up at least 50 % of Europe's power consumption. Figure 19



Agora Energiewende based on E3MLab/IIASA (2017)

5.3 Efficiency 2030: *Efficiency First* as the guiding principle

3) Make *Efficiency First* the guiding principle for planning and investment decisions	
Where we are today	→ In 2010, Germany set the following efficiency targets for 2020: -10 % power consumption (relative to 2008), -20 % heat consumption in housing (relative to 2008) and -10 % final energy use in transport (relative to 2005). → The situation as of 2015: gross power consumption -4 %, heat consumption in housing -11 %, final energy use in transport +1 %. The cars on the road today are not reaching efficiency targets set for them, and trucks have yet to receive any.
Where we want to be in 2030	→ Power consumption is at around 2015 levels, with increased energy efficiency offsetting additional power demand in heating and transport. → An 18 % reduction in total heat consumption relative to 2015 levels (-25 % in the building sector and -10 % in the industrial sector). → A reduction of one-third in the transport sector's final energy use relative to 2015 levels. → Energy efficiency and flexibility are merged to flex-efficiency.
How we get there	→ Make *Efficiency First* the guiding principle in all energy-related regulation. → Pass energy efficiency regulation that a) legally enshrines *Efficiency First* as a guiding principle; b) specifies targets for the power, heating and transport sectors; c) combines multiple pivotal measures (write-offs, auctions, standards, etc.); and d) provides secure, long-term funding of these measures totalling 5 billion euros a year.

Where we are today

Energy efficiency is crucial for the success of the energy transition. All the targets of the transition – environmental sustainability, economic competitiveness, security of supply – will be aided by more energy efficiency. This also applies to a world dominated by high shares of renewables. For efficiency means more than doing without coal, oil and natural gas; energy efficiency also has a system value. Every kilowatt hour that's not needed saves around 11 to 15 euro cents thanks to the avoided use of fuel, renewable energy, back-up power plants, storage and power grids.[59] As land becomes sparser and public support for new power grid infrastructure and wind turbines wanes, energy efficiency will become increasingly important.

Despite the general recognition of energy efficiency's value, it's yet to inspire the kind of effective legislation that exists for renewables and cogeneration plants. In the absence of such legislation, Germany will probably fall short of its efficiency targets for 2020, nowhere more so than in the transport sector.

Where we want to be in 2030

A central element in the successful energy transition is the establishment of *Efficiency First* as a guiding principle, which will help minimise the costs of the energy transition in the power, heating and transport sectors. By 2030, the goal is to decrease power consumption in heating by around 18 % and power consumption in transport by around 30 % relative to 2015 levels (section 3). Another goal is to keep power consumption roughly the same through 2030. Doing so will require that conventional power use be decreased by around 15 % relative to 2008 levels. The saved energy can then be used to cover additional demand from heat pumps, power-to-heat plants, electric cars and carbon-neutral synthetic fuels.

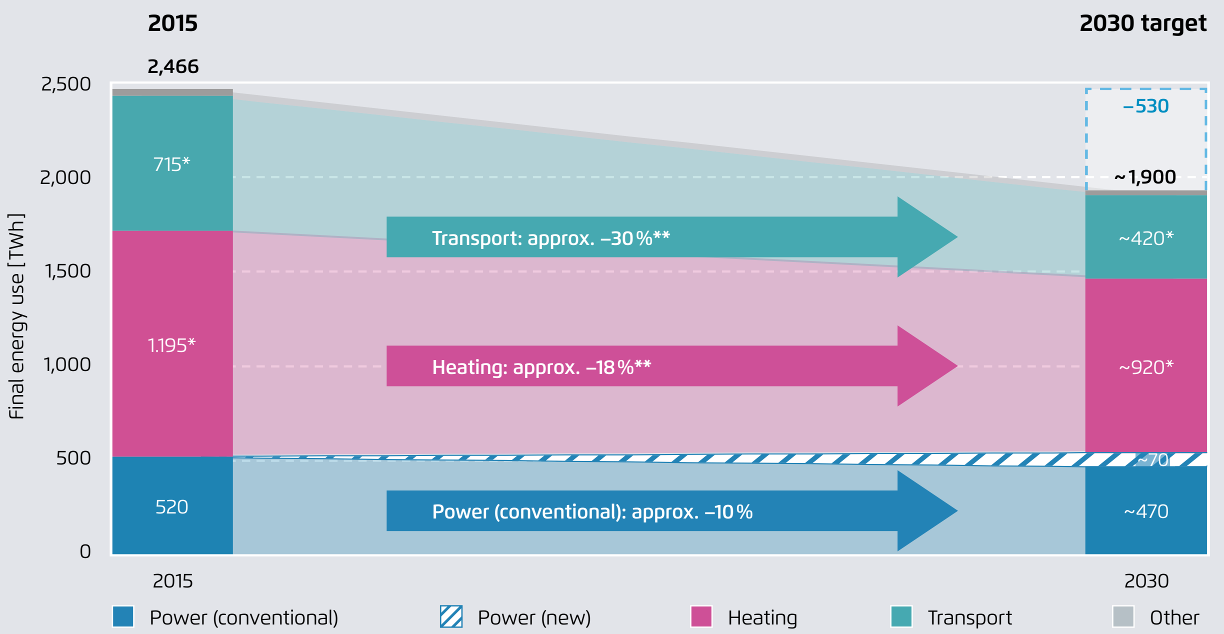
In 2030, efficiency will be combines with flexibility to what is known as flex-efficiency. For in a renewables-based power system, there's a time element to efficiency: it's most valuable when the supply of wind and solar power are low. Especially additional demand in transport and heating will have to be managed flexibly. Thereby, consumers benefit from low prices when wind and solar power are plentiful while the system as a whole becomes more affordable.

How we get there

To reach these goals, active efficiency policy is needed. Especially so as the the moderate prices for fossil fuels currently being projected will deincentivise investment in efficiency (section 1). Putting *Efficiency First* into practice requires three major steps:

- → Privilege energy efficiency (flex-efficiency respectively) in all planning and investment decisions when doing so leads to lower overall costs than those achieved by other CO_2 avoidance strategies (thereby applying the economic imperative).
- → Legally enshrine 2030 energy efficiency targets for all three sectors and institute effective support measures such as tax write-offs, auctions, guarantee schemes, support programmes and standards.
- → Secure long-term financial support for energy efficiency measures. We propose that 5 billion euros per year be set aside for this purpose.

Rigorous application of the *Efficiency First* principle will significantly decrease final energy use in all sectors by 2030 — Figure 20



*Not including power share **Including power share
Final energy use in heating and transport are given here without power share. Electricity in the heating/cooling sector in 2015 amounted to 178 TWh and by 2030 is expected to reach 200 TWh. Electricity in the transport sector was 12 Twh in 2015 and should reach 60 TWh by 2030.
AGEB (2016a); calculations based on Agora Energiewende (2016a), BMUB (2016), EWI/Prognos/GWS (2014a) Fraunhofer IWES/IBP 2017 and UBA (2017c)

5.4 Renewables 2030: Use wind and solar power to double the share of renewables by 2030

4) Use wind and solar power to increase the share of renewables to 60 % of the power sector and 30 % of primary energy consumption

Where we are today	→ Between 2000 and 2015, the share of renewables in Germany increased fourfold, nevertheless by 2015 their share in primary energy use was only 13 %. → Wind and solar power have established themselves as the leading renewable technologies – they are affordable and have the greatest potential. → As of 2015, the share of renewables in the energy system varied greatly: 32 % in the power sector, 13 % in the heating and cooling sector and 5 % in the transport sector.
Where we want to be in 2030	→ An energy system with renewables at its core, making up 60 % of power consumption and 30 % of primary energy use. → Wind and solar are leading technologies not only for power but also for heating and transport. In addition, CO_2 pricing must be sufficient to ensure that wind and solar are competitive, provide system services and contribute to the stability of the power grid. → Rising shares of wind and solar power-based synthetic fuels in petrol, diesel, heating oil and natural gas.
How we get there	→ Adjust 2030 targets in the EEG to 60 % so that new power demand in the heating and transport sectors can be covered with carbon-neutral energy. → Set new targets for added capacity in the EEG: 2.5 GW net annually for wind onshore; 20 GW by 2030 for wind offshore; 2.5 GW net annual for PV. → Add *power-to-gas* and *power-to-liquid* to natural gas, heating oil, petrol and diesel.

Where we are today

Today renewables are a permanent part of the power mix. Between 2000 and 2025 their share in primary energy consumption rose from 3 to 13 %.[60] Nevertheless, their presence varies greatly across the energy system: renewables have a 32 % share in the power sector, a 13 % share in the heating and cooling sector and a 5 % share in the transport sector.[61]

Wind and solar power are the most affordable, carbon-neutral energy sources available and have the greatest potential for expansion. All other alternative technologies – nuclear energy, carbon capture and storage, additional renewable power sources – are either too expensive or have limited availability, or both. In Germany's most recent auctions for wind power (onshore and offshore) and solar power, the winning bids were between 5 and 6 cents per kilowatt hour.

Where we want to be in 2030

By 2030, renewables need to be the leading technologies in the energy system. Their share in total primary energy consumption must be at least 30 %, their share in power consumption 60 %, their share in heat consumption 30 %, and their share in transport 15 %.

In this future, the generation costs of wind and solar power will be 3 to 5 cents per kilowatt hour, making them extremely affordable and competitive on the power market, given adequate CO_2 pricing. Combined with battery storage, renewables will increasingly be responsible for system services. By 2030, wind and solar power will make up 50 % of power generation and will supply energy to the heating and transport sectors by means of heat pumps, power-to-heat plants and electric vehicles. Wind and solar power will be supplemented by added capacities of solar heat and geothermal energy. In areas where wind and solar power cannot be used directly (aviation, ship traffic, parts of truck transport, high temperature processes in the industrial sector and CHP plants), carbon-neutral synthetic fuels from renewable electricity will play a central, and successively larger, role.

