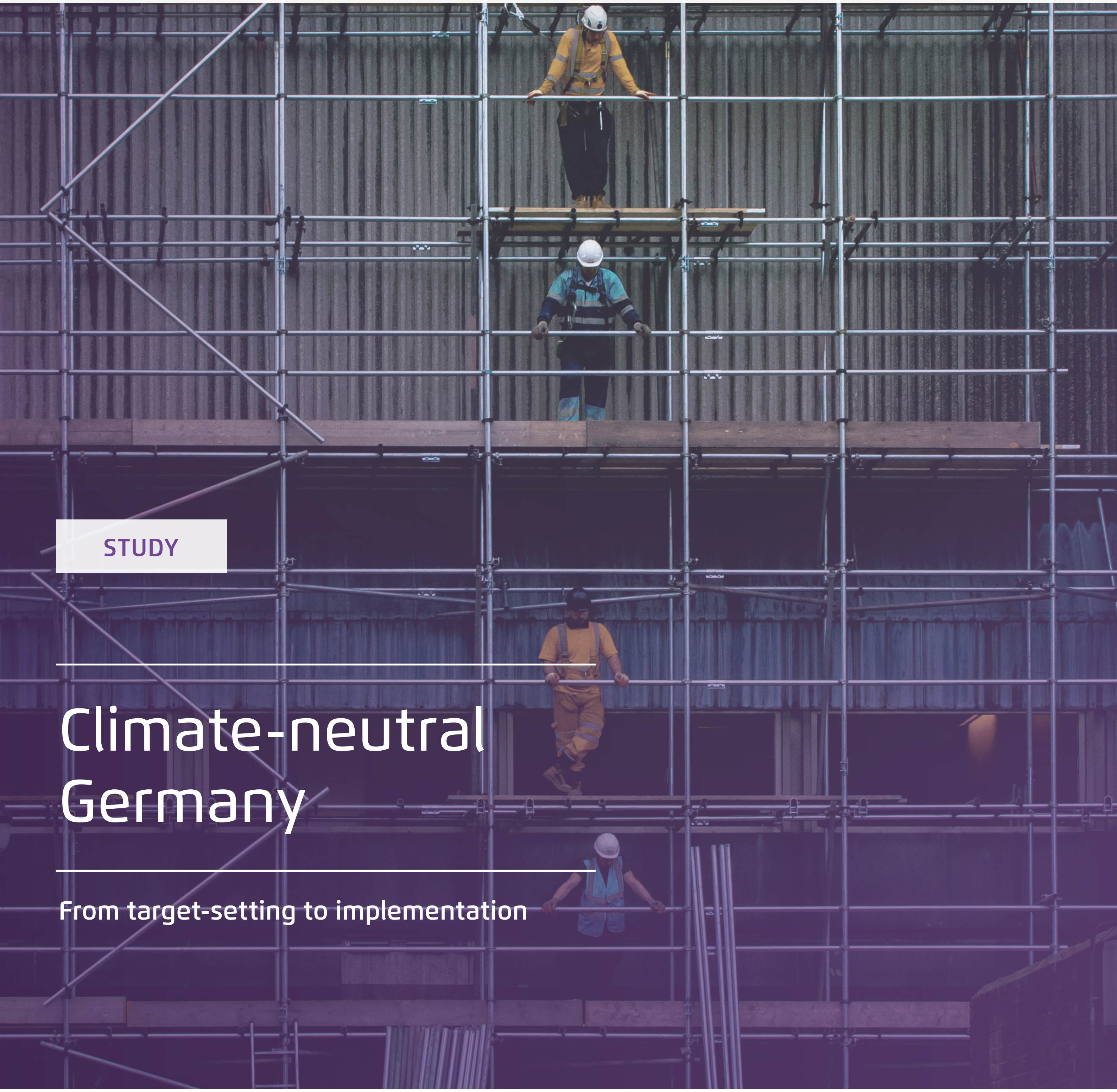
Agora Energiewende

Agora Industry

Agora Agriculture

Agora Verkehrswende



STUDY

Climate-neutral Germany

From target-setting to implementation

prognos

Wuppertal Institut

Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

UNIKASSEL VERSITÄT

Please cite as:

Agora Think Tanks (2024): Climate-neutral Germany. From target-setting to implementation.

Study
Climate-neutral Germany.
From target-setting to implementation.

Written by
Agora Think Tanks
Anna-Louisa-Karsch-Straße 2 | 10178 Berlin
P +49 (0)30 700 14 35-000
www.agora-thinktanks.org
info@agora-thinktanks.org

Authors
Lea Nesselhauf, Corinna Fischer, Simon Müller, Philipp Godron, Fabian Huneke, Mathias Koch, Niels Wauer, Uta Weiß (all Agora Energiewende); Julia Metz, Paul Münnich (both Agora Industry); Arnaud Brizay, Christine Chemnitz, Wilhelm Klümper (all Agora Agriculture); Carl-Friedrich Elmer, Marion Vieweg, Johanna Wietschel (all Agora Verkehrswende)

The scenario modelling and calculation of required investments were conducted by:

Prognos AG
Goethestraße 85 | 10623 Berlin
Elias Althoff, Hans Dambeck, Andreas Kemmler, Paurnima Kulkarni, Sven Kreidelmeyer, Saskia Lengning, Melina Lohmann, Sebastian Lübbers, Fabian Muralter, Alexander Piégsa, Nils Thamling, Minh Phuong Vu, Aurel Wünsch, Marco Wünsch, Inka Ziegenhagen

Öko-Institut e. V.
Borkumstraße 2 | 13189 Berlin
Wolf Kristian Görz, Konstantin Kreye, Klaus Hennenberg, Peter Kasten, Mirjam Pfeiffer, Margarethe Scheffler, Dennis Seibert, Kirsten Wiegmann

Wuppertal Institut für Klima, Umwelt, Energie gGmbH
Döppersberg 19 | 42103 Wuppertal
Georg Holtz, Sascha Samadi, Ylva Kloo, Süheyb Bilici, Mathieu Saurat, Annika Tönjes

University of Kassel
Mönchebergstraße 19 | 34109 Kassel
Clemens Schneider, Stefan Lechtenböhmer

Prognos was responsible for the scenario design, overall management of the project and the calculation of investment requirements. Prognos was also responsible for the analysis of the buildings and energy sectors and parts of the non-energy-intensive industrial sector. Öko-Institut focused on transport, agriculture, waste and land use, land-use change and forestry (LULUCF). The Wuppertal Institute worked together with the University of Kassel on the industry sector.

Agora Think Tanks was responsible for the concrete design of the policy instruments and the calculation of the public financial requirements.

Project lead
Lea Nesselhauf |
l.nesselhauf@agora-energiewende.de
Corinna Fischer |
corinna.fischer@agora-energiewende.de
Inka Ziegenhagen | inka.ziegenhagen@prognos.com
Marco Wünsch | marco.wünsch@prognos.com

Acknowledgements
This study was made possible through the dedication of many colleagues, to whom we are deeply grateful. We would like to extend our thanks to Joshua Grünberg, Katharina Hartz, Frank Jordans, Anna Kraus, Jahel Mielke, Aleksandar Nikolic, Julian Somers, Alexandra Steinhardt and Anja Werner (all from Agora Energiewende); Leandro Janke and Frank Peter (both from Agora Industry); and Christian Hochfeld, Philipp Prein and Wiebke Zimmer (all from Agora Verkehrswende) for their invaluable support.

Preface

Dear reader,

Germany has set out on the path to climate neutrality. Despite significant progress, such as the expansion of renewable energy, the current debate remains focused primarily on the challenges. It's true that the transition in transport and mobility and the climate-neutral modernisation of buildings are bringing about changes in citizens' daily lives. Meanwhile, a growing segment of the economy is facing significant structural challenges.

In updating our "climate-neutral Germany" scenario, we take these challenges into account and provide possible solutions. Our analysis demonstrates how a bold strategy can set the course for climate-neutral investments. It identifies key elements for socially equitable design and formulates a balanced policy mix to achieve this goal.

This pathway will certainly not unfold exactly the way we describe. However, the study presents a cohesive vision of the future and can thus form the basis for the solution-oriented discussions we need.

We hope you find it insightful.

Simon Müller
Director Germany, Agora Energiewende

Key findings at a glance

1 **The path to a climate-neutral Germany requires planning and investment certainty.** Climate policy works – emissions in the energy sector have fallen by around 40 percent since 2014. However, the transition in the transport sector, the climate-neutral modernisation of buildings and the necessary changes in the industry sector still pose challenges. To overcome these challenges, reliable climate and economic policy frameworks are crucial.

2 **Investments in climate neutrality boost innovation and improve structural competitiveness.** Three quarters of the investments in energy and transport infrastructure, industrial facilities and buildings required by 2045 are necessary regardless of the transition. Redirecting financial flows towards climate-neutral solutions through price incentives and market regulation is therefore crucial. Additional investments in climate action amount to an average of three percent of GDP. Many of these investments are already economically viable; for example, renewable energy projects and electricity grids can be 90 percent financed by market revenues and fees.

3 **Achieving climate-neutral and equitable housing and mobility requires extensive infrastructure expansion, targeted investment support and measures to correct social imbalances.** The scenario includes more targeted support for building retrofits, purchase incentives for electric vehicles that focus on small and used cars and the expansion of public transport infrastructure. These measures will help to bring down energy costs in the medium term. Until they take effect, vulnerable households will be compensated for cost increases by a temporary support mechanism, fed by ten billion euros per year from carbon pricing revenues.

4 **A balanced policy mix ensures successful implementation.** Relying solely on carbon pricing, market regulation, subsidies or infrastructure expansion has its disadvantages. By contrast, a combined approach allows for cost efficiency, planning certainty and social equity. Regardless of the exact composition of the policy mix, the path to climate neutrality requires a collective societal effort – and paves the way for a liveable future for everyone.

Content

List of abbreviations

BECCS	Bioenergy with Carbon Capture and Storage
BEG	Bundesförderung für effiziente Gebäude (Federal Funding for Efficient Buildings)
BEV	Battery Electric Vehicle
BEW	Bundesförderung für effiziente Wärmenetze (Federal Funding for Efficient Heating Networks)
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
CDR	Carbon Dioxide Removal
CHP	Combined Heat and Power
CO_2eq	CO_2 equivalent
DACCS	Direct Air Carbon Capture and Storage
DRI	Direct Reduced Iron
EEG	Erneuerbare-Energien-Gesetz (Renewable Energy Sources Act)
EPBD	Energy Performance of Buildings Directive
ETS I	EU Emissions Trading System
ETS II	EU Emissions Trading System for Buildings and road Transport
FCEV	Fuel Cell Electric Vehicles
GDP	Gross Domestic Product
GEG	Gebäudeenergiegesetz (Buildings Energy Act)
GHD	Gewerbe, Handel und Dienstleistungen
GW	Gigawatts
HGV	Heavy-goods vehicle
KSG	Bundes-Klimaschutzgesetz (Federal Climate Protection Act)
kW/kWh	Kilowatts / Kilowatt hours
KWKG	Kraft-Wärme-Kopplungsgesetz (Combined Heat and Power Act)
LULUCF	Land Use, Land Use-Change and Forestry
Mha	Million hectares
MW/MWh	Megawatts / Megawatt hours
PPAs	Power Purchase Agreements
PV	Photovoltaics
RED	Renewable Energy Directive
SME	Micro-, small- and medium-sized enterprises
TW/TWh	Terawatts / Terawatt hours
WPG	Gesetz zur Kommunalen Wärmeplanung (Municipal Heat Planning Act)

Summary

Germany moves from setting climate targets to implementation

In spring 2021, the study "Climate-neutral Germany 2045" *(Klimaneutrales Deutschland 2045)* showed for the first time how Germany can achieve climate neutrality by 2045 and remain competitive at the same time. As a result, the grand coalition of the Christian Democratic Union (CDU), Christian Social Union of Bavaria (CSU) and the Social Democratic Party (SPD) enshrined this target alongside a 2030 target of reducing emissions by 65 percent (compared to 1990 levels) in the Federal Climate Protection Act (*Bundes-Klimaschutzgesetz*, or KSG). Now, Germany has moved from the target-setting phase to the implementation phase.

However, this implementation phase brings with it new challenges. How can Germany's industrial base become climate neutral while strengthening its competitiveness? What does it take to make sustainable mobility and the climate-neutral modernisation of buildings affordable and practical for everyone? And how can we fully leverage the potential of agriculture and forestry for climate protection, biodiversity and healthy nutrition?

To address these questions, "Climate-neutral Germany: From target-setting to implementation" *(Klimaneutrales Deutschland – Von der Zielsetzung zur Umsetzung)* outlines a pathway to climate neutrality from three central perspectives. First, the scenario modelling shows a coherent and optimised roadmap to climate neutrality across all sectors. Second, detailed calculations estimate the necessary private and public investments for the transition, and by extension the funding requirements. Third, the scenario proposes a comprehensive package of balanced policy measures that would enable these investments while ensuring social equity and broad participation.

Key results of the climate-neutral Germany scenario along five overarching goals

The key results of the scenario can be summarised along five central objectives as follows:

Affordable and reliable energy supply

In the climate-neutral Germany scenario, by 2045, renewable energy sources expand to 180 gigawatts (GW) of onshore wind, 73 GW of offshore wind and 470 GW of PV, making it the most cost-effective form of generation while also exploiting potential savings in grid expansion. Electricity demand increases from 553 terawatt hours (TWh) in 2023 to 1 280 TWh by 2045. However, incentives for electrification ensure that supply and demand develop synchronously and that the electricity system costs per kilowatt hour (kWh) remains largely constant at 16 cents until 2030 and then falls to less than 13 cents by 2045. Accelerated digitalisation combined with price-based incentives to make electricity demand more flexible alongside storage systems ensure a reliable and cost-efficient energy supply. Overall, energy import dependency decreases by approximately 85 percent by 2045.

Stimulating an innovative and competitive economy

Investments in climate-neutral processes and products stimulate economic recovery, supported by a mix of price-based incentives and funding as well as instruments to improve planning security. The use of industrial heat pumps in combination with waste heat leads to a significant increase in efficiency and thus enable a competitive heat supply for industry. Natural gas consumption falls to almost zero by 2040 to 2045, while electricity consumption doubles compared with 2025 to more than 400 TWh. New value chains are created, for example by replacing previously imported fossil raw materials in the chemicals industry with sustainable, domestically grown biomass. By 2045, net negative emissions of 19 million tonnes of carbon dioxide (CO_2) are sequestered in the industrial sector.

Participation in sustainable housing for all

The scenario shows that the climate-neutral modernisation of buildings strengthens resilience to heat waves and simultaneously results in an increase in the value of the building stock. In the heating supply sector, the number of new buildings connected to district heating increases from 40 000 at present to 90 000 in 2030. From 2028, between 600 000 and 650 000 new heat pumps are installed every year, primarily in existing buildings. This is roughly equivalent to today's sales of gas boilers. A targeted and more demand-oriented funding framework ensures that homeowners and tenants are protected from excessive cost increases. Heat pumps and CO_2-free heating networks form the backbone of the heating supply – exceptions prove the rule. Needs-oriented and affordable housing solutions are increasingly created in existing buildings.

Clean and accessible mobility for all

Expanded public transport in the scenario enhances mobility options and thus the attractiveness of rural areas to live in. Targeted subsidies help people on low incomes to purchase efficient electric cars, with mobility allowances providing short-term relief. Reduced pollution and noise levels, increased exercise associated with cycling and walking, and reduced soil surface sealing have a positive effect on health and quality of life. By 2045, final energy demand from transportation drops to approximately 280 TWh, less than half of the final energy demand in 2023.

Productive and resilient agriculture and forestry

Greenhouse gas emissions from agriculture and peatlands used for agriculture fall substantially, while carbon storage on agricultural land and the carbon sink capacity of forests are stabilised. This is feasible if sustainability becomes economically advantageous for farmers through changes in the policy framework. Fair food environments that support easy, sustainable and healthy choices for consumers are also prioritised.

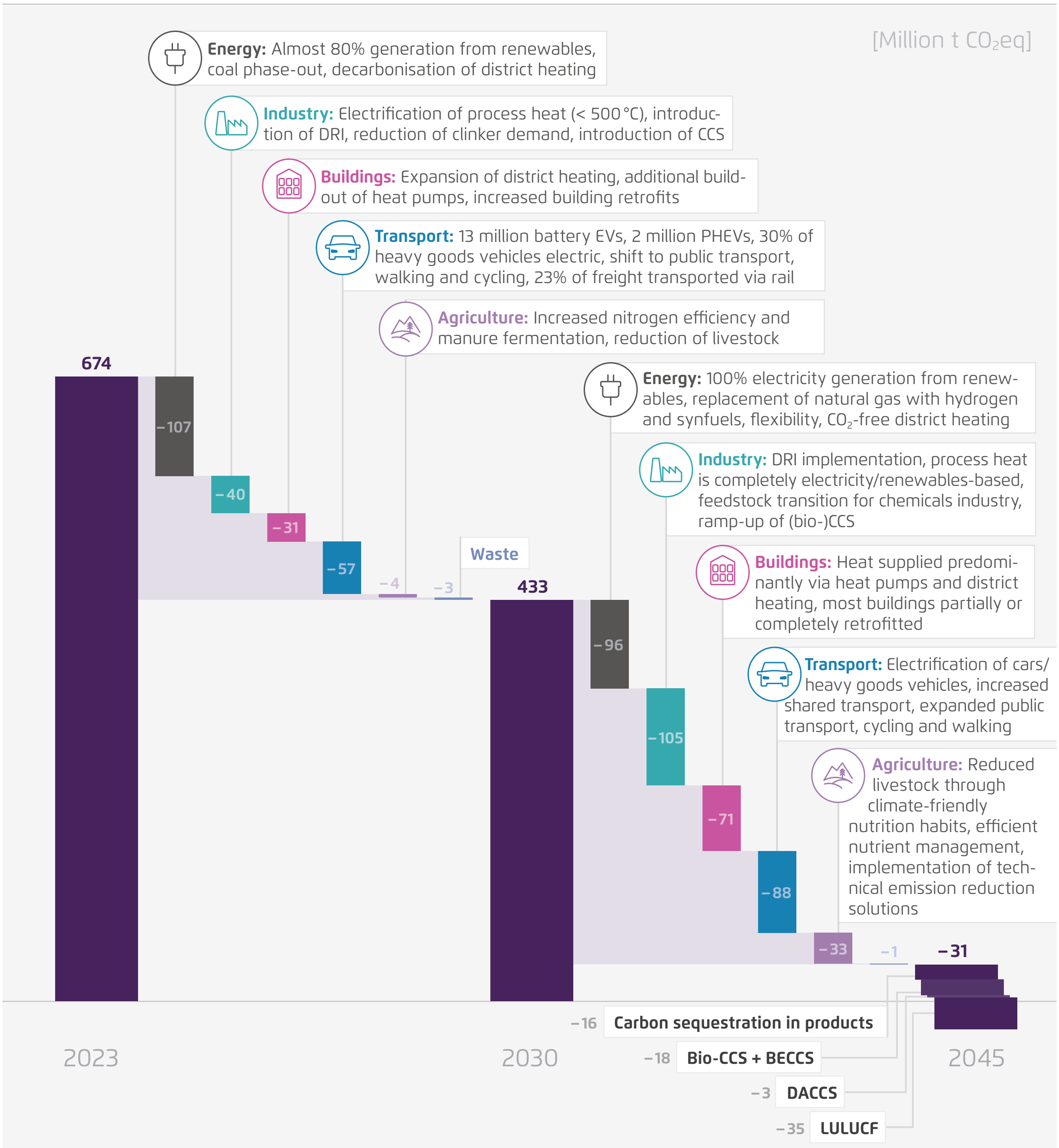
Biomass, hydrogen and carbon capture and storage (CCS)

In the scenario, biomass, hydrogen and CCS technologies have clearly prioritised, pivotal roles in achieving climate neutrality.

- → By increasing the use of residual and waste materials, **biomass** is made available more sustainably than it is today, with supply increasing slightly from 286 TWh in 2020 to 301 TWh by 2045. Use of biomass as a raw material, especially as a sustainable source of carbon for plastics production in industry is significantly more important at 74 TWh in 2045. The use of biogenic gas for energy decreases from 87 TWh in 2020 to 41 TWh in 2045, while the use of solid biomass for energy increases from 201 to 245 TWh.
- → For cost and efficiency reasons, **hydrogen** is primarily used as a seasonal energy storage medium in the electricity sector and in certain industrial processes in the steel and chemicals industries. The demand for hydrogen increases to just under 270 TWh by 2045 and is covered mainly by imports. In addition, 155 TWh of liquid hydrogen-based fuels (power-to-liquid) is used primarily in aviation and to a much lesser extent in the energy industry.
- → CCS is used at the few **fossil point sources that remain unabated in the industrial and waste sectors**. These include process emissions, particularly in cement and lime production, the non-biogenic share of waste

Measures in the climate-neutral Germany 2024 scenario

→ Fig. A



Agora Energiewende, Prognos, Wuppertal Institute, Öko-Institut and University of Kassel (2024). EV = electric vehicle; CO_2 = carbon dioxide, CCS = carbon capture and storage; DACCS = direct air carbon capture and storage; DRI = direct reduction of iron ore (in steel production) through hydrogen and natural gas; LULUCF = land use, land use change and forestry; PHEV = plugin hybrid electric vehicle

incineration and CO_2 generated during the chemical recycling of plastic waste. **CCS is also used in combination with biogenic CO_2** to offset residual emissions, particularly from agriculture. In addition, a small amount of CO_2 is captured directly from the ambient air. The total amount of CO_2 stored in 2045 is 45 million tonnes.

Resilient transition pathways

Recent years have made it clear that supply-chain problems and unexpected hurdles in implementation can delay the transition to climate neutrality. To account for these, resilient pathways are part of the climate-neutral Germany scenario. The scenario contains various sensitivities, including expanded CCS applications for industrial plants located in proximity to a CO_2 transport network, increased imports of intermediate products in industry, reduced building retrofits, and forest carbon sink vulnerabilities due to extreme weather such as storms or droughts.

In the scenario, the emission targets set by the Climate Protection Act for 2021 to 2030 are met, with greenhouse gas emissions dropping by more than 65 percent by 2030 compared to 1990. Germany achieves negative emissions of 30.7 million tonnes CO_2eq by 2045, with most emission reductions in the energy and industrial sectors completed by 2040, driven by developments in the European Union Emissions Trading System (ETS 1). By 2040, both sectors are almost completely climate neutral.

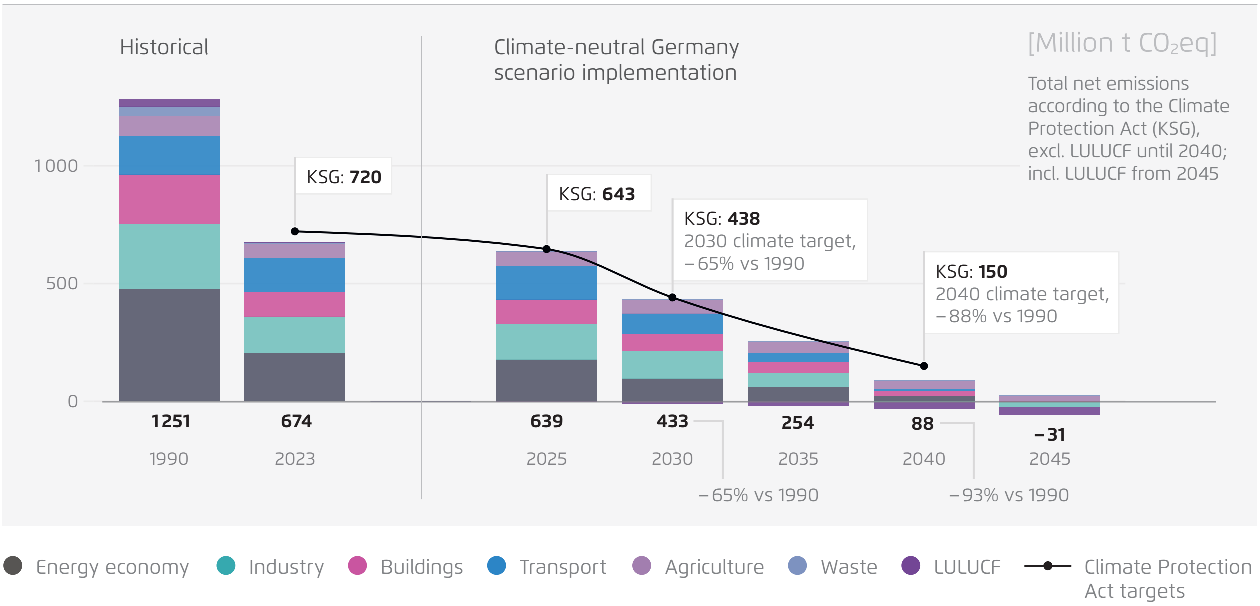
Three quarters of the investments in Germany up to 2045 would be required even without the transition to climate neutrality. All additional climate-specific investments from 2025 to 2045 amount to approximately 3 percent of gross domestic product (GDP).

Total investments during this period are projected to average EUR 540 billion (2023 values) per year – this corresponds to around 11 percent of Germany's economic product (GDP) in this period (Figure C). After an initial period of high investment, the overall need for investment is expected to decline significantly from 2030.

Total investments can be divided into **two categories**:

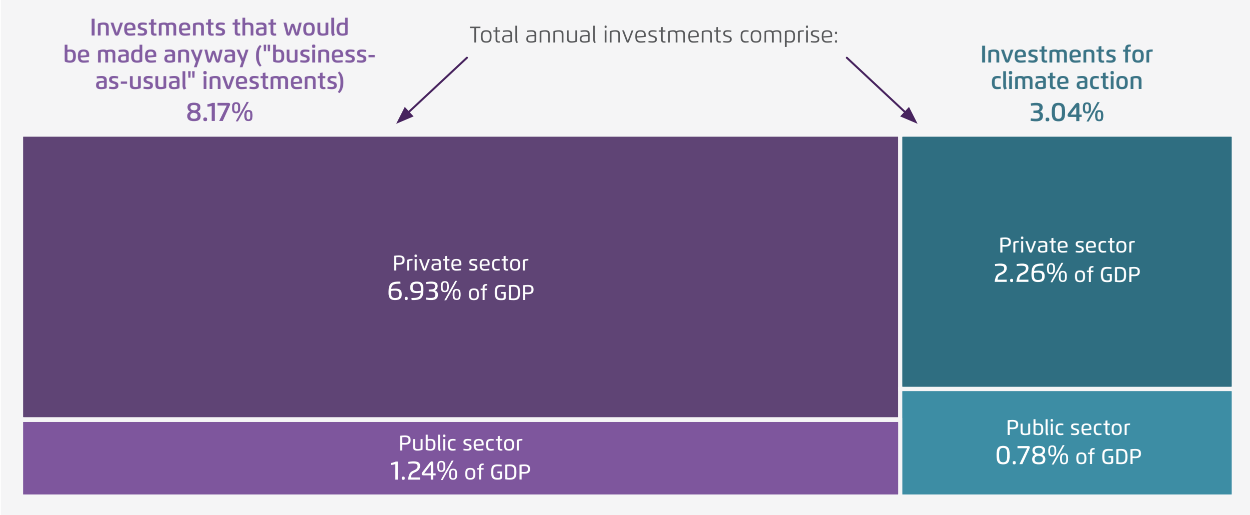
→ **Investments that would be made regardless of climate-neutrality objectives ("business-as-usual" investments): Around three quarters of the**

Greenhouse gas emission reduction pathways by sector, until 2045 → Fig. B



Agora Energiewende, Prognos, Wuppertal Institut, Öko-Institut and University of Kassel (2024), historical data: Umweltbundesamt (2024).
KSG = *Klimaschutzgesetz* (German Climate Protection Act).

The average annual investment volume is 11.2 percent of the gross domestic product (GDP) → Fig. C



Agora Energiewende, Prognos, Öko-Institut, Wuppertal Institute and University of Kassel (2024)

total would occur even without the transition to climate neutrality. In other words, this would be a redirection of investments from fossil-based technologies to climate-neutral alternatives. This would total an average of EUR 394 billion per year or 8.1 percent of GDP from 2025 to 2045 across all sectors. Private investments account for 85 percent of this, while public investments account for the remaining 15 percent.

