Agora Energiewende

Agora Verkehrswende

Stiftung Klimaneutralität

Towards a Climate-Neutral Germany

Three Steps for Achieving Climate Neutrality by 2050 and an Intermediate Target of -65% in 2030 as Part of the EU Green Deal

EXECUTIVE SUMMARY

prognos

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Towards a Climate-Neutral Germany: Three Steps for Achieving Climate Neutrality by 2050 and an Intermediate Target of -65% in 2030 as Part of the EU Green Deal

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In addition to overseeing the building and energy sectors in this study, Prognos was entrusted with overall project management and scenario design. Öko-Institut was responsible for transport, agriculture, waste and LULUCF (land use, land use change and forestry), as well as the derivation of emission reduction targets. The Wuppertal Institute was responsible for examining the industrial sector.

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Preface

Dear readers,

The third year of drought in Germany, devastating forest fires in Australia and California, record temperatures at the North and South Poles – scientists' dire climate warnings have become impossible to ignore. Fortunately, despite the COVID-19 pandemic, a number of countries have made major climate policy strides. The European Union, Great Britain, Japan, South Korea and many US federal states have all committed themselves to achieving climate neutrality by no later than 2050. Notably, China has also announced its own ambitious plans, recently pledging to make its economy climate neutral by 2060.

The climate policy developments in the past year point to the emergence of a new consensus. But achieving climate neutrality by mid-century will require more ambitious interim goals for 2030 than currently exist. The EU Commission has proposed that Europe increase its 2030 emissions reduction target from 40% to at least 55% relative to 1990 levels. Denmark plans to reduce its emissions by as much as 70%.

How can Germany build a society that does not rely on coal, oil and natural gas? And what will it need to do specifically over the next ten years? We commissioned Prognos, the Öko-Institut and the Wuppertal Institute to develop a feasible scenario for a climate-neutral Germany with economic efficiency, adherence to existing investment cycles and public acceptance in mind.

The resulting scenario shows that Germany can achieve climate neutrality by 2050 and reduce its emissions by 65% by 2030 as long as it greatly accelerates its pace of climate action. This report describes the concrete steps that German will have to take over the next 30 years in order to achieve these goals. We hope that the outlined proposals provide orientation in the ongoing debate, and serve as an impetus for new ideas as well.

Yours sincerely,

Dr. Patrick Graichen, *Director Agora Energiewende*
Christian Hochfeld, *Director Agora Verkehrswende*
Rainer Baake, *Director Stiftung Klimaneutralität*

Findings at a glance:

1. **Germany can achieve climate neutrality by 2050 in three steps while adhering to existing investment cycles.** The first step consists of a 65% reduction in emissions by 2030. The second step is the complete transition to climate-neutral technologies, for a total emissions reduction of 95%. The third step is the offsetting of residual emissions through carbon capture and storage.

2. **The path to climate neutrality involves a comprehensive investment programme comparable in scope to the German economic miracle of the 1950s and 60s.** The core elements of the programme are the creation of a renewable-based energy sector, mass electrification, a smart and efficient modernization of buildings and the development of a hydrogen economy for the industrial sector. Besides achieving climate neutrality, the programme will also improve people's quality of life by reducing noise and air pollution.

3. **An enhanced German reduction target of 65% for 2030, in line with the requirements of the European Green Deal, will require significantly accelerating the green transition in the energy, transport and heating sectors.** This includes the complete phase-out of coal by 2030, a 70% share of renewables in electricity generation, 14 million electric cars on the road, 6 million heat pumps, an increase in the green retrofit rate of at least 50% and the use of some 60 TWh of clean hydrogen.

4. **The next legislative period will determine how Germany goes about achieving climate neutrality by 2050 and a 65% reduction in GHG emissions by 2030.** Government action after the 2021 federal election will be pivotal for future climate policy. Intelligent policy instruments will be needed to modernise Germany's economy and make it sustainable and resilient. They will also be needed to ensure that the structural changes are as fair and inclusive as possible.

Content

Introduction

2020 will go down in history as the year of the COVID-19 pandemic. Every country of the world has experienced an unprecedented struggle to save human lives along with massive restrictions on economic and social life. The pandemic has represented a particularly daunting challenge for policymakers, who have had to make far-reaching decisions under enormous time pressure. But they have also shown all that can be achieved in response to a severe crisis.

It is quite possible that 2020 will also be remembered for another reason: the year that global CO_2 emissions began to decline. Many countries have begun one version or another of a green recovery strategy and have made economic aid for industries contingent on the prospect of climate neutrality. As a result of these activities, the 33 Gt of CO_2 released in 2019 may come to represent the highwater mark of annual global carbon emissions.

Whether it does or not, we are now locked in a race to achieve climate neutrality. The average temperature has already risen 1.1 degrees above pre-industrial levels. In order to keep the average temperature "well below 2 degrees," as required by the Paris Agreement, global greenhouse gas emissions must decrease significantly, and soon. At the same time, countries are already jockeying to be among the leading producers of key climate-neutral technologies, as recent policy announcements by China and California – the former aiming for carbon neutrality by 2060, the latter banning new internal combustion vehicles starting in 2035 – show.

In Europe, a climate policy sea-change is in the offing. Under the European Green Deal, the EU has committed itself to climate neutrality by 2050 and is currently debating increases in interim targets for 2030. In summer 2021, the EU plans to roll out an ambitious climate action programme.

This study spells out what EU's policies will mean for Germany – in terms of both achieving climate neutrality in 2050 and meeting its increased targets for 2030.

The path to climate neutrality by 2050, in three steps

Germany can achieve climate neutrality by 2050 in three steps while adhering to existing investment cycles. The first step is a 65% reduction of emissions relative to 1990 levels by 2030. The second step is a complete switch to climate-neutral technologies, leading to a 95% cut in emissions. The third step is the balancing of residual emissions through carbon capture and storage.

This study presents a path to climate neutrality optimised for cost and feasibility. The main criteria for the selection of measures were economic efficiency and adherence to existing investment cycles. The three steps build on previous reduction measures and policies.

Step one takes proven, cost-effective strategies and accelerates them to achieve a 65% reduction of greenhouse gas emissions by 2030 relative to 1990 levels. Three types of action are needed to meet this goal. The first is the rapid decarbonisation of the electricity sector by phasing out coal and expanding renewable energy generation. The low-carbon electricity will power climate efforts in the other economic sectors. The second is taking advantage of planned industrial refurbishments during the 2020–2030 period to introduce climate-neutral technologies and avoid stranded assets in the 2030s and 40s. And the third is the accelerated reduction of GHG emissions in Germany.

Step two on the way to climate neutrality by 2050 is the reduction of emissions by 95% relative to 1990 levels. To achieve this, Germany will have to eliminate coal, oil and natural gas in the energy, transport, buildings and industrial sectors. For this phase, it is crucial that Germany reduce the market share of traditional technologies (internal combustion vehicles, fossil-fuel heating systems, natural gas-based chemical plants) over the next decade and abandon the current business model for these technologies after 2030. Preparing for this transition will be one of the central tasks in the 2020s for policymakers as well as for businesses.

Step three involves the neutralisation of residual emissions through carbon capture and storage (CCS). Most of the remaining emissions will arise in the agricultural sector due to animal husbandry. (Because the study's scenarios do not presuppose drastic changes in eating habits – only modifications that reflect current trends – they take into account the continued existence of the meat industry.) Residual emissions are also expected in the cement industry despite the introduction of green technologies. The remaining emission total – 60 million tonnes of CO_2eq – are offset by the capture of CO_2 from biomass plants and the air. The captured CO_2 could then be stored in, say, empty gas fields or deep geological formations under the North Sea.

An open and honest discussion of the final step towards climate neutrality should take place sometime over the next few years. For one, policymakers need to devise a comprehensive strategy for biomass that harmonises agriculture, nature conservation and climate neutrality. For another, they need to formulate a CCS strategy to prepare CO_2 transport routes in Germany and identify possible carbon storage sites.