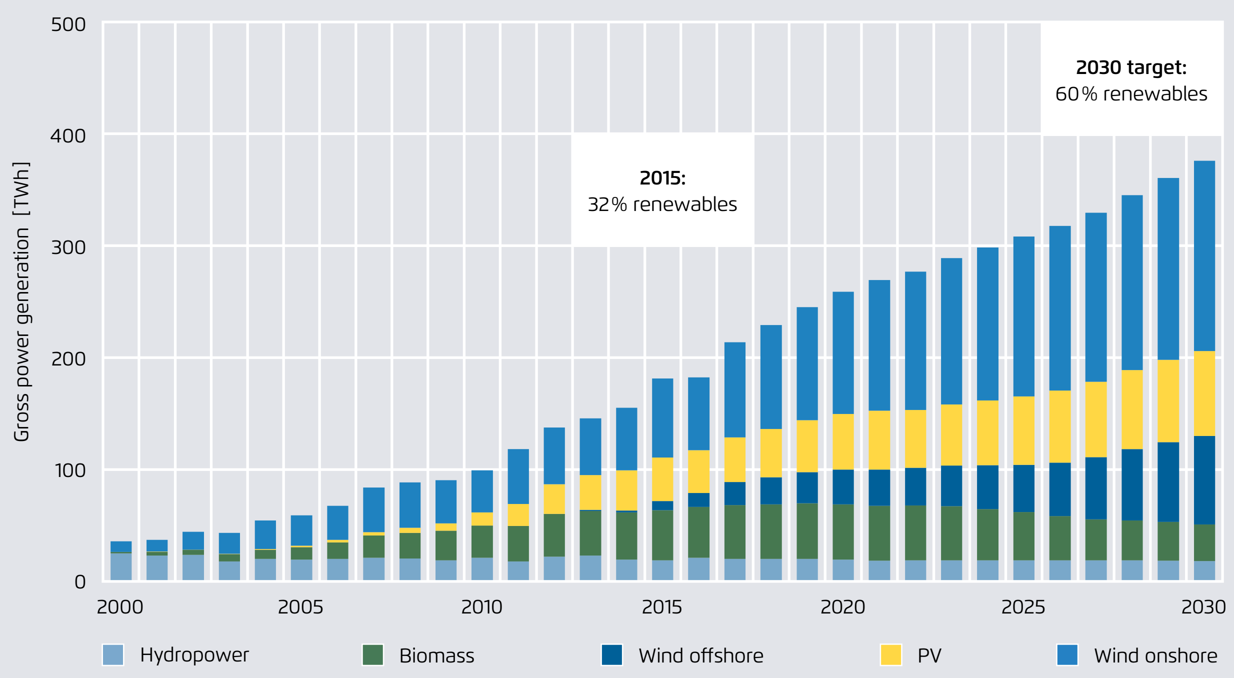
How we get there

The renewables target in the EEG must be increased to 60 % so that additional power demand in the heating and transport sectors can be covered with carbon-neutral energy. This means raising the annual net added capacity to 2.5 GW for both onshore wind and PV. By 2030, offshore wind farms should have a capacity of 20 GW.[62]

To increase the share of renewables in the heating sector, Germany needs to launch a nationwide program that converts its heating networks to low-temperature grids with gradually rising levels of renewables. Moreover, a nationwide rollout of electric cars and heat pumps (either in pure form or as hybrid systems with fossil fuel-fired boilers). To further reduce carbon emissions, conventional fuels must be gradually combined with PtG and PtL energy. These carbon-neutral synthetic fuels must either be produced in Germany or imported from abroad.

With wind and solar leading the way, the share of renewables in the power sector can roughly be doubled by 2030

Figure 21



AGEB (2017b); calculations by Agora, based on Öko-Institut (2017a)

5.5 Fossil Fuels 2030: Halving coal and oil use, introducing power-to-gas and power-to-liquid

5) Cut carbon-intense coal and oil, and introduce carbon-neutral synthetic fuels	
Where we are today	→ Over 80 % of emissions in the power sector are attributable to lignite- and hard coal-fired power plants. → Emissions in the heating sector are as follows: 23 % from coal, 28 % from oil and 44 % from natural gas. → The transport sector is almost completely dependent on petroleum. 99 % of the sector's emissions come from petrol and diesel.
Where we want to be in 2030	→ A 60 % reduction of energy-related greenhouse gas emissions relative to 1990 levels, which translates into a 50 % reduction of coal and oil use relative to 2015 levels. → A more efficient energy system with a greater share of wind and solar and a lower share of coal and petroleum thanks to, amongst other things, green retrofits of 50 % of buildings, fewer cars running on diesel and petrol, 10 to 12 million electric vehicles on the roads and 5 to 6 million heat pumps. → Larger market shares of carbon-neutral synthetic fuels (power-to-liquid and power-to-gas), which compete alongside petrol, diesel, heating oil and natural gas.
How we get there	→ Deploy an intelligent mix of instruments – CO_2 pricing, standards, subsidies and quotas. → On the basis of a broad political consensus, adopt policies in 2018 that (a) reduce coal use by 50 % by 2030, (b) provide a regulatory roadmap for shutting down fossil-fired power plants (3 GW per year) and open-pit mining and (c) that extend aid to regions affected by the coal phase-out. → On the basis of a broad political consensus, adopt policies in 2020 that reduce oil use by 50 % by 2030, that launch electric vehicle and heat pump initiatives and that devise a market strategy for synthetic fuels produced from renewable power.

Where we are today

Burning fossil fuels produces greenhouse gas emissions. Lignite and hard coal are the most carbon emitting energy sources, followed by petroleum. In 2015, coal was responsible for 82 % of greenhouse gas emissions in the power sector; coal and petroleum produced 51 % of emissions in the heating sector; and 99 % of emissions in the transport sector were attributable to petroleum.[63] Of these energy sources, only lignite plays a significant role in Germany's domestic economy.[64]

Where we want to be in 2030

Dramatically reducing the most carbon-intense forms of energy is a logical step for any climate policy that is sensitive to costs considering that carbon capture and storage is far more expensive than efficiency and renewable energy. The goal for 2030 is therefore to reduce coal and petroleum use by 50 % relative to 2015 levels. This would be halfway towards the elimination of coal in the power sector, two-thirds towards the elimination of petroleum in the heating sector and 40 % towards the elimination of petroleum in the transport sector. Due to natural gas's importance as a bridge technology until 2030, it will continue to play a substantial role in the power and heating sector and will therefore be reduced less.

Achieving this will require massive increases in energy efficiency and the electrification of much of the heating and transport sectors using wind and solar power. By 2030, there should be 10 to 12 million electric vehicles on German roads and 5 to 6 million heat pumps in its private households (only half of which will use hybrid systems with gas- or oil-fired back-up boilers).

By 2030, synthetic fuels produced from renewable power must be a significant source of energy in the power system. Their main applications will include high-temperature processes in the industrial sector, in aviation and in parts of the truck transport sector. Synthetic fuels will either be produced by specially built offshore wind farms or imported from abroad.

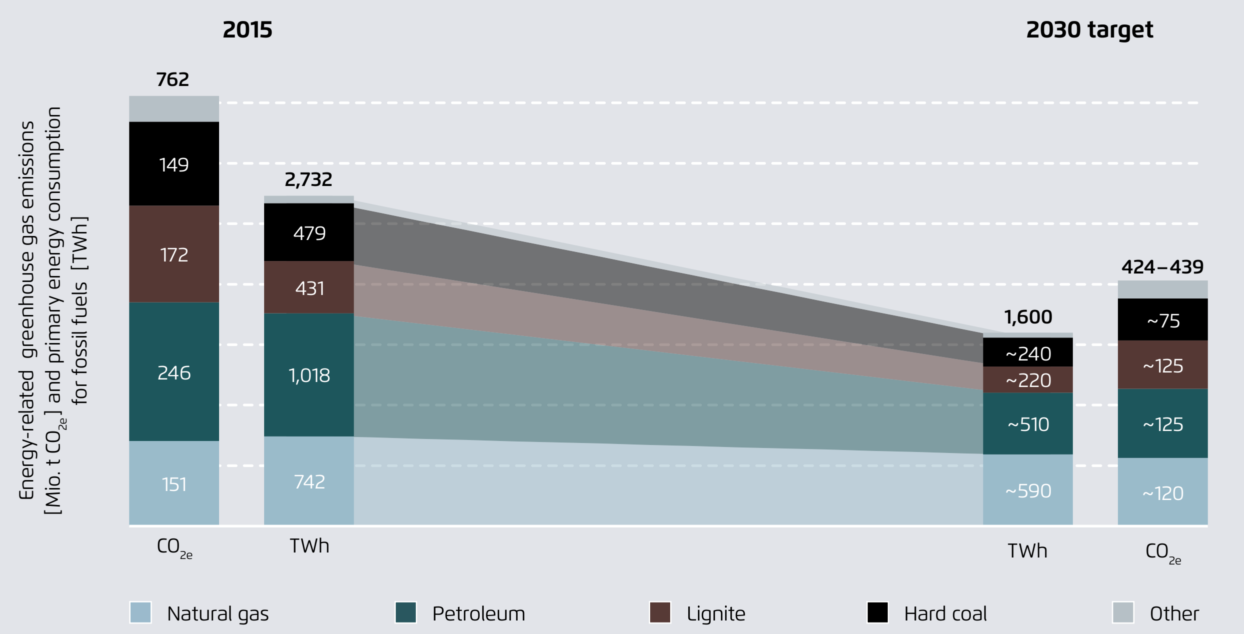
How we get there

A reform of CO_2 pricing is an essential part of an efficient 2030 strategy. (For more on this topic, see the next point on the agenda.) The reform needs to be accompanied by renewable energy and energy efficiency auctions, tax write-offs, regulations (e.g. on energy in buildings or CO_2 emissions of passenger cars and trucks) and quotas for adding synthetic fuels (e.g. to heating oil, natural gas, diesel and kerosene).

Moreover, the German government should hold a round table discussion in 2018 on phasing out coal. Together with all impacted stakeholders, they must reach a consensus on a gradual and socially responsible closure of lignite mines and coal-fired power plants. A similar consensus must be reached in 2020 for oil and natural gas in the heating and transport sectors. Among other things, the German government must send clear signals to the automobile and heating industries about future strategies for electrification and the introduction of carbon-neutral synthetic fuels.