→ **Investments for climate action: Only a quarter of total investments consist of targeted investments for climate action.** These are additional investments required for climate-neutral technologies as alternatives to fossil-based technologies. However, these investments do not always translate to higher lifecycle costs. For example, despite a higher initial purchase price, many electric cars are already more economical than gasoline and diesel vehicles due to lower operating costs over their entire lifecycle. From 2025 to 2045, targeted climate investments across all sectors are set to average EUR 147 billion per year, or about 3 percent of GDP. Private investments contribute 74 percent, with public investments covering the remaining 26 percent. In the scenario, around 90 percent of investments in renewable energy and grid infrastructure are financed by market revenues and fees.

Public funding helps bridge economic efficiency gaps and mitigate excessive cost burdens on citizens and companies.

While the majority of investments by companies and citizens is self-financing, the amount of investment required indicates that funds from the state budget will be needed to bridge cost gaps or ease the cost burden on households and companies. Until 2030, the annual requirement for public funding is expected to average EUR 58 billion. In contrast to other sectors, the largest cost in the energy sector results from existing renewable energy power generation plants, which will

→ Public funding requirements: From the state budget

Subsidies for investment and operating costs
→ Objective: Enable investments and close profitability gaps

Compensation payments for citizens and companies
→ Objective: Avoid excessive cost burdens

incur a total cost of EUR 95 billion by 2045. All new renewable energy plants that are added from 2025 onwards will require only EUR 45 billion by 2045 – even as electricity production increases fivefold.

A mix of policy tools can ensure these investments are made efficiently and equitably.

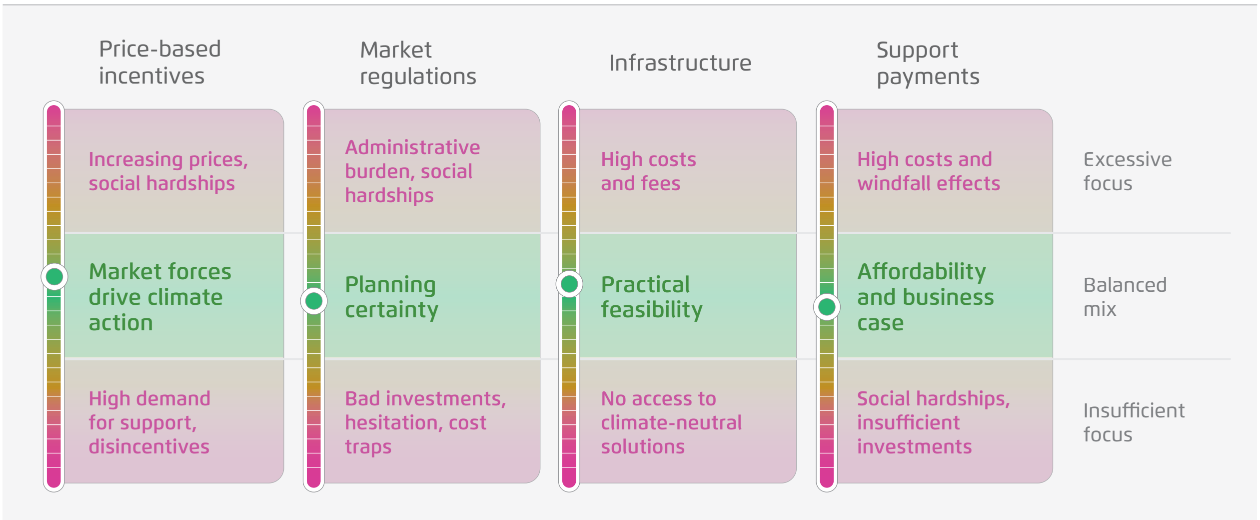
Four main policy instruments are available to facilitate the necessary change. Each of these make an important contribution, but also have their disadvantages:

→ **Price-based incentives:** Carbon pricing makes the use of fossil fuels more expensive, making climate-friendly technologies more competitive. However, upfront investment costs for climate-neutral alternatives remain unchanged. Putting a cost on emissions increases energy prices for both industry and consumers, potentially straining those with limited financial or infrastructural options to switch to climate-neutral technologies.

→ **Market regulation:** Restricting access to fossil technologies and regulating the distribution of costs can create investment security. Although such measures create demand for climate-friendly technologies, they do not guarantee affordability. For this reason, these measures should primarily be used where the cost gap between fossil-based and climate-neutral solutions is minimal or non-existent, but where there are other barriers to investment. Where cost gaps are larger - for example in the buildings sector - it is essential to combine them with financial support measures. Excessive regulation can complicate legislation and may stifle innovation if it becomes too detailed.

→ **Funding:** Financial incentives, such as grants or loans, can lower the initial investment barriers to climate-friendly technologies. These instruments are particularly useful when technologies are cost-effective over their lifecycle, but high upfront costs remain a hurdle. Targeted financial support can reduce additional costs and offset burdens for households and companies. However, excessive focus on state support can strain state coffers, while untargeted subsidies risk benefiting consumers who would have made these investments without assistance, driving up costs for the state and inhibiting a cost-efficient transition to climate neutrality.

A balanced policy mix is the key to climate neutrality → Fig. D



Agora Energiewende (2024)

→ **Infrastructure development:** Well-developed energy and transport infrastructure is essential for widespread adoption of climate-friendly technologies. Clear rules and strategic planning can ensure smooth and efficient development and make capital access easier for companies, facilitating their investments in climate-neutral technologies. However, overemphasis on infrastructure can result in additional economic costs and, depending on the financing model, higher state expenses or increased user fees.

A balanced combination of these elements reduces these drawbacks and maximises their strengths: market regulation offers planning security, price-based incentives activate market forces for climate action, and financial support ensures social equity. The climate-neutral Germany scenario developed in this study draws on this balanced approach, outlining each sector's central policy levers and their impact and interaction.

This future vision may not play out exactly as described. However, it provides an illustrative view forward of the transition to a climate-neutral Germany and thus provides a cohesive basis for discussing how to get there. The core elements of the scenario reinforce the roadmap already outlined in our 2021 study[1]. Regardless of where the political emphasis will be placed on the specific design of this transition pathway, one thing is clear: realising a socially equitable and prosperous climate-neutral Germany will require societal commitment, rapid technological advancements and ambitious policies.

1 Prognos et al. (2021): Towards a climate-neutral Germany by 2045

1 Introduction

In the spring of 2021, the study 'Climate-neutral Germany 2045' showed for the first time how Germany can become climate-neutral by 2045 while maintaining its competitiveness. In the meantime, this target has been enshrined in the Federal Climate Protection Act *(Bundes-Klimaschutzgesetz, KSG)* and has a consensus among the democratic parties. Germany has moved from the target-setting stage to the implementation phase.

In the energy sector, this implementation phase – hastened by the political crises of recent years – is already quite advanced. Russia's war of aggression against Ukraine and the subsequent energy price crisis, as well as increasingly noticeable climate change, have shown that independence from fossil fuels and the transition to climate neutrality are existential factors for protecting key societal values, such as health, prosperity, security of supply and political freedom. The flood disasters of recent years underline: it is more urgent than ever to invest in emission reductions as well as climate adaptation. Because only if world greenhouse gas emissions are brought to net zero can global heating be limited. The good news is: national and European climate policy is working. The climate protection gap for a 65 percent reduction in greenhouse gas emissions by 2030 (compared to 1990) has shrunk noticeably, while Germany has become less dependent on fossil energy imports.

Concurrently, the German economy is facing some considerable challenges: the aftermath of the fossil-energy price crisis is still very palpable and the outlook for Germany as a business location has deteriorated markedly since 2021. European emissions trading means that investments in fossil energy have no future. At the same time, there is a lack of viable framework and planning certainty to revitalise the industrial base through investments in a climate-neutral industrial location. However, this renewal is necessary – and at the same time offers the opportunity to make Germany and Europe more competitive through innovations and modern technologies.

Climate neutrality brings about some significant changes in many areas – from industry to the transport and buildings sectors to agriculture. Furthermore, after the German Constitutional Court's budget ruling, these questions arise more than ever: how can the path to climate neutrality be designed to save costs as much as possible? How can possible additional costs be fairly distributed? And where are compensation payments necessary? In short, the question is: how can implementation be achieved rapidly, fairly and in a way that creates prosperity?

The transition to climate neutrality is a unique political task. Support from broad sections of the population is one of the key factors for success. While the decarbonisation of the energy sector has hardly been noticeable for many citizens, there will also be changes in the coming years that will have tangible impacts on people's real lives. This is challenging and requires judiciously-planned measures which are communicated in an understandable way. At the same time, it is clear that unexpected problems will crop up repeatedly on the way to a climate-neutral Germany. The following aspects are, therefore, particularly important for successful implementation:

1. **Political frameworks for cost efficiency, investment security and financial support** – also extending across legislative periods. In order to show pathways towards solutions, the new scenario contains not only techno-economic modelling but also, for the first time, a calculation of investment needs and proposals for policy instruments.
2. **Resilience on the way to climate neutrality via technology buffers and diversification:** Actual investment decisions in most sectors confirm the fundamental technology pathways in the study 'Climate-neutral Germany 2045'[2]. At the same

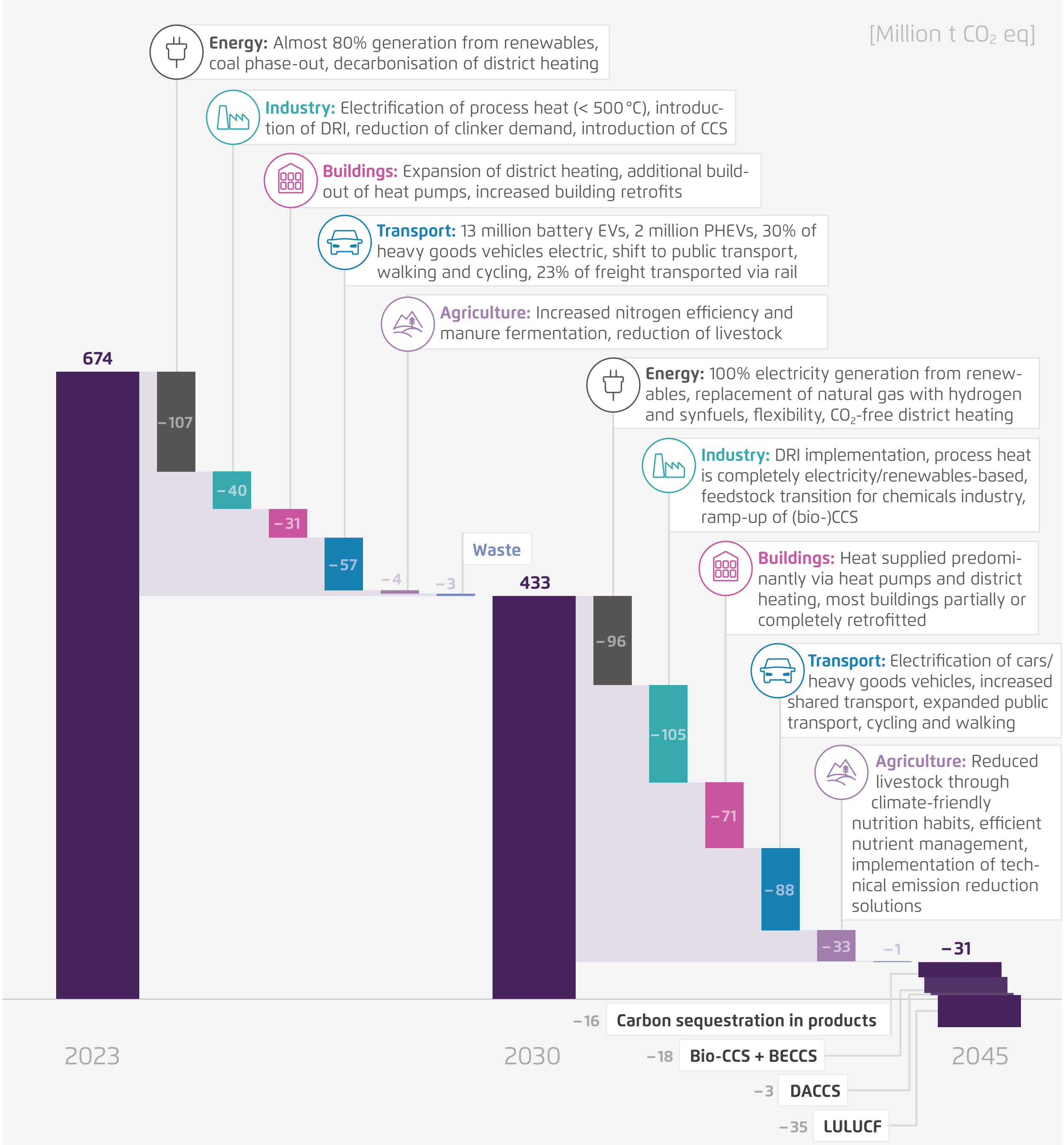
2 Prognos et al. (2021): Towards a climate-neutral Germany by 2045

time, recent years have illustrated that supply chain problems and unforeseen hurdles in implementation can delay the switch to climate neutrality. Resilient ramp-up pathways take account of these uncertainties. The scenario therefore includes various sensitivities, for instance, wider application of Carbon Capture and Storage (CCS) along a CO_2 transport network, reduced retrofitting activity or diminished carbon-sink capabilities of forests because of storms and droughts. But it is also clear: it will need an effort by society, rapid technological innovations and bold policies to turn the pathway outlined in this study into reality.
3. **Bolstering public trust in a socially-equitable transition to climate neutrality:** Climate neutrality offers numerous opportunities for prosperity and well-being – and particularly the possibility of improving the situation of people on low incomes. A prerequisite for this is active participation of citizens and companies in essential decisions. Moreover, public funding is required to provide the social backing for political measures. After all, a compelling vision of the future is needed, providing guidance and creating tangible opportunities.

This present study paints such a picture of the future for a successful climate-neutral Germany. The next chapter gives an overview of the scenario. Chapters 3 and 4 address individual sectors and policy instruments. Chapter 5 deals with investment needs and Chapter 6 examines aspects of social compensation, focussing on the buildings and transport sectors. The annexes contain an overview of central framework data and modelling results as well as a list of public funding needs.

2 The scenario at a glance

Measures in the climate-neutral Germany 2024 scenario → Fig. 1



Agora Energiewende, Prognos, Wuppertal Institute, Öko-Institut and University of Kassel (2024). EV = electric vehicle; CO_2 = carbon dioxide, CCS = carbon capture and storage; DACCS = direct air carbon capture and storage; DRI = direct reduction of iron ore (in steel production) through hydrogen and natural gas; LULUCF = land use, land use change and forestry; PHEV = plugin hybrid electric vehicle

Guiding principles of the scenario

The scenario 'Climate-neutral Germany – From Target-Setting to Implementation' is based on five overarching goals:

Affordable and reliable energy supply

The German energy system's conversion takes place in an economically efficient way. Renewable energies are consistently expanded as the most economical form of generation. Savings potentials are leveraged during grid expansion: cost optimisation is increased when connecting offshore wind farms and, more generally, a fundamental reform of regulation leads to greater efficiency in the utilisation and expansion of the electricity grids. Price-based incentives to boost flexibility of electricity demand and storage reduce the use of dispatchable power plants and the fuel consumption linked to them. Dependence on fossil energy imports comes to a complete end.

Stimulating an innovative and competitive economy

Investments in climate-neutral processes and products help the economy out of the crisis. New value chains are emerging, for example by replacing previously imported fossil raw materials in the chemical industry with sustainably grown biomass from within the country. Stable framework conditions and access to affordable energy ensure that German industry is sustained across the board. In this way, Germany assures that it occupies an important role in global growth markets, about three quarters of which are based on the transition to climate neutrality[3]. The early phase-out of fossil fuels secures a locational advantage for climate-neutral production and thus its long-term international competitiveness as a business location.

3 BDI (Federation of German Industries) (2024): Transformationspfade für das Industrieland Deutschland

Participation in sustainable housing for all

Climate-neutral refurbishment of buildings leads to an increase in the value of the building stock. A funding framework, graduated according to income, protects owners and tenants from excessive cost increases. Renovations boost resilience to heat waves, thus contributing to better health as well. Additional and affordable housing will be created in existing buildings with better adaptation to residents' needs than before.

Clean and accessible mobility for all

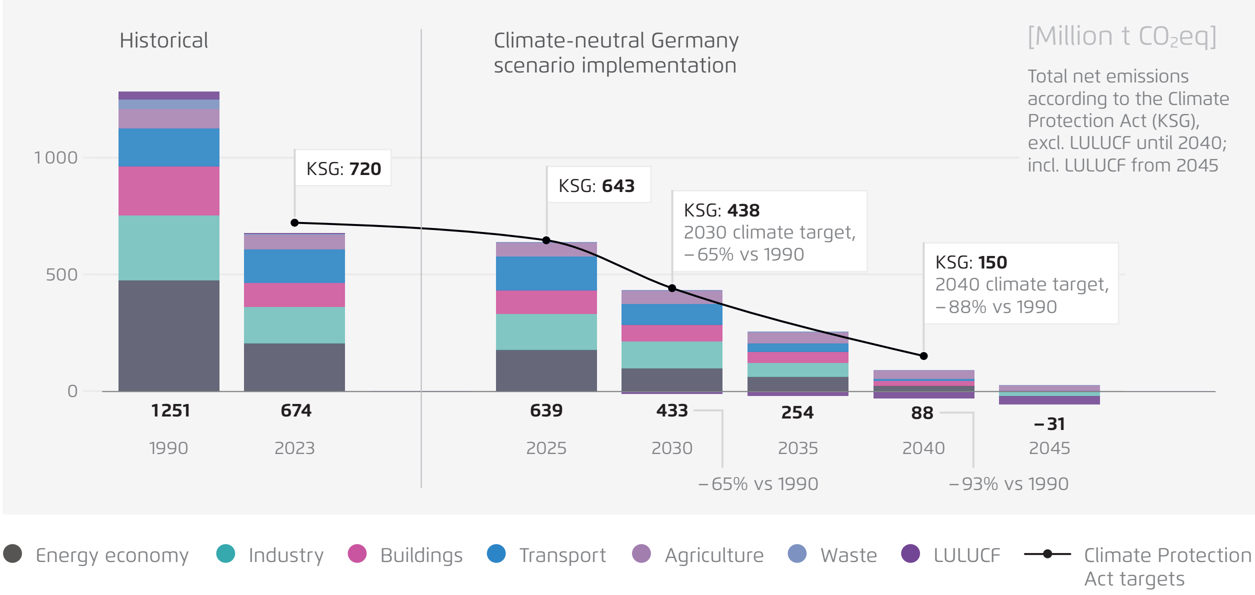
The expansion of public transport capacities improves mobility options for citizens and thus the attractiveness of rural areas. Targeted investment aid makes it easier for people on low incomes to purchase efficient electric cars and a mobility allowance supports them in the short-term. Lower pollution including from noise, exercise through cycling and walking and fewer sealed surfaces have a positive effect on health and the quality of life.

Productive and resilient agriculture and forestry

Agriculture makes a significantly greater contribution to climate neutrality than it does today, as its greenhouse gas emissions decrease substantially, more CO_2 is stored on agricultural land and it produces sustainably grown biomass for the bioeconomy. The measures help to strengthen animal welfare, increase biodiversity in agricultural areas and enhance resilience to climate change.

The scenario fulfils the constitutional requirement for Germany to achieve climate neutrality in the near future and thus not burden future generations by postponing emission reductions into the future. The target of 65 percent less greenhouse gas emissions in 2030 compared to 1990 is met and there is also compliance with the total amount permitted under the Federal Climate Protection Act *(KSG)* for the period 2021 to 2030. A large proportion of the emission reductions

Greenhouse gas emission reduction pathways by sector, until 2045 → Fig. 2



Agora Energiewende, Prognos, Wuppertal Institut, Öko-Institut and University of Kassel (2024), historical data: Umweltbundesamt (2024).
KSG = *Klimaschutzgesetz* (German Climate Protection Act).

will take place by 2040: incentivised by developments in the European Emissions Trading System (ETS I), both the energy sector and industry sector will be almost completely climate-neutral by that time. Enabled by a mix of price-based incentives, market regulation, infrastructure expansion and financial support, emissions in the buildings and transport sectors will also decrease considerably by 2040. Agriculture and forestry can significantly increase their contribution to climate neutrality by 2045 while simultaneously strengthening biodiversity conservation, health and other sustainability goals.

2.1 Total investments and climate protection investments

An essential building block for achieving climate neutrality is the investment shift away from fossil fuels to climate-neutral technologies and infrastructures. The amount of total and climate protection investments required was therefore also quantified in the scenario for the first time.

The **total investment** from 2025 to 2045 amounts to an average of 540 billion euros per year – this represents about 11 percent of Germany's economic output for this period (Figure 3). Around 18 percent of this must be made by the public sector. This includes investments coming directly from the state budget, such as schools, plus investments by companies that are wholly or partially publicly-owned, such as public utilities.

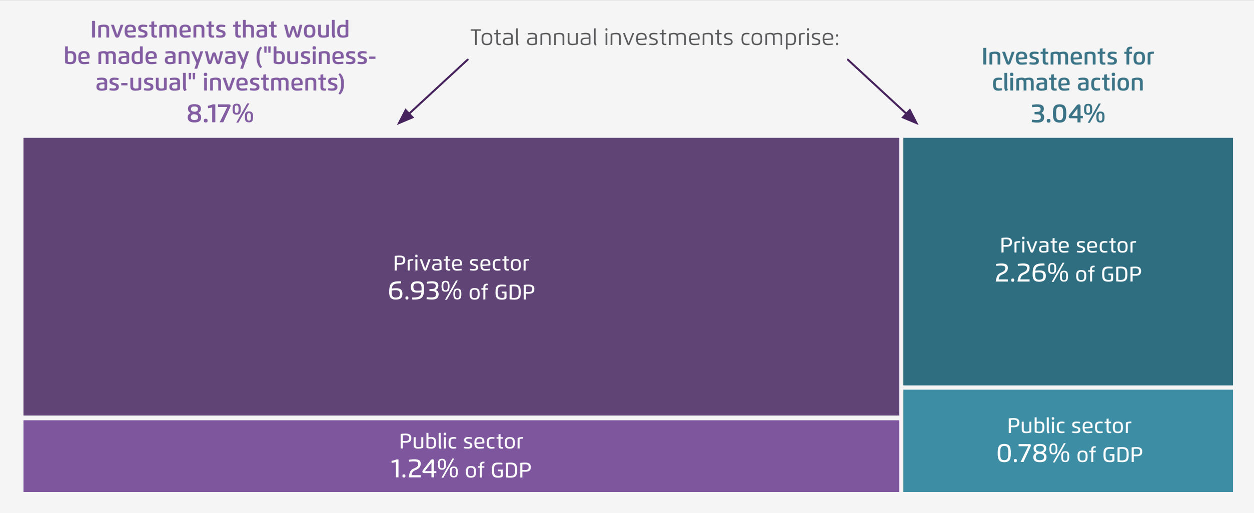
Total investments can be divided into **two groups** (Figure 3):

→ Around three-quarters of the sum would also be incurred without the switch to climate neutrality (so-called **„Business-as-usual" investments**) – hence this is about redirecting spending from fossil technologies towards climate-neutral investments.
→ A quarter of the total investment is allocated to so-called **climate protection investments**. These are **additional expenditures for the acquisition** of climate-neutral technologies as opposed to fossil reference technologies – for example, the higher purchase price of a heat pump compared to gas heating.

However, the higher investments do not always mean additional costs over the entire life cycle. For

The average annual investment volume is 11.2 percent of the gross domestic product (GDP)

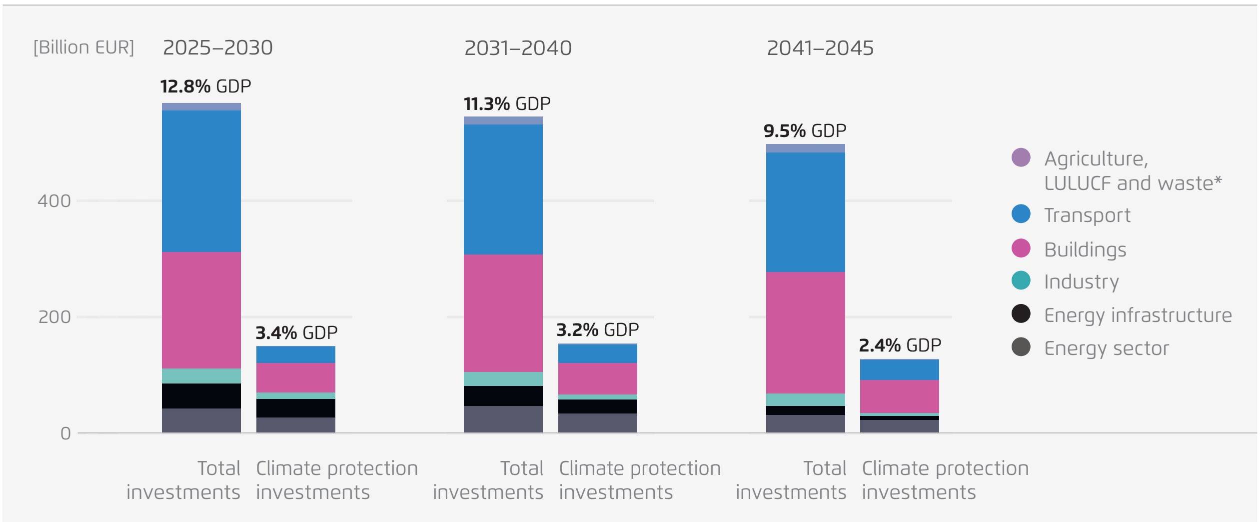
→ Fig. 3



Agora Energiewende, Prognos, Öko-Institut, Wuppertal Institute and University of Kassel (2024)

Total and climate protection investments in the sectors as a share of gross domestic product

→ Fig. 4



Agora Energiewende, Prognos, Öko-Institut, Wuppertal Institute and Kassel University (2024). Share of Gross Domestic Product in the respective time periods, in real prices (2023). *Calculations do not include all categories of necessary investments.

example, despite currently higher purchase costs, many electric cars are already more economical than petrol and diesel vehicles, given the lower operating costs over their whole lifespan.

The political challenge, especially for private households, ist the following: Whether or not additional costs will arise during the transition to climate neutrality is determined by household-specific factors: for instance, the condition of the building envelope for renovations, ownership or tenant status, the availability of transport and district heating infrastructure and so forth. Policy instrumentation cannot therefore be implemented with regard to an individual product's life-cycle costs but only by taking into account the overall circumstances. The necessary investments and public finance requirements are examined in more detail in Chapter 5.

2.2 Policy options for the transition to climate neutrality

Given this complex tangle, the state has several options to enable or smooth the switch to climate-neutral alternatives and to influence the distribution of purchase and operating costs:

Price-based incentives

Price-based incentives such as a CO_2 price can help to ensure pricing-in of negative environmental impacts and thus close the economic viability gap between climate-neutral technologies and fossil fuels. This will result in additional state revenues and means that fossil options become more expensive. This is done by making fossil options more expensive. The absolute costs of climate-neutral investments do not decrease thereby. For people on low incomes, this can lead to burdens that are socio-politically unacceptable, and for companies exposed to international competition, to the risk of industrial relocation. So further measures may be necessary to offset the additional costs. Revenues from CO_2 pricing can contribute to this.

Market regulation

Market regulation can take various forms. In the context of financing the shift to climate neutrality, important options for state action include market access regulations for technologies, requirements for cost allocation and price regulation for natural monopolies. Such measures do not directly burden the state budget.

→ Market regulation through **technology standards** has been successful on many past occasions, for example, the successive bans on using CFCs (chlorofluorocarbons) in new refrigerators or ending the use of leaded petrol. Market regulation creates planning and investment security for consumers as well as manufacturers. The demand for alternative products also goes up, helping to reduce the cost per product (economies of scale). But since this option does not necessarily make climate-neutral technology cheaper than the fossil model of reference, it should primarily be used when the cost difference is small anyway or in combination with financial support.

→ **Requirements for cost allocation** are particularly necessary when price-based incentives cannot have their full effect because the cost burdens and options for action diverge. One example of this is the Carbon Dioxide Cost Allocation Act *(Kohlendioxidkostenaufteilungsgesetz)*, which regulates the allocation of the CO_2 surcharge for fossil heating in the buildings sector. Before the regulation, tenants bore the CO_2 costs without any limitation but were not in a position to decide on remedies, such as the installation of heat pumps.