An investment and modernisation programme for Germany

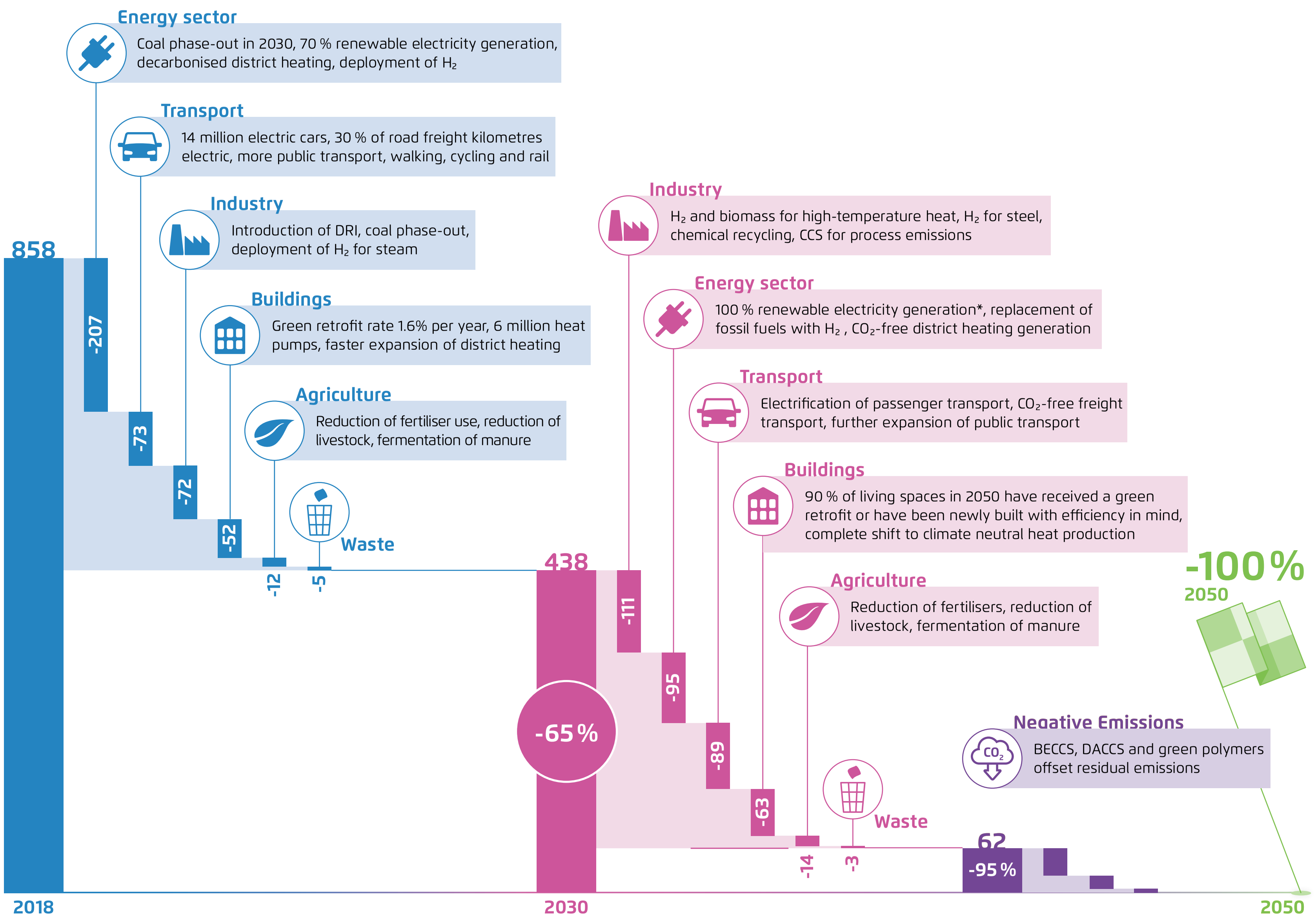
The path to climate neutrality consists of a comprehensive investment programme comparable in scope to the German economic miracle of the 1950s and 60s. The core elements of the programme are a digital energy economy based on renewable energies, an extensive electrification of transport and heat generation, a smart and efficient modernisation of buildings and the development of a hydrogen economy for the industrial sector. Besides reducing emissions, these measures will increase the quality of life by lowering noise and air pollution.

The path towards climate neutrality presented in this study does not explicitly rely on reduced consumption or a zero-growth strategy. Instead, it assumes an average economic growth of 1.3% per year through 2050. The basic idea of the study is to make Germany climate neutral through public and private investments. It describes a path that catches up on the investment backlog of recent years, modernising Germany's energy sector, transport system, buildings and industrial plants.

The study did not develop a "business-as-usual" scenario to quantify the additional investment needed for climate neutrality. Given the global urgency of climate action, "business as usual" is no longer a viable option. Besides, "Climate Paths for Germany", a 2018 study commissioned by the Federation of German Industries (BDI) and performed by Boston Consulting and Prognos, has already done the work: to cut 95% of emissions by mid-century, Germany will have to invest 70 billion euros per year from now through 2050. This projection may be on the high side – its assumptions regarding technological progress are conservative – but, even so, it corresponds to only 10% of Germany's current gross investment level. Thanks to today's low interest rates, meeting this level of investment is entirely within reach.

Policy measures in the Climate Neutral 2050 scenario (CN2050)
(GHG emissions in Mt CO_2eq)

Figure ES



H_2 = hydrogen
* Includes electricity generation from renewable hydrogen, and from stored and imported renewable electricity.
Prognos, Öko-Institut, Wuppertal Institut (2020)

A large portion of the investment must go to building an electricity system based entirely on renewables and capable of producing at least 50% more electricity in 2050 than today. In the transport and heating sectors, the leading technologies will be electric vehicles and heat pumps on account of their high efficiency advantages. Other technologies include green retrofits for buildings and the development of a hydrogen economy for industry, energy, shipping and air traffic. With the right investments, the Germany of 2050 will have a modern electricity and transport infrastructure, a sustainable hydrogen industry, energy efficient buildings and an industry at the forefront of global competition in future technologies. In the coming years, an important task of policymakers will be to initiate these investments and ensure that Germany benefits from the resulting economies of scale.

In addition to reducing emissions, the modernisation of the German economy will also improve quality of life. The electrification of the transport sector will lead to a significant reduction in air and noise pollution, while smart mobility services will decrease the number of parking spaces, freeing up areas for parks and leisure activities in dense urban zones. Residential buildings retrofitted for heat pumps or heating networks will be cosy in winter and cool in summer. As cities become warmer as a result of climate change, the "side effects" of efficient climate neutrality strategy will make life better for everyone.

The interim target: a 65% reduction of greenhouse gas emissions by 2030

The European Green Deal will require Germany to increase its 2030 reduction target to 65%. Hitting this target will mean a significant acceleration of the green transition in its energy, transport and heating sectors. This includes the complete phase-out of coal by 2030, a 70% share of renewables in electricity generation, 14 million electric cars on the road, 6 million installed heat pumps, an increase in the green retrofit rate of at least 50% and the use of some 60 TWh of clean hydrogen.

As part of the European Green Deal, the EU reduction target for 2030 is expected to increase from 40% to 55% relative to 1990 levels. In turn, Germany will have to increase its national target from 55% to 65%.

According to our study, the additional reductions for 2030 will mostly come from the energy sector. Germany's energy sector will have to cut 77 million additional tons of CO_2 beyond the current 2030 sector target defined by the Climate Protection Act. To do this, Germany would have to move up the date of the coal phase-out from 2038 to 2030 and increase the share of renewable energy in electricity consumption to around 70%. (This is even more of an achievement than it first appears: due to the integration of energy sectors, electricity demand in 2030 will be higher than it is today.) The coal phase-out is likely to be largely market-driven. The EU Commission will tighten emissions trading in order to meet elevated climate targets, and lignite-fired power plants will become uneconomical after CO_2 prices reach around 50 euros per tonne.

In addition to the accelerated clean-energy transition, the creation of a hydrogen economy for the industrial sector can save a further 17 million tons of CO_2 over the current sector target. Half the plants in Germany's basic materials industry will need refurbishment over the next 10 years, so climate protection and new investment will have to go hand in hand. The steel industry in particular could be a pioneer in this regard. Its old blast furnaces could be replaced by direct reduction systems fuelled mainly by hydrogen. Of course, that would require a policy that strategically promotes the development of a hydrogen economy.

The path to a 65% reduction of emissions also includes a faster transition to sustainable transport and heating. The additional reductions – 5 million tonnes per sector – are modest, but necessary.

The scenario assumes that electric cars and plug-in hybrids will quickly gain a large share of the market, accounting for 80% of new car sales in Germany by 2030, with the total electric fleet size reaching 14 million vehicles. This development is consistent with the recent announcement by the European Commission to further tighten the CO_2 limits for passenger vehicles, assisted by other policies at the national level. Preparation for a drastic increase in the sale of electric vehicles will safeguard the German automotive industry amid the clear shift to electrification signalled by California and China, each with their own massive market.

Finally, the transition to sustainable heating requires the establishment of an efficiency industry, the green retrofitting of existing buildings and the production of heat pumps on an industrial scale. The cost savings and scaling potential from automated production systems are far from exhausted in these areas.

In order to accelerate the green transition in the energy, industrial, transport and heating sectors, Germany will need a mix of instruments that intelligently combines market-based incentives, targeted support mechanisms and regulatory policies. To be certain, this will also require comprehensive reforms on energy taxes, levies and duties, because existing price structures tend to promote oil and natural gas and impede the use of renewable electricity.

Now it's up to government leaders

The next legislative period will determine how Germany goes about achieving climate neutrality by 2050 and a 65% reduction in GHG emissions by 2030. Government action after the 2021 federal election will be pivotal for future climate policy. Intelligent policy instruments will be needed to modernise Germany's economy and make it sustainable and resilient. They will also be needed to ensure that the structural changes are as fair and inclusive as possible.

The era of half-hearted climate action is over. After bold policy announcements from Brussels, China and California, it is time for Berlin to follow suit. The cross-party support for the European Green Deal must spark ambitious national action in Germany. In the first half of the 2020s, German leaders need to adopt a package of short-term measures for the next decade while creating a framework for achieving climate neutrality by 2050 at the latest.

A key part of that framework is ensuring reliable conditions for investment. To achieve this, Germany must pass policies that resolutely work to keep global warming well below 2 degrees above pre-industrial levels. For clearly, half measures will need correcting under the strain of worsening climatic conditions. The same applies to companies: it is no longer enough to manufacture products in compliance with current regulations. Any business model not geared to the Paris Agreement and to climate neutrality by 2050 will be unsustainable in the medium and long term. And companies that fail to get ahead of the curve will not be major players on the global markets of the future.

The clean-energy transition will require forward-looking policies and clear regulations. Investors in climate-neutral industrial plants and processes need to know that climate-neutral products will be competitive domestically and abroad. It is imperative that Germany either avoid or offset any competitive disadvantages that result from climate-neutral policies and the accelerated clean-energy transition in the run-up to 2030.

At the same time, German policymakers must ensure that the structural changes are fair. Many studies have shown that the path to climate neutrality creates economic growth and jobs – but that the fruits are not evenly distributed across industries and regions. Policymakers and business leaders must neither turn a blind eye to the effects of structural changes nor attempt to impede them. Rather, they must actively face economic changes and establish new business models and opportunities in affected regions.

The challenge of creating a climate-neutral Germany and a climate-neutral Europe by 2050 is enormous, but surmountable – provided that politicians do not drag their feet for another legislative period. The task of the German government after the 2021 elections will be to formulate the central policies and instruments needed to achieve climate neutrality. These will lay the groundwork not only for the mitigation of climate change but also for the creation of a stable economy and an improved quality of life for everyone.