If 2030 is to see a 60% reduction of energy-related greenhouse gas emissions from 1990 levels, today's coal and oil use must be cut in half

Figure 22



AGEB (2017a), UBA (2017a); calculations by Agora, based on EWI/Prognos/GWS (2014a)

5.6 Energy prices 2030: Reforming energy price components to achieve adequate CO_2 pricing

6) Reform taxes, levies, surcharges and network tariffs	
Where we are today	→ Germany's historical development of levies and surcharges, have left Germany with the second-highest electricity prices in Europe. → Its heating oil is relatively inexpensive compared to the rest of Europe, while its natural gas, petrol and diesel prices are about average. → These price distortions have prevented effective climate action across the power, heating and transport sectors. → Network tariffs in Germany vary greatly from region to region.
Where we want to be in 2030	→ CO_2 is adequately priced in the power, heating and transport sectors, making electricity consumption more affordable and fossil fuels more expensive. → Taxes, levies, surcharges and tariffs have been completely restructured, allowing for the most affordable climate action option to be considered in each sector.
How we get there	→ Introduce a minimum CO_2 price in the EU Emissions Trading System. → Harmonise climate-related levies (EEG/CHP surcharges, as well as environmental taxes on electricity, heating oil, natural gas, petrol and diesel) across sectors to reflect their CO_2 content. → Restructure network tariffs to attribute network costs according to their root cause. → Implement a revenue-neutral reform of taxes relevant to the transport and heating sectors (vehicle tax, company car tax, property tax, land transfer tax) based on carbon emissions.

Where we are today

Germany's historically developed system of energy taxes, levies and surcharges is a crucial obstacle for a cost-efficient energy transition. The taxes, levies and surcharges on power consumption are high, while those on petrol and diesel are moderate and those on heating oil are minimal. Consequently, Germany has the second-highest electricity prices in Europe, average prices for diesel, petrol and natural gas and prices in the lower tertile for heating oil.

The most economically effective strategy for climate action – uniform CO_2 pricing – is therefore not realized. This leads to very high prices for household wind and solar power, while fossil fuels remain barely taxed and therefore inexpensive. Moreover, Germany's current system of levies, surcharges and network tariffs prevents power consumers from responding flexibly to the amount of wind and solar power in the grid. Instead, rooftop PV systems are increasingly financed through exemptions of state-imposed energy taxes. And network tariffs in areas where the power grid is undergoing expansion are the highest, since network costs can only be passed on within regions.

Where we want to be in 2030

The goal for 2030 is to have a uniform CO_2 price across all sectors. Price competition will determine the most efficient technology for mitigating climate change in each sector. Consequently, energy demand will increasingly be covered by renewables while electricity will become more affordable and fossil fuels more expensive.

Energy levies, surcharges and tariffs should be designed in ways which distort the price signals of the spot price of electricity. This will reward flexibility in power consumption so that demand increases in times of high wind and solar power production and decreases when it is low.

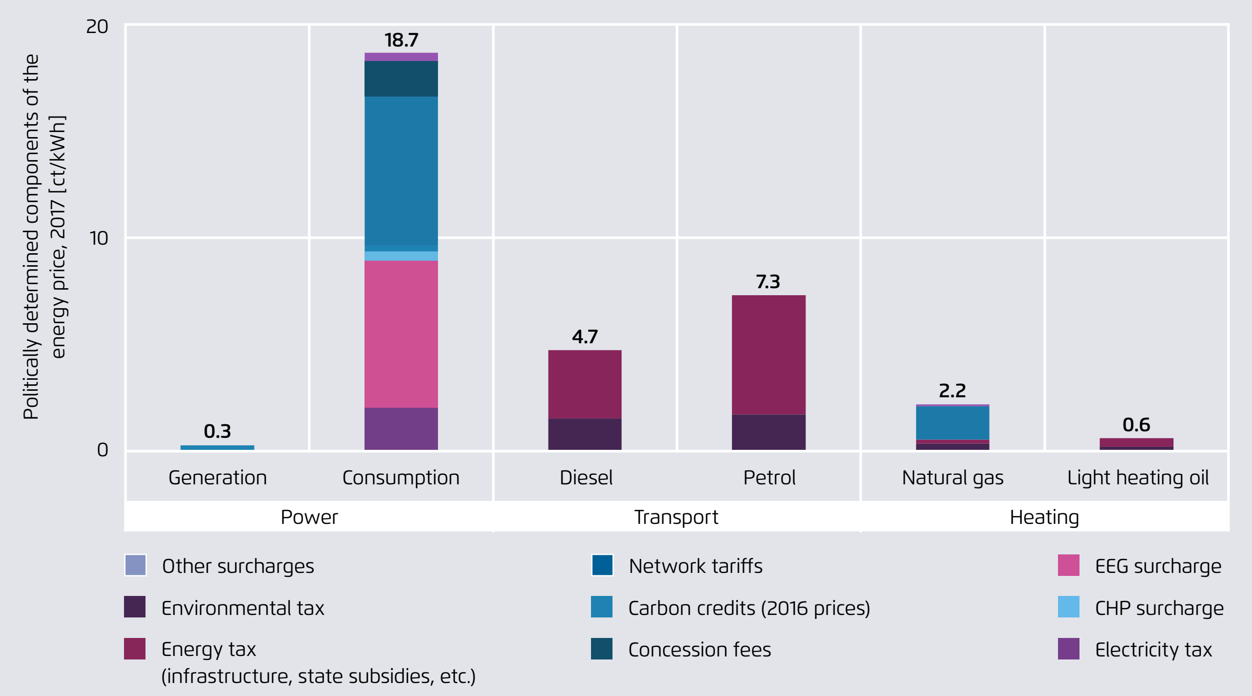
How we get there

A fundamental reform of Germany's energy taxes, levies and surcharges is urgently needed. As long as the energy price structure is lopsided, the energy transition is very unlikely to succeed. The most sensible approach would be to base energy taxes, levies and surcharges on carbon emissions. The core steps in such a reform would be as follows:[65]

- → Introduce a minimum CO_2 price in the EU Emissions Trading System.
- → Readjust environmental taxes on power, heating oil, natural gas, petrol and diesel (including EEG and CHP surcharges) based on uniform CO_2 pricing.
- → Restructure network tariffs to attribute network costs according to their root cause.

Changes are also needed to other tax regulations in the heating and transport sectors, such as the power vehicle tax, the company car tax, the land transfer tax and the property tax. These taxes must be subject to a revenue-neutral reform based on carbon emissions that will help transform the heating and transport sectors towards sustainability.

Taxes, levies, surcharges and tariffs in the energy sector are distributed very unevenly, with the majority falling on power consumption — Figure 23



Agora Energiewende (2017a)

5.7 Networks 2030: Expand and modernise power, heating and transport networks

7) Build new power grids, modernise heating and gas networks and electrify the transport sector	
Where we are today	→ The German electricity grid and the power market follow the "copper plate" principle and are organized in a single bidding-zone. Electricity prices are the same throughout Germany and don't take into account bottleknecks in the grid. → The expansion of the power grid has encountered much local resistance, slowing its progress. Of the planned 7,700 kilometres of new transmission lines, only 1,400 kilometres have been approved and only 850 kilometres have been built. → Gas and heating networks have yet to be significantly impacted by the energy transition and continue to largely be planned with fossil fuels in mind. → The transport system has yet to receive adequate electrical infrastructure.
Where we want to be in 2030	→ A target network for 2050 is being developed that builds on the already decided network expansion, but without adding new overhead power lines. → Low temperature heating networks absorb the ever-rising shares of renewable heat.Lower demand for heating and rising shares of power-to-gas are reflected in gas network planning. → The infrastructure for more rail transport and electric vehicles has been built.
How we get there	→ Amend legislation on the expansion of the power grid to reflect the 2050 target network, the introduction of innovative grid management and the establishment of regional smart markets. → Implement municipal heating strategies for 2050 across Germany that prepare heating and gas networks for falling heating demand and the introduction of low-carbon technologies. → Expand the electrification of the rail system, construct a nationwide charging infrastructure for electric vehicles and install overhead lines for hybrid trucks along central motorways.

Where we are today

Germany's power system follows the "copper plate" principle. This principle assumes a uniform domestic power market and ignores regional bottlenecks.
It's meant to minimise power system costs. But the assumption of a uniform domestic market, coupled with the fact that almost all of Germany's new wind power capacity is in the North, requires an expanded transmission network. The problem is that network expansion projects have encountered public resistance – of the planned 7,700 kilometres of new transmission lines, only 850 kilometres have been built. Similar controversies have yet to arise for heating and gas networks, which continue to be based on fossil-fired power plants and imported natural gas, with low shares of renewables. Likewise, policy-makers have devoted scarce thought to what infrastructure will be needed for transforming the transport system towards sustainability.

Where we want to be in 2030

By 2030, the planned expansions of the transmission grid must be completed. In addition, a power grid design must be developed for 2050 that eliminates new overhead power lines and abandons the "copper plate" principle. The new system will include innovative network management, increased capacity for existing power lines and regional smart markets for handling electricity transmission of renewables (whose share will have increased from 60 to 90 %).[66]
In designing a decarbonised heating infrastructure, the heating system must have low-temperature

networks that incorporate many low-carbon heat sources (solar, geothermal, large-scale heating pumps, electrode boilers, biomass facilities, waste heat). Gas networks must be redesigned for declining heating demand and increasing power-to-gas shares.

In 2030, the transport system should have a high and ever-increasing level of electrification. Railways will be expanded and electrified, infrastructure will exist for 10 to 12 million electric vehicles and overhead power lines for hybrid trucks along Germany's main motorways will frequently be used.