→ **Price regulation** by the state is particularly necessary when market competition is hampered by natural monopolies and a power imbalance emerges between suppliers and consumers. This is the case, for example, with energy infrastructure.

Infrastructure

The availability of energy and transport infrastructure such as electricity and heating networks, CO_2 infrastructure or local public transport is a basic prerequisite for switching to climate-neutral alternatives. In any case, government regulation is required here. Furthermore, clear legal regulations for infrastructure planning can ensure that the expansion is efficient and aligned with the objectives. The state can additionally bolster companies' financial strength through direct shareholding in grid companies, thus enabling access to capital on more favourable terms and on a larger scale. After all, (partial) financing of infrastructure from tax revenues is an option, as is currently the case in Germany with road construction.

Financial support

Financial support measures basically pursue two different purposes but they can also be combined in one instrument: on the one hand, support of investments in climate-neutral technologies and, on the other, compensation for additional burdens brought about during the shift to climate neutrality.

Support for investments in climate-neutral technologies can be provided through assistance for financing as well as government subsidies for purchase and operating costs. The extra costs incurred can be offset either by the overall state budget or in the framework of levies paid by a group that uses a particular good or service.

- → **Support for financing** is an option especially when investments are economically viable over the entire life cycle, but it is challenging for private individuals or companies to raise the higher initial investments. This can occur due to the current tense economic climate or insufficient savings.
- → **Subsidies for purchases and operating costs:** This can involve both financial support to acquire climate-neutral technologies, such as a subsidy for a heat pump, and support to operate a facility, such as payments for units of energy generated. So as to make the best possible use of limited budgetary resources, these subsidies should be limited to those citizens and businesses who really need them. The additional costs for the subsidy can be covered by raising a **levy**. In this case, the costs are not met by public-sector budgets, but by a group that uses a particular good or service. Electricity customers have in the past co-financed renewable energy expansion via the Renewable Energy Sources Act levy *(Erneubare-Energien-Gesetz, EEG)*.

The state can finance **compensation payments** from the budget to give targeted support to certain groups. This can make sense for industrial or social policy reasons. Thus, for example, electricity price compensation is intended to safeguard the competitiveness of energy-intensive companies. And as it will hardly be possible to accommodate all individual life circumstances by means of targeted investment aid, the payment of a general climate or mobility allowance may be advisable on a temporary basis.

2.3 From instruments to a package: reasons to combine different policy instruments

Greenhouse gas emissions in the absence of political intervention are a market failure because the environmental damage and associated prosperity losses are not reflected in prices. This suggests that pricing emissions could already be sufficient to trigger the investments needed to prevent this damage. The pricing of greenhouse gas emissions actually does play a central role in achieving climate neutrality. But there are a number of reasons why a combination of instruments in a so-called policy mix has clear advantages over emissions pricing alone or the unilateral use of other policy instruments.

These can be split into two groups: firstly, arguments for expanding policy instruments beyond emissions pricing. Secondly, a unilateral focus on regulatory instruments or financial support can also bring disadvantages. A well-gauged policy will, therefore, aim for a combination.

The reasons why emissions pricing alone is inadequate include:

- → **Certain market failures persist despite emissions pricing:** The specific composition of the policy mix should take into account the behavioural structures and particular characteristics of each respective area. In the buildings and transport sectors especially, a substantial part of the investment decisions are made by private individuals. Consumers often have only incomplete information about future cost developments. Moreover, studies show very clearly that the foreseeable future increase in fossil-fuel operating costs (such as an increase ensuing from the European Emissions Trading Systems ETS I for the energy sector, energy intensive industry, aviation and shipping or ETS II for the buildings and road transport sectors) is systematically underestimated when purchasing decisions are made.[4] Another example is the distribution of costs between tenants and landlords. Without additional measures, the costs of CO_2 pricing will be incurred by tenants and the costs of a new heating system by landlords. As a result, investments in climate-neutral technologies do not happen.

- → **Uncertainties on the way to climate neutrality and a consequent holding-back of investment:** The risk of a high CO_2 price is already sufficient to prevent investments in fossil fuel systems. However, this does not mean that a capital-intensive investment in a climate-neutral alternative might be profitable i.e. that it has a clear business case. This is one of the most pressing problems and the core challenge during the transition to a climate-neutral industry in Germany. Market regulation requirements and targeted funding programmes for investments can create the necessary investment- and planning-certainty here.
- → **Equality aspects:** The political and, above all, financial changes during the shift to climate neutrality are so great that they raise equity issues. From the welfare state principle in the constitution, the state derives a mandate to safeguard a just social order and not to leave this to market forces alone.
- → **Links to economic, geopolitical and security policy strategies:** The transition to climate neutrality is accompanied by a fundamental technological shift. This can result in industrial and geopolitical opportunities and risks. Owing to this, it may make sense to support the establishment or preservation of key industries for achieving climate neutrality in Germany, even if this is associated with budgetary burdens.
- → **Synergies with other policy areas:** The choice of certain policy measures also often depends on whether synergies can be made with the policy fields of health, biodiversity, social policy and so on. For instance, from a social and health policy perspective, it may be desirable to provide free meals in nurseries and schools.

4 See Castro et al. (2020): A review of agent-based modelling of climate-energy policy; Safarzynska (2017): Integrating behavioural economics into climate-economy models: some policy lessons

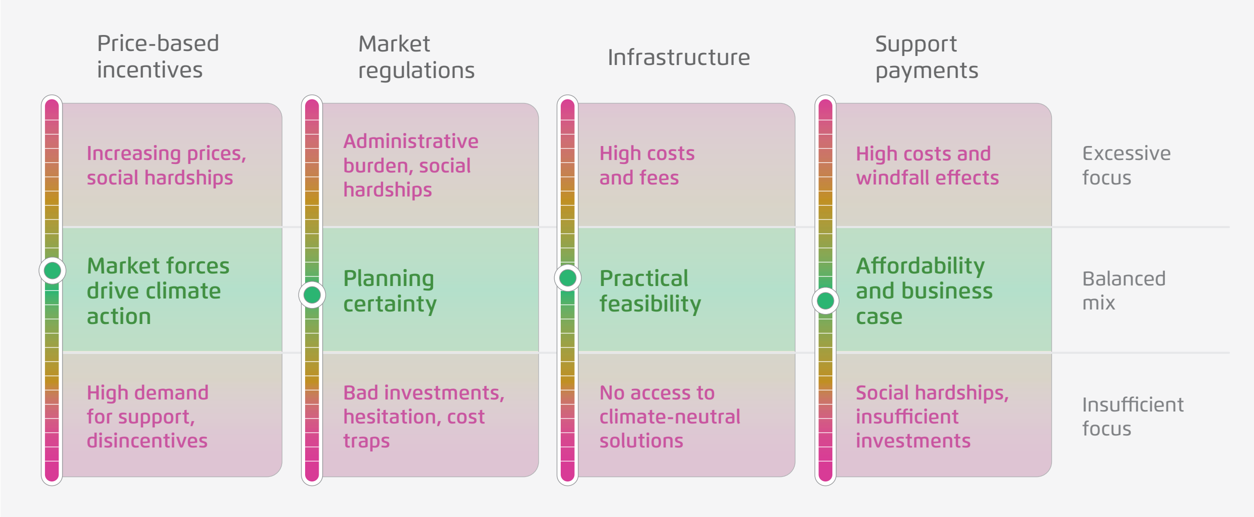
The drawbacks of the four categories of policy instruments can be summarised as follows:

- → **Price-based incentives:** Emissions pricing leads to energy price rises for industry and citizens, potentially causing a heavy burden for individual groups which have no opportunity to switch to climate-neutral technologies (whether for financial or infrastructure reasons).
- → **Market regulation:** A one-sided use of market regulation can greatly increase the complexity of legal regulations and inhibit innovation potential by attempting overly detailed controls. Furthermore, unless accompanied by financial support measures, this can also lead to burdens that are socio-politically unacceptable.
- → **Infrastructure:** Excessive state influence on the expansion of infrastructure can also result in inefficiencies and thus higher costs for the economy.
- → **Funding:** Too great a focus on state funding can lead to very high strain on the public budget and, with an indiscriminate use of grants, to deadweight effects, thus hindering a cost-efficient transition to climate neutrality.

A balanced combination of these elements reduces these negative effects and brings out the strengths of the respective approaches: Market regulation creates planning security, price-based incentives mobilise market forces for climate protection and financial support ensures social equity and that individuals are not overwhelmed. (Figure 5).

The scenario developed in this study builds on such a balanced approach. The following chapter presents the instruments underlying each respective sector. The focus of the analysis is not on presenting the instruments in as much detail as possible. It is, rather, about outlining the central political levers, their impact and interaction with each other.

A balanced policy mix is the key to climate neutrality → Fig. 5



Agora Energiewende (2024)

3 The sectors in detail

3.1 Energy sector

The energy sector includes production of electricity and district heating as well as the gas supply, petroleum refineries and production of coal products such as coke and briquettes. On the path to climate neutrality, the importance of electricity and district heating will increase significantly, while the supply of fossil gas, petroleum processing and production of coal products will gradually come to a halt. Conversely, hydrogen and electricity-based energy sources are used. This significantly reduces Germany's import dependence.

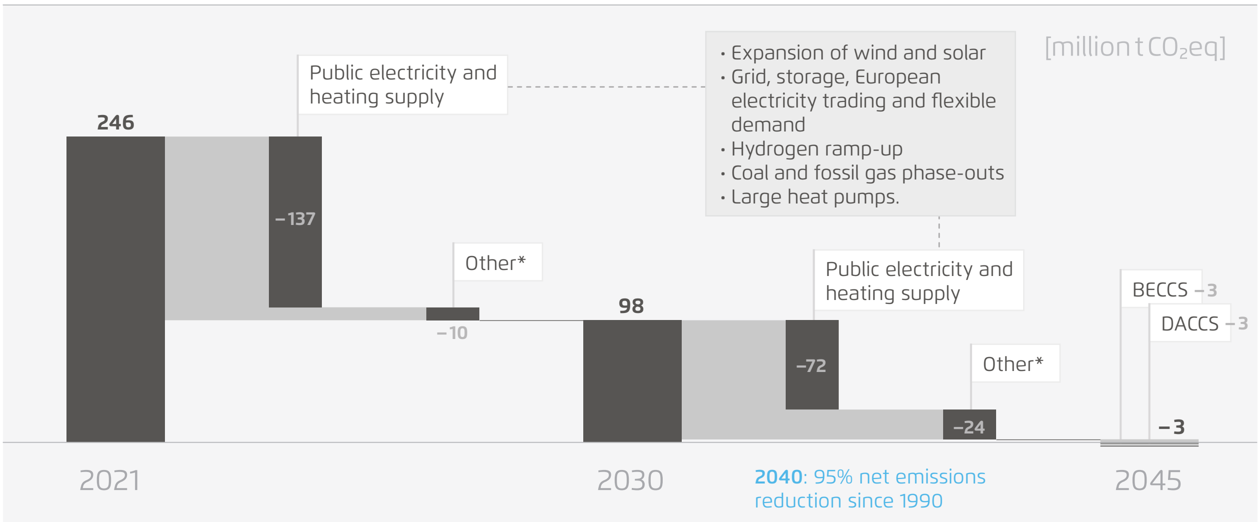
The energy sector accounted for more than a third of total German greenhouse gas emissions in 2022, with 257 out of 746 million tonnes of CO_2 equivalents ($MtCO_2eq$). Emissions in the energy sector have fallen by around 40 percent since 2014, mainly due to climate policy measures at EU and national level. The main reason for this was the expansion of renewable energies – which accounted for 52 percent of electricity generation in 2023.

The electricity sector forms the foundation of a climate-neutral energy system, as electricity is in most cases the most cost-effective and efficient form of meeting demand from industry, buildings and transport in a climate-neutral way. The essential pillars of a future-proof, modernised electricity system are consistent expansion of renewable energies plus electricity grids, including connections to neighbouring countries. There is additionally an expansion of energy storage and strong flexibilisation of electricity demand (Figure 6). As for district heating, alongside a robust expansion of electricity-based heat generation, other climate-neutral heat sources are tapped, such as geothermal energy and unavoidable waste heat.

The greater use of electricity increases the energy system's efficiency. Dependence on energy imports will also decrease from just under 2500 TWh in 2019 to 390 TWh in 2045, meaning a reduction of almost 85 percent (Figure 7).

At the same time, specific electricity system costs remain relatively constant over this period: the

Energy sector – reduction of greenhouse gas emissions → Fig. 6



Agora Energiewende and Prognos (2024). * Oil refineries (CRF 1.A.1.b), Production of solid fuels and other energy producers (CRF 1.A.1.c), diffuse emissions (1.B), pipeline transport (1.A.3.e).

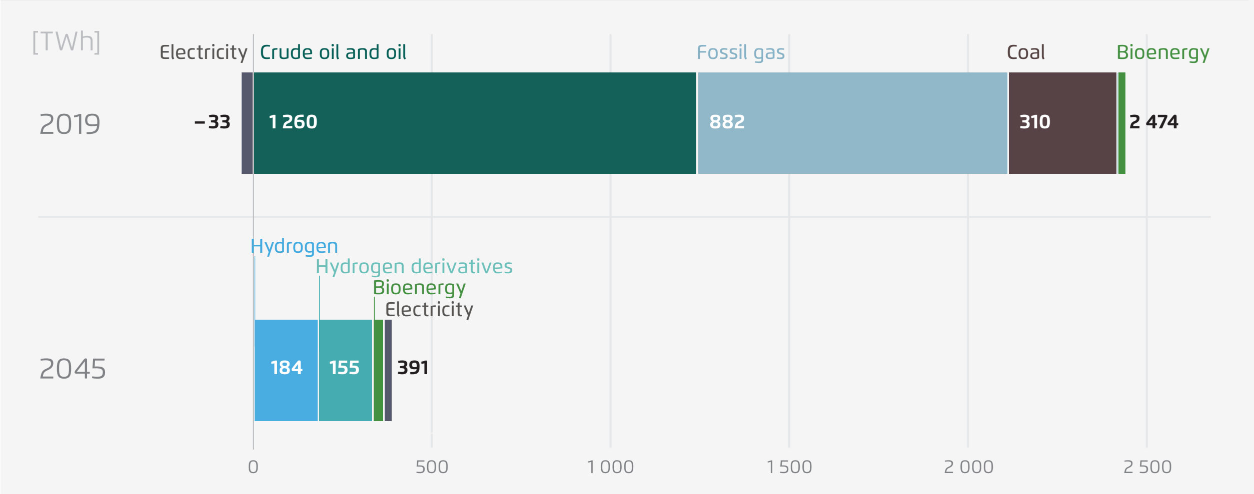
significant investments are offset by a considerable expansion in electricity demand so that average costs fall. They will remain at a similar level from 2025 to 2030 at 16 cents per kilowatt hour (kWh) and decrease to less than 13 cents per kWh between 2030 and 2045.

2025 to 2030: The sprint up to 2030

In the scenario, developments in the energy sector up to 2030 are shaped by a strong expansion of renewable energies and – in the course of accelerating electrification in industry and transport – a significant increase in electricity demand.

Reduction in net imports of energy sources up to 2045

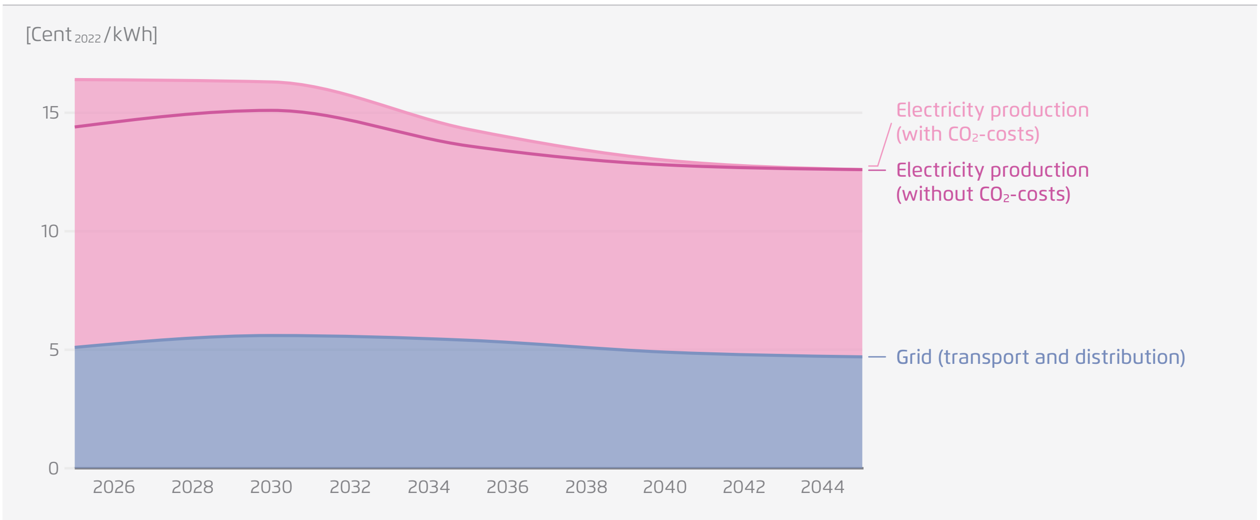
→ Fig. 7



Agora Energiewende, Prognos, Öko-Institut, Wuppertal Institute and Kassel University (2024), historical data: AG Energiebilanzen (2024).
Positive value is net import, negative value is net export.

Specific electricity system costs up to 2045

→ Fig. 8



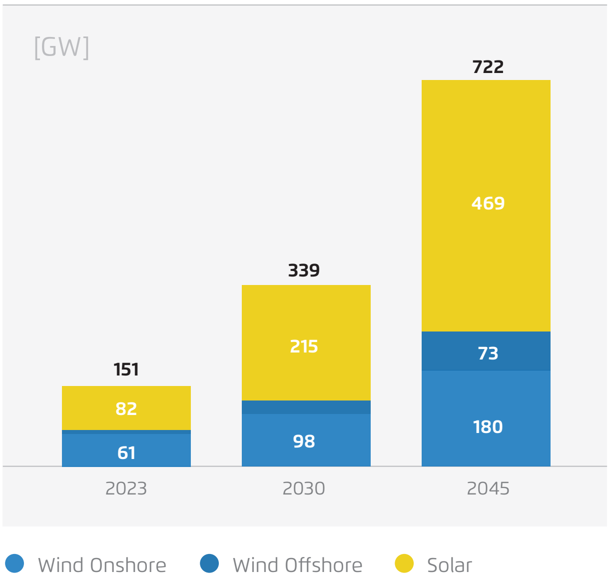
Agora Energiewende and Prognos (2024). H_2 grid costs are included proportionately in the fuel costs of electricity production.

Expansion of renewable energies

The extension of photovoltaics (PV) continues to increase from the current 15 gigawatts (GW) per year so that the expansion target in the Renewable Energy Sources Act *(EEG)* of 215 GW in 2030 is met. Roofs suitable for PV are covered as extensively as possible. Areas are utilised efficiently and profitably for all of society via multi-use approaches by installing PV that respects nature conservation criteria, such as agri-PV, moorland-PV and car park-PV. Opportunities for involvement at the local government level also ensure acceptance of wind turbines and PV on open areas.

On the other hand, expansion of onshore wind power will only reach 98 GW in 2030, instead of the *EEG* expansion target of 115 GW (Figure 9). Despite a significant increase in additional development, it is not possible to completely make up for the low expansion in the first half of the 2020s. As for offshore wind power, the expansion target of 30 GW will also be missed (with 26 GW actually installed), mainly due to grid connection delays. Against this backdrop, the share of renewables in the increased gross electricity demand will reach 76 percent in 2030 and the *EEG* target of 80 percent will be attained in 2032.

Installed capacity → Fig. 9



Agora Energiewende and Prognos (2024)

The Renewable Energy Sources Act *(EEG)* is being further developed to facilitate the most cost-efficient expansion. In the case of rooftop PV systems, incentives for on-site consumption and a subsidy mechanism with low hurdles ensure a well-balanced incentive for feed-ins. The economic viability of new, large RE (renewable energy) plants is ensured by a so-called "production-independent instrument". This, on the one hand, secures the plant operators' investment via state guarantees, and on the other, provides incentives to design and operate wind or PV plants in the most system-optimised way. It is supplemented by Power Purchase Agreements (PPAs).

Flexibility

Thanks to considerable progress in digitalisation, companies and citizens in 2030 can choose electricity tariffs that will allow them to react far more flexibly to electricity supply and demand than today, without sacrificing any comfort. Electricity suppliers offer dynamic electricity tariffs and grid fees are designed to be "time of use". Households charging electric vehicles and using heat pumps and home storage systems in a flexible way benefit from favourable electricity prices. Grid charges for energy-intensive industry are structured such that, instead of inefficient continuous use, more flexible usage behaviour becomes economically attractive (wherever this is technically and organisationally possible). New electrolysers (6 GW), batteries (60 GW, including home storage) and 6 GW power-to-heat boilers are operated dynamically, adapting to electricity prices and grid bottlenecks. In this way, market values stabilise, solar and wind plant curtailments decrease and fuel-based power plants are used less frequently.

Dispatchable power plant output

The ETS I reduction path with implementation of the reforms means that the last new CO_2 certificates will be issued on the market in 2039. In the scenario, the EU ETS I price rises to around 130 EUR_{2022} / t CO_2. As a result, the more expensive coal power generation is completely forced out of the market by 2030 – but some of the power plants will be kept in reserve. This

Energy sector – key policy instruments

→ Fig. 10

Market regulation	Price-based incentives	Financial support
→ Securing RE expansion: investments instrument (federal), accelerated land-use decisions (states) and rapid permitting (municipalities)	→ Option to combine PPAs and state investment instruments which reflect price signals	→ Ensuring economic viability of roof PV through a combination of on-site use and a simple feed-in premium
→ Obligation on electricity suppliers to guarantee supply security for their customers (decentralised capacity mechanisms/hedging)	→ Removal of uniform price zone and phase-in of dynamic grid charges and tariff models	
→ End to the issue of state CO_2 certificates in 2039 (ETS I)	→ CO_2 price path per tonne rising to 132 then 194 in 2030 and 2045 respectively (ETS I)	→ Tenders for dispatchable back-up power plants, support for H_2 usage via a levy system
→ Gas distribution networks: enable decommissioning, avoid stranded assets and disproportionate increases in network use charges	→ District heating consumer protection via a transparency platform and ex-post price supervision	→ Continuation of Federal Funding for Efficient Heating Networks at 3 billion EUR/year, risk hedging for the expansion of district heating

Agora Energiewende (2024)

means that the question of guaranteed power plant output is becoming increasingly important. In the scenario, 10 GW of new gas-fired power plants will be built by 2030, and another 15 GW will be added by 2035, with the prospect of them operating on hydrogen. In order to facilitate development of these projects at the necessary speed, government tenders to build H_2-ready gas power plants are being carried out, and the Combined Heat and Power Act *(Kraft-Wärme-Kopplungs-Gesetz, KWKG)* is being oriented towards hydrogen use. Future use of fuels is simultaneously being minimised by decentralised, market-based capacity mechanisms which incentivise a wide range of flexibility technologies via competition. In addition, CHP (combined heat and power) operation is exclusively electricity-driven.

District heating

District heating demand from the buildings and industry sectors rises by almost 10 percent to 122 TWh between 2020 and 2030. The number of residential buildings connected to the district heating network increases from around 1.4 million today to 2.2 million in 2030.

The switch to climate-neutral heat generation takes place much faster than before, mainly through the use of new large heat pumps and electric boilers. In total, climate-neutral sources generate 32 TWh of heat (excluding bioenergy). This development is made possible by a mix of instruments: a reduction in electricity taxes together with "time of use" grid charges reduce electricity costs for large heat pumps and promote their system-optimised operation. An increase and expansion of support is guaranteed by the Federal Funding for Efficient Heating Networks *(Bundesförderung Effiziente Wärmenetze)*, in the short term by adjusting the Combined Heat and Power Act *(KWKG)* and in the long term by a new instrument. In order to secure the necessary capital for the investments, certain risks are covered by the public sector: for example, an insufficient quantity of connections to make the expansion of heating networks viable.

These measures and market developments reduce greenhouse gas emissions to 98 million t CO_2eq by 2030. They are thus 55 percent lower than in 2020.

Fossil gas

Fossil gas consumption falls to 739 TWh, a 16 percent decrease by 2030 compared to 2021. Most of the decline is attributable to the buildings sector: the gradual transition to heat pumps and district heating reduces fossil gas consumption here by more than a quarter. At the same time, industrial gas demand falls. In electricity generation, on the other hand, fossil gas consumption temporarily rises due to the coal phase-out.

On the grid side, the decline in consumption has the greatest impact on the gas distribution networks. In the area of local authorities' heat planning, municipalities develop strategies for dealing with the increasingly underutilised gas distribution networks. In parallel, the regulatory framework for gas distribution networks is revised to enable network operators to close parts of the networks with a reasonable lead-in time so that stranded assets can be avoided and customers shielded from disproportionate increases in charges for gas network usage. Only a small part of the gas distribution networks will be converted to hydrogen networks later; for the remaining networks, decommissioning will become the norm – legally prescribed criteria minimise dismantling obligations and thus reduce costs.

2030 to 2040: On the way to a climate-neutral electricity system

Expansion of renewable energies

The specific CO_2 emissions of electricity generation in 2040 will be only 13 grams per kilowatt hour (kWh), 98 percent lower than in 1990. Wide-ranging electrification in all sectors will increase electricity demand from 730 TWh in 2030 to around 1 000 TWh in 2040. The pace of the further expansion of renewable energies stays at a high level, so that the total number of plants increases, even if many first-generation RE installations have to be replaced. Following completion of the coal phase-out, financing for the rollout of large RE plants can now increasingly be carried out via market mechanisms.

The expansion to 67 GW of offshore wind facilities by 2040 is implemented efficiently: it is part of a system coordinated with neighbouring countries which improves the yields of offshore wind farms and requires a smaller number of installations for the same total yield than in a system optimised purely at national level. This is especially true for Germany, which has comparatively small areas of sea within its exclusive economic zone. The wind turbines themselves and their grid connections are European interconnection systems. The grid connection capacity to Germany for projects from 2030 onwards can be 35 percent lower than the installed wind capacity, thus saving costs.

Germany benefits from its progressive integration into the European electricity market in another way too: in the scenario, cross-border interconnector capacities, which determine the electricity exchange capacities between Germany and its neighbouring markets, will be expanded beyond the previously planned level to 48 GW in 2040.

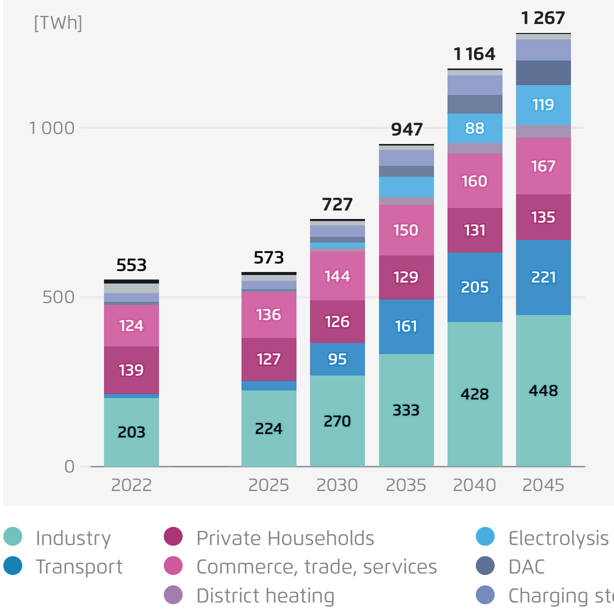
Flexibility

Locally differentiated price signals become increasingly important to coordinate supply and demand and reduce overall system costs. Different electricity price zones within Germany or local wholesale prices can, more efficiently than before, convert weather-dependent consumption, generation and time-dependent grid restrictions into efficient daily deployment planning for power plants, storage facilities and flexible consumers; they can also influence location decisions for new plants so that they bring most benefit to the energy economy.

At the distribution grid level, dynamic local grid charges become the new norm from a comprehensive range of options by 2040. This increases the number of flexible electricity consumers. The scenario assumes that additional grid bottlenecks will be minimised by them.