1 Summary

This study describes paths that Germany can take to achieve climate neutrality by 2050. Climate neutrality refers to the complete or near-complete elimination of greenhouse gas (GHG) emissions across all sectors of the economy and the offsetting of remaining emissions through negative emission technologies. Some sectors – agriculture and certain industrial processes, in particular – will not be able to eliminate all emissions by 2050. If Germany is to become climate neutral, these remaining emissions will have to be balanced by removing CO_2 from the atmosphere through carbon capture and storage (CCS) technologies.

The study presents a strategy for achieving climate neutrality in Germany by 2050 that is optimized with regard to cost and feasibility. The Climate Neutral 2050 (CN2050) scenario describes a decarbonization path with a 65% reduction milestone in 2030. The study also considers a variant decarbonization path with a 60% reduction of GHG emissions in 2030.

The study takes into account not only energy-related emissions but also GHG emissions from all sectors. It examines the oft neglected areas of agriculture, waste and land use in detail, along with methane and nitrous oxide emissions from biomass and other smaller sources of emissions. The study indicates the absorption of carbon by forests and soils but it does not count their effect towards emission reductions. The data and forecasts on natural carbon sinks are still imprecise, and, currently, the likelihood that climate change will render forests and soils into CO_2 sources over the coming decades is greater than the likelihood that they will remain sinks. The study's accounting of GHGs is identical to the approach used in the national inventory reports of the United Nations Framework Convention on Climate Change (UNFCCC).

The study's scenarios for achieving climate neutrality assume a variety of measures in the economic sectors. The main selection criterion for the measures was economic efficiency. That is to say, measures with lower CO_2 abatement costs were generally preferred to more expensive measures. The other criterion was feasibility, because rapid transformation and market ramp-up is required in many areas. In order to obtain robust scenarios, we focused on technologies possessing the lowest possible technological and economic risks. Accordingly, we kept CCS use to a minimum and selected alternative technologies wherever possible.

Our study explicitly does not rely on reduced consumption as a necessary prerequisite for achieving climate neutrality. We assume that the living space per capita continues to rise and that mobility levels stay the same. In the area of nutrition, we have adjusted our parameters to reflect social trends such as the moderate decrease in milk consumption and the shift from eating meat towards eating more poultry and organic food. We assume that Germany maintains its high level of industrial production. Finally, we assume average annual GDP growth of 1.3%. We do not explicitly examine the economic effects of anticipated climate protection measures. However, past studies (such as BDI 2018) have shown that with international cooperation, ambitious climate protection can be implemented without macroeconomic losses.

In sum, the path we examine represents a realistic, ambitious scenario for how Germany can become climate neutral while increasing its prosperity and securing its appeal as a place to do business. All needed investments are designated for normal modernization cycles.

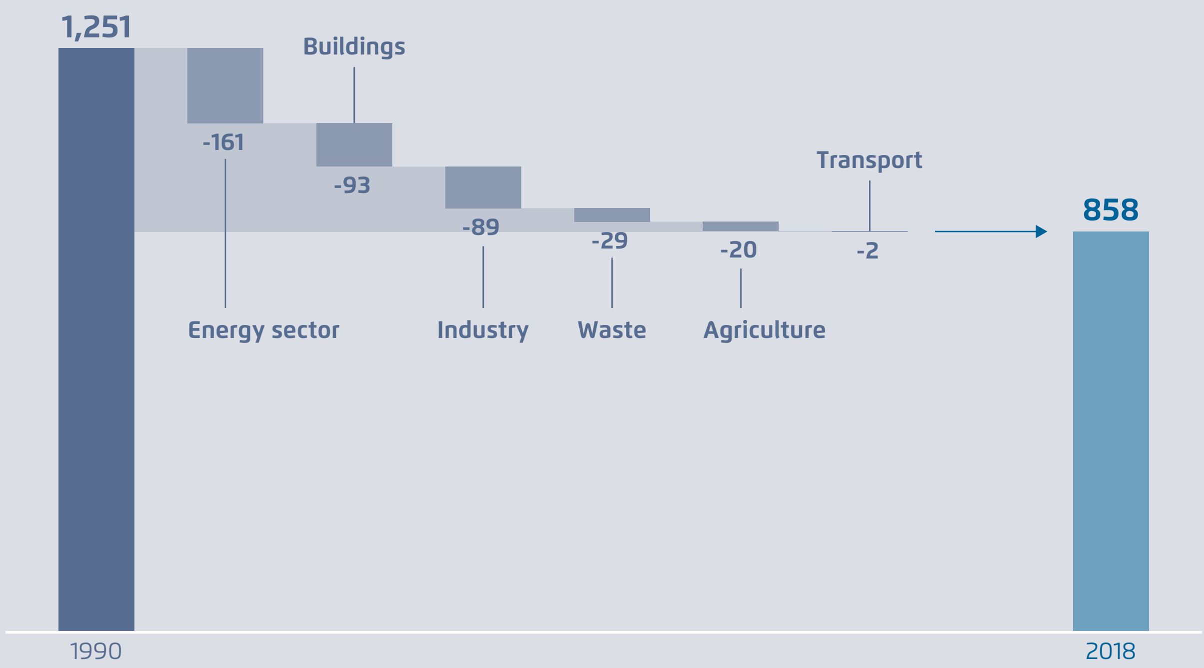
Germany One-Third of the Way to Climate Neutrality

Energy policies to reduce energy consumption – whether because of supply security, air pollution, resource scarcity, or geopolitical dependence – have been around for a very long time. Climate considerations are a more recent development. After the UN Framework Convention on Climate Change was adopted at the environmental summit in Rio de Janeiro in 1992, the first UN World Climate Conference (COP-1) took place three years later in Berlin. The result was the *Berlin Mandate*, which formed the basis for the binding emissions reduction targets set by the 1997 Kyoto Protocol. EU-15 countries committed themselves to an 8% reduction in greenhouse gas emissions by 2012 relative to 1990 levels. As part of EU burden-sharing, Germany signed its first international agreement for reducing greenhouse gas emissions.

By 2018, Germany had reduced its greenhouse gas emissions by around 31% relative to 1990 levels. (Preliminary data indicate that it decreased emissions by another four percentage points in 2019.) This means that Germany is around one-third of the way to achieving climate neutrality.

Most of the emissions reductions since German reunification have occurred in the **energy sector**. The modernization of electricity and heat supply in the former East German states, which had been predominantly based on lignite, played an important role, particularly in the 1990s. With the turn of the millennium and the introduction of the German Renewable Energy Sources Act (EEG), the expansion of renewables for electricity generation became the main driver of emissions reductions. The share of renewables in electricity consumption increased from just 6.5% in 2000 to 37.8% by 2018 (and to 42.1% in 2019). Electricity generation is the area in which

The reduction of greenhouse gas emissions from 1990 until today (in Mt CO_2eq) Figure 1



UBA (2020)

renewable energy has gained the fastest foothold and will provide the basis for achieving zero-carbon emissions in other sectors. Thanks in large part to reductions in electricity generation, emissions in the energy sector had fallen by 161 Mt CO_2eq by 2018, even though gross electricity generation had increased by 17% and the share of nuclear energy in the electricity mix had decreased from 28% to 12%.

GHG reductions in the **industrial sector** were particularly pronounced in the 1990s, mostly due to the contraction of East German industry, efficiency gains in production, the manufacture of more resource-efficient products and a significant reduction in process emissions. Additional savings resulted from the increased electrification of production processes. Since 2000, industrial emissions have scarcely decreased. Germany's relatively strong economic growth has offset additional reductions through efficiency and the use of low-carbon fuels over the past two decades.

In the **building sector**, emissions have decreased significantly and continuously since 1990. By 2018, emissions had fallen by 44%. The main drivers were the use of fuels with lower CO_2 emissions, an increase in the use of renewables, more efficient heating systems (condensing boiler technology), the expansion of district heating, green retrofits and more efficient new buildings. Thanks to the measures taken, GHG emissions fell significantly even as living space increased by 39%.

GHG emissions in the **transport sector** fell slightly between 2000 and 2009, but they increased again and are now as high as they were in 1990. From 1991 to 2018, car traffic measured in passenger-kilometres increased by around 31%. During the same period, the volume of road freight traffic roughly doubled. Even though traffic growth and emissions have decoupled, the sector has not contributed to climate change mitigation in absolute terms. Moreover, the average emissions for new cars in real driving conditions have not dropped any further in recent years. Without the increasing share of biofuels, the transport sector would have seen a significant increase in GHG emissions.