How we get there

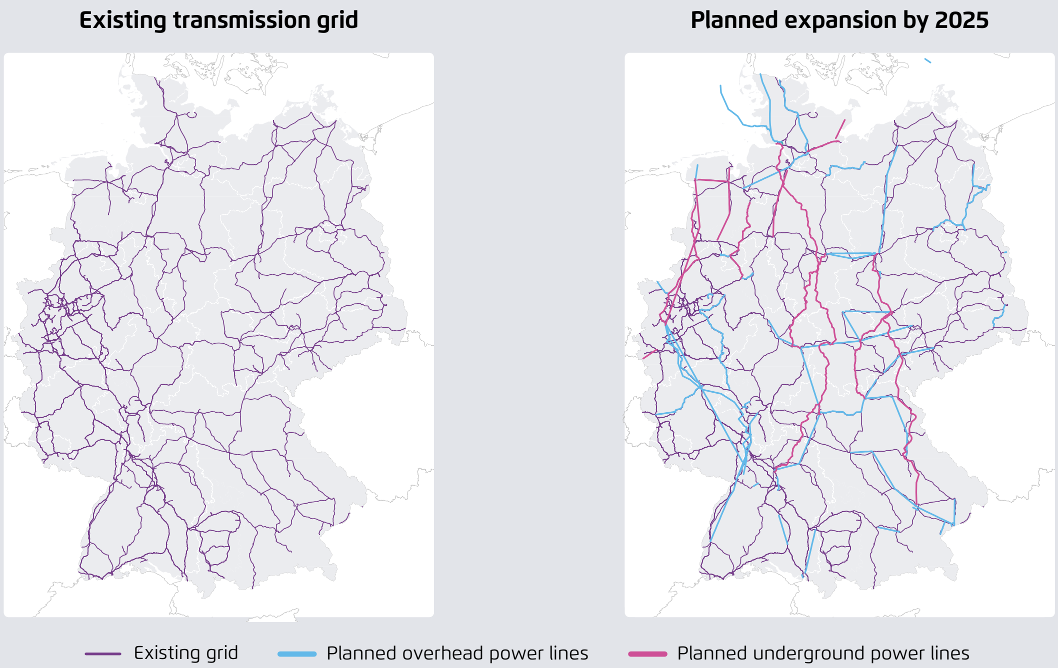
The current process of designing expansion plans for transmission lines every two years must be abandoned in favour of planning and working towards a target grid 2050. In addition, automated system management needs to be established as a standard by 2030, and power market design must include regional smart markets.

Moreover, municipalities, with the financial support of the federal government, should develop heating strategies for 2050. These strategies will plan heating and gas networks for a future of declining heat demand and ever-rising shares of renewables.

Germany's 2030 Plan for Federal Traffic Routes must be revised to reflect a sustainable transport strategy. This new strategy should prioritise investment for the expansion and electrification of the rail system, the construction of a charging infrastructure for electric cars and the installation of overhead power lines for hybrid trucks.

Around 7,700 km of new power lines are to be built by 2025 – yet progress has been sluggish

Figure 24



Figures based on BNetzA (2016), Tennet (2017), Tennet (2017) and TransnetBW (2017)

5.8 Power market 2030: Digitalisation, flexibility and a reliable investment framework

8) Organise a flexible, digital power market that incentivises investment	
Where we are today	→ Today's power market 2.0 is characterised by a liquid electricity exchange and a competition between many providers and products. However, balancing energy and flexibility are mostly supplied by fossil fuel-fired power plants. → Renewables are financed by means of auctions as specified in the EEG; back-up power plants are to be refinanced on the power market through peak prices. → Security of supply is very high.
Where we want to be in 2030	→ The power market is digitalised and can adapt to changes in supply or demand at a moment's notice. All energy providers and consumers are networked, delivering both flexibility and balancing energy. → Renewable energy, back-up power plants, electricity storage and demand side management are primarily financed by means of the power market. → The power supply is as secure as it is today.
How we get there	→ Fully digitalise the German power sector, including through the introduction of smart meters and variable electricity tariffs. → Reform the system of levies, surcharges and balancing energy so that demand and storage can flexibly respond to the market. → Ensure that the CO_2 price is at least 30–50 EUR/t to create a market-driven expansion of renewable energy. → Introduce capacity auctions to safeguard renewable expansion targets. → Security of supply is guaranteed by a capacity reserve, which is only replaced by a capacity market if it becomes too large (>15 GW).

Where we are today

Today's power market is shaped by a liquid electricity exchange. Consumers can choose from a variety of electricity providers. But in its essential respects, the power market is outdated. Flexibility is provided almost exclusively by coal- and gas-fired power plants, renewable energy installations receive fixed tariffs, and most power consumers are unable to respond flexibly to price fluctuations on the power exchange.

The redesign of the power market in 2016 was a response to this situation.[67] The new regulation introduced auctions to promote renewable installations. Power traders are now subject to high penalties (20,000 euros per megawatt hour) if they are unable to cover electricity demand. The redesign also provided a capacity reserve to eliminate risks to security of supply. And starting in 2017, all households will gradually receive smart meters.

Where we want to be in 2030

By 2030, 50 % of power production will come from wind and solar sources. In this scenario, the power market must be able to balance fluctuating levels of supply and demand by the minute. And precise billing and price models will be needed linking providers, consumers and storage batteries. Proactive electricity providers will offer customers individual solutions that, depending on the situation (rooftop solar, electric car, heat pumps, battery storage), optimise price, residential power generation levels and comfort. In this flexible power market, renewables, back-up power plants, battery storage and demand side management will mostly be financed by the market. Government interventions will be reduced to a minimum to ensure that CO_2 targets are reached and security of supply is kept stable.

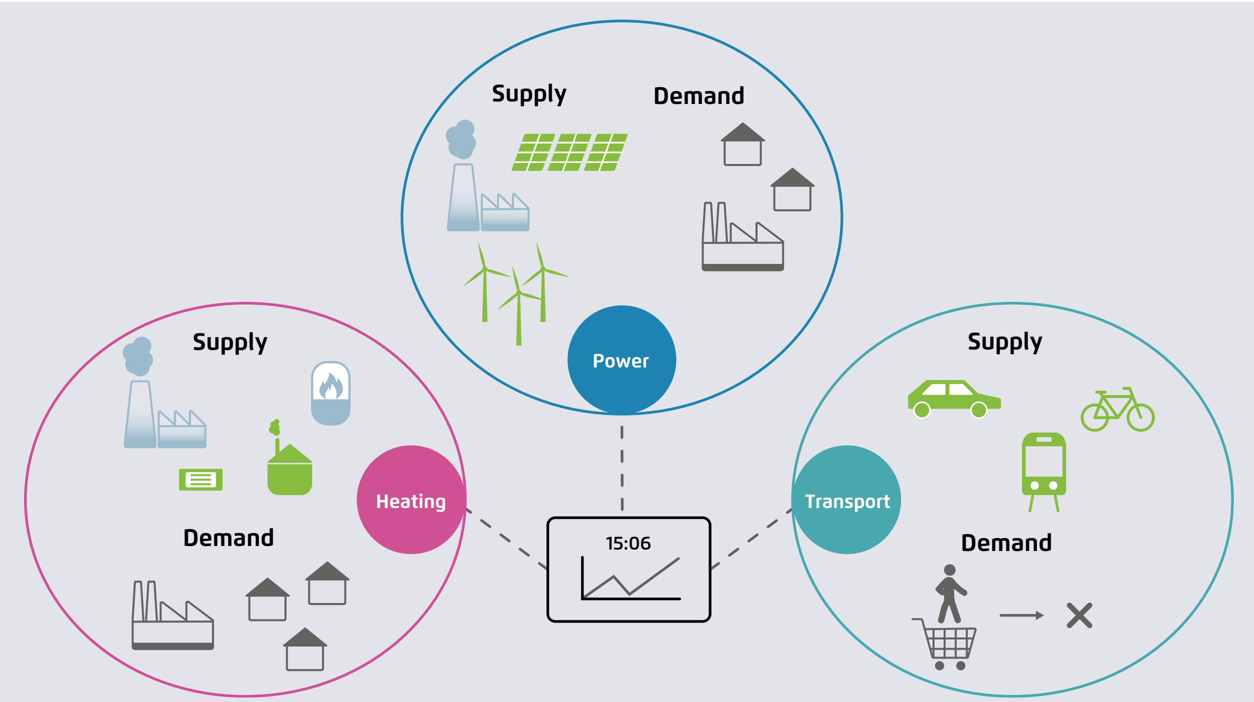
How we get there

The following steps must be taken so that power supply and demand can be balanced by the minute and investments can flow into new power plants:

- → Introduce smart meters and variable electricity tariffs across Germany. By 2030, all consumers with variable demand (industrial operations and private households with heat pumps, PV storage systems, electric cars) will have to respond flexibly to the market with minute-by-minute power pricing. It is also crucial that levies and surcharges do not distort the flexibility signals sent by the power network.
- → Introduce adequate CO_2 pricing to support a 50 % reduction of coal consumption in the power sector by 2030 and to enable renewable installations to compete with existing coal- and gas-fired power plants when prices for fossil fuels drop.[68] The compensation paid to owners of renewable energy plants should no longer be based on kilowatt hours, but on kilowatt premiums to optimise the deployment of renewables in the power and balancing energy markets.
- → If the power system does not regularly produce peak prices for refinancing back-up power plants and battery storage, then those power plants should be shut down and placed in the capacity reserve. If the capacity reserve becomes too large (>15 gigawatt, say), then it makes sense to replace the capacity reserve by a capacity market, unless doing so undermines the coal phase-out.