Electricity demand by sector

→ Fig. 11



	2030	2045
	Production 11 TWh H_2 (electrolysis)	84 TWh H_2 2.5 million t CO_2 DAC
	6.0 million heat pumps, efficient lighting, efficient devices and processes	Over 60% of apartments and 55% of non-residential buildings heated with heat pumps, efficient devices and processes
	13 million BEVs and 2 million PHEVs, one-third of truck mileage running on electricity	Almost complete electrification of passenger-car and truck transport
	Electrification of process heat (< 500°C), efficient cross-cutting technologies	Electrification of process heat, electricity for CO_2 capture, battery cell production

Agora Energiewende, Prognos, Öko-Institut, Wuppertal Institute and Kassel University (2024). H_2 = hydrogen; DAC = Direct Air Capture; BEV = Battery Electric Vehicles; PHEV = Plug-in Hybrid Electricity Vehicles; Storage use (gross) includes pump storage and stationary battery storage in public supply. Electricity use of household batteries combined with PV systems not included here.

Dispatchable power plant output

In addition, the gradual conversion of fossil gas power generation to hydrogen gains momentum. The share of hydrogen in the electricity sector rises to 54 percent by 2040. An H_2 fuel cost subsidy is introduced from 2035 to reduce the operating hours of fossil gas power plants and curb price peaks. This can be financed by a levy on the consumer electricity price, should budget funds be limited. A large proportion of fuel-based power plants are used only very rarely. 10 GW of power plant output is thus operated by cost-saving synfuel power plants in 2040. Since although they have higher fuel costs, the capital costs are much more significant when they are used for less than 300 hours. This also reduces the infrastructure needs for hydrogen networks and storage facilities.

District heating

The amount of heat generated rises by around 20 percent to 168 TWh between 2030 and 2040, due to a further increase in the number of buildings connected. On the other hand, demand declines in the industrial sector, as process steam in particular is increasingly produced on-site.

The largest contribution to heat generation is made by large-scale heat pumps which supply 60 TWh of heat per year up to 2040. Alongside this, deep geothermal energy (14 TWh), industrial waste heat (9 TWh), biomass (22 TWh, including biogenic waste), heat from hydrogen CHP plants (24 TWh) and 19 TWh of fossil gas are also used. In addition to short-term heat storage to bridge gaps of a few hours, large seasonal heat storage also plays an increasing role, supplying a total of 8 TWh of heat in 2040. Heat generation from fossil waste in incineration plants decreases due to inclusion of waste incineration in CO_2 pricing and progress of the circular economy; CCS will be used for the remaining hard-to-abate emissions from waste incineration of 2 million tonnes of CO_2 in 2045.

Fossil gas

Between 2030 and 2040, the decline in gas consumption in industry and buildings speeds up considerably. The shortage of emission certificates after 2035 in the

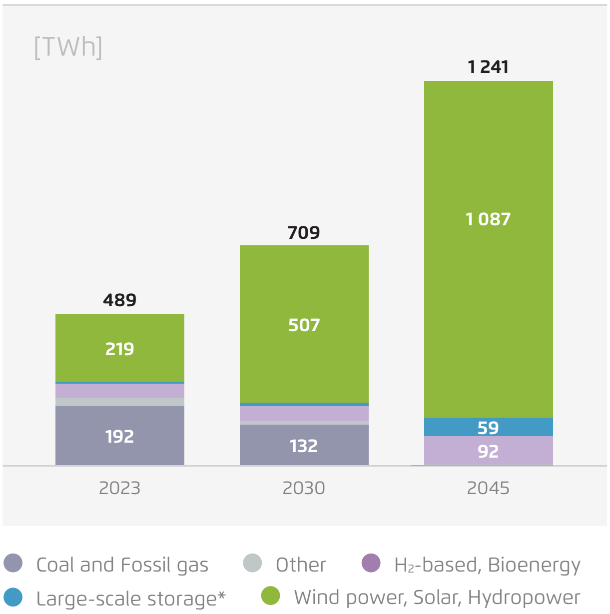
EU ETS I takes effect very quickly so that the phase-out of industrial fossil gas is almost complete by 2040. In the buildings sector, heat pumps and district heating become very widespread in existing buildings.

Since the remaining fossil gas use is concentrated in the power plant sector, the need for grid infrastructure is significantly reduced. The situation is similar for hydrogen which is gradually being used more extensively, mainly in the energy sector and energy-intensive industries: here too, the focus of supply is on transmission networks at higher pressure levels. The majority of fossil gas distribution networks are therefore shut down during this period – and this in turn drives the switch in energy sources within the demand sectors.

2040 to 2045: On the way to net zero and negative emissions

Electrification in buildings, transport and industry raises net electricity consumption to just under 1 241 TWh by 2045 (Figure 12). The installed capacity of renewable energies reaches 180 GW for onshore wind, 73 GW for offshore wind and 470 GW for solar PV, of which 251 GW is on roofs. Between 2040 and 2045, there is a complete switch from fossil gas to hydrogen and, to a lesser extent, to liquid synthetic energy sources.

Net electricity production → Fig. 12



Agora Energiewende and Prognos (2024). * including Vehicle-to-Grid, excluding household storage.

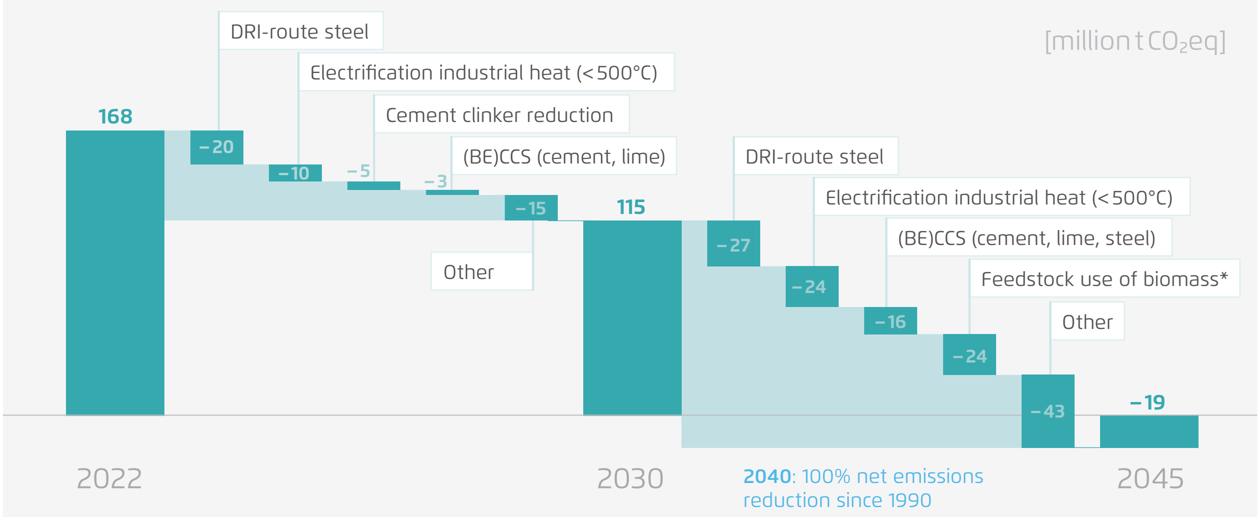
85 percent of the electricity is generated directly by renewable energies. However, despite battery storage, flexible electricity consumers and expansion of electricity exchange capacities with European neighbours, there remains a residual demand for electricity during the six months of winter. This is covered by dispatchable H_2 and synfuel power plants (7 percent of electricity generation) as well as battery storage and pumped storage power plants (a further 6 percent). Hydrogen power plants generate about 65 TWh of electricity. Synfuel power plants provide 30 GW of guaranteed capacity in 2045, but are only rarely used to cover peak loads, generating just 10 TWh of electricity.

As most buildings have been renovated for energy efficiency, the amount of heat produced in district heating will remain largely constant between 2040 and 2045, even though around 3.2 million buildings are now connected to heating networks. During this period, the final steps towards (near) climate neutrality are taken.

3.2 Industry

The **industrial sector** includes manufacturing and construction. Around 60 percent of industry's greenhouse gas emissions are attributable to the production of steel, cement and chemical products. The remaining 40 percent is accounted for by the production of other energy-intensive products, especially glass, lime, paper and aluminium, as well as products from less energy-intensive industries. Around two-thirds of industrial emissions are energy-related from the combustion of mostly fossil fuels and one-third are process-related emissions.

Industrial sector – reduction of greenhouse gas emissions → Fig. 13



Agora Energiewende, Prognos, Wuppertal Institute and Kassel University (2024). *in the chemicals industry, incl. Bio-CCS.

In 2022, the **greenhouse gas emissions** of the industrial sector were 168 million tonnes CO_2eq, according to the definition in the Federal Climate Protection Act *(KSG)*[5]. Emissions fell sharply in 2022 and 2023, mainly as a result of declines in production caused by economic conditions and energy prices. These primarily include supply bottlenecks in the context of the Covid-19 pandemic and the fossil-energy price crisis triggered by Russia's war of aggression against Ukraine. At the same time, the ETS I reform has set an ambitious climate neutrality target for industry: with the last emission certificates being issued in 2039, industry must be largely climate-neutral by 2040.

Support for industry in a tense economic situation demands, above all, planning certainty. Investments in climate-neutral production processes must be accelerated significantly so that industrial sector emissions fall, even as production volumes pick up again.Key issues here are also the availability of competitively-priced electricity and hydrogen including the necessary infrastructures ("upstream") as well as the creation of new markets for climate-friendly basic materials ("downstream").

5 This and the following statements on greenhouse gas volumes by 2023 are according to Deutscher Bundestag (2024): Klimaschutzbericht 2024; Abb. 27: Entwicklung und Zielerreichung der Treibhausgasemissionen in Deutschland im Sektor Industrie des KSG

2025 to 2030: Electricity replaces fossil gas as the key energy source

Industrial **greenhouse gas emissions** decrease by around 40 million tonnes of CO_2eq to 115 million tonnes of CO_2eq by 2030.

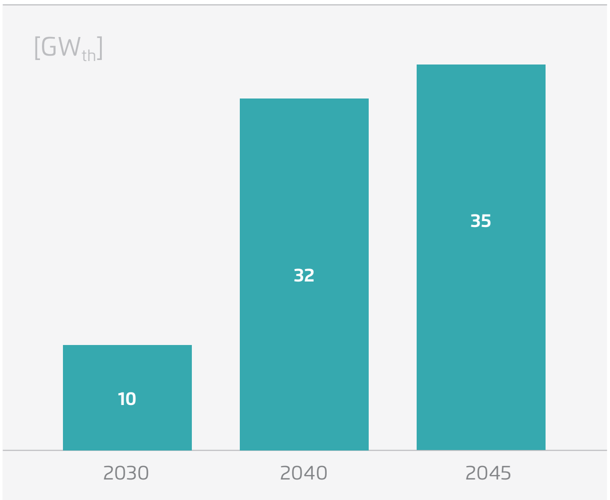
Electricity becomes economically attractive compared to fossil gas and increasingly replaces it as the main energy source for industry. This is made possible by the steady ramp-up of renewable energies and the expansion of electricity and hydrogen networks, a tax reform, including for grid charges, and investment grants for industrial heat pumps to incentivise electrification of industrial process heat. The technology ramp-up for direct electric solutions will happen by 2030, followed by widespread market penetration by 2040 (Figure 14).

Steel industry

Around one third of the savings come from the steel industry via successful construction of plants for direct reduced iron (DRI) on the scale of the investments already announced and supported by the federal, state (Länder) and EU levels. These are initially operated with fossil gas and hydrogen and, to a small extent, with syngas obtained from biomass. It is assumed that steel demand will stabilise again at 2019 levels by 2030 and steel production will also recover.

Additional costs of lower-CO_2 base material production at the product level comprise just a small proportion of the purchase price – due to "green" steel use in vehicles, for example, the extra costs are 1 to 2 percent of the vehicle price. In a highly competitive market, for example, public procurement requirements for vehicles made with green steel can help to tap into the corresponding willingness to buy, without adding very large extra costs.

Roll-out of industrial heat pumps → Fig. 14



Agora Energiewende, Prognos, Wuppertal Institute and Kassel University (2024)

Cement industry

The second highest absolute savings are in cement production, as demand for cement clinker falls by more than a quarter. This is due to the demographic-related decline in new builds together with increased timber construction, a more efficient use of cement for concrete production plus a reduction in the clinker content of cements. Greater material efficiency along the value chain is stimulated by adjustments to cement and building standards, as well as so-called embodied carbon standards, which set limits for the CO_2 content in buildings. Another milestone by 2030 is the introduction of CO_2 capture and storage, incentivised by the rising price signal of ETS I and supported by government subsidies.

Chemical industry

By 2030, the chemical industry starts converting input materials for chemical processes – so-called feedstocks: chemicals and plastics are increasingly produced with recycled plastics as a basis, instead of crude oil. This reduces emissions in the waste sector as less plastic is burned. Development in the plastics field is incentivised by CO_2 pricing in the waste sector, quotas for the use of recyclates or the use of renewable raw materials in the production of packaging. Minimum requirements for product groups are introduced in the context of the EU Ecodesign Regulation and in public procurement specifications. Decarbonisation of fertiliser production is achieved through increased imports of green ammonia. Germany also retains its own production facilities to secure fertiliser and food production.

Cross-sector developments

In order to facilitate this ramp-up in technology, companies use upcoming investment cycles for climate-friendly investments: every system gaining new investment is almost climate-neutral. In particular, from 2027 onwards, EU emissions trading exerts an incentive effect in favour of low-emission processes via introduction of the Carbon Border Adjustment Mechanism (CBAM) and the associated phase-out of free allocations[6]. In parallel, subsidy programmes close the remaining cost gap to conventional technologies. Carbon contracts for difference for energy-intensive industries are continued and further developed such that they are also accessible to micro-, small- and medium-sized enterprises (SMEs) and they find additional areas of application (e.g. steam generation). On the **demand side**, incentives

6 Industry, which is currently covered by the EU ETS I, largely receives the necessary emission certificates free of charge to prevent the transfer of emissions abroad (carbon leakage). From 2026, this system of protection against carbon leakage will be gradually replaced by the CBAM. The free allocation for goods production covered by CBAM will be gradually reduced from 2026 to 2034.

Industrial sector – key policy instruments → Fig. 15

Market regulation	Price-based incentives	Financial support
→ Labels for climate-friendly basic materials	→ EU-ETS I: Phase-out of free allocations, introduction of CBAM, end of CO_2 certificate issuing 2039	→ Carbon contracts for difference; continuation and further development for energy-intensive industries and SMEs
→ Quotas for climate-friendly basic materials in public procurement, embodied-carbon standards for buildings	→ Price signals for substituting fossil raw materials with biomass and recycling	→ Investment support for industrial heat pumps, Focus SMEs (funding programmes, investment bonuses)
→ Needs-based CO_2 and H_2 infrastructure	→ Reform of grid-charge regulation for flexibility	→ Continutation of electricity price compensation, electricity tax reductions
→ Accompanying dialogue about industrial transformation with economic, political and science sectors	→ Financial incentives for use of climate-friendly basic materials in end products	→ Boosting of research and development funding

Agora Energiewende (2024)

to buy climate-neutrally produced goods support the necessary investment decisions, including for example, labels for climate-friendly raw materials.

The **guiding principle** in all regulatory projects is to reduce complexity so as to achieve the necessary speed. Practicability of implementation is the focal point. When new measures are introduced, consideration is given to where existing frameworks can be used or simplified, while maintaining the degree of ambition and effectiveness of the measures.

2030 to 2040: The end of the fossil era

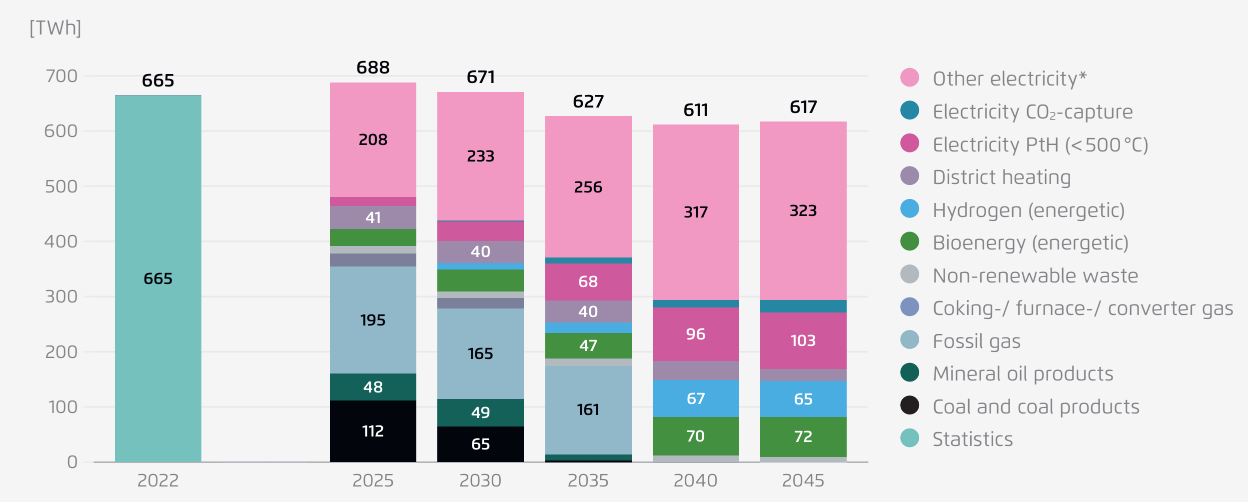
In the 2030s, processes in all industrial sectors will be converted across the board to **climate-neutral technologies**: greenhouse gas emissions are largely avoided through electrification, an enhanced circular economy and material efficiency, as well as the use of hydrogen and biomass. CCS is used for unavoidable and negative emissions and is already extensively scaled up by 2040, so that 25 million tonnes of CO_2 is stored in 2040. Industry is already net climate-neutral by 2040 thanks to these measures and the shortage of emission allowances under the EU ETS I accelerates the process. Fossil gas consumption sinks to almost zero by 2040 whereas electricity consumption increases by 90 percent to 428 TWh by 2040, compared to 2025 (Figure 16).

Since many companies are still in the midst of the switch to climate-neutral technologies and are facing cost-intensive modernisations, funding programmes such as carbon contracts for difference continue to be important. The transition is accompanied by an industrial policy strategy and an institutionalised dialogue with business, politics and civil society. In response to emerging regional or sector-specific challenges, the economy is supported through structural policies.

Steel industry

By 2035, the **steel industry** switches completely from the coal-based blast furnace route to DRI plants which are initially powered mainly by fossil gas.

Final energy consumption by energy source in the industrial sector → Fig. 16



Agora Energiewende, Prognos, Öko-Institut, Wuppertal Institute and Kassel University (2024), historical data: AG Energiebilanzen (2024).
* Other electricity includes conventional, industrial electricity demand, additional power for electrifying process heat above 500°C as well as for newly established industries, particularly battery and chip production. PtH = Power to Heat.

At locations where CO_2 infrastructure is needed anyway in the long term, some of the CO_2 produced can be captured and stored via CCS. By 2040, all DRI plants are operated with hydrogen and biogenic synthesis gas. By capturing and storing the resulting quantities of biogenic CO_2, negative emissions of 3 million tonnes of CO_2 are achieved within the steel industry by 2040.

Cement industry

The cement industry reduces its net CO_2 emissions to one million tonnes of CO_2 by 2040. There is an efficiency increase regarding clinker use along the whole concrete construction value chain so that CO_2-intensive clinker production continues to decrease. This is achieved despite construction activity increasing again due to the infrastructure expansion needs in civil engineering. The complete ramp-up of CO_2 capture takes place at almost all remaining cement kilns by 2040.

Chemical industry

In the chemical industry, chemical recycling and the material use of biomass is expanded from 2030. Domestically available biomass replaces fossil naphtha in the production of chemicals and plastics. Process-related biogenic CO_2 generated while processing biomass is captured and geologically stored at locations with favourable infrastructure (so-called bio-CCS): a total of 12 million tonnes of CO_2eq of biogenic carbon is bound in products and geological storage facilities. Imported petroleum product use is thus reduced by around 60 percent, compared to pre-pandemic levels. By converting production processes, using domestic biomass and developing new business models, new value is created in the country, especially in rural regions.

Financing mechanisms, such as a levy on plastic products, are needed to enable scaling-up of innovative biomass-based processes. In the medium term, it also seems sensible to have a pricing system for fossil carbon used as a feedstock, for example in the form of a resource consumption tax.

Cross-sector developments

The **process steam** needed in the chemical and paper industries will be generated almost completely fossil-free in the scenario up to 2040. Heat pumps play a central role here in the temperature range up

What if green energy-intensive intermediate products are imported inexpensively?

Due to international competitive pressure, part of the value chain of the basic materials industry could shift to other countries – either because the regulatory framework for an attractive climate-neutral production location in Germany has not been created or because green, energy-intensive intermediate products are available more quickly and cheaply on the world market. As a result, contrary to what was assumed in the main scenario, there would be extensive importation of **energy-intensive intermediate products**. Thus in one variant, there was an examination of the impact of imports of both directly reduced iron (DRI), which has by far the highest energy needs in the steel value chain, and methanol for plastics production. The downstream production stages are retained in Germany. The possible impacts on value creation and jobs were not examined in this study. However, previous studies have found only a limited effect in these areas.[7]

In such an alternative scenario, where 2.9 million tonnes of DRI are imported in 2030, 16.3 million tonnes in 2035 and 17.3 million tonnes in 2045, the demand for electricity, hydrogen and steam decreases significantly. Overall, industrial hydrogen demand is 8 percent lower in 2035 and 35 percent (35 TWh) lower in 2045 than in the main scenario. There will additionally be savings of 6.9 TWh of electricity and 17.5 TWh of steam by 2045.

Due to methanol imports totalling 7.8 million tonnes, the demand for woody biomass decreases by 14.4 million tonnes, thereby displacing domestic production of biogenic feedstocks in combination with CCS. As a result, 13 million tonnes less CO_2 is stored from 2040 onwards. The need for CO_2 capture and storage also decreases in steel production, as in this variant there are no fossil-gas-powered direct reduction plants with CO_2 capture. The CO_2 infrastructure can, therefore, have smaller dimensions than would be needed for more complete preservation of the entire value chains in Germany.

7 Agora Industry (2023): 15 Insights on the Global Steel Transformation.

to 200 °C and electric boilers at higher temperatures. When electricity prices are high, especially in winter, they are supplemented by hydrogen-powered CHP and biomass boilers. Steam supply in CHP plants becomes increasingly flexible and is optimised in line with the electricity market. This allows the downstream industrial processes to obtain the necessary steam at any time.

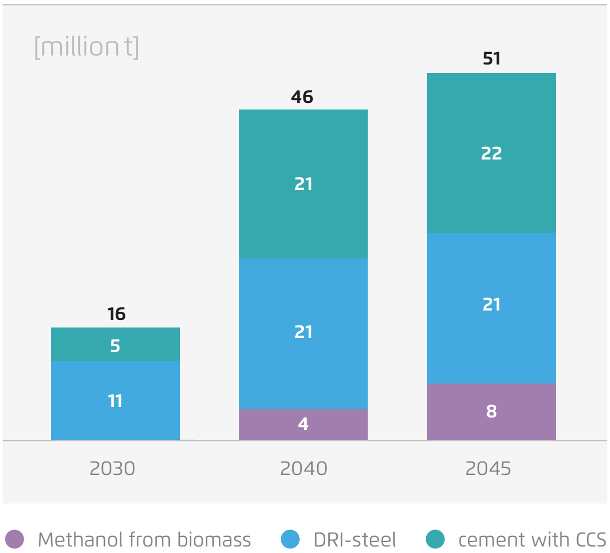
A crucial role is played by **markets** for basic materials and products that are produced with low emissions. The key ramp-up takes place in the 2030s, so that a large proportion of basic materials are produced with low emissions by 2040 (Figure 17). As well as labels, there is wide use of quotas and fiscal instruments to encourage the use of climate-friendly basic materials in end products.

2040 to 2045: Industry as a net carbon sink

After 2040, industry plays a crucial role in biogenic carbon sequestration, alongside the land use sectors. In 2045, net negative emissions of 19 million tonnes of CO_2 will be sequestered within the industrial sector.

The chemical industry plays a decisive role in this: bio-CCS and recycling will capture and store a total of 14 million t of CO_2eq in 2045.[8] By 2045, a large proportion of fossil feedstocks is replaced by material use of domestic biomass, recycling of plastic waste and imported methanol. By 2050, the chemical industry completely phases out the use of fossil raw materials.

Availability of low-emissions* basic materials → Fig. 17



Agora Energiewende, Prognos, Öko-Institut, Wuppertal Institute and Kassel University (2024). *Basic materials with significantly reduced CO_2 emissions compared to conventional production, including cement with only partial CO_2 capture as a transition and DRI steel using natural gas, also as a transition.

In addition, the last **industrial power plants** are converted from fossil gas to climate-neutral hydrogen. All remaining kilns in the cement and lime industry are equipped with CCS in 2045. Since the demand for clinker continues to fall in the 2040s, it no longer makes economic sense to retrofit individual kilns just before 2040 for a few years of operation, so they are shut down in 2045.

3.3 Buildings

In the scenario, the buildings sector comprises the subsectors of private households as well as commerce, trade and services.[9] Private households account for around three quarters of energy consumption and greenhouse gas emissions. The majority of the energy (again, about three quarters) is used for space heating and hot water.

For the future, the scenario envisions sufficient residential and commercial space available which is affordable and suitable for users' needs. It aims at a climate-neutral building stock that enables healthy living and working, given the prospect of more frequent extreme weather. The building stock is developed in a space- and resource-efficient manner. The following core strategies serve this purpose:

The **heat supply** will be converted to renewable energies. Decarbonised heating networks and heat pumps using renewable electricity are key technologies. A significant increase in **building efficiency** and decrease in energy consumption compensate for lower renewable-electricity generation in winter.

This is achieved through more rapid and thorough building renovations. At the same time, they create an increase in value and contribute to healthier, more climate-resilient living. An important key to resource-efficient housing provision are increased **housing modifications in the existing building stock** (adding storeys, converting, repurposing of commercial properties).

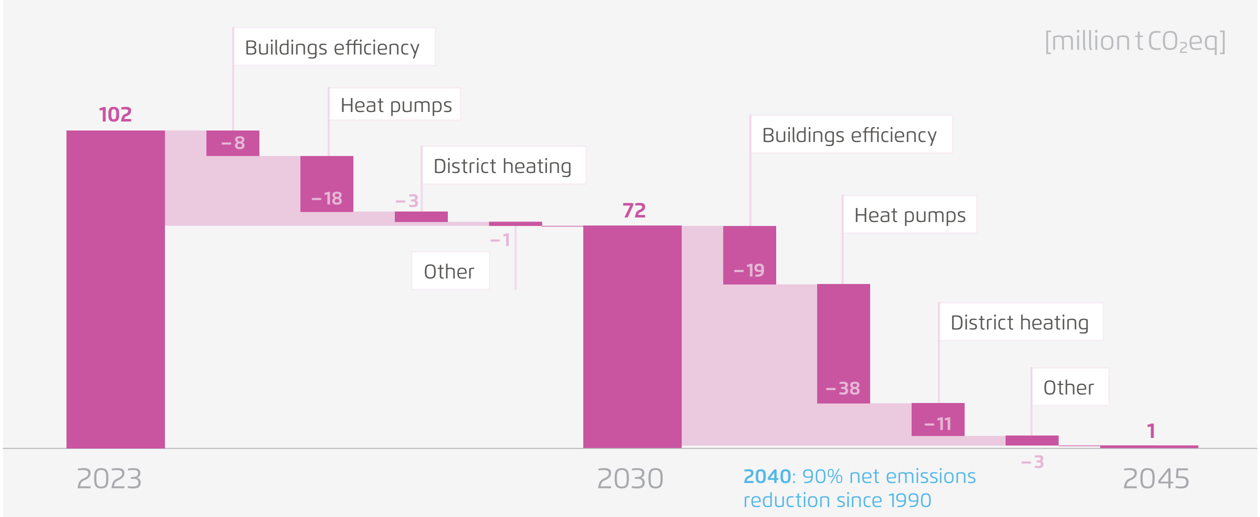
Progress in the building sector has so far been limited. Over 65 percent of space heating and hot water consumption is met by fossil gas and heating oil. Renovation activity in building envelopes did not increase significantly in the past. And only about

8 One million tonnes of CO_2eq will additionally be captured and stored in steam crackers powered by fossil feed stocks.

9 The presentation of energy consumption for private households and the commerce / trade/services sector includes use of electricity and district heating. In keeping with the Federal Climate Protection Act's delineation, only fuel emissions are included in the presentation of emissions.