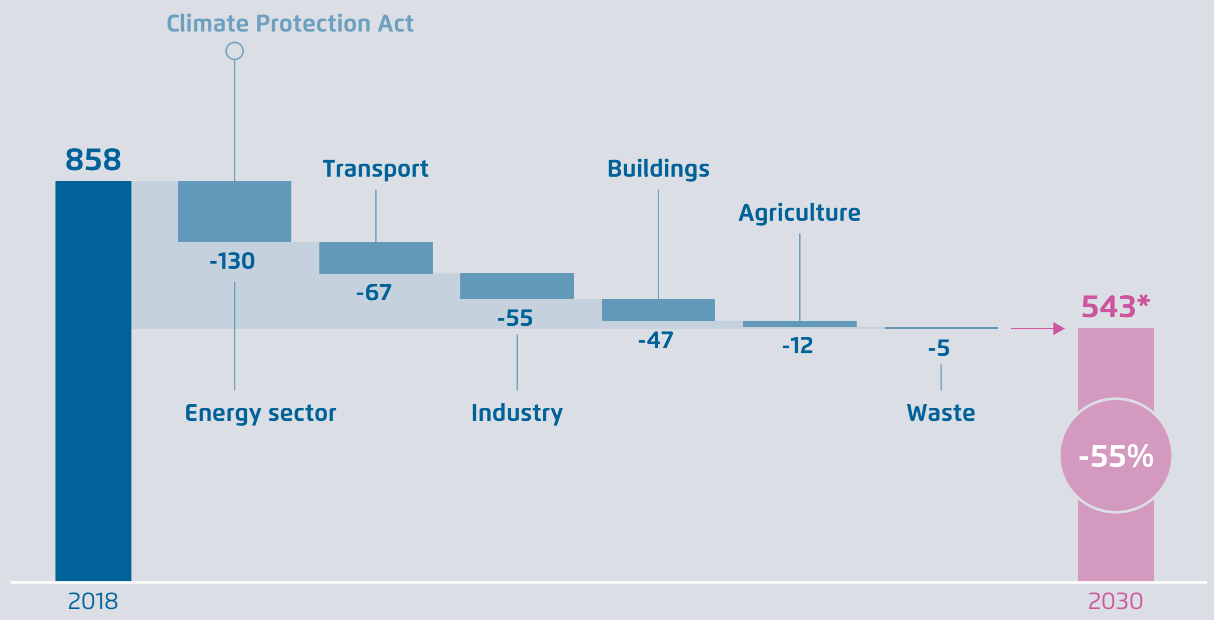
Since 1990, emissions in the **agricultural sector** have declined, particularly in the 1990s, on account of reductions in the number of dairy cows and beef cattle. Their number has fallen again somewhat because of low milk prices and the scarcity of green fodder due to drought. Nitrogen discharge and nitrous oxide emissions from agricultural soils have been at a high level since the 1990s. At the same time, agricultural yields have increased, improving nitrogen efficiency. Stricter fertilizer regulations and the drought of the past two years have reduced fertilizer use, which has led to a decrease in emissions from agricultural soils.

In the **waste sector**, emissions fell by 75% between 1990 and 2018. This is mainly attributable to the decrease in methane emissions from landfills due to a reduction in the amount of deposited organic waste in the wake of a 2005 ban. A large portion of waste is now incinerated, where it is recycled in the form of heat and electricity so that it shows up in the energy sector balance. The area of wastewater treatment has also seen emissions reductions. This was on account of a new law requiring buildings to be connected to the public sewer system and improved wastewater and sewage sludge treatment.

The Climate Action Plan and the Climate Protection Act

In November 2016, the German federal government passed the Climate Action Plan 2050. Three years later, it legally enshrined the plan in its Climate Protection Act, which requires that Germany cut its GHG emissions by at least 55% relative to 1990 levels by 2030 and become GHG-neutral by 2050. The Climate Action Plan also specifies 2030 climate targets for individual sectors. The Climate Action Programme 2030, passed in fall 2019, lays the groundwork for legislation to achieve the climate targets, such as the Coal Exit Act and the Fuel Emis-

Existing targets based on Germany's Climate Protection Act (GHG emissions in Mt CO_2eq) Figure 2



* Sectoral targets specified in the Climate Protection Act add up to a 56.5% reduction relative to 1990 levels.
German Climate Protection Act (2020)

sions Trading Act. According to recent BMU and BMWi projections, however, current policy measures will fall 3 to 4 percentage points short of the 55% reduction target stipulated by the Climate Action Programme 2030.

Three steps to climate neutrality: Step 1 – Reduce emissions by 65% by 2030

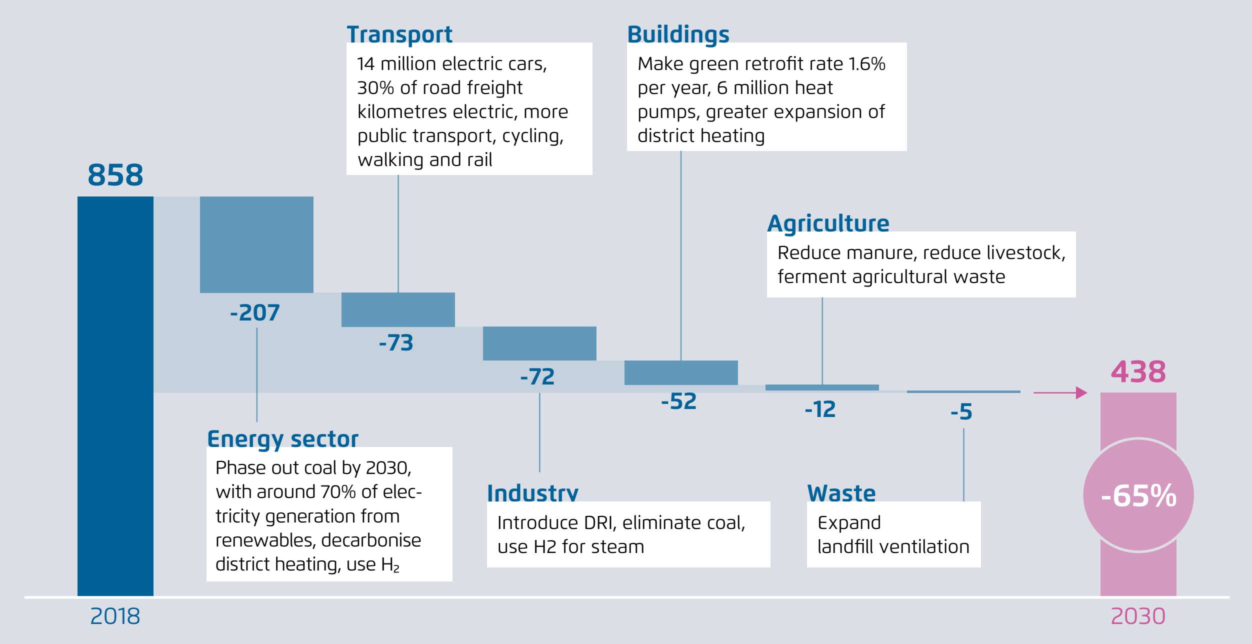
An important step to climate neutrality by 2050 is a 65% reduction of emissions by 2030. Actions taken in the 2020s will decide whether climate neutrality can be achieved by the middle of the century. In the event that the EU raises its reduction target for 2030 from 40 to 55%, Germany will have to reduce its own emissions by about 65% by 2030.

The 2019 Climate Protection Act provides a solid foundation for a further reduction in emissions. The additional reduction potentials relative to previous targets vary across sectors, and some are harder to realize than others. According to the calculations in this study, further reductions in the agriculture and waste sectors are very unlikely, while in the transport and building sectors, additional cuts of 5 Mt each are possible. The greatest potential reductions are in the industry and energy sectors, at 17 Mt and 77 Mt, respectively.

The **energy sector** has the potential to cut emissions by 207 Mt CO_2eq by 2030, or 77 Mt CO_2eq more than the sector target established in the Climate Protection Act. The primary means for achieving the additional reductions is an accelerated phase-out of coal (2030 instead of 2038) and the increased expansion of renewable capacity in electricity generation. The use of hydrogen for fueling power stations and CHP plants starting in the late 2020s will also contribute to the decline. A phase-out of coal by 2030 will likely occur in the context of tightened EU reduction targets

Three steps to climate neutrality: Step 1 – Reduce emissions by 65% by 2030 (GHG emissions in Mt CO_2eq)

Figure 3



H_2 = hydrogen
Prognos, Öko-Institut, Wuppertal Institut (2020)

(from 40 to 55%) and adjustments to the EU ETS, largely due to the changing market conditions for coal-fired power generation.

Growing electrification in all sectors will increase electricity consumption by 51 TWh, or 9%, relative to 2018. In 2030, renewable energy will make up around 70% of gross electricity consumption. This will require increasing capacities in offshore wind to 25 GW, in onshore wind to 80 GW and in PV to 150 GW.

Meeting climate targets in the **industrial sectors** will require the introduction of new processes in the basic materials industry. Over the next 10 years, around 50% of the central plants in the German basic materials industry are scheduled for modernisation. This gives Germany a good opportunity to introduce new technologies without stranding assets. The steel industry in particular could be a pioneer in this regard. Its old blast furnaces could be replaced by direct reduction systems fuelled mainly by hydrogen and smaller proportions of natural gas.

Investment in new technologies based on electricity or (mainly) renewably produced **hydrogen** is required in other sectors as well. The creation of an accompanying infrastructure is needed not only for industrial hydrogen supply but also for CCS in the cement and lime industries. Moreover, it is important that German industry invest quickly in more recycling and in increased quantities of secondary raw materials so that these solutions can exploit their full potential after 2030. The first CCS systems in the cement industry could be operational as early as 2030.

In the **building sector**, the additional reductions can be achieved through changes in heating systems, an expansion of heating networks and around a 50% increase in the green retrofit rate. Among new heating installations, heat pumps will gain a large market share by the mid-2020s, particularly for single- and two-family homes, leading to a total of 6 million heat pumps by 2030. Green district heating will gain increasing importance in urban areas. After 2025, new heating systems fuelled by heating oil or natural gas may only be used in exceptional cases.

In the **transport sector**, there is a change in current trends. People stay as mobile as before, but they use public transport, cycle or walk significantly more. In 2030 there will be 14 million electric cars (including plug-in hybrids) on the road. Rail will be used to transport a larger volume of goods, while one-third of road-freight kilometres will be covered by electric trucks powered by batteries, overhead lines and fuel cells.