The cost-efficient power market of 2030 is digital and flexible and provides a high degree of security of supply

Figure 25



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5.9 Industry 2030: The energy transition as a programme of industrial modernisation

9) Use opportunities, minimise risks: introduce a forward-looking industry policy for the energy transition	
Where we are today	→ German industry is internationally competitive. The same applies to its energy costs thanks to industrial exemptions. → Much of the industrial sector is uncertain about what the energy transition will bring and the continued existence of the exemptions. → The automobile industry faces strong global competition on the emerging electric vehicle market. → Worldwide, twice as much is being invested in renewables as in fossil energies.
Where we want to be in 2030	→ German industry is internationally competitive – especially with regard to energy costs and security of supply – despite a 60 % share of renewables in the power sector. → Modern production processes use flex-efficiency. → German industry uses the growth opportunities offered by the energy and transport transition and the global transformation of energy and automobile markets.
How we get there	→ The federal government and the private sector agree on a "Future Pact for Energy Transition and Industrial Policy". The pact will obligate the industrial sector to acknowledge Germany's climate targets and support its climate policy. In return, the German government will ensure that energy costs in Germany remain competitive. → Institute targeted incentives to make production processes more efficient and flexible; create a joint research agenda to ensure the necessary innovation and investments in the German industrial sector. → "Energy Transition Made in Germany" becomes the brand essence of an export promotion offensive.

Where we are today

In the past 15 years, the share of renewables in Germany's power supply rose from 6 % to over 30 % as industrial output grew by 25 %. Thus, energy transition and industrial development have generally followed the same upward trajectory. This is due to competitive German wholesale prices and thanks to the fact that sufficient exemptions have been made for industries from energy taxes, levies and surcharges.

Some of Germany's industrial sector is sceptical about the energy transition. The main cause is uncertainty about whether the exemptions will survive multiple legislative periods. This uncertainty can impede investment and delay the energy transition.

The risk is that the German industry might not be able to keep up with the continually growing market for products aiding the energy and the transport transition. In 2015, the worldwide investment in renewables totalled 260 billion U.S. dollars – double as much as in new fossil-fired power plants. A similar development is imminent in the electric vehicles sector.

Where we want to be in 2030

The 2030 goal is to ensure that the German industrial sector remains competitive – low energy costs, stable security of supply – despite a 60 % share of renewables in the power sector. In this scenario, the industrial sector will have modern production plants based on flex-efficiency – a combination of low energy use and flexible operation.[69] Moreover, the German economy will take advantage of the many growth opportunities afforded by the energy and transport transition. The automobile industry in particular will have mastered the challenges associated with transport transformation and offer globally successful low-carbon vehicles and mobility services.

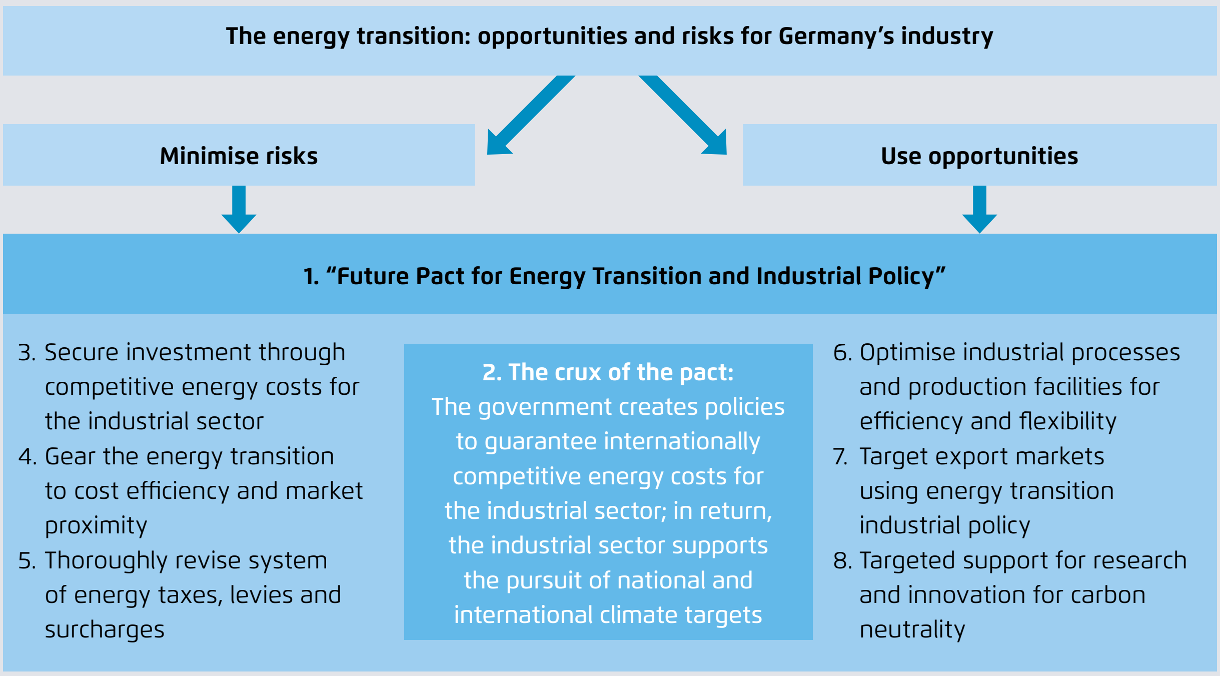
How we get there

The federal government and the private sector must agree on a "Future Pact for Energy Transition and Industrial Policy" that uses the chances of the energy transition and avoids its risks.[70] This requires the federal government to guarantee competitive energy prices for German industry, especially the energy-intensive branches, during the energy transition. It also requires German industry to embrace the Paris Agreement and support the 2030, 2040 and 2050 climate targets identified by the German federal government and approved by the Bundestag.

The federal government and the private sector must also come up with a plan to secure the Germany economy a strong position in the world's growing clean-energy market. Among other things, this plan should identify the basic elements of "Future Pact Energy Transition and Industrial Policy", push for more efficiency and flexibility in new production facilities, develop a research agenda for low-carbon technologies in the industrial sector and launch an export offensive under the slogan "Energy Transition Made in Germany."

A charter to make energy transition industrial policy a success

Figure 26



Agora Energiewende/Roland Berger (2017)

5.10 Using the *Energiewende* to strengthen communities

10) Make the energy transition a collective endeavour	
Where we are today	→ The energy transition in the power sector enjoys wide public support in Germany. But similar transitions in the heating and transport sectors have yet to generate the same level of consensus. → The diversity of actors participating in the energy transition and number of innovative concepts in the power, heating and transport sectors have increased significantly. → After rising for years, energy costs for private households have been falling again since 2013. → The numerous wind turbines and solar parks dotting Germany's landscape are impossible to miss and have become a thorn in the side of many.
Where we want to be in 2030	→ The energy transition, and therefore the transition in the power, heating and transport sectors, has wide support and helps to create value for the local economy. → A wide diversity of actors is maintained, while municipal utility companies become service providers in a cross-sectoral energy transition at the communal level. → Energy costs remain affordable for private households, particularly for those with lower incomes. → Local conflict related to the impact of transmission lines and wind turbines on the landscape is held to a minimal level.
How we get there	→ Place more value on participant diversity, prosumer solutions and local power generation and use. → Reform energy levies and surcharges; increase efficiency with a focus on low-income households. → Public participation in the development of network infrastructure and wind farms is ensured in clever ways; municipalities share in the financial benefits of the Energiewende through concession revenues from new wind farms.

Where we are today

A vast majority of Germans support the energy transition. Since 2012, 90 % of the respondents to annual surveys have rated the energy transition as "important" or "very important." Notably, many individuals participate in the energy transition through rooftop PV systems, through citizen energy company or indirectly through municipal utility companies.

At the same time, the new power lines and wind farms that have been cropping up in the countryside trigger regular local protests. Moreover, the energy transition is often exclusively associated with the transition in the power sector. The awareness that changes are also necessary in the heating and transport sectors has yet to catch on.

Where we want to be in 2030

By 2030, the energy transition must be a joint effort of the entire society and encompass the power, heating and transport sectors. Proximity of the new energy system to people will be used to boost local economies. Rooftop PV systems should be standard on single-family homes and apartment buildings. New mobility concepts that use intelligent technology to combine public and private forms of transportation will make urban transport quieter and more comfortable.

In 2030, there will be a variety of participants – private citizens, innovative start-ups, municipal utility companies – that contribute to a networked and cross-sector energy supply and add local economic value in doing so. Energy costs continue to make up less than 10 % of consumer spending. And low-income households will pay no more than 10 % of their income on power and heating. Public participation in the development of network infrastructure and wind farms is ensured in clever ways.

How we get there

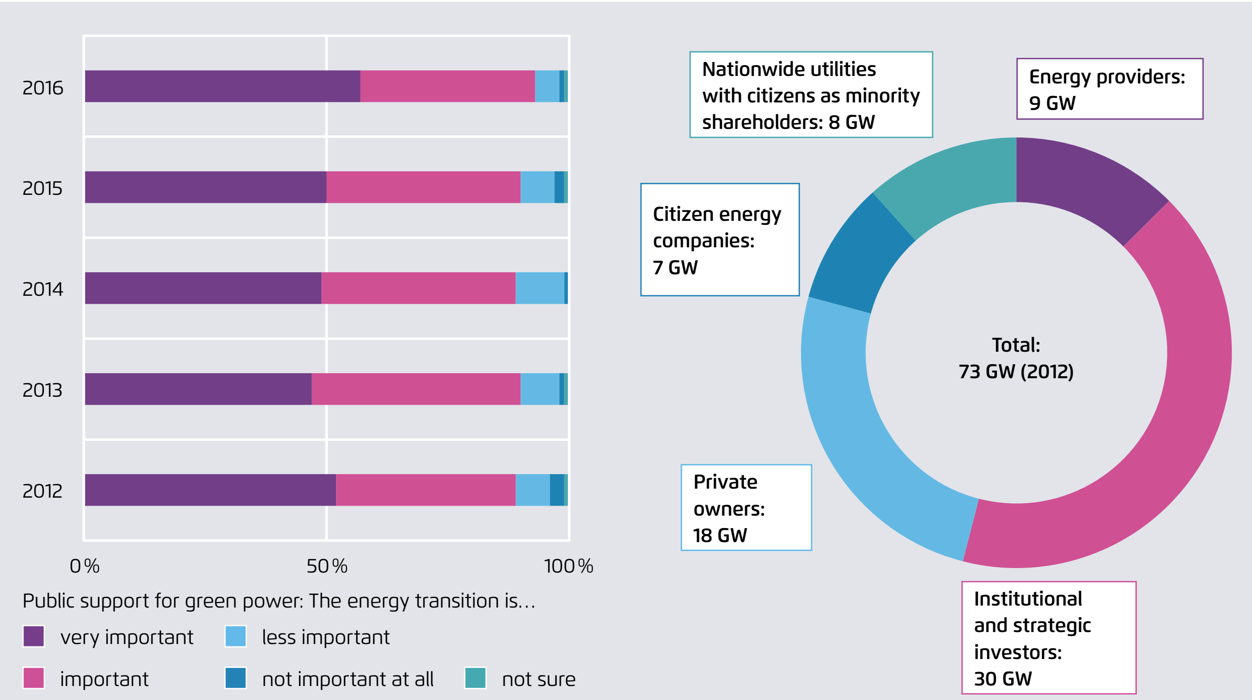
Three measures are necessary to ensure that the energy transition is a joint effort of the entire society:

→ Place more importance on participant diversity and on-site generation when developing energy and transport legislation. Therefore, a clear regulatory framework needs to be introduced to encourage rooftop PV systems, tenant electricity models and shared-mobility concepts. Municipal utilities should serve as local energy transition service providers for power networks, district heating and public transport.