Buildings sector – reduction of greenhouse gas emissions

→ Fig. 18



Agora Energiewende and Prognos (2024)

10 percent of new housing has been created in existing buildings annually since 2005.

As a result, annual emissions fell from 119 to around 102 million tonnes of CO_2eq between 2020 and 2023 but the sector repeatedly missed its target under the Federal Climate Protection Act *(KSG)*. Furthermore, part of the savings so far have been due to particularly warm winter weather.

Owing to the long operational life of buildings and facilities, incentives to convert the heat supply and carry out energy retrofits only take effect slowly. It is therefore particularly important to introduce them quickly. Besides, early action has the advantage that the switch can be managed within the natural technological life cycles of building installations.

2025 to 2030: Rapid entry into green heat supply and building renovation

Renewable heating and efficient buildings

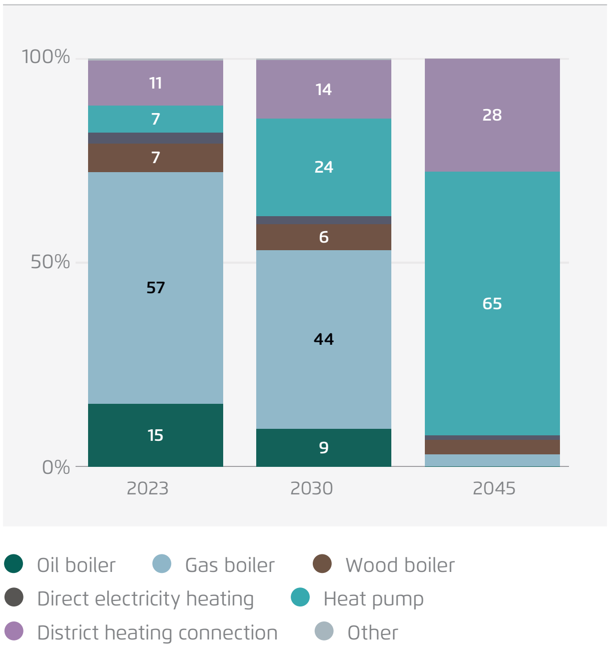
In the area of **heat supply**, the number of buildings newly connected to district heating each year increases from the current 40 000 to 90 000 by 2030. 600 000 to 650 000 new heat pumps are installed annually from 2028, mainly in existing buildings. This is roughly equivalent to today's sales of gas boilers. The majority of these are air-to-water heat pumps. A new component is air-to-air heat pumps – small and inexpensive, air-conditioning-like devices that can also cool. Among other uses, they can replace single-storey heating *(Etagenheizung)* or be used, temporarily, in combination with existing gas heating systems. The importance of wood as a building material increases. At the same time, wood-fired boilers retain a share of around 6 to 7 percent of the heating market. In 2030, 14 percent of buildings' floor space is heated by district heating and 24 percent by heat pumps (Figure 19).

To reduce the **demand for space heating,** the retrofitting rate increases to around 1.6 percent by 2030. In the case of full refurbishment, the third-highest efficiency class at least is achieved (class B)[10]. However, partial renovations of individual building components are much more common; in these cases, the component efficiency is compatible with class B. An increasing proportion of new **living space** is created by adding storeys, converting office space or converting and subletting large flats and houses.

10 The scale of energy efficiency classes for residential buildings ranges from A+ to H.

Greenhouse gas emissions fall to 72 million tonnes of CO_2eq in 2030. The Federal Climate Protection Act's *(KSG)* target of a maximum of 66 million tonnes of CO_2eq will, however, be missed, as building renovation especially is only slowly bearing fruit.[11]

Heating structure in building stock → Fig. 19



Agora Energiewende and Prognos (2024)

In order to accomplish this development, financial, political and social challenges must be overcome. The upgrading of buildings, heating networks and heating systems requires substantial investments: in the scenario, they increase from 200 billion euros per year in the 2025–2030 period up to 210 billion euros per year in the period from 2040 to 2045. A smart policy framework is required to stimulate the necessary private investment. And it is important to protect vulnerable groups from energy poverty and, in the rented stock, to distribute the costs and benefits of climate policies fairly between tenants and landlords.

In the scenario, an effective and balanced policy mix is used to address these challenges.[12]

Efficient price incentives

Economic incentives are an essential building block. The CO_2 price rises to 124 EUR_{2022} / t by 2030. A reform of taxes, charges and levies concurrently makes green electricity more competitive compared to fossil gas. A reform of grid fees creates incentives for flexible electricity consumption and reduces the electricity costs of heat pumps. The EU Taxonomy will be restructured so as to reward renovation of the most inefficient buildings.

But this in itself is not enough to initiate a change of direction. Due to high investment costs and uncertainties about future prices, many property owners cannot or do not want to invest. In addition, high CO_2 prices typically reduce available financial resources. The incentive is also weaker for rented stock, as fuel costs and parts of the CO_2 price are borne by the tenants. CO_2 prices should not, after all, rise arbitrarily because they weigh particularly heavily on lower-income households.

Future-proof market regulation

Hence, infrastructure planning and market regulation provide planning certainty and the speed and ambition necessary to keep CO_2 prices lower. In the case of **heat supply**, the Municipal Heat Planning Act *(Gesetz zur Kommunalen Wärmeplanung, WPG)* and the amendment to the Buildings Energy Act *(Gebäudeenergiegesetz, GEG)* have already set an important course. But in the short term, the public debate about the Buildings Energy Act triggered uncertainty. So as to achieve long-term investment security and initiate future-proof conversion of the heat supply before 2026 or 2028, the scenario assumes that municipalities quickly draw up heat plans that are compatible with the targets. Even before the planning is completed, citizens are informed about areas

11 Based on the provisions of § 5 (5) in accordance with Annex 2a adjusted annual emission quantities in the Federal Climate Protection Act (Status: 29.09.2024).

12 CO_2 price, market regulation and funding instruments were directly modelled in terms of their impacts. Other supporting instruments are described qualitatively.

Creating investment and planning security through a national minimum CO_2 price for buildings and transport

From the beginning of 2027, the EU-wide emissions trading system ETS II comes into force which primarily prices emissions from the building sector and road transport. Estimates of the expected CO_2 price levels are subject to great uncertainty; they range from 50 EUR_{2022} / t CO_2 to over 200 EUR_{2022} / t CO_2 for 2030.[13] The price level is mainly influenced by whether and how promptly countries with high ETS II emissions, such as Germany in particular, adopt further effective climate protection instruments which reduce CO_2 emissions and hence also demand for CO_2 certificates. In the scenario and against the background of the additional climate protection instruments, a CO_2 price of 124 EUR_{2022} / t CO_2 was assumed for 2030, rising to 188 EUR_{2022} / t CO_2 by 2045.

However, if additional climate protection measures are not implemented, prices could increase rapidly. There could be high political pressure in this case – especially without sufficient social compensation mechanisms – to cap the ETS II price at a low level through additional interventions. This would probably lead to failure to meet the European climate targets and, in Germany, to a potential price decline compared to the national CO_2 pricing system in force until 2026. In order to avoid this and give citizens and businesses planning and investment security, the introduction of a national minimum CO_2 price at the level mentioned above would be sensible. A CO_2 surcharge on the energy tax could be an option to implement this in a legally secure way.

13 Agora Energiewende and Agora Verkehrswende (2023): The CO_2 price for buildings and transport

which are either priority or barred when expanding the heating network. Consumer protection and trust in district heating are strengthened by rules on both price transparency and price supervision. In the scenario, gas distribution operators are also given the legal option to shut down parts of gas networks, assuming sufficient prior notice. Households can, in this way, invest in alternatives in good time and protect themselves from high gas prices.

In the **building renovation** field, requirements for partial renovations are made stricter to be future-proof, making them compatible with building efficiency class B. In keeping with the European Energy Performance of Buildings Directive (EPBD), the 16 percent of most inefficient non-residential buildings are renovated by 2030. A minimum efficiency level also applies to residential buildings in the scenario: single-family houses in 2027 must be at least class G, with at least class F for buildings housing several families. The more ambitious standards for the latter serve to protect tenants from high heating costs, also considering that high standards are easier to achieve there due to the better ratio of volume to exterior surface. The standards rise by one class in 2030. Exceptions apply in cases where refurbishment is economically unreasonable. A subsidy bonus is granted for achieving the standards ahead of schedule. Building law simplifications make construction more economical and make it easier to create more **living space** in the existing building stock.

Reliable funding

Reliable funding support helps to cover high initial investment costs. The Federal Funding for Efficient Buildings *(Bundesförderung Effiziente Gebäude, BEG)* and other support programmes are continued, with the funding stabilised at a level of some 17 billion euros per year (20 billion after 2030). Part of the funds is used to alleviate high cost burdens for households with limited financial resources.

Buildings sector – key policy instruments → Fig. 20

Market regulation	Price-based incentives	Financial support
→ Consistently planned pathway of minimum efficiency requirements for residential and non-residential buildings, taking hardship cases into account	→ CO_2-price path in ETS II: 124 EUR_{2022}/ t 2030 and 188 EUR_{2022}/t 2045	→ Continuation and socially equitable design of Federal Funding for Efficient Buildings (renovation and heating replacement), totalling 20 billion EUR/year
→ Continuation of 65% renewables requirement for heating in the Buildings Efficiency Act	→ Introduction of a national minimum CO_2 price	→ New models of loan financing
→ Partial renovations: requirements for components compatible with efficiency class B	→ Revision of the EU taxonomy to offer incentives to renovate the most inefficient buildings	→ Expansion of funding programmes to create new housing in existing buildings
→ Legal possibility to decommission gas grids, given due notice	→ Favourable electricity-/gas-price ratio by reducing grid charges and electricity taxes; heat pumps become more attractive	

Agora Energiewende (2024)

Simultaneously, financing via discounted loans with simplified access terms gains in importance. These specifically address the problem of high initial costs and, at the same time, save public budget funds.

In the area of **heat supply**, the funding is reallocated entirely to renewably-powered heating. Hybrid solutions and wood heating systems are no longer subsidised as wood is to be used chiefly as a material. From 2025, subsidies for the **building envelope** no longer flow into already very efficient new construction, but wholly into retrofitting existing buildings. The funding programme for stand-alone renovation measures is boosted to facilitate pragmatic, step-by-step refurbishments, combined with building-specific renovation plans. Existing funding schemes for **storey additions, conversion or repurposing** of existing buildings are continued and greatly expanded. The Federal Funding for Efficient Heating Networks *(Bundesförderung Effiziente Wärmenetze, BEW)* is continued to finance network expansions and renewable heat generation. The funding is increased to around 3 billion euros per year and is thus better adapted to the needs.

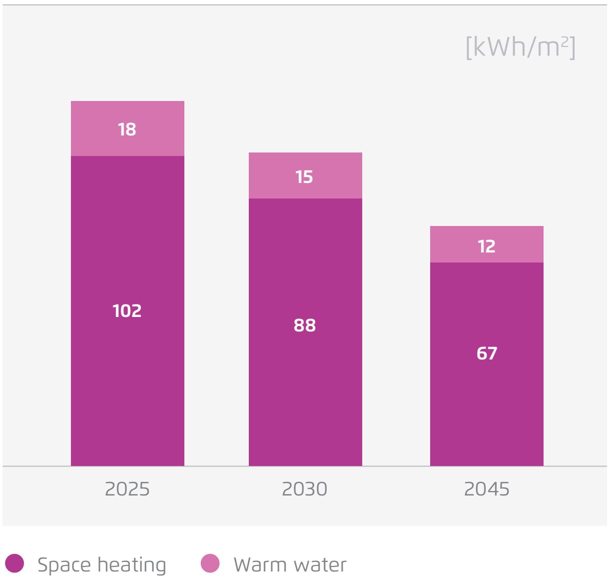
Alongside the policy mix, new sales models (such as “heat as a service”) ease the switch to heat pumps. Serial retrofits and “renovation sprints” enable faster refurbishments, realise economies of scale and allow skilled workers to be deployed more efficiently.

2030 to 2040: Consolidating the conversion of the building sector

In **heat supply**, expansion of heat networks accelerates after completion of municipal heat planning. The number of newly-connected buildings each year increases to 110 000 by 2040. Electric heat pumps are mainly purchased for buildings which are not connected to heating networks. New fossil-fuelled heating systems are no longer installed in view of the approaching climate neutrality target and corresponding regulatory requirements. In the scenario, the share of usable space in buildings that is heated with gas thus falls from 57 percent today to 18 percent in 2040. Of this, 14 percent is with fossil gas; 3 percent of buildings, especially in rural areas, are heated with biomethane; and one percent, situated in proximity to large H_2 purchasers, with H_2 gas boilers. With falling gas consumption, the cost per kilowatt hour delivered rises, so consumers increasingly move away from fossil gas. More and more gas networks consequently become uneconomic and are shut down. The use of wood as an energy source declines from 2030 onwards while, at the same time, wood as a building material keeps on growing in importance.

Energy consumption also continues to fall due to improved heat insulation (Figure 21). The renovation rate remains high, at around 1.65 percent; the level of ambition is approximately class B.

Specific final energy demand in building stock → Fig. 21



Agora Energiewende and Prognos (2024)

These changes are made possible by continuing the policy mix from the previous period. The ETS II price rises to 172 EUR_{2022} / t CO_2 by 2040. The minimum efficiency requirements for residential buildings increase in three-year steps until 2036; they will then be at efficiency class D for single-family homes. In line with the EPBD, the 26 percent most inefficient non-residential buildings have been renovated by 2033.

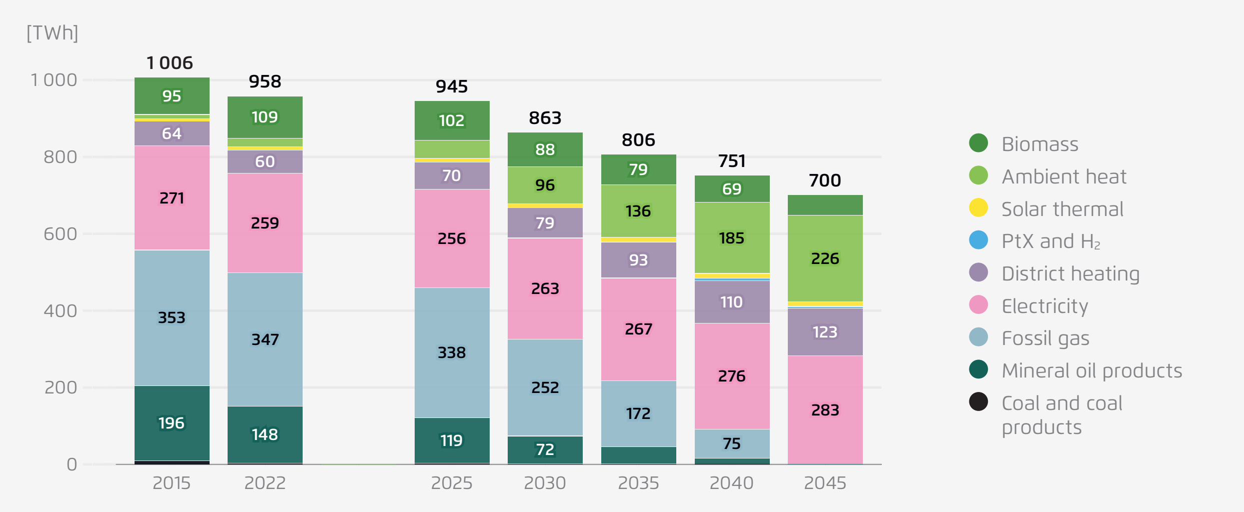
2040 to 2045: The buildings sector becomes climate-neutral

The instruments described are continued; the ETS II price rises to 188 EUR_{2022} / t CO_2. In **heat supply**, gas and oil boilers have already been largely replaced by heating networks or decentralised heat pumps before 2045. The gas boilers remaining in 2045 (3 percent of usable space in buildings) are powered entirely by biomethane or hydrogen. Electric heat pumps become the most important heat generator, accounting for 65 percent of usable space in buildings. In densely-populated areas with high heat density, district heating is also very important; a total of 28 percent of usable space in buildings is warmed by district heating. Wood still accounts for 4 percent.

The amount of **new buildings** remains – as it has been since 2025 – at a lower level than in the 2015 to 2020 period. This is essentially due to the stagnating or slightly declining population. The preservation and upgrading of current housing, transformation of commercial into residential space and improved utilisation of existing buildings also help to reduce the need for new construction. Given a continued high level of **renovation activity** at a refurbishment rate of around 1.5 percent, a significant part of value creation in construction comes from renovations.

Figure 22 shows the resulting developments in energy consumption. Although electricity is gaining great significance as a heat source, its consumption barely rises, due to efficiency increases in buildings and devices. As a result, the building sector emits just 1 million tonnes of CO_2eq annually by 2045 which is more than offset by negative emissions in the LULUCF (Land Use, Land Use-Change and Forestry) and industrial sectors.

Final energy consumption by energy source in the buildings sector → Fig. 22



Agora Energiewende and Prognos (2024), historical data: AG Energiebilanzen and UBA (2024)

3.4 Transport

The **transport sector**, as delimited in the Federal Climate Protection Act *(KSG)*, includes road and rail transport, coastal and inland-waterway transport as well as domestic air transport. At over 95 percent, almost all of the sector's national emissions are attributable to fossil-fuel combustion in road transport, with passenger cars accounting for around 60 percent and commercial vehicles for just under 40 percent of emissions. In addition, there is international air traffic and maritime shipping which, however, do not come under the scope of the Federal Climate Protection Act (*KSG*). Progress in the transport sector has been limited to date. Emissions have only fallen by some 10 percent since 1990 and the sector missed its *KSG* reduction targets by a large margin in both 2022 and 2023.

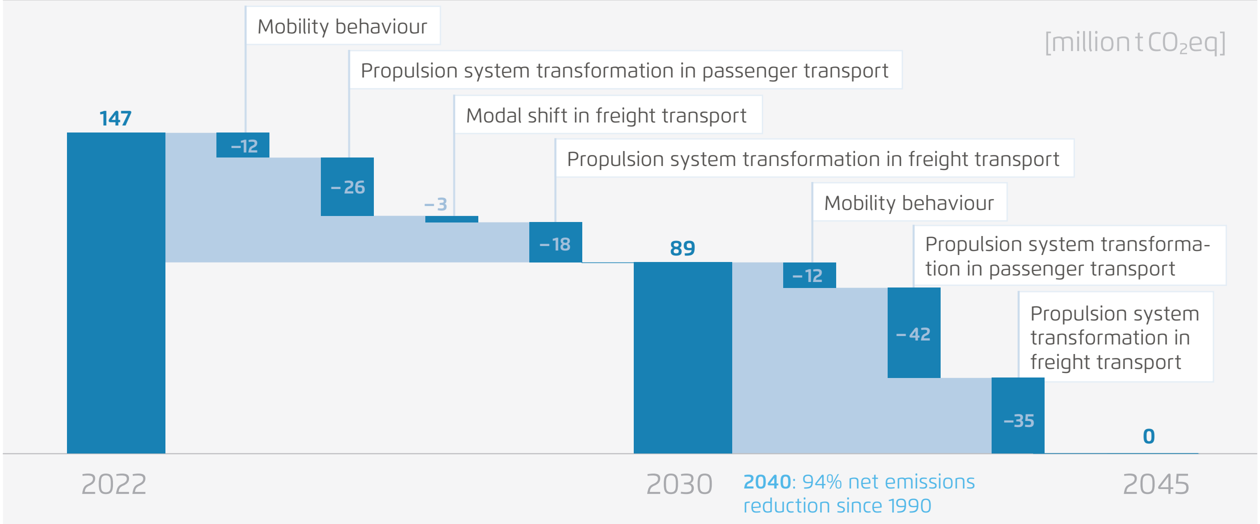
The most effective measure for reducing emissions is **electrification of passenger and road freight transport**; it must be accompanied by a **mobility transition**, meaning a shift from motorised individual transport to walking, cycling and public transport. Both strategies ensure accessible and affordable mobility for all citizens and businesses – overall transport performance in both passenger and freight transport increases by 2045. Lower pollution and noise levels, physical exercise linked to cycling and walking as well as less paved areas all contribute to better health and improved quality of life. These developments benefit low-income households in particular.

Given the long operating life of vehicles, **prompt implementation of measures** to accelerate the propulsion system change for passenger cars and trucks is vital to achieving climate neutrality by 2045. Since increasing public transport capacities generally, and for railways especially, is very time-consuming and an investment backlog has developed too, timely investments in infrastructure are also needed.

2025 to 2030: The transport sector catches up

Even though the propulsion-system and mobility transition in transport picks up considerable speed by 2030, helped by numerous climate-protection measures, the sector misses its indicative Federal Climate Protection Act target, reaching 89 million tonnes of CO_2eq in 2030. The cumulative shortfalls from 2021 to 2030 amount to 133 million tonnes of CO_2eq – but these are 64 million tonnes of CO_2eq below the "With-Additional-Measures-Scenario" in the Federal Government's forecasting report (Projektionsbericht 2024, "Mit-Weiteren-Maßnahmen-Szenario").

Transport sector – reduction of greenhouse gas emissions → Fig. 23



Agora Verkehrswende and Öko-Institut (2024)

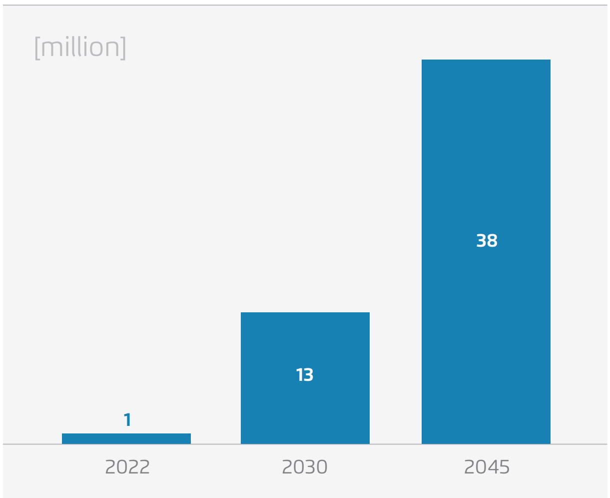
Propulsion-system transition in passenger transport

Progress will be achieved through a **mix of price-based instruments, market regulation and financial support** – but the measures only take full effect after 2030 because of the high initial number of passenger cars with combustion engines and infrastructure that has not yet been fully expanded.

Price-based instruments address vehicle use as well as purchase decisions. This especially includes a more emissions-oriented vehicle tax that comes into effect upon initial registration. The revenues are used to fund financial support instruments which specifically enable the purchase of inexpensive and energy-efficient fully electric cars and close the affordability gap that still exists; low-income households especially are supported in switching to electric mobility via various purchasing models, including for used cars. As for new business vehicle registrations, electrification is supported by reform of company car taxation; the tax paid on perks for combustion engine company cars rises from 1 percent today to 1.5 percent. Nevertheless, due to the delays that have already occurred, the German government's target of 15 million fully-electric passenger cars on the roads in 2030 will not be met (12.6 million, see Figure 24).

These price-based instruments aimed at vehicles bolster the impact of the CO_2 emission limits: the latter ensure planning certainty to consumers and infrastructure providers as well as investment security and development pressure on car manufacturers.

Stock of fully electric passenger cars → Fig. 24



Agora Verkehrswende and Öko-Institut (2024), historical data: *Kraftfahrtbundesamt* (2024)

Replacement of the commuter allowance with financial support for work-related mobility, which is not linked to income, cushions the cost impact of the CO_2 price for vulnerable groups. The introduction of a general speed limit of 130 km/h on motorways reduces the energy needs for road transport and hence also the emissions of combustion engines run on fossil fuels. Due to the EU Directive on the promotion of clean and energy-efficient road vehicles as well as CO_2 emission limits, buses in urban transport are mostly electric from the start of the 2030s; and they are also affordable for transport companies, thanks to government subsidies.

Shift to public transport

The expansion of public infrastructure promotes a shift from motorised individual transport to public transport as well as cycling and walking. Incentives for the change are provided by more frequent services, increased punctuality, more accessible stops, simplified fare structures as well as integrated and flexible services. Continuation of the nation-wide public transport pass gives an affordable, ongoing alternative to private cars. The transformation is also supported by the parallel increase in the cost of fossil-fuelled car transport via carbon pricing, alignment of tax rates on diesel and petrol plus the introduction of inflation compensation for the energy tax. Furthermore, a distance-based toll on private cars is introduced at the end of the decade which helps to finance transport infrastructure and attractive public transport and brings further incentives for the shift; the previous annual vehicle tax for all passenger cars is scrapped during this process.

Comprehensive **upgrading and modernisation plus expansion of the rail network** bring about the first stage of the planned nationwide regular-interval service and benefit rail freight transport too; they lead to a phase of growth and shifting of goods transportation onto rail.

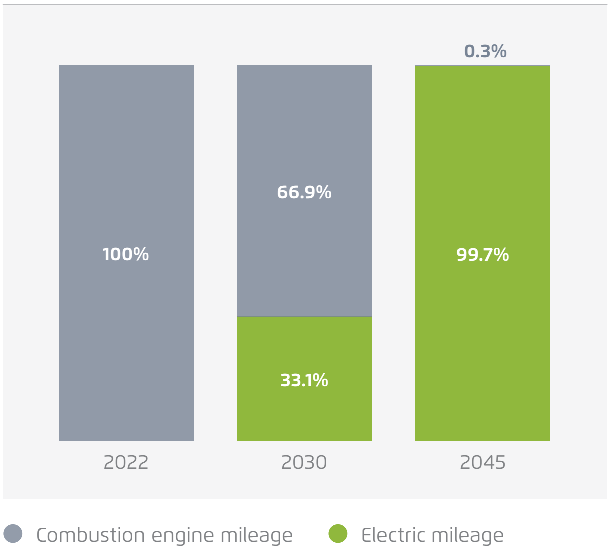
The Federal Government's ambitious transformation targets for 2030 of doubling mileage in rail passenger transport and rail freight transport reaching a 25 percent share of overall freight transport volume are, however, not achieved because of past failures.

Propulsion-system transformation in road freight transport

The government's goal of having, by 2030, a third of heavy trucks' mileage powered electrically or using electricity-based fuels is reached. As regards heavy trucks, which cover most of their total mileage in the first years of use, the proportion of new registrations of vehicles using alternative propulsion systems has risen to over 70 percent. The share of electrically-driven mileage in road freight transport is 33 percent (Figure 25).

In particular, the CO_2 differentiation in the truck toll, the CO_2 emission limits for heavy-goods vehicles (HGVs) and alignment of the energy tax for diesel ensure the rapid market ramp-up of all-electric trucks. The switch becomes worthwhile for more and more usage situations because of the strong price pressure in the logistics sector. So as to achieve this, public spaces are earmarked for charging stations, charging installations are standardised and grid capacities created. Funding programmes at the federal and state levels support the development of truck-charging infrastructure,the acquisition of

Share of electric-powered mileage in road freight transport → Fig. 25



Agora Verkehrswende and Öko-Institut (2024), historical data: *Kraftfahrtbundesamt* (2024)

Transport sector – key policy instruments → Fig. 26

Market regulation	Price-based incentives	Financial support
→ Increase and consolidation of financial means as well as accelerated planning for a rapid expansion of rail, pedestrian and cycle infrastructure plus local public transport services	→ Introduction of a national minimum CO_2 price → Vehicle tax reform (payment on initial registration, stronger CO_2 orientation), company car taxation (increase of the taxable benefit-in-kind for combustion engines)	→ Attractive and simple local public transport prices, continuation of the nation-wide public transportation pass → Purchase subsidies for EVs, tiered according to price and energy consumption plus socially-equitable design
→ General speed limit on motorways	→ Gradual introduction of mileage-based passenger car toll	→ Conversion of mileage allowance for commuters into a mobility allowance
→ Greenhouse gas emissions quotas for fuels (particular focus on air and sea transport)	→ Inflation adjustment and alignment of energy tax rates → Energy taxation of intra-EU flights	→ Support for rapid development of charging infrastructure, especially for trucks

Agora Verkehrswende (2024)

more efficient trailers and the transition to alternative drives by contributing to the additional costs of the vehicles or providing liquidity assistance.