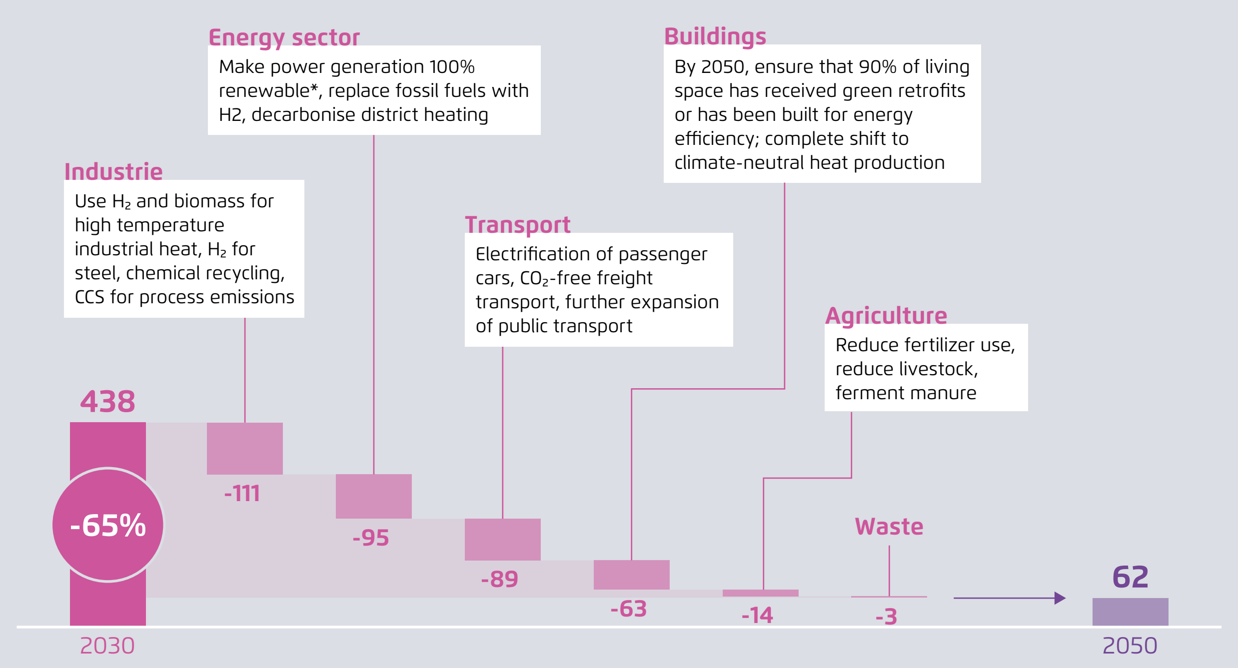
By 2030, the **agricultural sector** will have implemented available mitigation measures such as the fermentation and improved storage of farm manure and the use of low-emission muck spreaders. Additional reductions will be achieved through changes in agricultural production, including the expansion of organic farming, the switch to crops with lower nitrogen requirements and the reduction of livestock. The changes in production reflect changes in demand as people consume fewer animal products and the sector shifts from gaseous to solid biofuels.

In the **waste sector**, methane emissions from landfills will continue to decrease through 2030. The reduction of methane emissions will be accelerated by expanding landfill ventilation measures. Other areas in the sector have little potential for reductions by 2030.

Three steps to climate neutrality: Step 2 – Reduce emissions by 95%

By 2030, two-thirds of the GHG reductions needed to achieve climate neutrality will be achieved. The last third will be eliminated or offset by 2050.

Step 2 – 95% reduction without negative emissions (GHG emissions in Mt CO_2eq) Figure 4



* Includes power generation from renewable hydrogen together with stored and imported renewable electricity.
Prognos, Öko-Institut, Wuppertal Institut (2020)

Electrification will continue **across all sectors** in the remaining two decades before 2050, and hydrogen will become increasingly important as a secondary energy carrier and raw material. Efficiency improvements are also needed to help reduce emissions in all economic sectors. Biomass will play an increasingly important role. Cultivation will shift towards solid biomass and its use will be concentrated on areas in which no good alternatives are available and that are suitable for CCS (especially in the chemical and steel industries).

Below are the sector developments needed for climate neutrality in detail:

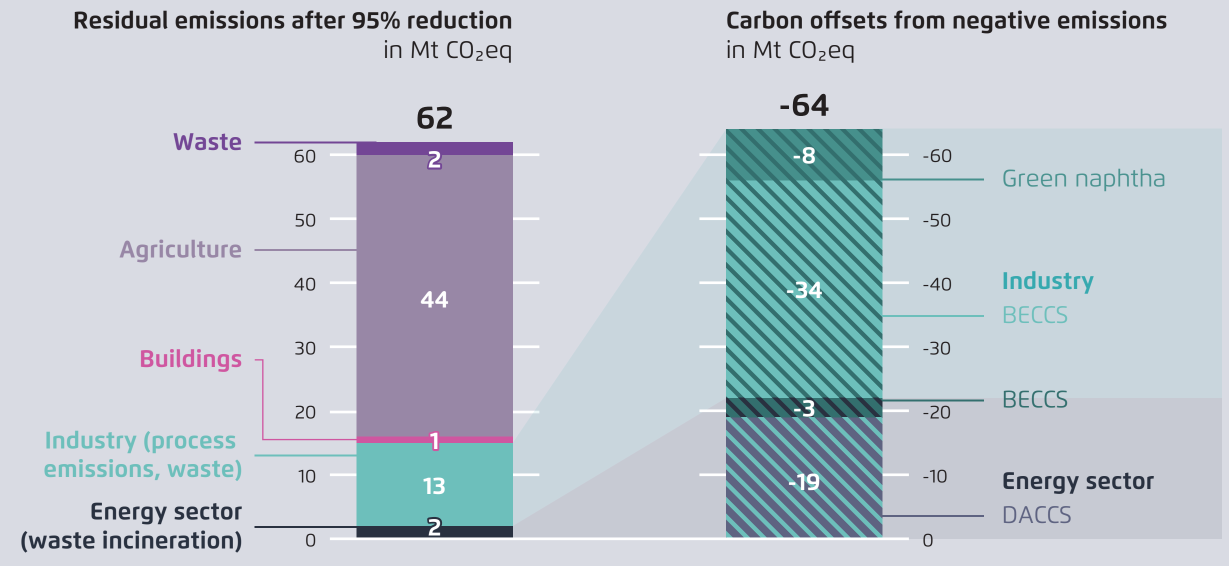
- → The **energy sector** will continue to expand renewables. Electrification and increased hydrogen production will raise electricity consumption by 50%, reaching around 960 TWh in 2050. Renewable energy expansion after 2030 must continue to focus on wind energy and photovoltaics. As hydrogen becomes increasingly important, it will replace natural gas as the most important energy source for generating residual electricity starting in 2040. By 2050, electricity and district heating will be 100% CO_2-free.
- → The **industrial sector** will continue its trend of using more and more electricity, hydrogen and biomass, becoming largely climate neutral by 2045. Raw materials for chemicals will also be successively replaced by recycled products and synthetic feedstocks based on non-fossil CO_2 starting in 2030. By 2050, almost the entire cement industry will be linked with CCS infrastructures capable of capturing nearly all emissions.
- → In the **building sector**, green retrofits and the construction of energy-efficient buildings will continue after 2030. Between 2000 and 2050, 90% of buildings will either have received green retrofits or have been constructed with energy efficiency in mind. Through the progressive installation of zero-carbon heating systems (totalling 14 million heat pumps by 2050) and the use of district heating networks, it will be possible to eliminate building emissions almost entirely.
- → Overall, the volume of **passenger transport** will remain roughly the same as today. Shared vehicle use via carpooling and public transport will increase capacity and reduce total vehicle-kilometres. The remaining road passenger transport will be provided almost entirely by battery-electric vehicles. Trucks powered by batteries, overhead lines and fuel cells will put road freight transport on the path to climate neutrality. At the same time, more and more goods will be transported by rail. Air transport and shipping will be powered entirely by electricity-based synthetic fuels.
- → In **agriculture**, further emission reductions will be achieved by 2050 through decreases to livestock and the fermentation of large quantities of manure in biogas plants. In the area of agricultural soils, significant emission reductions will already be achieved by 2030. In addition, some small reduction potentials will come from cultivating low-nitrogen crops and changing wetland use.
- → In 2050, the **waste sector** will still have residual emissions from landfills, biological treatment of organic waste and wastewater treatment. Emissions from biological processes cannot be entirely avoided. Reductions will be achieved in all areas by 2050.

Three steps to climate neutrality: Step 3 – Offset residual emissions with CCS and negative emissions

Residual GHG emissions are the emissions that cannot be eliminated by mitigation measures. In the agricultural sector, these arise through biological processes in soils (fertilizers) and in animal husbandry. Residual emissions will also exist in industrial processes and waste management.

By contrast, energy-related GHG emissions can be almost completely eliminated by using renewable energy sources. Only very small amounts of methane

Step 3 in detail – residual GHG emissions and their compensation in 2050 Figure 5



Prognos, Öko-Institut, Wuppertal Institut (2020)

and nitrous oxide emissions from the storage, transport and combustion of biomass and synthetic fuels will remain.

Total residual emissions will amount to 62 Mt CO_2eq, which corresponds to 5% of emissions in 1990. The remaining emissions will be offset primarily by biomass CCS, direct air carbon capture and storage and the absorption of CO_2 by green polymers. These technologies capture CO_2 directly or indirectly from the atmosphere and place it in long-term storage. Based on our calculations, these technologies create negative emissions that are somewhat greater than the remaining emissions, resulting in slightly negative total emissions.

→ Bioenergy with carbon capture and storage (BECCS) is the capture and geological storage of CO_2 that is created from the combustion of biomass. Since biomass is largely CO_2-neutral when cultivated sustainably and used as a waste material, BECCS can remove CO_2 from the atmosphere in the long term. The use of BECCS is limited by the amount of sustainably available biomass.

→ Direct Air Carbon Capture and Storage (DACCS) is the capture of CO_2 directly from the air and its subsequent storage in suitable geological formations. The ambient air is sucked in by fans and bound by a sorbent. The energy consumption and the costs of DACCS are significantly higher than for BECCS.