→ Reform the energy levies and surcharges to lower energy costs for consumers, and finance some of the cost elements from state budgets. In addition, introduce special efficiency programmes to decrease energy demand in low-income households.

→ Reform public participation in new wind farms and power networks to allow local municipalities to actively participate in planning and approval processes. In addition, introduce concession fees for wind farms that boosts municipal economies.

The energy transition continues to enjoy broad support among Germans – many of whom participate directly with their own power plants — Figure 27



BDEW (2016), trend:research & Leuphana Universität Lüneburg (2013)

Conclusion

Today, the transition away from coal, petroleum and natural gas and towards renewable energy and energy efficiency has become a global trend that continues to gather momentum. Around 60 % of the world's newly installed power capacity is now renewable energy (figure 28). There is almost monthly news of wind and solar projects across the globe being realised at record-low prices (figure 29).

Germany sees itself as a pioneer in energy transition and climate protection. Having already completed the first phase of the energy transition, it does indeed have a leg up on many other countries as it embarks on the second phase of the energy transition. But some nations are quickly closing the gap in new renewable capacity. When it comes to electric vehicles, Germany is rather a laggard than a leader. This is why it's all the more important that Germany make the most of its current lead, both for the sake of its own energy transition and for the sake of the global energy transition. The second phase of the energy transition, which extends through 2030, will be both easier and harder than the first phase (2000 to 2015). It will be easier because the megatrends of the energy transitions – the seven D's described in section 1 – make the technological and economic framework for energy policy relatively predictable. Wind and solar power have emerged as the leading renewable energy technologies. They are the most affordable carbon-free energy sources, and in many regions of the world they are less expensive than coal, oil and natural gas. Hence, wind and solar power must become the primary sources of energy not just for the power sector but also for heating and transport – either directly in real time or indirectly via battery storage and power-to-X technologies. Decentralisation, digitalisation and democratisation will be other central factors in the energy economy of the future.

Since 2013, more renewable energy capacity has been added each year than all conventional technologies combined

Figure 28

IRENA (2015) and FS UNEP (2017)

The second phase of the energy transition is also *more difficult* because it entails the transformation of the energy system. While in past years the increases of renewables could be integrated into the existing energy system with fairly little effort, in the period until 2030 wind and solar power will become the leading technologies of the energy system, covering more than half of supply in the power system. Moreover, energy efficiency, which previously played a secondary role in energy policy, must come to the fore of the energy transition in accordance with the *Efficiency First* principle.

Given these difficulties, it is important to have a clear compass for navigating the coming phase of the energy transition. Agora Energiewende has provided such a compass with its specific target recommendations in environmental sustainability, economic competitiveness and security of supply for 2030: reduce energy-related emissions by 60 % below 1990 levels; ensure energy costs remain below 10 % of spending in the industrial sector and in private households; keep power outages to under 20 minutes per customer per year; and lower the share of primary energy from imports to below 60 % (section 2). We also suggested three strategies for reaching these targets in a cost-efficient manner: increase energy efficiency to lower energy consumption by around 30 % relative to 2015; nearly double use of renewables relative to 2015 (60 % for power, 30 % for primary energy consumption); and cut coal and petroleum use in half relative to 2015 levels (section 3).

Based on the technology available today, alternative measures such as increased use of synthetic fuels will be much more expensive than the measures we suggest. To ensure that its benefits for the German economy outweighs its costs, the energy transition must focus on efficient technology, wind and solar power expansion and the increased electrification of the heating and transport sectors through 2030 (section 4). Finally, research and market launch programmes should soon be introduced to lower the costs of power-to-gas and power-to-liquid technologies, which will play a significant role in the third phase of the energy transition.

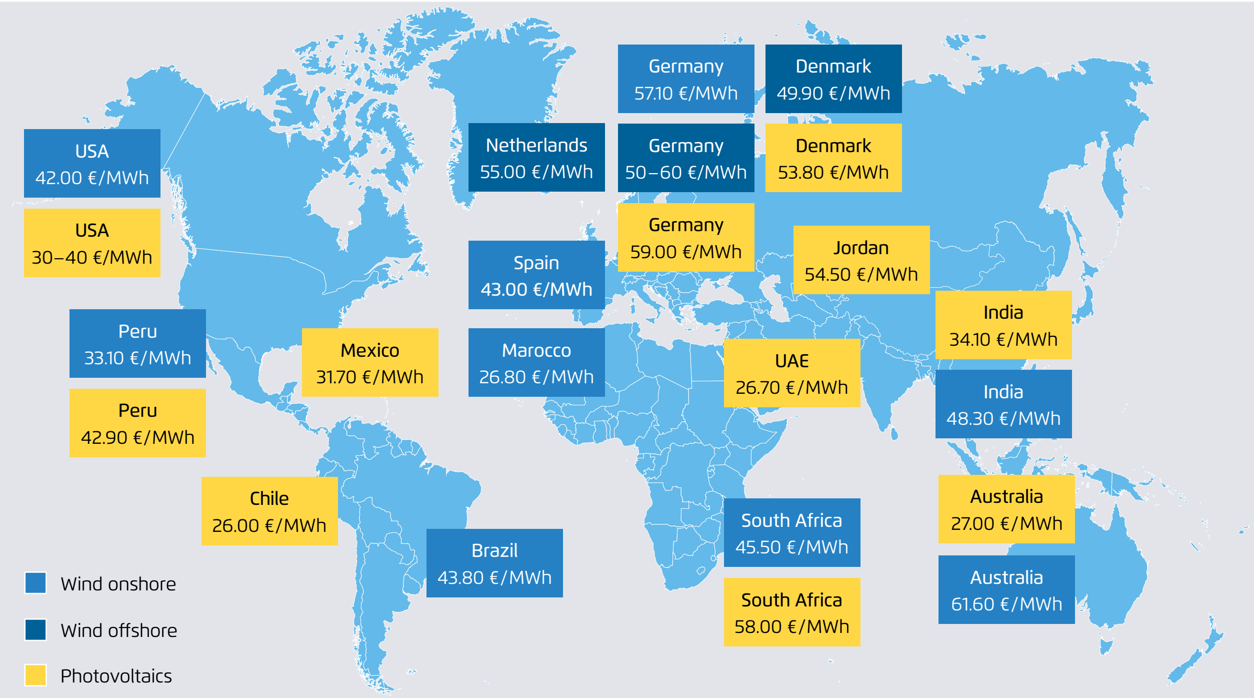
These aims and strategies will implement themselves on their own. The energy transition agenda for 2030 (section 5) describes 10 specific fields of activity in energy policy to make the energy transition a success. They include new and revised legislation (on energy targets, on the expansion of renewables, on energy efficiency), the construction of new infrastructure, reform taxes, levies and surcharges, and create broad-based consensus with impacted regions and industries on the gradual phase-out of coal, petroleum and natural gas. Last but not least, the agenda proposes the creation of green industry policy together with stakeholders from the private sector and from German society, ensuring that the energy transition is a collective endeavour.

The energy transition is not merely a matter of energy policy. It is a vast undertaking that will change people's everyday lives. For instance, wind turbines and new overhead powerlines will alter the appearance of the countryside, often to the chagrin of local residents. New concepts are therefore needed to minimise these incursions and, when they can't be avoided, limit their negative effects by involving the public in decision-making. But the energy transition will also contribute significantly to improving people's quality of life. Electric cars and shared mobility will deliver noticeable improvements to air quality and noise levels, especially in cities. Smart home technologies will optimally manage rooftop PV systems, power and heating supply, heat pump use and the charging of electric cars, supplying residents with a great deal of comfort.

Germans are not known to be particularly optimistic about the future. But when it comes the energy transition, optimism is very much warranted. All the technologies and concepts needed for the second phase of the energy transition are available today. And it is possible to pursue the energy transition through 2030 in a way that benefits industries and individuals as well as the climate. Progress, at any rate, is of utmost importance. The climate continues to change – in 2016 the earth's temperature had already climbed to 1.1° C above preindustrial levels – and German industry faces strong competition in technologies aiding the energy transition.

Though Germany contributes just over 2 % of the world's greenhouse gas emissions, its energy transition remains a yardstick by which many around the world measure their own. For this reason, too, success is not only in Germany's interest. It is also in the interest of other countries, and that of future generations.