Air transport

Energy taxation of fuels in intra-European transport and increased ticket taxes lead to greater internalisation of aviation's external costs. The European ReFuelEU Aviation quota stimulates use of the first amounts of renewable fuels.

2030 to 2040: From problem child to pioneer

The transport sector goes from being a problem child to a pioneer during the 2030s. The propulsion-system and mobility transition causes transport emissions to fall rapidly in the 2030s, to 10 million tonnes of CO_2eq by 2040.

Propulsion-system transition in road transport

Road transport electrification continues at a high pace from 2030 onwards. Only emission-free passenger cars are permitted from 2035, predominantly Battery Electric Vehicles (BEVs). Fuel Cell Electric Vehicles (FCEVs) play a negligible role due to their significantly higher total usage costs. The number of passenger cars with combustion engines swiftly declines; rising usage costs, mainly due to the CO_2 price, cause households to part with their combustion-engine cars earlier than is usual nowadays.

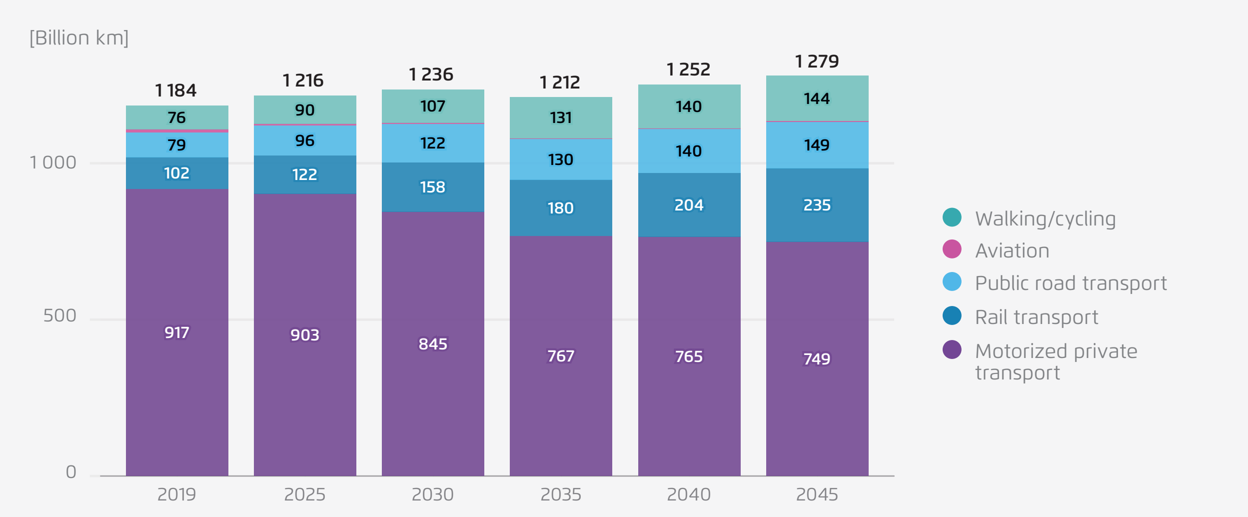
A secondary effect of advancing electrification is steadily declining energy tax revenues. A distance-based passenger car toll is gradually implemented in full to secure expansion and maintenance of the transport infrastructure and to distribute costs fairly among all types of propulsion.

After urban buses, regional- and long-distance buses also run mainly on electricity.

As for HGVs, the share of new registrations of all-electric vehicles in 2035 is also almost 100 percent, with BEVs dominating with almost 80 percent and FCEVs accounting for just under 20 percent.

Development of passenger transport demand

→ Fig. 27



Agora Verkehrswende and Öko-Institut (2024)

Biofuel use in road transport declines steadily from 2030 and ends in 2040; its use is increasingly focused on air and sea transport where, unlike road transport, more cost-effective direct electrification is not possible. Residues and waste materials increasingly serve as basic raw materials for biofuel production (advanced biofuels), in line with the European Renewable Energy Directive (RED).

Shift to public transport

The shift away from motorised individual transport to public transport as well as cycling and walking continues, not least due to continued investments in infrastructure. Rail transport performance doubles between 2019 and 2040, public road transport grows by 77 percent over the same span and cycling and walking by 85 percent (Figure 27). In addition to the increase in public transport's attractiveness, expansion of shared mobility services (car sharing, ride-sharing, autonomous on-demand services) helps to steadily reduce the number of passenger cars.

Air transport

An admixture quota for sustainable aviation fuels (SAF) is used to reduce aviation emissions and continues to rise progressively up to 2040 – and beyond. Non-CO_2 impacts are also taken into account in emissions trading from 2030 and free allocations are completely abolished.

Rising ticket taxes and the ongoing expansion of rail infrastructure give further encouragement to shift from planes and cars to rail. A portion of the revenues from the aviation tax and the ETS are utilised to support the production ramp-up for alternative fuels.

2040 to 2045: Climate protection catches on

Final energy demand in transport is around 280 TWh in 2045, less than half of its final energy demand in 2023. While maintaining a high degree of mobility, the main drivers of this energy saving are the more efficient electric propulsion systems plus the shift to rail and public passenger transport on the roads. 80 percent of final energy demand in 2045 is met by electricity, another 12 percent by hydrogen and 8 percent by electricity-based fuels.

The passenger car and truck fleets are **almost completely electrified** by 2045. The trend has set in towards using public transport that is well-developed in terms of quality and quantity, as well as cycling and walking. Even more households are disposing of their combustion-engine cars, with only about 2.4 million combustion and hybrid cars remaining on the roads in 2045, with the total fleet still comprising just over 40 million passenger cars. This is achieved through consistent implementation and continuation of the measures described above, with the need for subsidies for households and businesses decreasing significantly over time.

In road freight transport, the share of combustion-engine trucks over 12 tonnes is 3 percent whereas battery-electric trucks account for 85 percent and fuel-cell trucks 12 percent. Stimulated by the greenhouse gas reduction quota for road traffic rising to 100 percent, the last remaining demand for liquid and gaseous fuels is covered by electricity-based fuels.

A very small residual amount of fossil kerosene is still used in national aviation, as sufficient quantities of emission-free aviation fuels are not available until 2050. Because the fuel mix in domestic aviation will not be fully renewable until 2050, low residual emissions of less than 0.1 million tonnes of CO_2eq are generated in 2045.

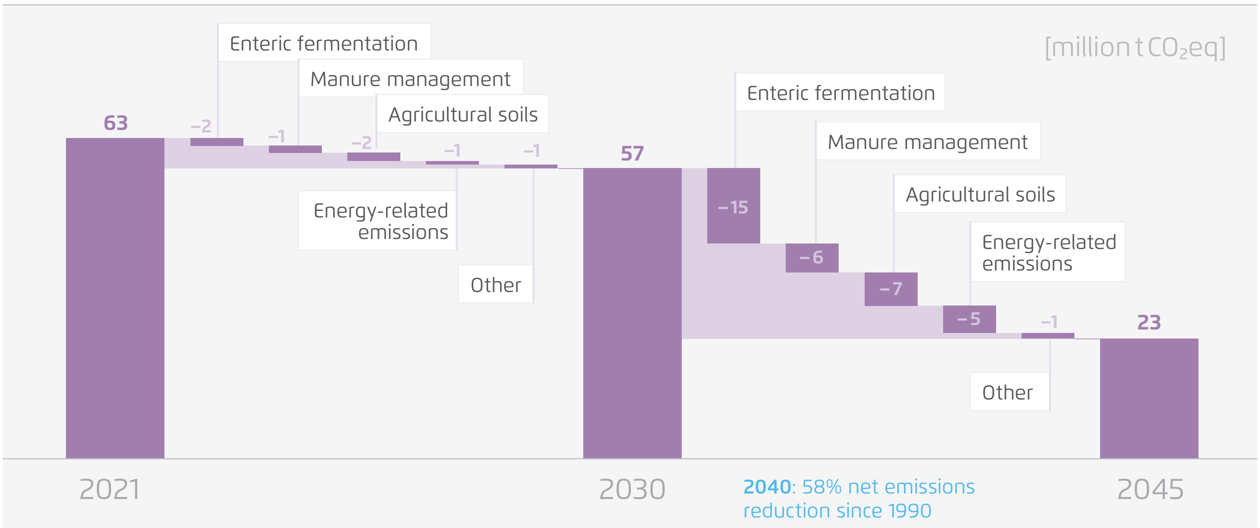
3.5 Agriculture

The agricultural sector essentially comprises emissions from livestock farming, manure management and nitrous oxide emissions from agricultural soils. More than half of the emissions come from livestock farming – mainly due to methane emissions from anaerobic digestion by ruminants. About a quarter are nitrous oxide emissions from agricultural soils; energy-related emissions account for only about 10 percent. Agricultural emissions have decreased by only 6 percent since 2005. Decreasing livestock numbers were the main reason for the slight decline.

Agriculture and the agricultural use of peatland soils, which are recorded in the LULUCF sector, caused about 12.6 percent of German greenhouse gas emissions in 2021. This share will rise in the coming years due to falling greenhouse gas emissions in other sectors.

Agriculture produces not only food and feed and renewable raw materials for the bioeconomy. It maintains and shapes landscapes and ecosystems, is responsible for animal welfare of livestock and can help to remove CO_2 from the atmosphere and

Agriculture sector – reduction of greenhouse gas emissions → Fig. 28



Agora Agrar and Öko-Institut (2024) based on UBA (2023), Agora Agriculture (2024) and the Federal Government's forecasting report (2024) sequester the carbon in plants and soil. Agriculture can make a far greater contribution to climate neutrality than hitherto if its greenhouse gas emissions fall substantially, more carbon is stored on agricultural land and it produces more biomass for the bioeconomy. At the same time, it is possible to increase biodiversity in agricultural landscapes and improve animal welfare. However, agriculture will not become climate-neutral because not all of the emissions linked to animal husbandry and soil management can be avoided. The remaining emissions must, therefore, be offset by negative emissions in 2045.

It is also important to adapt agriculture to the consequences of climate change. Resilient systems are an important basis for the sector's productivity. Measures for agricultural climate protection and adaptation are particularly valuable if they provide additional benefits for other environmental goals, such as the protection of biodiversity, soil and water.

Important areas of action for a greater contribution to climate protection are promotion of more plant-based nutrition and an associated reduction in the consumption and production of animal products; support for structurally diverse agricultural landscapes containing more woody plants like hedges, fast-growing trees or agroforestry systems than today; and the efficient use of fertilisers. Technical measures to reduce greenhouse gas emissions in both animal husbandry and arable farming can also make a relevant contribution to reducing emissions.

Agriculture's potential can be mobilised if, via the political framework, contributions to sustainability turn into economic opportunities for farmers. Furthermore, there is a need for fair food environments for consumers that make it easy for them to eat healthily and sustainably.

2025 to 2030: Beginning change

Based on the assumption that demand for animal products continues to decrease up to 2030 and that a more plant-based diet gains in importance, the decline in livestock numbers, which has been occurring since 2018, continues in the scenario up to 2030. A development like this is a challenge for many livestock farms and it is therefore important to open up other income opportunities for them. Rewarding greater animal welfare is one such income opportunity.

With declining livestock numbers in the animal-intensive regions, less farm manure is produced and regional nitrogen balance surpluses are decreasing. This tendency, combined with more efficient nutrient management, has the potential to reduce greenhouse gas emissions. More efficient nutrient management includes, among other things, reduction of nitrogen losses in barns and storage facilities, an increase in farm manure fermentation and use of low-emission spreading technologies.

The use of other mitigation technologies to reduce greenhouse gas emissions gains importance in the scenario. These include supplementation with additives (e.g. feed additives, substances to acidify slurry, nitrification inhibitors and other fertiliser additives) and precision agriculture. However, due to their limited adoption, these technologies do not yet make a substantial contribution to reducing emissions by 2030.

Moreover, the stronger integration of tree and shrub areas on agricultural land has diverse potential, in the form of short-rotation plantations and agroforestry systems, for instance. When integrated sensibly into the agricultural landscape, trees and shrubs bind CO_2 from the atmosphere into the above-ground biomass and into root systems; they produce biomass that can replace fossil-based raw materials; and they contribute to biodiversity protection and the adaptation of agriculture to climate change.

Selected measures

So that agriculture can fulfill its sustainability potential, political frameworks should be designed such that economic opportunities emerge from contributions towards sustainability. A comprehensive climate policy for agriculture can have a hand in this. Its cornerstones should be developed by 2030. This includes definition of a reduction

Agriculture sector – key policy instruments

→ Fig. 29

Market regulation	Price-based incentives	Financial support
→ Definition of a reduction goal for agricultural greenhouse gas emissions for the years following 2030	→ Policy mix to reduce GHG emissions from livestock farming, incl. pricing	→ Common Agricultural Policy (CAP) payments to remunerate the provision of public goods
→ Standards and labelling to improve animal welfare	→ Pricing of nitrogen surplus	→ Long-term animal welfare payments
→ Health quality standards in public catering to create fair food environments	→ Financial incentives to reduce risks from pesticides	→ Funding for GHG-reduction technologies in livestock and arable farming
	→ Support for fair food environments	→ Stronger coordination at landscape level and in innovation partnerships

Agora Agrar (2024)

target for greenhouse gas emissions for the years after 2030.

The EU's Common Agricultural Policy (CAP) should increasingly be used to remunerate services desired by society. These include, for example, a diverse crop rotation adapted to the locality, cultivation on small agricultural plots of land, preservation and care of semi-natural landscape elements, as well as conservation and careful land-management of permanent grassland. The expansion of tree and shrub areas can be supported with investment grants and, if appropriate, conservation bonuses for carbon or biodiversity services.

Measures promoting animal welfare should be supported with government animal-welfare payments so that animal husbandry in Germany can be internationally competitive. It is important that farmers can rely on long-term remuneration for improved animal welfare so that they can make the appropriate investment decisions.

Fair food environments help ensure that healthy and sustainable diets are accessible and affordable for all citizens. This includes, inter alia, that public institutions, such as hospitals, schools or care facilities, offer meals that adhere to health quality standards. Sustainable, contribution-free catering in nurseries and schools give all children access to healthy meals and 'hands-on' experience of learning about nutrition.

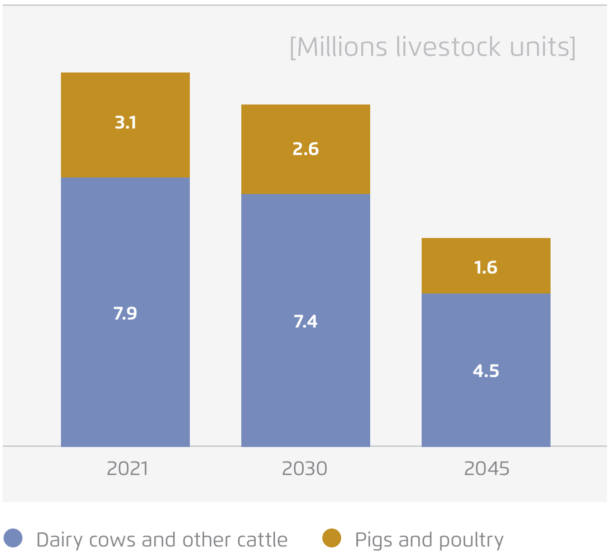
Incentives for a more plant-based diet can also be given by changing how food is taxed: for example, by gradually raising the reduced VAT rate for animal products to the standard level and by reducing tax rates on fruit, vegetables or legumes. At the same time, it is important that social and fiscal policy supports access to healthy and sustainable nutrition in socioeconomically vulnerable parts of society too, thus reducing food poverty.

2030 to 2040: Climate and biodiversity protection as an economic opportunity for the farming sector

In the scenario, many of the policy measures outlined above will take effect across the board between 2030 and 2040, making the reduction pathway for greenhouse gas emissions steeper.

An important element is the widespread creation of fair food environments, which, among other things,

Development of livestock → Fig. 30



Agora Agrar and Öko-Institut (2024) based on UBA (2023), Agora Agriculture (2024) and the Federal Government's forecasting report (Projektionsbericht 2024)

contribute to reducing the demand for animal products. Emissions from livestock farming decrease in the scenario (Figure 30) and are not just displaced by higher imports of animal products from other countries.

Technical measures to reduce greenhouse gas emissions are increasingly used from 2030 onwards, such as administering feed additives to reduce methane emissions, the use of additives during farm manure storage and fertiliser spreading.

Smaller plots, preferably in strip cultivation, plus a significantly larger proportion of wood elements (such as hedges, fast-growing trees and agroforestry systems on agricultural land) combine biodiversity protection with the establishment of carbon sinks and replacement of fossil raw materials.

Selected measures

Clear agreements on targets for greenhouse-gas emission levels for the years 2040 and 2045 are important building blocks for ambitious climate protection in agriculture. Emissions pricing, but also remuneration for negative emissions, set the right incentives for climate protection.

One possible instrument is an emission trading system for agriculture and peatlands used for agriculture. This type of emissions trading should include the most important sources: emissions from animal husbandry and agricultural peatlands as well as nitrous oxide emissions from farm soils. Emissions pricing from animal husbandry should be accompanied by a border adjustment mechanism for emission-intensive products such as milk powder, butter and beef.

Farmers utilising peatlands should receive emission certificates free of charge in the first few years because, for now, there is a lack of both the preconditions for rewetting and value chains for the use of rewetted land. If rewetting is carried out early, farmers could sell the certificates and thus generate new income through avoided emissions.

Because of their contribution to carbon sequestration, the planting of trees and shrubs on agricultural land can be largely remunerated with climate finance funds, without directly including the negative emissions in the ETS.

2040 to 2045: Sustainable and productive – the future of land use

An important element for further reduction of emissions by 2045 is continuation of the trend towards a plant-based diet outlined in the scenario. Based on the assumption that about half as many animal products are consumed in 2045 compared to 2021, this development will contribute to livestock numbers being almost halved too by 2045. In parallel, technical measures have been established to reduce emissions in animal husbandry and arable farming, together with payments for public goods. In the scenario, annual greenhouse gas emissions in the agriculture reporting category are around 23 million tonnes of CO_2eq (Figure 28).

Energy-related emissions can be largely avoided by 2045 through energy efficiency improvements and by using renewable energies. In the field of agricultural machinery, a portion of energy demand can be

Opportunities for strengthening rural areas

Germany's economic development will be shaped by the transition to climate neutrality over the coming years. This can also open up opportunities in rural regions but, at the same time, carries the risk of widening inequalities between urban and some rural areas. In order to exploit the opportunities and contain the risks, investments in rural areas must help to address the structural challenges faced by some of these areas. This is also a contribution to stabilising or regaining trust in politics. The following approaches are suited to this:

- **Strengthening forward-looking economic sectors:** Investments should facilitate forward-looking business models which generate income while contributing to climate neutrality: for instance, building value chains for the agricultural use of rewetted peatlands that also cater to the construction sector's demand for climate-neutral insulation materials.
- **Income from renewable energy production:** Onshore wind turbines are almost exclusively built in rural areas. The same applies to ground-mounted solar PV, where appropriate in combination with other land use options. Assuming a figure of EUR 0.5/MWh, rural area districts will generate 3.5 billion euros by 2045 which they can, in turn, invest in improved local services.
- **Low regional grid charges favour the development of key industries:** The development of new key industries, such as battery factories, takes place in rural areas because of the geographical proximity of RE plants. A reform of grid charges, privileging regions where wind energy is generated, creates important incentives. So as to secure the energy supply for these new industries, politically desirable locations in rural areas are also a factor when planning energy infrastructure (for example, the core network for hydrogen).
- **Building renovations and conversions help preserve the value of buildings:** Real estate value and the prospects for value preservation and appreciation can differ drastically from region to region. This also means that owners can benefit to varying degrees from renovation or conversion of their buildings, depending on their location. These differences affect their medium-term financial performance and the economic viability of a renovation or conversion. These aspects should be considered when designing funding and financing instruments as well as building efficiency requirements.
- **Investments in local public transport infrastructure:** A large-scale investment offensive to expand local public transport, aimed at providing an extensive mobility guarantee, particularly benefits structurally weak rural areas where few services have existed and mobility poverty is high. This is especially important for people in the lowest income deciles who cannot afford cars.

electrified, whereas the power needs for many field operations, such as soil cultivation or harvesting, continue to be met with liquid fuels from biomass or power-to-liquid. Simultaneously in this scenario phase, a major contribution to the energy transition is made through the establishment of wind and solar energy on agricultural land.

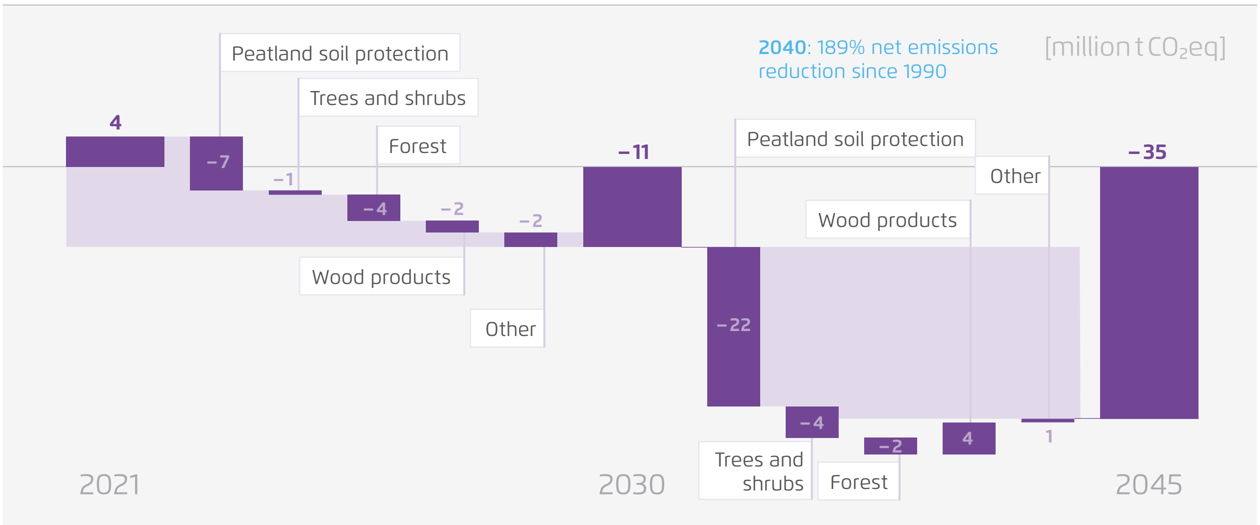
New value chains also help to ensure that biomass from agriculture makes an important contribution to a climate-neutral economy as a whole.

3.6 LULUCF

The **LULUCF sector** comprises emission sources and carbon sinks from land use and forests. Most of the emissions arising in the LULUCF sector are caused by agricultural use of drained peatlands. For centuries, the draining of peatlands was supported by society and made an important contribution to a sufficient supply of food in many regions. Drained peatlands, which constitute just 7 percent of Germany's agricultural land, contribute almost 5 percent

LULUCF – reduction of greenhouse gas emissions

→ Fig. 31



Agora Agrar and Öko-Institut (2024)

to German greenhouse gas emissions, with around 40 million tonnes of CO_2 equivalent per year.

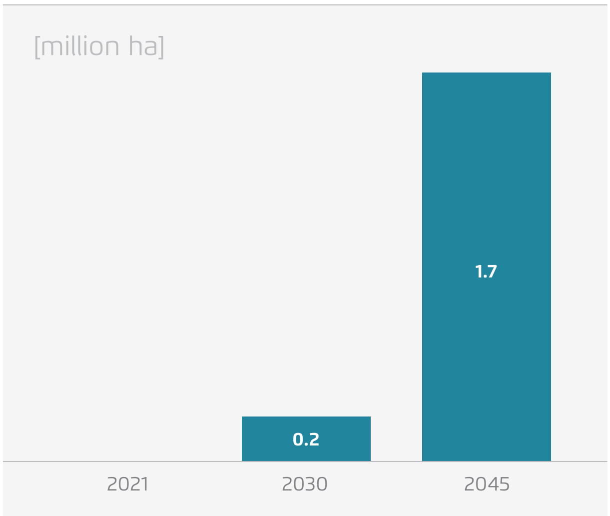
Forest is the most important carbon sink in the LULUCF sector. It absorbs CO_2 from the air and binds the carbon mainly in trees and forest soils. The forests' carbon sink capacity reduces Germany's total annual emissions by about 5 percent. However, this carbon sink capacity has fallen from 55 million tonnes annually (average value 2013 to 2017) to 40 million tonnes CO_2eq (average value 2018 to 2022).[14]

The LULUCF sector was overall a net sink, with negative emissions of approximately −9 million tonnes of CO_2eq per year from 2013 to 2017, and then a net source of around 2 million tonnes of CO_2eq per year between 2018 and 2022. To improve the LULUCF sector's contribution to climate neutrality, it is important to reduce greenhouse gas emissions from peatlands used for agriculture, maintain carbon storage in forests and increase it on agricultural land.

The emissions caused by peatlands can be reduced by three measures: a) rewetting drained peatlands used for agriculture, (they can, to a large extent, still be farmed when wet), b) ending peat extraction and c) optimising wetland management.

New trees and shrubs on agricultural land

→ Fig. 32



Agora Agrar and Öko-Institut (2024)

In the scenario, the forests' carbon sink capacity is stabilised by slightly reduced timber removal[15] in specially selected forests and management measures,

14 The results of the fourth Federal Forest Inventory (Bundeswaldinventur, BWI) have not yet been taken into account in this study. Information on past greenhouse gas balances is based on official reporting.

15 Timber harvesting removes captured carbon from forests. When the wood is decomposed or burned, the carbon is released as CO_2. If the wood is used for wood products, the carbon remains stored.

such as adapting forests to climate change. The natural carbon sink capacity is supplemented by new forest areas (0.3 million hectares (Mha) by 2045) and the planting of trees and shrubs on agricultural land (1.7 Mha) in the form of short-rotation plantations, agroforestry systems and hedgerows (Figure 32). The extent of forests' carbon sink capacity depends on how climate change affects forests in the future and the degree to which climate-sensitive forest management strategies are implemented.

2025 to 2030: Laying the foundations for change

By starting the rewetting of agricultural peatlands, reducing peat extraction and optimising water levels in existing wetlands, a reduction in annual emissions of 7 million tonnes CO_2eq by 2030 is achieved in the scenario.

Concurrently, the first measures to stabilise forests' carbon sink capacity are implemented: in stands of stable deciduous trees, the harvest is slightly reduced and the forest actively adapts to climate change by, among other things, replacing stands of conifers with deciduous trees. Furthermore, the first areas are reforested and new carbon sinks are created by planting trees and shrubs on agricultural land.

Selected measures

Rewetting peatlands is the most effective measure to prevent greenhouse gas emissions in the LULUCF sector. Due to the great historical significance of drainage, rewetting is a task for society as a whole which can only succeed in close cooperation with farmers. In this respect, it is important that the wet use of peatlands opens up economic prospects for them.

The following funding areas are important for rewetting:

- → Funding for rewetting: Rewetting premiums for farmers, investment subsidies for planning, construction activities, hydrological management and maintenance.
- → Funding for using rewetted areas: Investment funds for paludiculture cultivation[16], grants to purchase new machinery, support for new value chains to use products from paludicultures.

16 Growing plants on wet peatland soils, for example reeds or reedmace.

LULUCF – key policy instruments

→ Fig. 33

Regulatory framework	Price-based incentives	Financial support
→ Ending of peat extraction	→ Pricing of GHG emissions from peatlands used for agriculture	→ Long-term financial incentives to rewet peatlands used for agriculture
		→ Funding of new value chains for paludiculture
	→ Incentives for material use of biomass	→ Funding for woody structures on agricultural land
		→ Financial incentives for carbon storage in forests

Agora Energiewende (2024)

What influence do natural disturbances in forests have on net emissions in the LULUCF sector?

In the scenario, forests sequester some 5 million tonnes more CO_2 by 2045 than in 2021 through a reduction in hardwood use, converting stands of conifers and a moderate reforestation. However, alongside forest management measures, forests' carbon sink capabilities are also influenced by natural disturbances which are increasing due to advancing climate change. Prolonged extremely dry periods reduce growth and, like storms or bark beetle infestations, contribute to higher mortality in tree populations.

Three variants with low, medium and high natural disturbances[17] and their effects were analysed for the scenario. Depending on the variant, LULUCF sector emissions for the year 2045 are -18 to -53 million tonnes CO_2eq. Medium-level natural disturbances in forests are assumed for the cross-sectoral description. This results in -35 million tonnes of CO_2eq for the LULUCF sector in 2045.