→ Green naphtha / absorption of CO_2 to green polymers: Biomass or CO_2 absorbed from the air via direct air capture can be used in combination with renewables-based hydrogen in Fischer-Tropsch plants to create green naphtha and other bio-based hydrocarbons. These can then be processed into polymers and plastics. With an improved recycling system, the plastics can be permanently kept in the material cycle. Coupled with CCS for waste incineration, this technology can prevent the re-emission of captured carbon.

Industry will play an important role in the deployment of BECCS. The high concentrated heat requirements of the steel and chemical industries are particularly well suited for the large-scale use of biomass and for the capture of the resulting CO_2. The carbon can then be stored using the CO_2 infrastructure needed for the cement industry. The near complete recycling of plastics, primarily through chemical recycling, will make up another important contribution to climate neutrality on the part of the industry.

The study's scenarios indicate that more CO_2 will be removed from the atmosphere in 2050 than emitted. Most of the remaining emissions will consist of methane and nitrous oxide. Other options for generating negative emissions exist, but for reasons of cost and potential, our scenarios relied exclusively on the above carbon capture technologies.

The scenarios considered measures in Land Use, Land-Use Change and Forestry (LULUCF), such as the restoration of wetlands, to ensure that the sector remains a carbon sink over the long term. The measures in the LULUCF sector will result in a carbon sink of -10 Mt CO_2eq in 2050. The current capacity of the carbon sink – -27 Mt CO_2eq – will not be able to be maintained. We indicate the capacity of natural sinks, i.e. the carbon uptake by forests and soils, but do not count them towards the climate change mitigation goals in this study.

Three pillars of the transition to climate neutrality: Pillar 1 – Energy efficiency and the reduction of energy demand

In the study's Climate Neutrality 2050 scenario, primary energy consumption, i.e. all energy sources used in Germany directly or for conversion to secondary energy sources, falls by 50%, from around 13,000 PJ today to around 6,600 PJ, by 2050.

Two changes will spearhead the reductions: lower losses from energy conversion and a decrease in final energy consumption.

Between 2018 and 2030, energy consumption drops by 16%, from around 9,000 PJ to around 7,500 PJ. By 2050, final energy consumption will have to fall to 5,800 PJ, a decrease of around 35% relative to 2018. The main drivers for the decline will be building retrofits, more efficient lighting, low-energy electric devices and more efficient transport through electrification. The increasing use of heat pumps to generate space heating and hot water will reduce fuel consumption through the use of environmental heat.

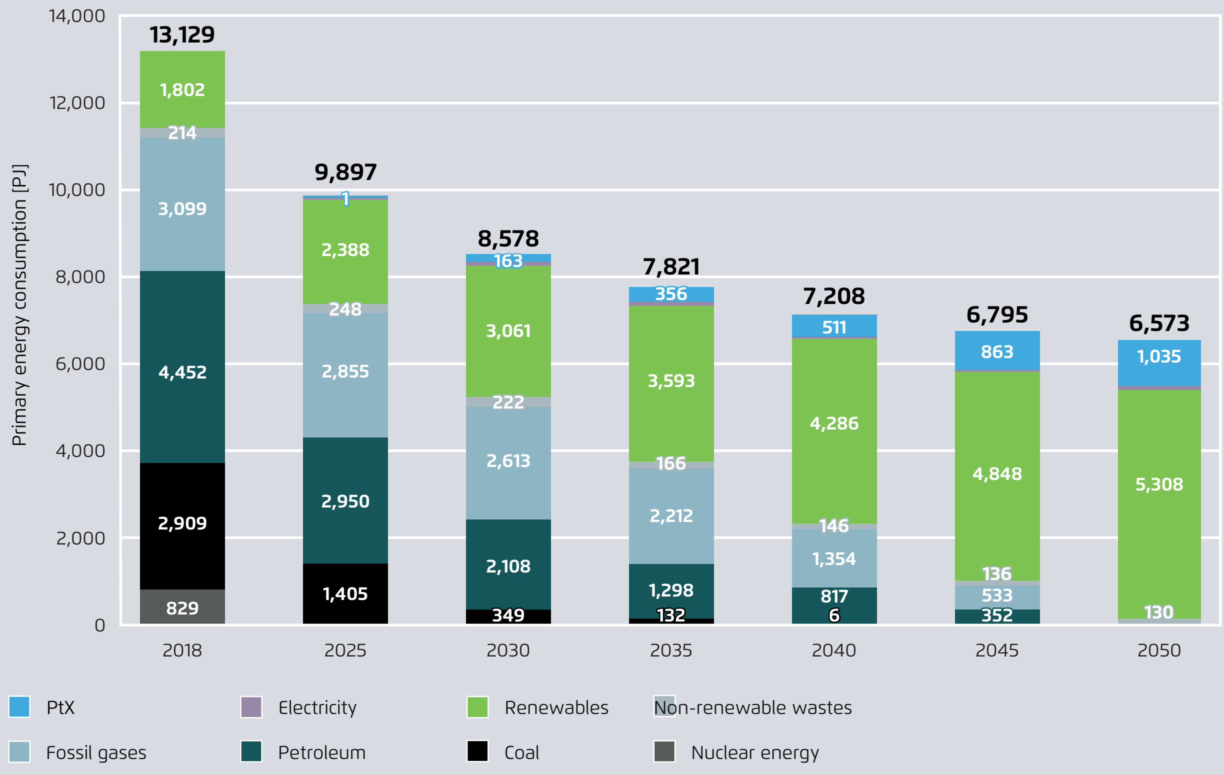
Energy conversion will also see significant primary energy reductions in the period up to 2050, especially in the area of electricity generation. While in 2018 almost three-quarters of electricity was generated from thermal power plants, which have high conversion losses, fuel-based electricity generation will decrease to around 7% by 2050. Most electricity will be generated from wind energy and photovoltaics, which have no conversion losses.

In addition to changes in the total amount of primary energy consumed, the types of energy used will also see significant changes by 2050. The consumption of coal, natural gas and oil will fall to zero by 2050. Nuclear energy will already be phased out by 2022.

The share of renewables in primary energy consumption will increase from 14% in 2018, to 38% by 2030 and to 81% by 2050. Imports of synthetically produced energy sources will account for around 16% of primary energy in 2050. The remaining 3% of primary energy in 2050 will come from other energy sources such as waste and small amounts of imported electricity.

Primary energy consumption

Figure 6



Prognos, Öko-Institut, Wuppertal Institut (2020)

Three pillars of the transition to climate neutrality: Pillar 2 – Renewable electricity generation and electrification

The importance of electricity will continue to grow as Germany works towards climate neutrality. Electricity is a very efficient energy source for many applications, particularly in the transport and heating sectors, where it delivers significant advantages compared with combustion engines and boilers.

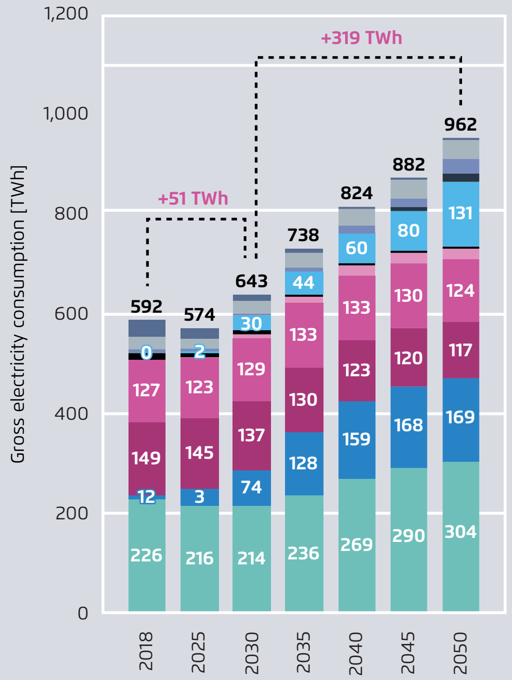
Electrification and the production of renewable hydrogen will be the main reasons why electricity consumption will have increased to around 960 TWh by 2050, or 370 TWh higher than that of today. Of that, about 160 TWh will come from the transport sector, 130 TWh from hydrogen production and 70 TWh from industry. Electricity consumption in the building sector will decline slightly. Efficiency improvements in electrical appliances and lighting and the replacement of backup heaters and electric boilers will save more than added heat pumps will consume.

To make electricity generation completely climate neutral, the installed capacities of renewables will increase to 130 GW for onshore wind, to 70 GW for offshore wind and to 355 GW for solar.

In 2050, the electricity system will be based entirely on renewables. Including hydropower and biomass, renewables will directly cover 88% of electricity consumption. A mere 7% will be supplied by gas-fired power plants powered by renewable hydrogen. The remaining 5% will be covered by stored or imported electricity. To achieve these targets, the electricity system will have to become significantly more flexible – through more battery storage, through the deployment of heat pumps, through electrolysers and electric cars and through more electricity trading with other countries. The spatial and temporal distribution of generation will balance variable generation and enable the efficient use of renewable electricity.

The short-term balancing of electricity demand and supply will take place primarily through battery storage, load management and electricity trading. Balancing seasonal variations in electricity supply will be primarily achieved through the generation and reconversion of hydrogen as well as through the use of large storage power stations in Scandinavia and the Alps. Electricity exports to these countries will protect storage levels – especially in summer and autumn – so that compared with today more electricity will be available in winter.