The costs of wind and solar power have hit record lows all around the globe — Figure 29



This figure shows the auctions result and power purchase agreements from 2016/2017. See Fortum (2016).
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Appendix

Overview

	2015*	Target value by 2030**
	TWh	TWh
Primary energy consumption	**3,683**	**~ 2,600**
Energy consumption	3,418	~ 2400
Hard coal	479	~ 240
Lignite	431	~ 220
Oil	1,018	~ 510
Natural gas	742	~ 590
Nuclear energy	278	0
Renewables	457	~ 820
Other	61	~ 40
Electricity	–48	0
Non-energy consumption	265	~ 200
Power sector	TWh	TWh
Gross power generation	**647**	**~ 610**
Renewables	187	~ 370
Nuclear energy	92	0
Lignite	155	~ 80
Hard coal	118	~ 60
Natural gas	62	~ 70
Other	34	~ 30
Power consumption	**647**	**~ 610**
Final energy consumption for electricity (traditional)	520	~ 470
Final energy consumption for electricity (new)	0	~ 70
Losses/pumped storage	38	~ 40
Internal power consumption of power plants	36	~ 30
Exports	54	0
Heating sector	TWh	TWh
Final energy consumption	**1,373**	**~ 1,100**

Coal		126	~ 60
Mineral		205	~ 90
Natural gas		588	~ 450
District heating		115	~ 100
Renewables		139	~ 200
Other		21	~ 20
Electricity		178	~ 200
Transport sector		TWh	TWh
Final energy consumption		**727**	**~ 500**
Fossil fuels (including natural gas)		685	~ 410
Biofuels		30	~ 30
Electricity		12	~ 60
Greenhouse gas emissions		Million tons of CO_{2e}	Million tons of CO_{2e}
Energy-related emissions from combustion		**762**	**435 (424–439)**
By energy source	Hard coal (CO_2 only)	149	~ 75
	Lignite (CO_2 only)	172	~ 85
	Oil (CO_2 only)	246	~ 125
	Natural gas (CO_2 only)	151	~ 120
	Other	46	~ 30
By sector	Power	312	~ 165 (159–166)***
	Heating	289	~ 170 (170–175)***
	Transport	161	~ 95 (95–98)***
Non-energy-related emissions		**140**	**~ 130 (119–123)*** **
Total		**902**	**~ 560 (543–562)**

* AGEB (2016a), AGEB (2017a), UBA (2016), UBA (2017a) and UBA (2017b); calculations by Agora based on BMUB (2016), UBA (2017c)

** Calculations based on Agora Energiewende (2016), BMUB (2016), EWI, Prognos & GWS (2014a), Fraunhofer IWES & IBP (2017), UBA (2017a) and UBA (2017c)

*** Values in parentheses represent sector target ranges for electricity, heating and transport that accord with the 2050 Climate Action Plan; calculations by Agora based on BMUB (2016), Öko-Institut & Fraunhofer ISI (2015), UBA (2017a) and UBA (2017c)

Notes

1. Even the zero-cent bids in the offshore wind farm tenders from early 2017 assumed wholesale prices of 5 to 6 cents per kilowatt hour.
2. See Agora Energiewende (2015).
3. See WMO (2017).
4. See McGlade and Ekins (2015).
5. Fixed costs include investment and capital costs as well as operation costs.
6. See Agora Energiewende (2017c).
7. This does not mean that the new energy system will be decentralised in its entirety. Central elements will continue to play a role in generation (e.g. offshore wind farms) and system management (e.g. control rooms).
8. See Öko-Institut & Fraunhofer ISI (2015).
9. Calculations are based on BMUB (2016) and Öko-Institut & Fraunhofer ISI (2015). They factor in the sector targets for power, buildings, and transport as well as the energy share of the industry sector target.
10. See Statistisches Bundesamt (2016a).
11. See Expertenkommission zum Monitoring-Prozess "Energie der Zukunft" (2016).
12. See BMWi (2017).
13. SAIDI stands for "System Average Interruption Duration Index".
14. See BNetzA (2017).
15. There is debate among experts whether SAIDI is an adequate measure of security of supply. We reference this value here because unplanned power outages are a central problem of supply security, and because other power quality values are likely to correlate positively with SAIDI.
16. For all intents and purposes, power supply security is a common good. A complete privatisation would mean that, in the event of a supply shortage, power would have to be shifted from customers whose utility companies had failed to secure adequate supply – and this is neither technologically feasible nor socially desirable.
17. See consentec & r2b (2015).
18. See Europäischer Rat (2014). As part of its legislative package Clean Energy for All Europeans, the EU Commission proposed in November 2016 that the efficiency target be raised by 30 %.
19. See Knopf et. al (2015) and Europäische Komission (2014).
20. See CE Delft & Microeconomix (2016).
21. Around 7 % of primary energy goes towards materials, mostly as petroleum for the chemical industry.
22. This figure refers to the share of primary energy used for secondary energy. See AGEB (2017a).
23. See UBA (2017a).
24. This figure refers to the share of primary energy used for secondary energy. See AGEB (2017a).
25. Due to the existing interconnections between them, the power, heating and transport sectors cannot be clearly delineated. For instance, a portion of electricity is eventually used for heating and cooling (cooking, warm water, air conditioning, etc.). Data on the size of individual sectors is meant only as a rough estimate.
26. Cf. EWI, Prognos & GWS (2014a), Fraunhofer ISE (2013), Fraunhofer IWES et. al (2015) and Öko-Institut & Fraunhofer ISI (2015).
27. This decreases primary energy use for energy carriers by 29 % and primary energy use for materials around 24 %.
28. Calculations are based on BMUB (2016), Öko-Institut & Fraunhofer ISI (2015) and UBA (2017c).
29. See Prognos & IAEW (2015).
30. The heating sector covers all final energy used for households, for business, trade and services, for industry and transport, for space heating, for process heat and refrigeration, for air conditioning and for district heating.
31. See AGEB (2016a). Of this, electricity supplies 178 terawatt hours.
32. Alongside heating facility modernisation, the expansion of district heating and the accompanying shift of emissions from the housing to the energy sector also play a role here.
33. Following AGEE-Stat (2017), the renewable share of electricity and electricity use is not factored

into the calculation of renewable's share in the heating and cooling sector.
34. See AGEB (2016a).
35. Calculations based on BMUB (2016) and Öko-Institut & Fraunhofer ISI (2015).
36. See AGEB (2016a). Energy consumption in the transport sector also includes kerosene use for international aviation. Air traffic emissions were not included in the 2015 figures and were not considered in the 2030 climate targets.
37. See UBA (2017b).
38. See Destatis (2016b).
39. See TNO & ICCT (2016).
40. See BMUB (2016). This translates into a reduction of 40 to 42 % relative to 1990 levels.
41. See Agora Verkehrswende (2017).
42. Since other technologies – nuclear fusion, osmotic power, tidal power, second-generation biofuels – are still in early development, it is unlikely that their costs can be sufficiently reduced to compete with wind and solar energies by 2030.
43. See Frontier Economics (2017).
44. If only half the targeted reduction is achieved in the heating and transport sectors (approx. 240 TWh), additional volumes of renewables totalling some 480 TWh (with a PtL/PtG total efficiency of 50 %) will be needed.
45. Because of today's low equity yield rate, lower network charges were projected. See BNetzA (2015).
46. See Expertenkommission zum Monitoring-Prozess "Energie der Zukunft" (2016).
47. See Destatis (2016a). The largest portion of 2015's private energy expenditures falls on fuels (43 %, or 51 billion euros), power (31 %, or 36 billion euros) and heating (26 %, or 31 billion euros).
48. See Destatis (2016a). Since 1991 the mean has been 7.6 %, though the share of energy costs in total expenditures fluctuated greatly, with a maximum of 9 % in 2013 and a minimum of 6.5 % in 1998.
49. See the Expertenkommission zum Monitoring-Prozess "Energie der Zukunft" (2016).
50. The rough calculation is as follows: EEG differential costs of 22 billion euros plus 0.6 billion euros for the CHP Act minus the merit-order effect (1.0 ct/kWH, or 4.5 billion euros) plus renewables-related grid costs of 2 billion euros.
51. Calculations are based on BMWi (2016a), BMWi (2016b) and Öko-Institut (2017c).
52. For 2017 and beyond, Germany's budgetary plans provide for yearly rises of approx. 3 billion euros a year.
53. See EWI, Prognos & GWS (2014b).
54. See EWI, Prognos & GWS (2014b), Fraunhofer ISE (2015a), Fraunhofer IWES (2015), Öko-Institut & Fraunhofer ISI (2015) and Öko-Institut (2017a).
55. The external costs of CO_2 are far higher than the economic avoidance costs of 50–60 EUR/t CO_2. Germany's Federal Environment Agency recommends a mean price of 80 EUR/t CO_2 for the time being and 145 EUR/t CO_2 for 2030. See Umweltbundesamt (2013).
56. See EWI, Prognos & GWS (2014b).
57. See Öko-Institut & Fraunhofer ISI (2015). The investment multiplier effects of the Fraunhofer-ISI model are generally greater than those of the GWS model. The differences result from varying fuel assumptions and model mechanisms.
58. The present EU climate target of a 40 % reduction in emissions by 2030 (relative to 1990 levels) is an insufficient interim goal for reaching the -80 to 95 % reduction targeted by the EU for 2050. For this requires annual emission reductions of only one percentage point between 2015 and 2030 but a rapid doubling of annual reductions to between 2.0 to 2.75 percentage points for the subsequent two decades.
59. See Prognos & IAEW (2015).
60. See AGEB (2017a).
61. See AGEE-Stat (2017).
62. Alternative distributions of added capacity among wind onshore, wind offshore and photovoltaics are also imaginable. What is decisive is that total added power generation from these renewable sources must amount to around 12 terawatt hours per year.

63. Calculations are based on AGEB (2017a), BMUB (2016), UBA (2016) and UBA (2017a).
64. See Öko-Institut (2017b).
65. See Agora Energiewende (2017a).
66. See Ecofys & Fraunhofer IWES (2017).
67. See Agora Energiewende (2016b).
68. This is also the assumption of those who placed bids for zero-market premiums. The bidders expect governments to settle on an adequately high CO_2 price by the time the projects are to be realized (2025). This price will enable the refinancing of renewables based on market prices.
69. See Ecofys (2016).
70. See Agora Energiewende & Roland Berger (2017).

References

AGEB – AG Energiebilanzen (2016a): Anwendungsbilanzen für die Endenergiesektoren 2013 bis 2015.

AGEB – AG Energiebilanzen (2016b): Auswertungstabellen zur Energiebilanz für die Bundesrepublik Deutschland 1990 bis 2015.

AGEB – AG Energiebilanzen (2017a): Energiebilanz der Bundesrepublik Deutschland 2015.