17 See details on the assumptions of the intensity of natural disturbances in Pfeiffer et al. (2023).

The financial resources can come from the EU Common Agricultural Policy as well as from other budgets. But expansion of voluntary carbon markets can also serve as a finance source, remunerating additional efforts for climate protection as a supplement to the compulsory climate-protection measures. Another option is the pricing and inclusion of emissions from drained peat soils in a possible EU emissions trading system for agriculture and agriculturally used peatlands. Farmers should receive the emissions certificates for peatland soils free of charge for the medium term.

Another important contribution to reducing emissions from the LULUCF sector is ending peat extraction by 2040 and rewetting the former peat-extraction areas.

The forests' carbon sink capacity has a social value and should, therefore, be rewarded and supported with public funding. Both standard budget funds and revenues from an ETS or voluntary carbon markets can be used for financing.

An expansion of carbon storage in wood products can be strengthened by remunerating carbon storage in durable wood products (especially in construction) and supporting cascades in wood-product life cycles.

To promote material use, the assumption of carbon neutrality in the use of wood for energy under the ETS should also be reviewed.

These scenario measures can lead to net balance negative emissions of around -11 million tonnes in the LULUCF sector in 2030. This would mean that the sector would fall well short of the Federal Climate Protection Act's target of -25 million tonnes of CO_2eq for 2030.[18]

18 Greenhouse gas targets for the LULUCF sector were derived in the Federal Climate Protection Act using greenhouse-gas reporting before 2021 as a basis. Significant methodological changes after 2021, particularly regarding carbon sequestration in forest soils and methane emissions from artificial standing water such as fish ponds, lead to a deterioration in the LULUCF sector's reported greenhouse gas balance by approximately 17 million tonnes of CO_2eq. Since the results of this study build on the 2023 greenhouse gas inventory, this purely methodological change should be considered when interpreting the LULUCF results.

2030 to 2045: Rewarding carbon sinks

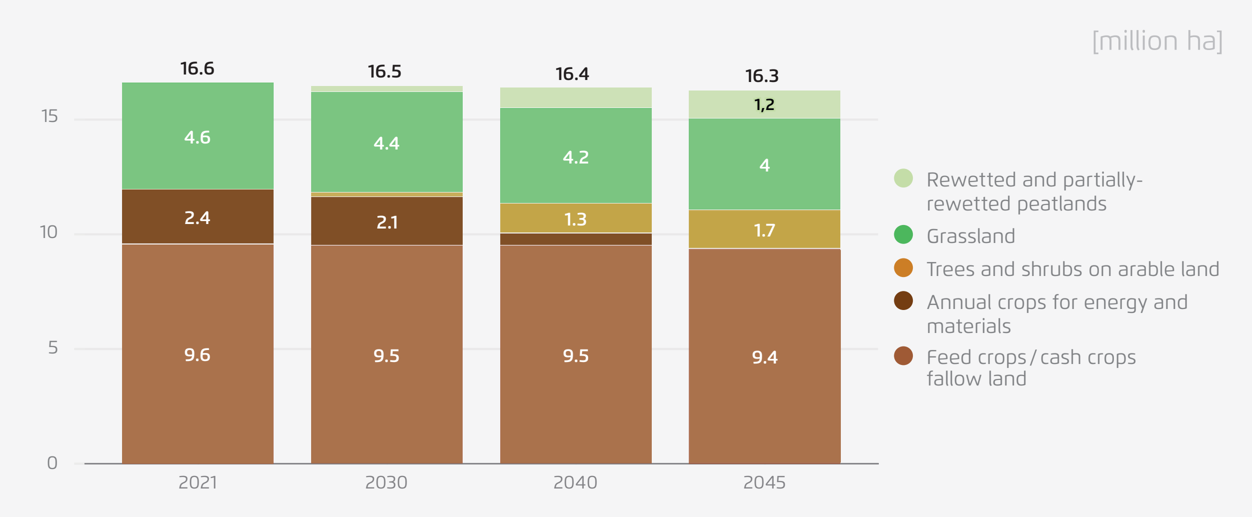
In the scenario, slightly less than 80 percent of agricultural peatlands have been completely rewetted by 2045 with some 15 percent partially rewetted (Figure 34), and the water levels in currently existing wetlands are optimised. Peat extraction stops from 2040. Moreover, forests' carbon sink capacity was further stabilised by measures set up in the preceding period.

Growing trees and shrubs on agricultural land can absorb additional greenhouse gases from the atmosphere. They offer new income opportunities for agriculture by providing biomass, for example as feedstock for the chemical industry, and by remunerating carbon storage.

With these measures, it is possible for the LULUCF sector to achieve a net carbon sink capacity and thus negative emissions of -35 million t CO_2eq. Nevertheless, the Federal Climate Protection Act target of -40 million tonnes CO_2eq is just missed in the scenario (Figure 31).

Development of land use

→ Fig. 34



Agora Agrar (2024) and Öko-Institut based on FNR (2023), Destatis (2023), the Federal Government's forecasting report (2024).

4 Cross-cutting themes

4.1 Biomass

Biomass that is produced and used sustainably can make an important contribution to climate neutrality in Germany. In 2045, biomass is primarily used in places where no other more efficient options are available to replace fossil raw materials. By using more biomass for materials and feedstocks and less for energy, it can serve industry as a sustainable source of carbon, for example in plastics production. Furthermore, CO_2 from biomass can be removed and stored long term (Bio-CCS).

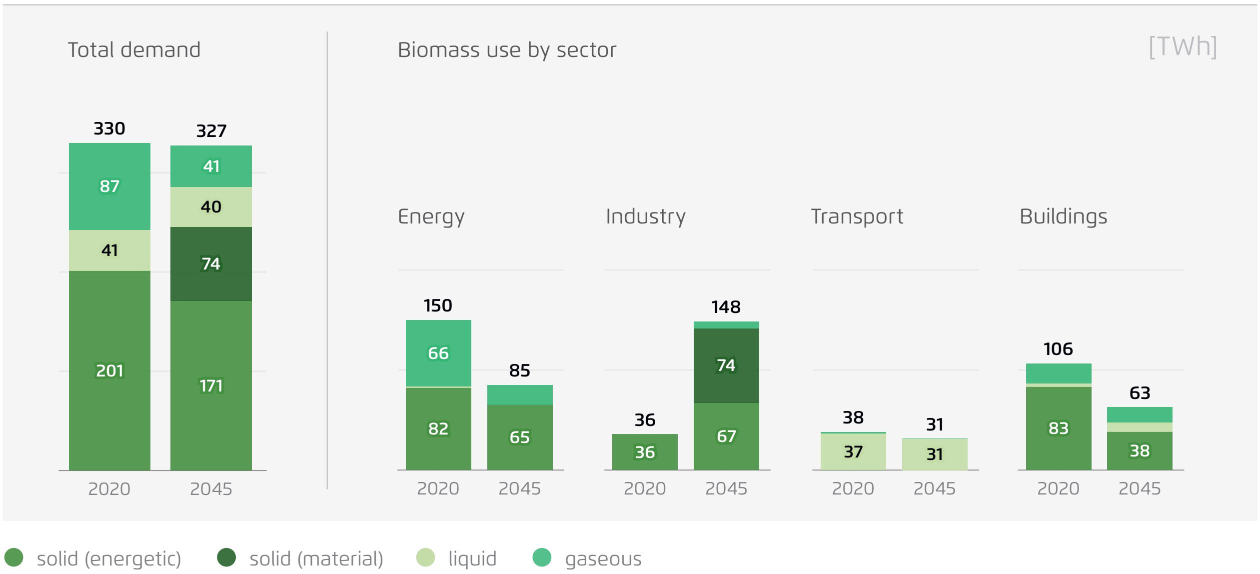
Sustainable production of biomass via agroforestry systems and other woody materials is an opportunity for agricultural incomes, carbon storage and biodiversity. This type of biomass production gradually replaces annual energy crops by 2045. This creates carbon sinks on agricultural land and greatly reduces the risk of indirect land use effects. Residual and waste materials are increasingly used and timber extraction from forests is reduced, which also strengthens natural sinks.

Areas of application in the scenario

The most important form of use for biomass is construction timber. By using it, the biogenic CO_2 is stored long-term in buildings. For detached and semi-detached houses, the share of construction using wood rises from around 21 percent currently to about 35 percent, and for apartment buildings and non-residential buildings from less than 5 percent currently to 15 to 20 percent.

For the remaining biomass, the usage of 327 TWh remains at roughly the same level as in 2020 (330 TWh). However, there is a shift in usage. The use for materials and feedstocks is increasing while energetic use is falling. Since solid biomass mainly goes into material and feedstock use, its usage rises by 22 percent in the period from 2020 to 2045, reaching 245 TWh. The

Energetic and material biomass use by sector* → Fig. 35



Agora Energiewende, Prognos, Öko-Institut, Wuppertal Institute and Kassel University (2024). * excluding construction timber.

use of biofuels, liquid biofuels as well as biogas correspondingly declines.

Feedstock use

The use of biomass as a raw material in industry also becomes significantly more important, rising to 74 TWh by 2045. Biogenic carbon is stored in chemical products (plastics) in particular; the durability of the carbon storage is increased by circulating the products in an efficient circular economy. During the feedstock use of biomass in the chemical industry, CO_2 is produced which is captured and stored, thereby creating negative emissions (bio-CCS). Innovative biomass-based processes in the chemical industry could be given appropriate financial support. The financial resources needed for this could be generated, for example, by a levy on plastic products. In the medium term, it also seems sensible to price fossil carbon that is used as a material (see Chapter 3.2 Industry).

Energetic use

By 2045, the energetic use of biomass in industry doubles compared to 2020, rising to 74 TWh. Biomass is mainly used to generate particularly high temperatures. In the other sectors, the use of biomass for energy declines: in heating for buildings, wood-heating systems lose market share to heat pumps for cost reasons. A similar trend away from biomass and towards electricity can be observed in road transport. Only in international aviation and shipping does the biomass demand for fuels increase from 2030 onwards to 31 TWh by 2045, due to a lack of cost-effective, climate-neutral alternatives.

In the energy industry, around three-quarters of bioenergy (excluding the biogenic portion of waste) is currently generated decentrally in small to medium-sized biogas plants. In order to take account of the future energy system's requirements, the stock of these relatively inflexible plants is reduced in the long term. Solid biomass is used in CHP plants for heating networks without a hydrogen connection and to cover peak demand in winter.

Sustainable supply of biomass

Wood extraction for energy use decreases by 31 percent by 2045 compared to 2022 in order to reinforce the forests' function as carbon sinks. At the same time, however, trees and shrubs as well as paludicultures are grown and used on agricultural land, increasing the supply of solid biomass from 191 TWh in 2020 to 246 TWh in 2045. The area for annual crops (maize, rapeseed, cereals) providing biogas and biofuels is correspondingly reduced.

This change in land use can play a valuable part in diversifying the landscape structure with a consequent reduction in pesticide and fertiliser use. Wood elements create carbon sinks on the land, contribute to biodiversity conservation and facilitate adaptation to climate change. By remunerating land users for the provision of public goods in the areas of carbon storage and biodiversity, this type of biomass production becomes competitive.

The use of cultivated biomass for biogas production is gradually phased out up to 2045 and partially offset by using residual materials. The supply of residual materials from agriculture (manure fermentation, catch crops, straw and other crop residues) more than doubles by 2045 compared to today.

The share of cultivated biomass in biofuel production also falls by 2045 and the use of residual and waste materials goes up. Imports of sustainably produced biofuels and limited domestic production of biomass-to-liquid also cover part of demand in aviation and shipping.

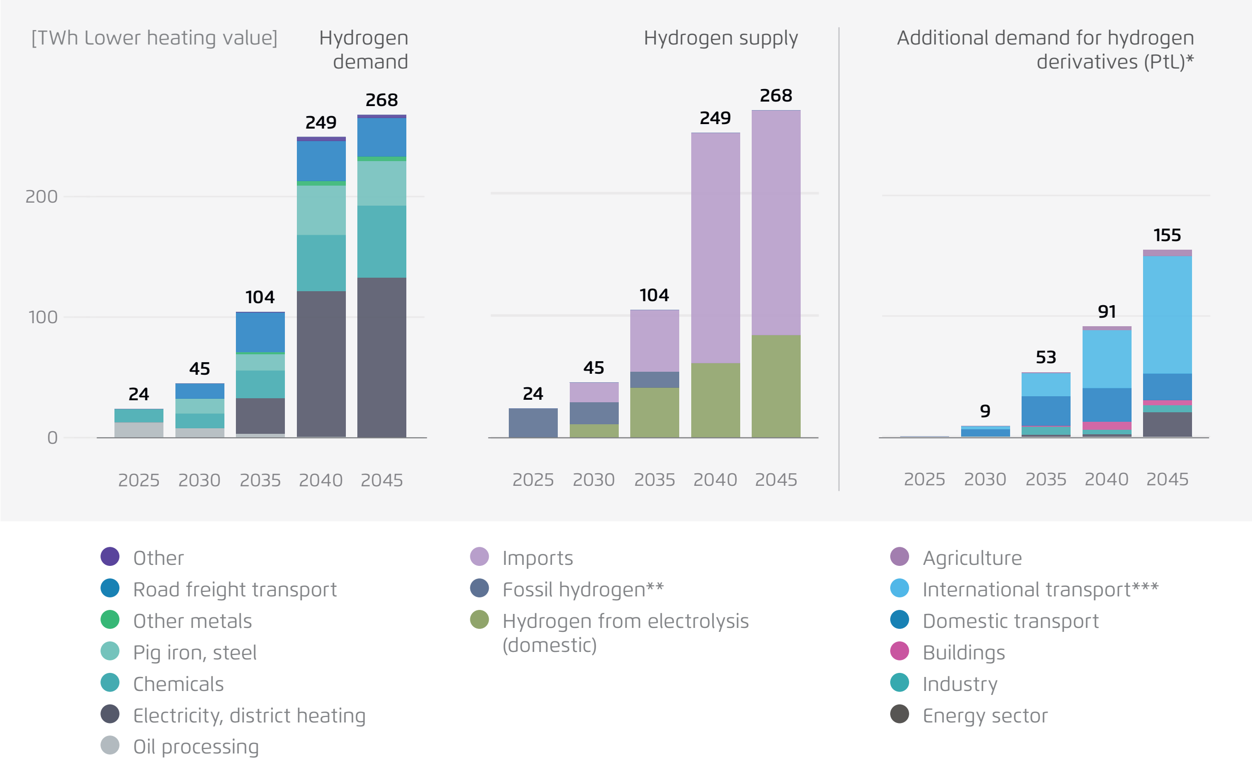
4.2 Hydrogen and electricity-based energy sources

Energy and industry as the most important demand sectors for hydrogen

For cost and efficiency reasons, hydrogen is mainly used for seasonal energy storage in the electricity sector and in certain industrial processes in the steel and chemical industries.

Hydrogen demand and hydrogen production

→ Fig. 36



Agora Energiewende, Prognos, Öko-Institut, Wuppertal Institute and Kassel University (2024). * covered by imports; ** from steam reforming; *** international aviation and maritime transport.

The total demand for climate-neutral hydrogen increases to 268 TWh per year by 2045 (Figure 36). The largest part of this is taken up by the **energy sector** where hydrogen is used as a fuel in dispatchable power plants and in electricity-driven CHP. Besides pure hydrogen, liquid hydrogen-based fuels (power-to-liquid) are also used here. The next largest demand sector is industry, where hydrogen is utilised, among other things, in DRI plants for steel production and the enhancement of syngas from biomass gasification to produce basic chemicals in the chemical industry.

Hydrogen demand in the **transport sector** is almost entirely related to road freight transport (fuel-cell trucks) and, to a small extent, to public road transport (fuel-cell buses). In the long term, nearly 100 TWh of hydrogen-based fuels for aviation and maritime transport and around 20 TWh of hydrogen-based fuels for domestic transport are added. In the **building sector**, hydrogen is not used to a significant extent because of the high costs.

Import and storage infrastructure

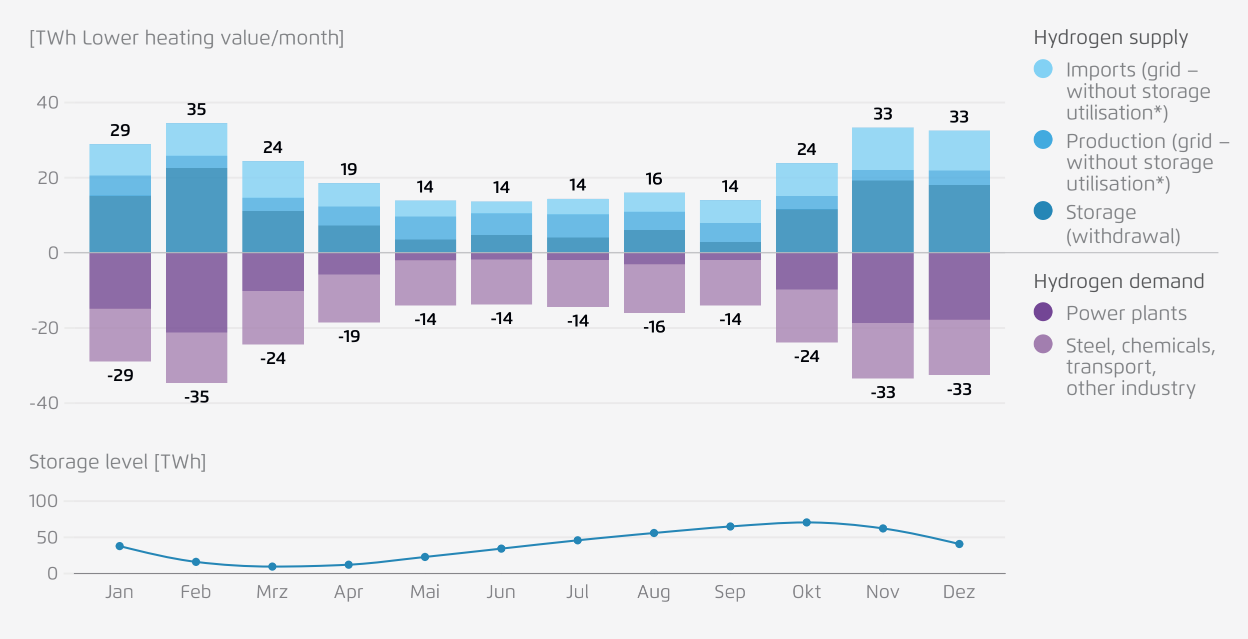
A large part of hydrogen demand will be imported in the future. Pipeline corridors from European and neighbouring production countries become the backbone of the hydrogen supply. Already in the early 2030s, large quantities of renewable hydrogen can be imported via these corridors.[19]

Imports of low-carbon hydrogen can complement the renewable hydrogen supply, especially during the ramp-up phase. It is important that residual emissions are as low as possible so that hydrogen makes an effective contribution to climate protection. This can be attained through CO_2 capture rates of over 90 percent, low upstream emissions and not using CO_2 for Enhanced Oil Recovery.[20]

19 Agora Energiewende and Agora Industry (2024): Wasserstoffimporte Deutschlands
20 Agora Energiewende and Agora Industry (2024): Low-carbon Hydrogen in the EU

Seasonality of hydrogen production and demand in 2045

→ Fig. 37



Agora Energiewende and Prognos (2024). *Storage from production and imports not shown.

Hydrogen demand from power plants is concentrated in the six months of winter, the reason for the hydrogen system's strong seasonality. Hydrogen is stored on a large scale in summer, allowing the high winter demand to be met. The maximum storage level reaches 73 TWh in 2045. Around 80 TWh of hydrogen storage is therefore required when a resilience buffer is included (Figure 37). Around 30 TWh can be retrofitted from existing fossil gas storage facilities, according to industry associations. The remaining 50 TWh is obtained through new construction.

Four areas are key to policy instrumentation:

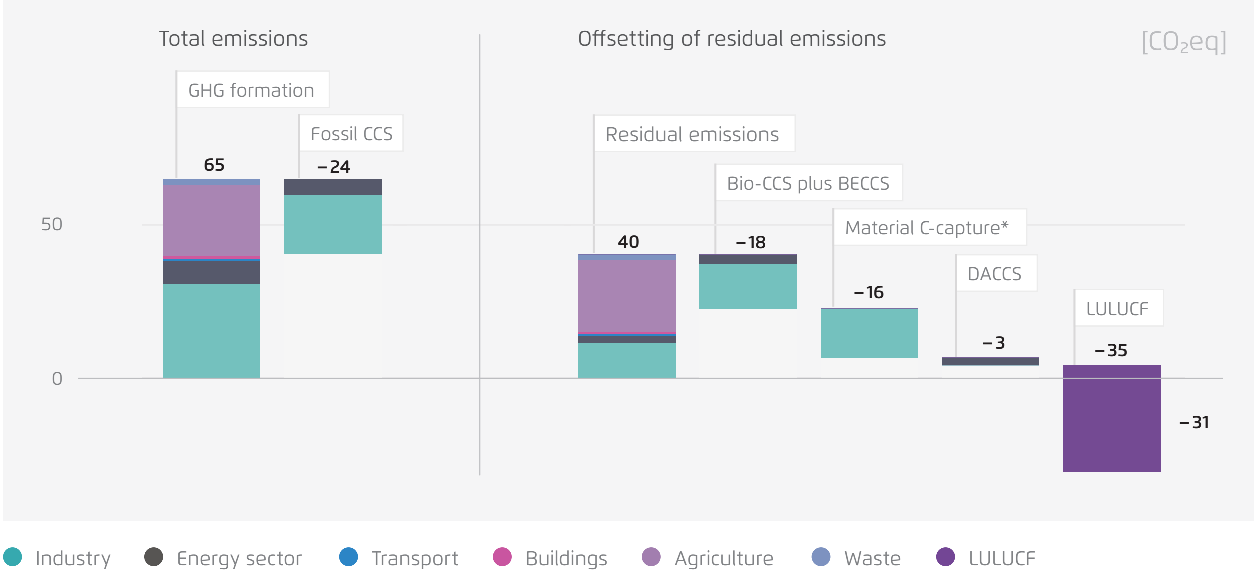
1. **Further securing of demand creates the basis for H_2 offtake agreements:** Hydrogen use in the electricity sector is mainly achieved through levy-funded fuel cost subsidies and support for constructing dispatchable power plants. Industrial demand is secured by a combination of quotas, carbon contracts for difference and green lead markets *(Leitmärkte)*.
2. **Ensuring construction of import corridors**: Via more intensive dialogue with European and non-European production and transit countries, an agreement can be reached on cost and risk sharing for the corridors. As a result, instruments such as an amortisation account and government capacity bookings lead to sufficient investment security.
3. **An instrument for ramping up hydrogen storage:** A suitable hedging instrument will incentivise conversion and construction of hydrogen storage facilities.
4. **Support for domestic electrolysis:** Implementation of the previously announced tenders for electrolysers bolsters domestic hydrogen production.

4.3 Carbon Management and Carbon Capture and Storage (CCS)

Carbon management encompasses a range of technologies for dealing with CO_2 or carbon. With CCS, the CO_2 is usually captured in large industrial plants, transported away and stored underground.

The CO_2 can come from fossil or biogenic sources, be captured at point sources or taken directly from the air. This has implications for CCS accounting: CO_2 originating from fossil material or from processes and which is captured at point sources counts as avoided emissions. Biogenic CO_2 captured in combustion or

Residual emissions and their offsetting in 2045 → Fig. 38



Agora Energiewende, Prognos, Öko-Institut, Wuppertal Institute and Kassel University (2024). * Materially captured biogenic carbon in chemical products; stringent recirculation is required to enable long storage duration.

processing procedures at point sources (BECCS) is recorded as a negative emission because, throughout the process from biomass cultivation to CO_2 capture, there is an overall CO_2 removal from the atmosphere. Direct Air Carbon Capture and Storage (DACCS) is likewise counted as a negative emission. The latter two technologies, together with natural carbon sequestration via afforestation or sustainable management of forests and agricultural land, count as methods of CO_2 removal from the atmosphere (Carbon Dioxide Removal or CDR).

Carbon Capture and Utilisation (CCU) captures and uses CO_2 of fossil or biogenic origin. So that CO_2 remains stored for as long as possible, CCU should mainly be used in the manufacture of durable products.

CCS is a necessary building block for achieving climate neutrality

So as to reach climate neutrality by 2045 and, in the long term, the Federal Climate Protection Act's target for negative emissions, CCS is needed in two settings: firstly, to capture and permanently store ongoing residual emissions (from processes or fossil materials) in the industrial and waste sectors; secondly, to offset residual emissions, especially from agriculture (Figure 38).

A broader application of CCS in fossil energy generation comes with both climate risks as well as a series of costs and implementation risks:

- → Firstly, any new CO_2 molecule formed from fossil fuels must be stored long term and competes for the same storage capacities with applications that remove CO_2 from the atmosphere. The ongoing use of fossil fuels thus further increases the efforts needed in CO_2 storage. The decision of the UN Climate Change Conference COP28 to phase out the use of fossil fuels in energy systems also has to be understood against this background.
- → Secondly, methane emissions are produced along the fossil gas value chain and additionally need to be offset, thus pushing up costs and further raising essential storage requirements.
- → Thirdly, the injection capacities available constitute a relevant bottleneck, at least in the medium term.

- Fourthly, current cost estimates for CO_2 storage vary widely due to the limited number of projects implemented and uncertainties regarding the geological conditions in potential storage sites.

The application of CCS technologies in the scenario is therefore focused on the above-mentioned areas, thereby ensuring their successful scale-up.

Carbon management in the scenario

CCS associated with fossil fuels is done, firstly, at remaining **fossil point sources in the industrial and waste sectors**. These include process emissions, particularly in cement and lime production, the non-biogenic share of waste incineration and CO_2 volumes generated during the chemical recycling of plastic waste. CCS is also used temporarily in DRI plants for steel production which are initially operated with fossil gas, until sufficient renewable hydrogen is available.

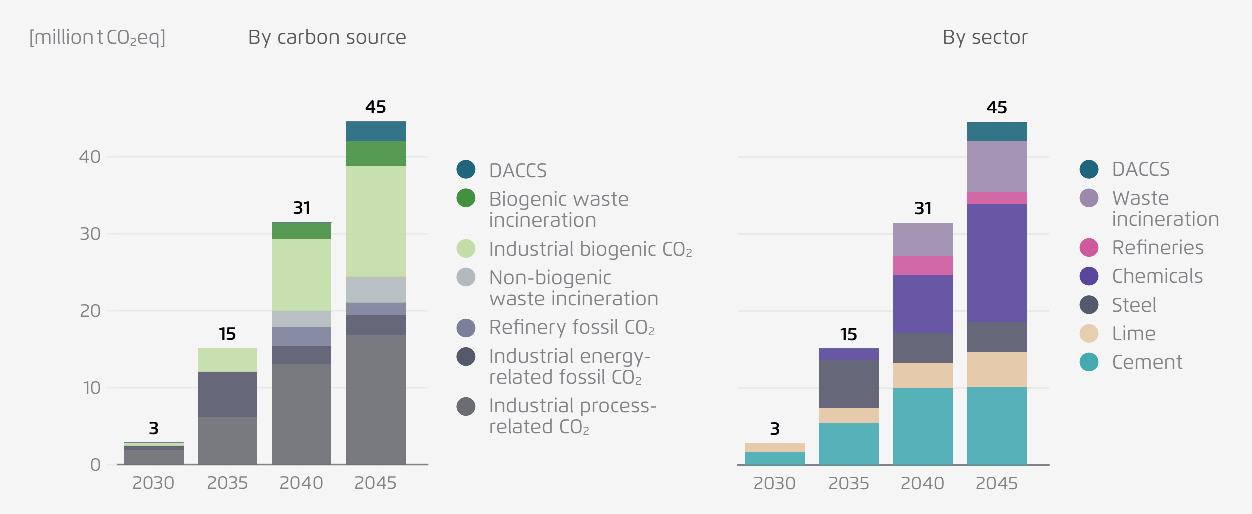
In addition, **CCS is deployed in combination with material use of biomass**. Domestic biomass is used to produce basic chemicals (with methanol as the intermediate step), replacing fossil oil as a carbon source.[21] CO_2 emissions are generated throughout this biomass processing, which are captured and stored geologically where possible (bio-CCS). A large part of the carbon contained in biomass is materially bound in methanol and the chemical products based on it. Using recycling methods, the bound carbon is kept in the cycle for as long as possible, especially in the case of plastic products. At the end of the life cycle, CCS use in waste incineration plants ensures that the carbon is fed into long-term geological storage, thereby generating permanent negative emissions.