Gross electricity consumption | Figure 7

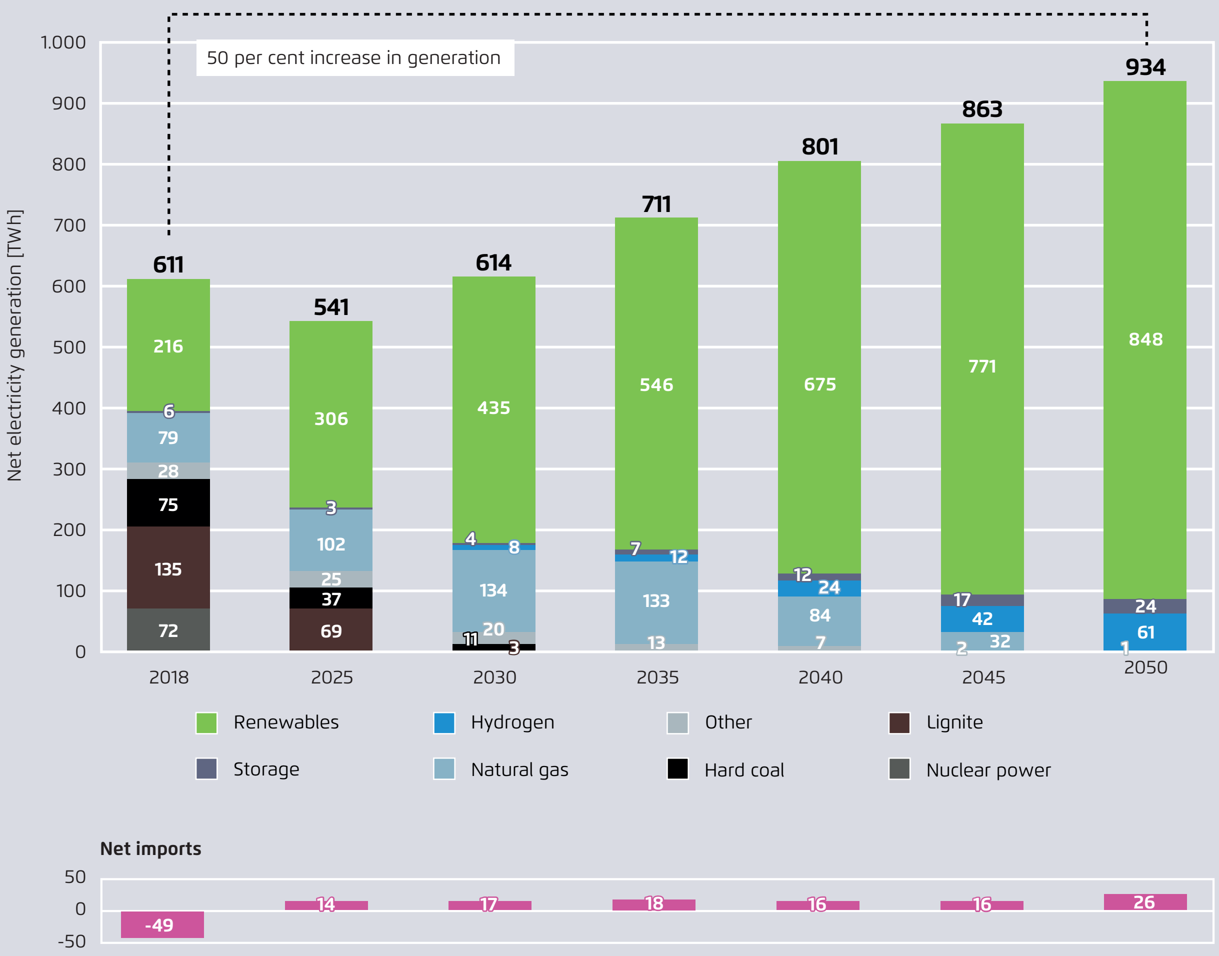


	2030	2050
H_2/CO_2	Production 19 TWh H_2	84 TWh H_2, 19 Mt CO_2 DAC
	5.6 million heat pumps, efficient electric appliances, efficient lighting, decline of direct electric heaters	13.8 million heat pumps, increasing for cooling and ventilation, efficiency with heat pumps, decline of direct electric heaters, efficiency with electric appliances
	Heat pumps, efficient lighting	Heat pumps, efficient lighting
	27% of road freight km via trucks powered by batteries and overhead lines, 14 M electric cars	78% of road freight km via trucks powered by batteries and overhead lines, 30 M electric cars
	Electrification of process heat, electricity-based steam production, efficient cross-cutting technologies	Electrification of process heat, CO_2 capture, steam production in electric boilers and high-temperature heat pumps

H_2 = hydrogen. PP = power plant. DAC = direct air capture. HH = households. ITS = industry, trade and services. Gross storage use comprises pump storage and stationary battery storage in the public supply. The figure does not consider the electricity consumption of household batteries combined with PV installations.
Prognos, Öko-Institut, Wuppertal Institut (2020)

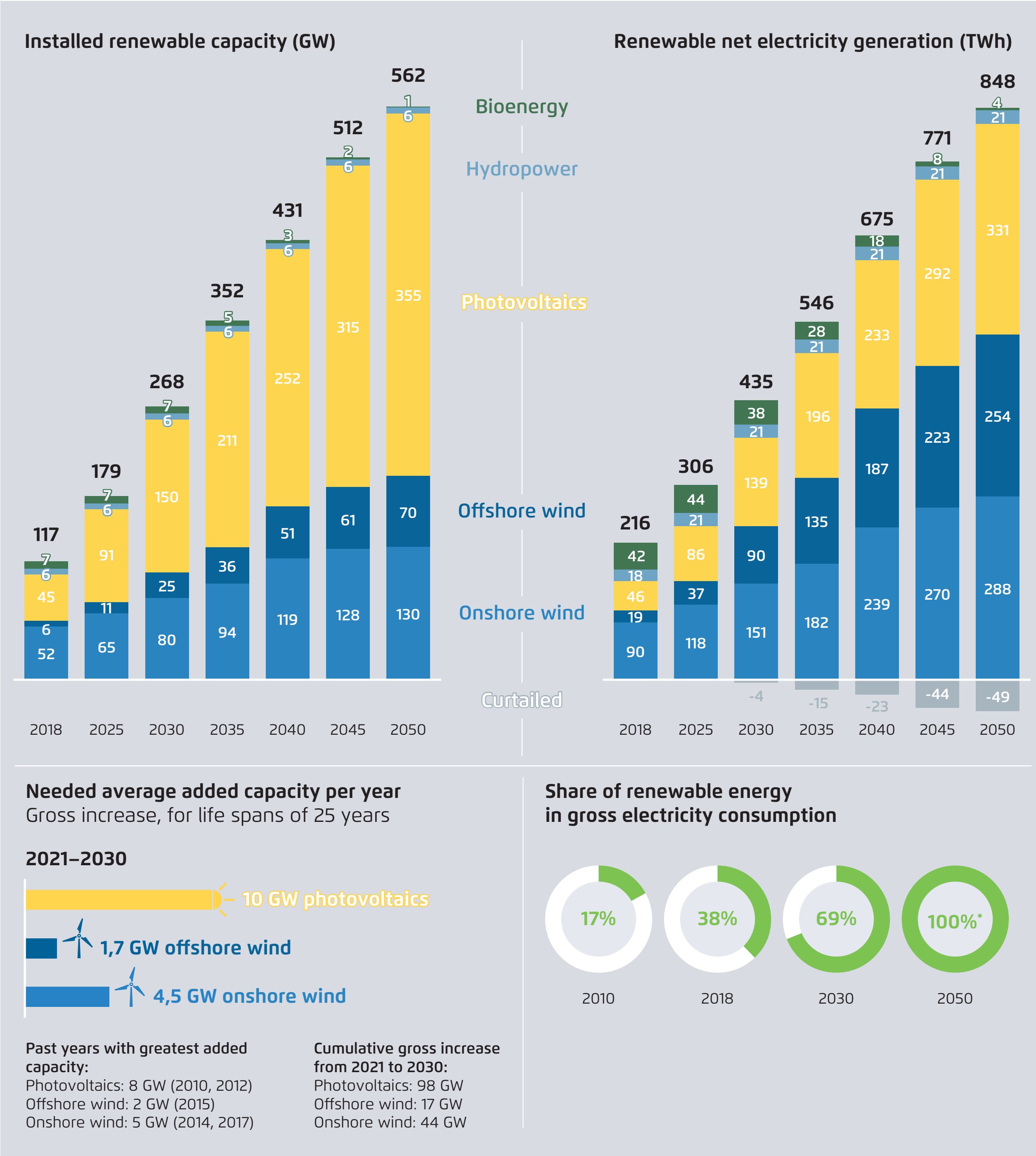
Net electricity generation and net imports

Figure 8



Other energy sources for electricity generation: blast furnace gases, waste incineration, petroleum, other sources. Storage: generation from battery storage and pump storage
Prognos (2020)

Renewble energies Figure 9



* Includes electricity generation from renewable hydrogen together with stored and imported renewable electricity.
Prognos (2020)

Three pillars of the transition to climate neutrality: Pillar 3 – Hydrogen as an energy source and raw material

Alongside electricity, hydrogen will play a very important role in creating a climate-neutral economy. Hydrogen demand in 2050 will be around 270 TWh. 31% of that will be produced in Germany. The rest will be imported.

In the industrial sector, hydrogen will mainly be used for the direct reduction of iron ore for CO_2-free steel production, for the generation of process steam and as a raw material for basic chemicals.