AGEB – AG Energiebilanzen (2017b): Bruttostromerzeugung in Deutschland ab 1990 nach Energieträgern.

AGEE-Stat. – Arbeitsgruppe Erneuerbare Energien Statistik (2017): Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland.

Agora Energiewende (2015): The Integration Cost of Wind and Solar Power.

Agora Energiewende (2016a): Elf Eckpunkte für einen Kohlekonsens. Konzept zur schrittweisen Dekarbonisierung des deutschen Stromsektors (Langfassung).

Agora Energiewende (2016b): *Energiewende* – was bedeuten die neuen Gesetze?

Agora Energiewende (2017a): Neue Preismodelle für Energie. Grundlagen einer Reform der Entgelte, Steuern, Abgaben und Umlagen auf Strom und fossile Energieträger.

Agora Energiewende (2017b): Wie sieht ein effizientes Energiesystem in Zeiten der Sektorkopplung aus?

Agora Energiewende (2017c): Energiewende und Dezentralität. Zu den Grundlagen einer politisierten Debatte.

Agora Energiewende & Roland Berger (2017): Entwurf einer Charta für eine Energiewende-Industriepolitik.

Agora Verkehrswende (2017): Transforming the Transport Sector: 12 Insights into the Verkehrswende.

BDEW – Bundesverband der Energie- und Wasserwirtschaft (2016): Energiemonitor.

BMUB – Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2016): Klimaschutzplan 2050.

BMWi – Bundesministerium für Wirtschaft und Energie (2016a): Erneuerbare Energien in Zahlen 2015.

BMWi – Bundesministerium für Wirtschaft und Energie (2016b): EEG in Zahlen: Vergütungen, Differenzkosten und EEG-Umlage 2000 bis 2017.

BMWi – Bundesministerium für Wirtschaft und Energie (2017): Energiedaten - Gesamtausgabe.

BNetzA – Bundesnetzagentur (2015): Bericht zur Netzentgeltsystematik Elektrizität.

BNetzA – Bundesnetzagentur (2016): Leitungsvorhaben nach Bundesbedarfsplangestez (BBPlG) und Energieleitungsausbaugesetz (EnLAG) (Stand: Dezember 2016).

BNetzA – Bundesnetzagentur (2017): Versorgungsqualität - SAIDI-Werte 2006–2015.

CE Delft & Microeconomix (2016): Refining Short-Term Electricity Markets to Enhance Flexibility. Study on behalf of Agora Energiewende.

Consentec & r2b (2015): Versorgungssicherheit in Deutschland und seinen Nachbarländern: länderübergreifendes Monitoring und Bewertung.

Destatis – Statistisches Bundesamt (2016a): Private Konsumausgaben und verfügbares Einkommen. Beiheft zur Fachserie 18 der volkswirtschaftlichen Gesamtrechnungen.

Destatis – Statistisches Bundesamt (2016b): Verkehr im Überblick 2015. Fachserie 8, Reihe 1.2.

Destatis – Statistisches Bundesamt (2017): Volkswirtschaftliche Gesamtrechnung. Lange Reihen.

E3MLab & IIASA (2017): Technical Report on Member State results of the EUCO policy scenarios – Corrected version dated 25 January 2017.

Ecofys (2016): Flex-Efficiency. Ein Konzept zur Integration von Effizienz und. Flexibilität bei industriellen Verbrauchern. Studie im Auftrag von Agora Energiewende.

Ecofys & Fraunhofer IWES (2017): Smart-Market- Design in deutschen Verteilnetzen.

Europäische Kommission (2014): Impact Assessment accompanying the document "A policy framework for climate and energy in the period from 2020 up to 2030".

Europäischer Rat (2014): Schlussfolgerungen der Tagung des Europäischen Rates vom 23./24. Oktober 2014.

EWI, Prognos & GWS – Energiewirtschaftliches Institut an der Universität zu Köln, Prognos AG & Gesellschaft für wirtschaftliche Strukturforschung mbH (2014a): Entwicklung der Energiemärkte - Energiereferenzprognose.

EWI, Prognos & GWS – Energiewirtschaftliches Ins- titut an der Universität zu Köln, Prognos AG & Gesellschaft für wirtschaftliche Strukturforschung mbH (2014b): Gesamtwirtschaftliche Effekte der Energiewende. 2014.

Expertenkommission zum Monitoring-Prozess „Energie der Zukunft" (2016): Stellungnahme zum fünften Monitoring-Bericht der Bundesregierung für das Berichtsjahr 2015.

Forschungsstelle Energienetze und Energiespeicher & Energy Brainpool (2015): Bedeutung und Notwendigkeit von Windgas für die Energiewende in Deutschland.

Fortum (2016): View on the Future Energy Market and Strategic Choices.

Fraunhofer ISE (2013): Energiesystem Deutschland 2050.

Fraunhofer ISE (2015): Was kostet die Energiewende?

Fraunhofer IWES et al. – Fraunhofer IWES, Fraunhofer IBP, IFEU & Stiftung Umweltenergierecht (2015): Interaktion Strom, Wärme und Verkehr.

Fraunhofer IWES (2015a): Geschäftsmodell Energiewende.

Fraunhofer IWES (2015b): Wie hoch ist der Stromverbrauch 2015? Energiepolitische Zielszenarien 2050 - Rückwirkungen auf den Ausbau von Windenergie und Photovoltaik.

Fraunhofer IWES (2015c): The European Power System in 2030: Flexibility Challenges and Integration Benefits. An Analysis with a Focus on the Pentalateral Energy Forum Region. Analysis on behalf of Agora Energiewende.

Fraunhofer IWES & IBP – Fraunhofer IWES & Fraunhofer IBP (2017): Wärmewende 2030. Schlüsseltechnologien zur Erreichung der mittel- und langfristigen Klimaschutzziele im Gebäudesektor. Studie im Auftrag von Agora Energiewende.

Frontier Economics (2017): Aktuelle und künftige Kosten von Power-to-Gas und Power-to-Liquid. Study on behalf of Agora Energiewende und Agora Verkehrswende (forthcoming).

FS UNEP – Frankfurt School UNEP Collaborating Centre for Climate & Sustainable Energy Finance (2017): Global Trends in Renewable Energy Investment 2017.

FS UNEP (2017): Global Trends in Renewable Energy Investment

IEA & NEA – International Energy Agency & Nuclear Energy Agency (2015): Projected Cost of Generating Electricity.

IEA – International Energy Agency (2016): World Energy Outlook 2016.

IRENA (2014): Rethinking Energy

IRENA (2015): Green Quality Dialogue

Knopf, Brigitte, Paul Nahmmacher & Eva Schmid (2015): The European renewable energy target for 2030 – An impact assessment of the electricity sector. in: Energy Policy, 2015, 85, p. 50–60.

McGlade, Christopher & Paul Ekins (2015): The geographical distribution of fossil fuels unused when limiting global warming to 2 °C. in Nature, 517, p. 187–190.

MunichRE (2016): NatCatSERVICE.

Öko-Institut (2017a): Erneuerbare vs. fossile Stromsysteme: ein Kostenvergleich. Studie im Auftrag von Agora Energiewende.

Öko-Institut (2017b): Die deutsche Braunkohlenwirtschaft. Historische Entwicklungen, Ressourcen, Technik, wirtschaftliche Strukturen und Umweltauswirkungen. Studie im Auftrag von Agora Energiewende und der European Climate Foundation (ECF).

Öko-Institut (2017c): EEG-Rechner. Berechnungs- und Szenarienmodell zur Ermittlung der EEG-Umlage. Erstellt im Auftrag von Agora Energiewende.

Öko-Institut & Fraunhofer ISI (2015): Klimaschutzszenario 2050. 2. Endbericht.

Prognos (2013): Ermittlung der Wachstumswirkungen der KfW-Programme zum Energieeffizienten Bauen und Sanieren.

Prognos & IAEW – Prognos AG & Institut für Elektri- sche Anlagen und Energiewirtschaft (2015): Positive Effekte von Energieeffizienz auf den deutschen Stromsektor. Studie erstellt im Auftrag von Agora Energiewende, RAP and ECF.

Roland Berger (2017): Abschlussbericht Dialog Energiewende und Industriepolitik. Erstellt im Auftrag von Agora Energiewende.

Tennet (2017): Südostlink Vorschlagskorridor.

TNO & ICCT (2016): From Laboratory to road. A 2016 Update of official and 'real-world' fuel consumption and CO_2 values for passenger cars in Europe 2016. TransnetBW (2017): Ultranet. 2017

trend:research & Leuphana Universität Lüneburg (2013): Definition und Marktanalyse von Bürgerenergie in Deutschland.

UBA –Umweltbundesamt (2013): Schätzung der Umweltkosten in den Bereichen Energie und Verkehr.

UBA – Umweltbundesamt (2016): Entwicklung der spezifischen Kohlendioxid-Emissionen des deutschen Strommix in den Jahren 1990–2015.

UBA – Umweltbundesamt (2017a): CO_2-Emissionen aus der Brennstoffnutzung.

UBA – Umweltbundesamt (2017b): Nationale Trendtabellen für die deutsche Berichterstattung atmo- sphärischer Emissionen.

UBA – Umweltbundesamt (2017c): Klimaschutz im Stromsektor 2030.

U.S. Department of Energy (2016): Revolution … Now.

WMO – World Meteorological Organization (2017): WMO confirms 2016 as hottest year on record, about 1.1 °C above pre-industrial era.

World Bank (2017a): Commodity Price Data (The Pink Sheet).

World Bank (2017b): Market Price Forecast, January

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Agora Energiewende develops evidence-based and politically viable strategies for ensuring the success of the clean energy transition in Germany, Europe and the rest of the world. As a think tank and policy laboratory we aim to share knowledge with stakeholders in the worlds of politics, business and academia while enabling a productive exchange of ideas. Our scientifically rigorous research highlights practical policy solutions while eschewing an ideological agenda. As a non-profit foundation primarily financed through philanthropic donations, we are not beholden to narrow corporate or political interests, but rather to our commitment to confronting climate change.

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