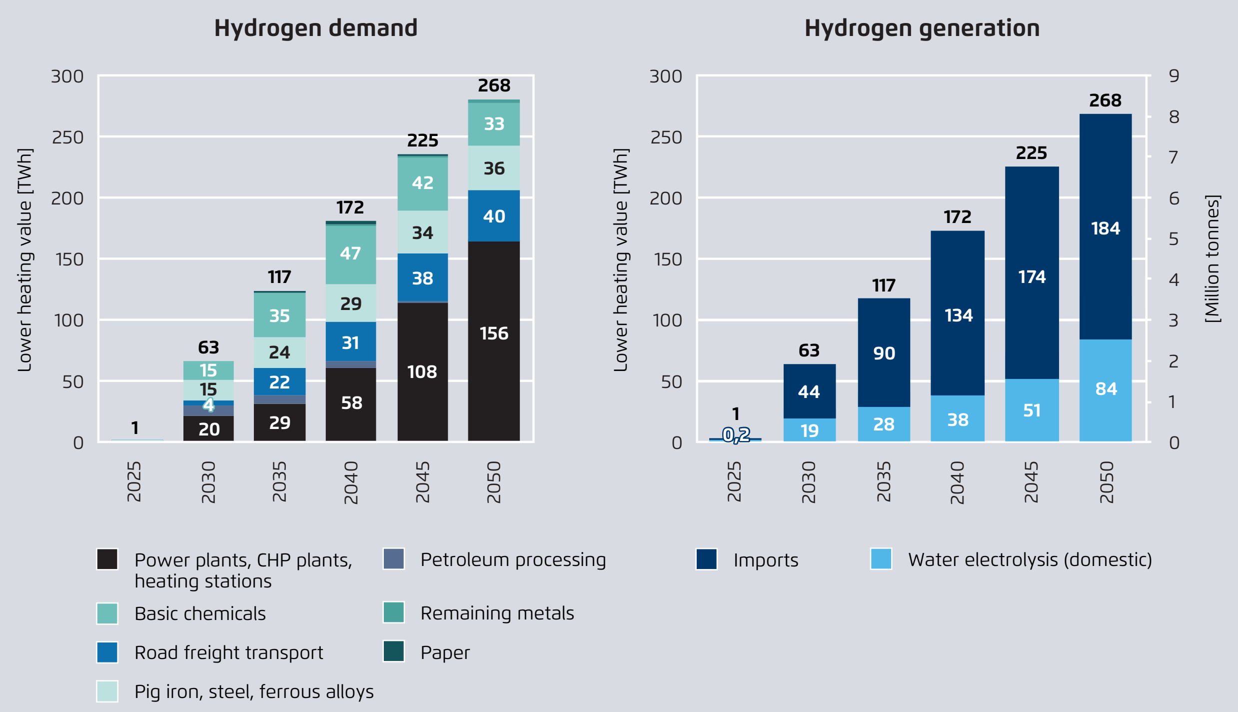
40 TWh of hydrogen will be used in the transport sector, primarily for freight. Trucks and articulated vehicles will use hydrogen fuel cells. Light commercial vehicles will also run on hydrogen but to a lesser extent.

Most of the hydrogen will be used to generate electricity. In times when there is residual demand, hydrogen will be used to fuel gas-fired power plants. Some of these are combined heat and power plants for district heating. For cost reasons, no hydrogen will not be used for powering on-site building heating systems.

The study's scenario also relies on other synthetic fuels in addition to hydrogen. It uses CO_2-neutral PtL fuels for shipping and air transport and, to a much smaller extent, for road transport, where they power internal combustion vehicles that remain in use. Green naphtha will be used for industrial materials that recycling cannot provide. The needed electricity-based fuels and green naphtha – totalling 120 TWh – will have to be imported.

In total, demand for hydrogen and other synthetic fuels in 2050 will amount to 391 TWh, of which 307 TWh will be imported.

CO_2-free hydrogen generation and use in Germany — Figure 10



Prognos, Öko-Institut, Wuppertal Institut and our own calculations | Values in TWh (lower heating value)

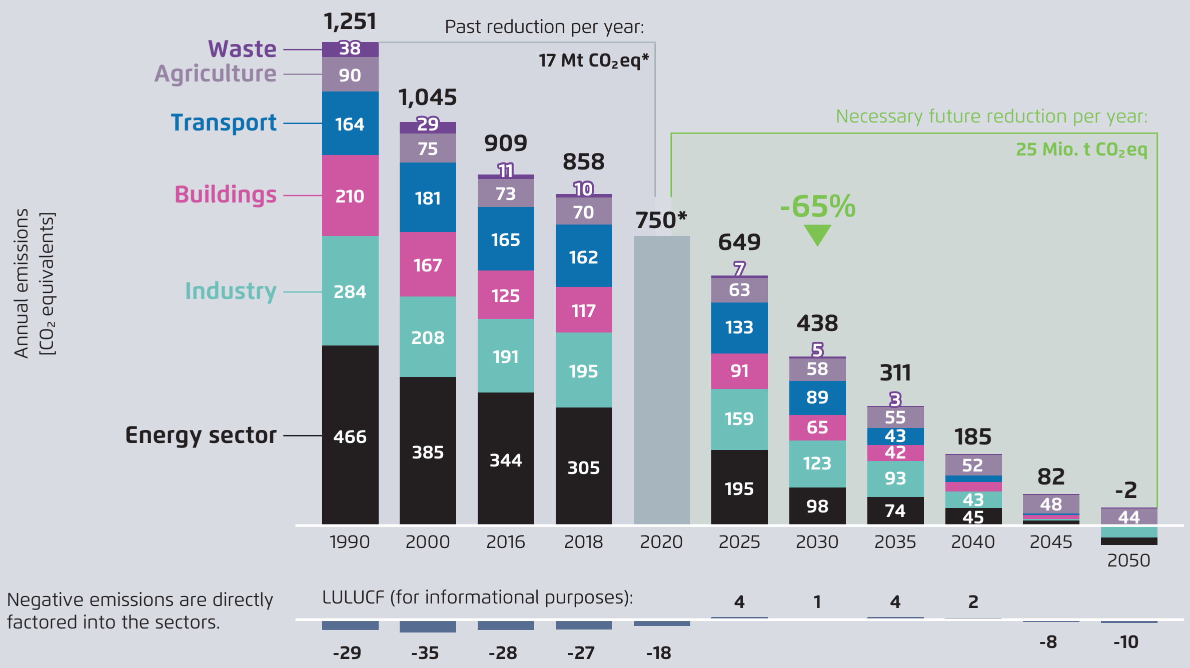
The Climate Neutral 2050 scenario at a glance

Key indicators in the Climate Neutral 2050 scenario — Figure 11

CN2050	2018	2030	2040	2050	2018–2030 p.a. net	2030–2050 p.a. net
Greenhouse gas emissions* ($Mt CO_2eq$)						
Energy sector	305	98	45	-19	-17	-6
Industry	195	123	43	-30	-6	-8
Transport	162	89	18	0	-6	-4
Buildings	117	65	24	1	-4	-3
Agriculture	70	58	52	44	-1	-1
Waste / other	10	5	3	2	0	0
Total	**858**	**438**	**185**	**-2**	**-35**	**-22**
Reduction relative to 1990	31	65	85	100		
LULUCF (for informational purposes only)	-27	1	2	-10	2	0
Primary energy consumption (PJ)	**13,129**	**8,578**	**7,208**	**6,573**	**-379**	**-100**
Coal	*2,909*	*349*	*34*	*0*	-213	*-17*
Petroleum	*4,452*	*2,108*	*817*	*2*	-195	*-105*
Fossil gases	*3,099*	*2,613*	*1,354*	*3*	-41	*-131*
Gross electricity consumption (TWh)	**595**	**643**	**824**	**962**	**4**	**16**
Share of renewables in gross electricity consumption (%)	38	69	82	100**		
Onshore wind (GW)	52	80	119	130	2	3
Onshore wind (GW)	6	25	51	70	2	2
Photovoltaics (GW)	45	150	252	355	9	10
Number of electric cars, including plug-in hybrids (millions of units)	0	14	32	30	1	1
Rail freight transport (billions of tkm)	135	190	210	230	5	2
Number of heat pumps (millions of units)	1	6	11	14	0.4	0.4
Useful energy demand in residential buildings ($kWh/(m^2 \cdot a)$)	106	85	71	60	-2	-1
Electrolyser capacity in Germany (GW)	0	10	25	51	1	2
Hydrogen use (TWh)	0	63	172	268	5	10
Generation of renewable hydrogen in Germany (TWh)	0	19	38	84	2	3
Imported hydrogen (TWh)	0	44	134	184	4	7
Other imported synthetic fuels (TWh)	0	1	8	123	0	6
Carbon capture and storage (gross volume, $MT CO_2$)	**0**	**-1**	**-22**	**-73**	**0**	**-4**
Process emissions and waste ($Mt CO_2$)	*0*	*-1*	*-5*	*-18*	*0*	*-1*
Negative emissions ($Mt CO_2$)	*0*	*0*	*-17*	*-56*	*0*	*-3*
Negative emissions including carbon absorption ($Mt CO_2$)	**0**	**0**	**-17**	**-64**	**0**	**-3**
Bioenergy CCS (BECCS, $Mt CO_2$)	*0*	*0*	*-15*	*-37*	*0*	*-1*
Direct air capture CCS (DACCS, $Mt CO_2$)	*0*	*0*	*-2*	*-19*	*0*	*-1*
Imported green polymers ($Mt CO_2$)	*0*	*0*	*0*	*-8*	*0*	*0*
Population in Germany (millions)	83	83	81	79	0	0
EU-ETS, EUR_{2019}/t	16	52	70	90	3	2

* Negative emissions are directly factored into the sectors.
** This includes electricity generation from renewable hydrogen together with stored and imported renewable electricity.
Prognos, Öko-Institut, Wuppertal Institut (2020)

GHG emissions by sector, 1990–2050 — Figure 12



* Target for 2020: GHG reduction of 40% relative to 1990.
Prognos, Öko-Institut, Wuppertal Institut (2020)

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How do we accomplish the clean-energy transition? Which legislation, initiatives and measures do we need to make it a success? Agora Energiewende and Agora Verkehrswende are helping Germany set the course towards a fully decarbonised energy system. As think-&-do-tanks, we work with key stakeholders to enhance the knowledge base and facilitate a convergence of views.

The Climate Neutrality Foundation was established to develop cross-sectoral strategies for a climate-friendly Germany in close cooperation with other think tanks. Based on sound research, it aims to provide information and advice - beyond individual interests.

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