Moreover, biomass combustion is utilised for pure energy production and subsequent CO_2 capture and storage (BECCS) (10 million tonnes in 2045.[22] CO_2 use to produce hydrocarbons (**CCU**) and direct removal of CO_2 from the atmosphere (**DACCS**) play a subordinate role in the scenario, due to the high energy intensity of the relevant processes.

21 There is an assumption in the scenario of pyrolysis and subsequent gasification of biogenic residues and woody biomass from short-rotation plantations. Compared to conventional agricultural land use, CO_2 absorption is thus increased and biodiversity is boosted.
22 Incl. biogenic parts from waste materials and capture of biogenic CO_2 in bio-syngas-DRI-CCS.

Captured and geologically stored CO_2

→ Fig. 39



Agora Energiewende, Prognos, Öko-Institut, Wuppertal Institute and Kassel University (2024)

The **LULUCF** sector's sink function is bolstered, among other things by expanding the forest sink and setting up agroforestry systems, and reaches a total capacity of 35 million CO_2eq per year in 2045.

Directing funding and the CO_2 infrastructure towards the core areas

CCS use is prioritised in the application areas above, particularly via the allocation of subsidies.

The geographical configuration and dimensioning of pipeline-based CO_2 infrastructure is oriented towards the planned locations for the plants with these areas of application and the volumes of CO_2 captured there.

So as to guarantee planning certainty for companies and not to delay investments in climate-neutral alternatives, a planning and financing blueprint for CO_2 infrastructure is promptly developed and implemented in the scenario, with (federal-level) state involvement.

→ What if CCS is used more widely throughout the CO_2 infrastructure?

In one scenario variant, the effects of an additional industrial application of CCS were investigated. Provided there is sufficient injection capacity, this is especially pertinent if industrial sites are already situated on the CO_2 transport infrastructure needed. Two application areas were considered:

- → Expansion of CCS for DRI plants in steel production which use fossil gas with CO_2 capture. This increases fossil gas use by 20 TWh in 2035 and by 50 TWh in 2045 compared to the baseline scenario. The additional quantities of CCS in steel production create an additional CO_2 storage requirement of 6 million tonnes of CO_2 in 2045.
- → CCS utilisation at industrial CHP plants powered by fossil gas and located at chemical sites. These are, in any case, connected to the CO_2 infrastructure due to the material processing of biomass. The additional CCS application at CHP plants in the chemical industry increases fossil gas consumption by 5 TWh in 2035 and by 29 TWh in 2045. An additional 4 million tonnes of CO_2 will have to be stored in 2045.

In this scenario variant, hydrogen demand is 60 TWh lower in 2045. This reduced demand brings with it risks for the hydrogen ramp-up. Due to incomplete sequestration rates in CO_2 capture and upstream fossil gas emissions, the ongoing residual emissions would have to be offset using technical sinks such as DACCS or BECCS. This would lead to high costs, be electricity-intensive or be reliant on sufficient quantities of sustainable biomass.

5 Investments and public funding needs

An essential building block to reach climate neutrality is the shift of investments from fossil fuels to climate-neutral technologies and infrastructures. Thus, the amount of total and climate protection investments required was also quantified in the scenario for the first time.

The **total investments** can be divided into **two groups**: About three-quarters of the sum would also be incurred anyway without the transition to climate neutrality (so-called **„business-as-usual investments"**) – so this is about redirecting spending from fossil technologies towards climate-neutral investments. A quarter of the total investment comes under the so-called **climate protection investments**. This is **additional expenditure to purchase** climate-neutral technologies as opposed to fossil reference technologies – for example, the higher price of a heat pump compared to a gas heating system.

The **total investment** from 2025 to 2045 amounts to an average of 540 billion euros per year – equivalent to around 11 percent of Germany's annual economic output in this period. About 18 percent of this must be carried out by the state; these are especially investments in electricity and district heating networks as well as transport infrastructure.

A distinction should be made between public investment and **public funding needs**. These arise for two reasons:

- → Investment and operating cost subsidies from budget resources to enable private and public investment.
- → Compensation payments for social equity or to generally reduce prices for citizens and businesses.

It should be noted here that the additional burden on public budgets cannot be readily established: investment subsidies frequently also benefit the public portion of the investments, so municipalities are regularly supported by state *(Land)* or federal *(Bund)* funding programmes. In many cases, operating cost subsidies also ultimately serve to refinance investments upstream in the value chain and thus cannot simply be added to the investment needs.

Both indicators – public investment and public finance needs – therefore provide complementary information, but they partially overlap: the investment needs indicate how much expenditure needs to be covered in total – but many refinance themselves through market revenues and fees. The public funding needs show what funds from the state budget are required to close gaps in economic viability and prevent excessive cost burdens for citizens and companies.

5.1 Energy sector and infrastructure

Modernisation of the energy sector and its associated infrastructure is the precondition for the demand sectors of industry, buildings and transport becoming climate-neutral.

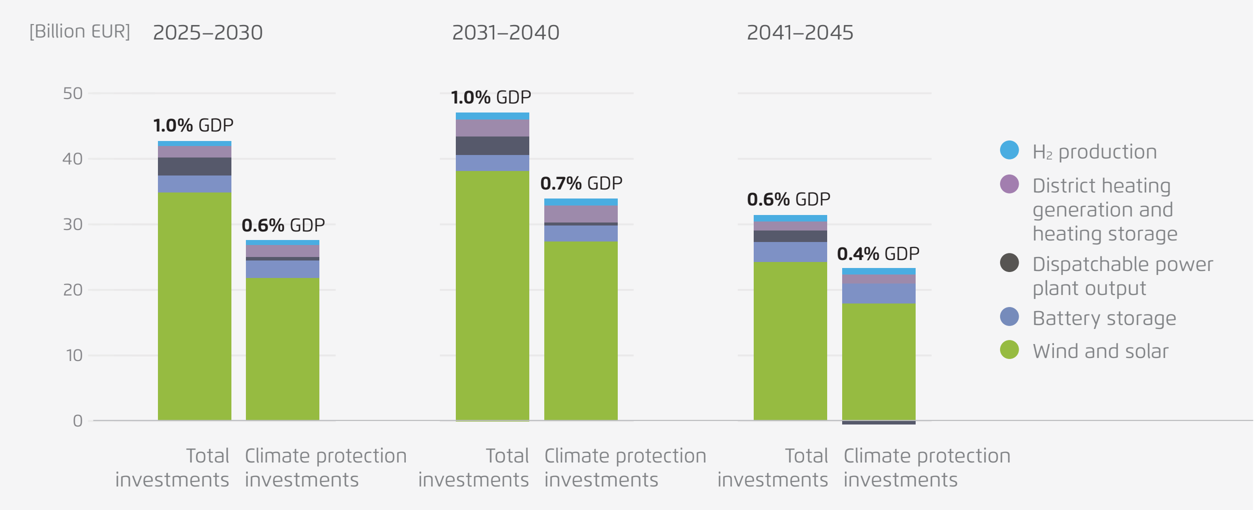
Compared to other sectors, the share of climate protection investments in the energy industry is high – resulting from the shift from a fossil-fuel electricity system with higher operating costs to a climate-neutral electricity system with higher investment costs. Moreover, the importance of electricity grids is growing considerably so that higher investments are required here too. However, the investments are also offset by fuel cost savings. And the power grid costs are spread over a significantly larger volume of electricity. Consequently, around 90 percent of investments in renewable energies and electricity grids refinance themselves through revenues from the electricity market and grid fees.

Investment needs

Investment requirements are shown separately for the energy industry and energy infrastructure. The

Energy sector: total and climate protection investments as an annual average and their share of gross domestic product

→ Fig. 40



Agora Energiewende and Prognos (2024). Y-axis corresponds to the annual average during the period in billion EUR; Annotation: share of gross domestic product during each period, in real prices (2023).

energy sector includes generation plants, storage facilities and electrolysers. Energy infrastructure comprises investments in electricity, hydrogen, heat and CO_2 transport networks.

In the energy industry, investments in wind and photovoltaics represent by far the largest share of climate protection investments. These will amount to 0.5 percent of GDP (gross domestic product) by 2030, rising slightly to 0.6 percent per year (27.4 billion EUR) by 2040, before falling again between 2041 and 2045 to 0.3 percent of GDP or 17.9 billion EUR (Figure 40).

The public sector share of climate protection investments is 12.2 percent. This happens because the public sector has a stake in a number of energy supply companies which are expected to make the investments.

In terms of energy infrastructure, the expansion of electricity grids dominates. This reflects the growing importance of electricity as an energy source. However, a notable decrease in investment requirements can be observed over time. If 0.6 percent of GDP is required annually for climate protection investments in the electricity grid sector from 2025 to 2030 (28.2 billion EUR), the requirement will halve to 0.3 percent of GDP (16.1 billion EUR) in the period from 2031 to 2040. According to the scenario, no further climate protection investments for electricity grids are required from 2040 onwards (Figure 41).

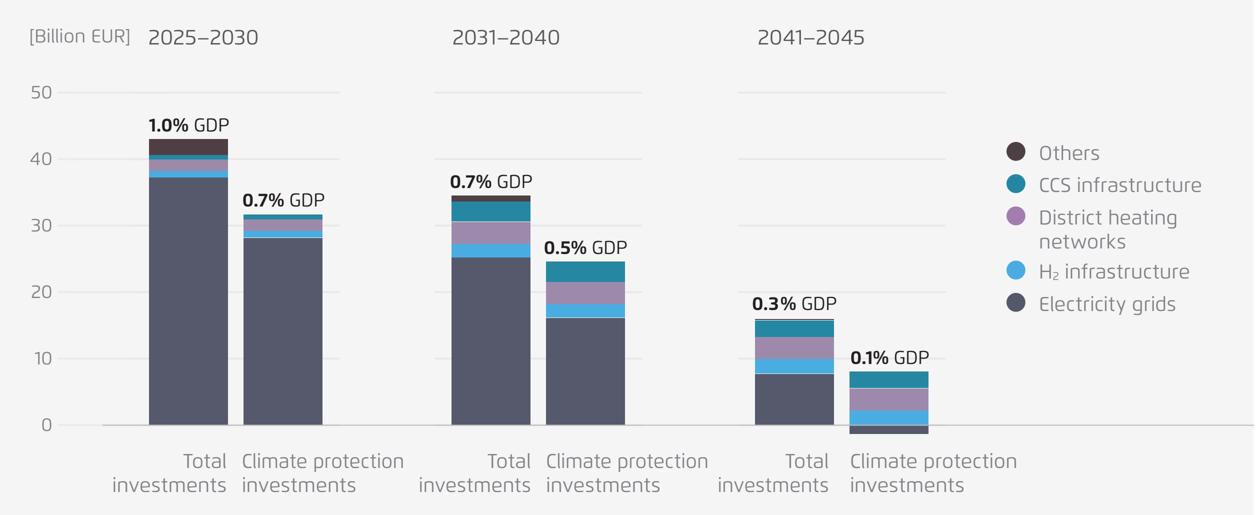
The public share of climate protection investments totals 51.1 percent and results from the public-sector equity investments in grid operators.

Facilitating investments

In the energy industry, a key role is played by a combination of price-based incentives via European emissions trading and long-term offtake agreements for electricity producers. Alongside this, start-up financing is required in the area of hydrogen production. Hydrogen use in dispatchable power plants will also be subsidised to compensate for the rising operating costs of utilising hydrogen. Market regulation is also necessary because of the natural monopoly position in the field of energy infrastructure. Increased state equity investments in energy infrastructure would also be possible to bring down financing costs.

Energy infrastructure: total and climate protection investments as an annual average and their share of gross domestic product

→ Fig. 41



Agora Energiewende and Prognos (2024). Y-axis corresponds to the annual average during the period in billion EUR; Annotation: share of gross domestic product during each period, in real prices (2023).

Public finance requirements to support investments

To give financial support to the necessary investments, the **following funding needs** arise:

→ **Expansion of renewable energies:** In the past, the focus of the renewable energy expansion was on closing a cost gap. The principle of long-term revenue security does remain in the scenario. However, the role of this instrument is moving away from covering cost gaps to ongoing hedging of favourable financing conditions. In line with this, the largest block of costs is the repayment for existing installations which were constructed by 2023 and which will still amount to a total of 95 billion euros up to 2045. All new plants to be added from 2025 onwards will require a total of just 45 billion euros up to 2045, with 55 percent of this going towards rooftop PV systems. These needs arise in the federal budget.

→ **Dispatchable power plant capacities and storage:** The introduction of a capacity market finances necessary investments via levies on the electricity price or through price surcharges by suppliers. Financing for storage takes place through the electricity market and so there are no additional public financing needs.

→ **Hydrogen ramp-up and use in dispatchable power plants:** Funding is needed for the market ramp-up of hydrogen usage, particularly its use in power plants. The programmes earmarked for this purpose in the Climate and Transformation Fund *(KTF)* are extended for the period up to 2030. Hydrogen use in power plants is also financially supported via a levy. Hydrogen production requires start-up financing so that large-scale expansion of electrolysers is possible as a precondition for further developing this technology. The budgetary impact comes to an annual average of 2.8 billion euros up to 2030.

→ **District heating generation and storage:** The upgrading of heat generators, heat storage and heat networks in district heating is facilitated by a combination of the CHP Act *(KWKG)* and the Federal Funding for Efficient Heating Networks *(BEW)*. The latter also includes funds to expand the heating networks. The CHP Act *(KWKG)* is financed by a levy on the electricity price so that no direct financial needs arise from this. The Federal Funding for Efficient Heating Networks *(BEW)* will incur average annual costs from the federal budget of 1.7 billion euros until 2030. This amount rises to 3.7 billion euros for the period from 2031 to 2045.

Enabling investments in energy infrastructures

Since energy infrastructures are natural monopolies, **market regulation** is key here. In principle, investments in energy grids are refinanced through grid charges. Therefore, the scenario contains no financing needs for funding the energy grids – however, the subsidies to expand heating networks are included in the estimated costs for Federal Funding for Efficient Heating Networks *(BEW)* (see above).

There is currently some controversy over what role **greater state involvement in energy infrastructure** could entail. The private sector can generally offer only less added value for a cost-efficient transformation in the area of regulated monopolies, as competition is not possible or only very limited. Moreover, the transition to climate neutrality entails additional risks: in particular, very high investments must be made in the electricity grids by 2030 and the latter's capacity could also be negatively affected by delays in electrification. This would be reflected in rising grid charges which could, in turn, inhibit progress towards electrification.

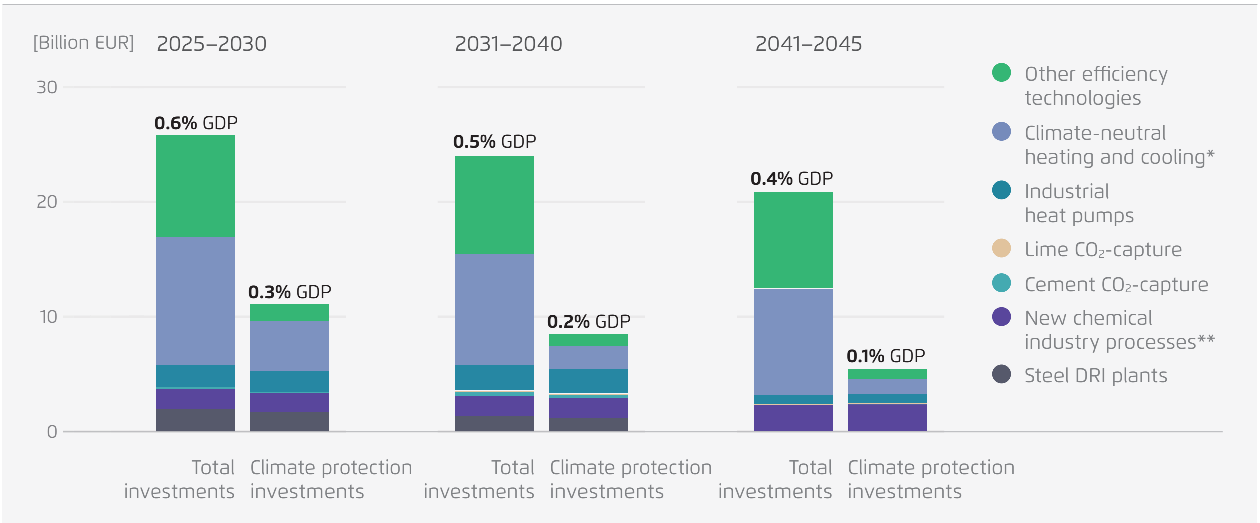
This raises more significant questions about allocation when network charges are structured and could argue in favour of greater state involvement. Furthermore, financing costs have a decisive influence on the level of grid charges.

5.2 Industry

The transformation to climate neutrality is a vital opportunity for the German economy to emerge from the current crisis by investing and modernising. Large swathes of the economy are currently weakened by declining global demand and high energy prices. Even though the German economy is strongly innovative and thus adaptable and resilient, government support is needed for the required modernisation.

The ability to innovate should be sustained through good framework conditions for research and development investments as well as financing of start-ups. Furthermore, government action is needed so that the economy can pull itself out of the downturn through investment. The necessary incentives and support for

Industrial sector: total and climate protection investments as an annual average and their share of gross domestic product → Fig. 42



Agora Energiewende, Prognos, Wuppertal Institute and Kassel University (2024). Y-axis corresponds to the annual average during the period in billion EUR; Annotation: share of gross domestic product during each period, in real prices (2023). *excluding industrial heat pumps; **includes methanol production and processing, recycling, biomass processing, CO_2 capture and electrification of steam production.

investments are needed quickly as industrial plants especially have long investment cycles – cement plant kilns, the blast furnaces of primary steel producers and steam crackers in the basic chemicals sector often have technical lifespans of 50 years or more.

Investment needs

Climate-neutral modernisation of the industrial sector requires investments in DRI plants in the steel sector, in CO_2 capture in cement and lime production and in the conversion of chemical industry production processes. In addition, investments in the widespread ramp-up of industrial heat pumps, climate-neutral cooling and heating as well as other energy efficiency technologies are needed (Figure 42).

Facilitating investments

In the industrial sector too, ETS I and, from 2027, ETS II provide a strong **price-based incentive** to reduce emissions, due to the shortage of certificates. The **expansion of electricity, hydrogen and CCS infrastructure** is vital to enable companies to produce in a climate-neutral way. An efficient expansion of energy infrastructure forms the basis for keeping the costs of a climate-neutral economy low.

Setting up lead markets *(Leitmärkte)* and credits or quotas for using recyclates or renewable raw materials, for example in plastics, as a form of **market regulation** stimulates demand for climate-neutral products. Public procurement standards, for instance for utilising "green" steel, are another option here for securing sales markets.

In the context of **financial support**, the starting assumptions for the various economic players should be considered. For **SMEs**, which account for 90 percent of manufacturing sector companies, investments in climate-neutral technologies are associated with higher financing costs; so their main need is for unbureaucratic financing instruments such as low-interest loans, state-backed securities or guarantees. For **energy-intensive industrial companies** exposed to international competition, the operating costs for energy are more significant, alongside the investment costs. In order to strengthen national resilience and preserve a broad range of industry, some energy-intensive production processes can only be retained with government subsidies.

Public financing requirements to support investment

For the financial support of the necessary investments and compensation payments, the **following financing requirements** arise:

- → The **carbon contracts for difference** *(Klimaschutzverträge)* for industry are continued. They offset the additional costs which more climate-friendly production processes incur, compared to the methods used so far, and thus play a key role in investment security. The scope of the carbon contracts for difference will be extended, particularly to include steam generation. This results in a financing requirement from the government budget of 2.4 billion euros on average annually from 2025 to 2030, decreasing to 2.1 billion euros per year by 2045.
- → In addition, **SMEs should be supported** by a simplified form of the carbon contracts for difference. The requirement for this is estimated at an annual average of 0.7 billion euros from 2025 to 2030.
- → **Accelerated depreciation** also plays a relevant role in supporting private-sector investment. Because of the complexity of determining the actual impact of accelerated depreciation on the budget, this item was not explicitly included in the overview of finance needs. The instrument leads to a reduction in revenues.
- → Affordable renewable energy is the basis for the competitiveness of a climate-neutral industrial or business location. A tax reform provides **relief with grid charges for companies** and a far-reaching exemption from state levies. There are no direct expenses to the budget here either.
- → The **power price compensation** *(Strompreiskompensation)* will also be continued and expanded to retain a broad spectrum of energy-intensive industry in Germany, thus

securing independence from imports of important raw materials. This will incur annual costs averaging 3.6 billion euros between 2025 and 2030.

5.3 Buildings

Investment needs

A climate-neutral building stock requires investments in the switch of the heat supply to renewable energies, particularly in CO_2-free district heating and heat pumps, and in retrofitting existing buildings. Furthermore, investments are needed for building envelopes in climate-neutral new construction and for energy-efficient equipment, processes, lighting and ventilation. The highest demand is for building envelopes, in both new and existing buildings. The "business-as-usual" share in the buildings sector represents about three quarters of the total investment required (Figure 43).

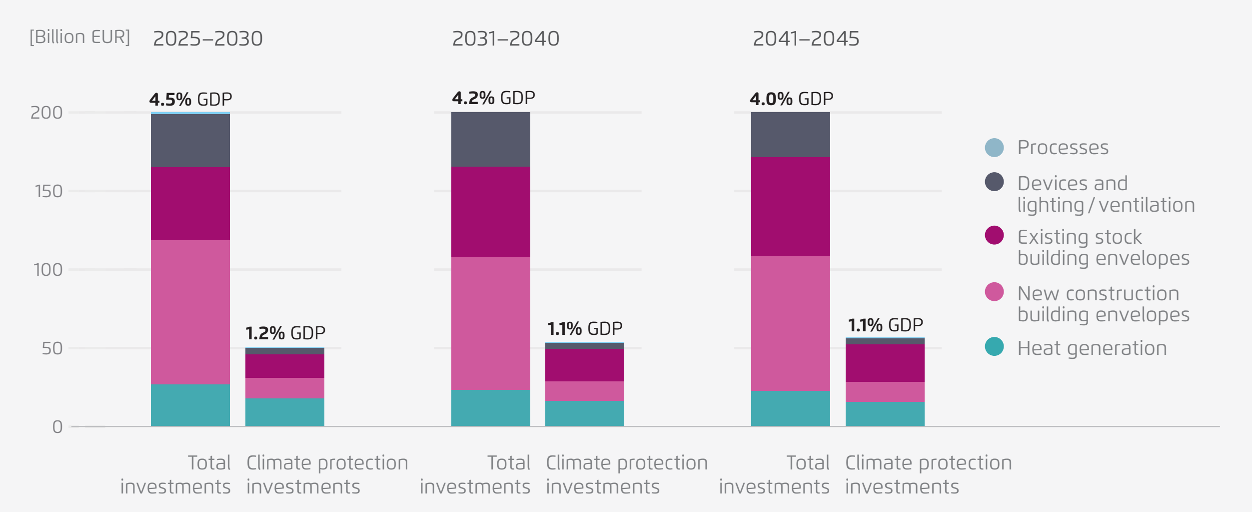
The public-sector share of climate protection investments in the buildings sector is 2.7 percent. This arises, firstly, from state equity holdings in housing companies, which are likely to make the investments, and secondly from the state's direct ownership of public buildings such as town halls, schools and swimming pools.

Facilitating investments

A characteristic of the buildings sector is a very high degree of consistency in investment activity. This is mainly due to the fact that it is a sector with very long investment cycles and the capacity to renew the existing stock is limited. Given this background, it is vital to make investments compatible with climate-neutrality as swiftly as possible. This underlines the importance of **regulatory measures** in this sector.

Moreover, stronger CO_2 pricing can create **price-based incentives** for retrofitting and heating system replacement. To ensure that these price signals are also felt by house owners, the CO_2 Cost Allocation Act *(CO_2-Kostenaufteilungsgesetz)*, which regulates the distribution of CO_2 costs between tenants on the one hand and landlords on the other, needs to be evaluated and, if necessary, adapted. So as to protect tenants from sharp price increases following efficiency

Buildings sector: total and climate protection investments as an annual average and their share of gross domestic product → Fig. 43



Agora Energiewende and Prognos (2024). Y-axis corresponds to the annual average during the period in billion EUR; Annotation: share of gross domestic product during each period, in real prices (2023).

measures, different instruments might be useful. Examples are a reform of the modernisation levy or financial investment support for landlords, granted on condition that a rent cap is adhered to.

But higher CO_2 prices do not yet allow especially those homeowners with low incomes and assets to manage the initial investments, which are sometimes substantial. In order to avoid placing too heavy a burden on this group, instruments for **financial support** are crucial, particularly for heating replacement and building renovation.

Public finance requirements to support investment

→ The **Federal Funding for Efficient Buildings** *(Bundesförderung für Effiziente Gebäude, BEG)* is continued and expanded. Together with other funding programmes for the buildings sector, a public **financing requirement** arises of around 17 billion euros annually for 2025 until 2030, increasing to 20 billion euros per year by 2045.[23] The programme's loan funding component is strengthened, compared to the grant funding component, to enhance funding efficiency. By boosting funding for lower- and middle-income groups and reinforcing minimum efficiency standards, Federal Funding for Efficient Buildings *(BEG)* resources have a much broader impact than today. Staffing at the Federal Office for Economic Affairs and Export Control *(BAFA)* and the *KfW* development bank must be improved and application processes streamlined to make sure that these funds are accessed and spent in a targeted manner. Especially people with low incomes and assets must be actively and specifically addressed, informed about funding opportunities and supported throughout the application process. The estimated financing needs will be distributed across the Federal Funding for Efficient Buildings *(BEG)* and other funding programmes. The following items are financed from this:

- **Replacing heating systems:** The **income-related subsidy** is continued. In the future, **assets** might be used as a further criterion when calculating the grant levels.
- **Building envelope renovation:** The principle of an **income- and asset-related subsidy** is also applied to building envelope renovation. A new element is a focus on the most inefficient buildings. These offer the highest potential for emission reductions and the highest funding efficiency, Furthermore, this protects lower-income groups who often live in these buildings.
- So that it is easier for property owners to achieve the tiered minimum efficiency standards within the national implementation of the EPBD, the **subsidy is harmonised with the minimum standards in a second stage** (for example, by defining tiered targets based on energy-efficiency classes). This can provide extra incentives for early-stage renovations.
- **Social funding in the rented sector:** A subsidy bonus will be created for the housing industry which can be utilised in combination with a temporary cap on rents. This is a way of incentivising renovations in the rented sector and protecting tenants at the same time.
- **Creating more living space in existing buildings:** Existing funding programmes for adding storeys, converting or repurposing existing buildings are continued and extended to provide housing in a space- and resource-efficient way and reduce embodied carbon emissions.

→ **Affordable rates for heat pumps:** A favourable electricity-gas price ratio is an important factor in making the business case for heat pumps more attractive and incentivising the switch from gas heating to heat pumps. Electricity purchases for heat pumps are thus temporarily exempted from state taxes and grid charges are lowered. Widespread installation of smart meters is needed to make these heat pump rates possible on a wide scale. The essential part of the heat pump rates comes from a reduction in grid charges, meaning no direct requirement from

23 The funding need is based on compensation for additional costs of 100 percent for the lower third of incomes and around 30 percent for the middle third of incomes. The requirement for expansion and decarbonisation of district heating is reported under 'energy industry'.

public-sector budgets. Lowering the electricity tax to the European minimum of 0.05 cents/kWh results in a tax revenue reduction which was not quantified in detail in this study.

→ **Compensation payments:** Nonetheless, there will always be circumstances when cost increases cause unreasonable burdens and a structural solution cannot be implemented quickly enough. Temporary financial compensation is needed in these cases. Around 10 billion euros per year are redistributed to citizens for this purpose, in the form of direct payments. Entitlement to such a payment and its amount is assessed on the basis of social criteria and existing obstacles for switching to climate-neutral solutions. For administrative reasons, however, a lump sum 'climate dividend' *(Klimageld)* may make sense as an interim solution.

5.4 Transport

Investment needs

A climate-neutral transport system requires investments in road transport electrification, the charging and refuelling infrastructure needed for this, expansion of cycle paths and rail infrastructure as well as in vehicles for public transport on road and rail (Figure 44).

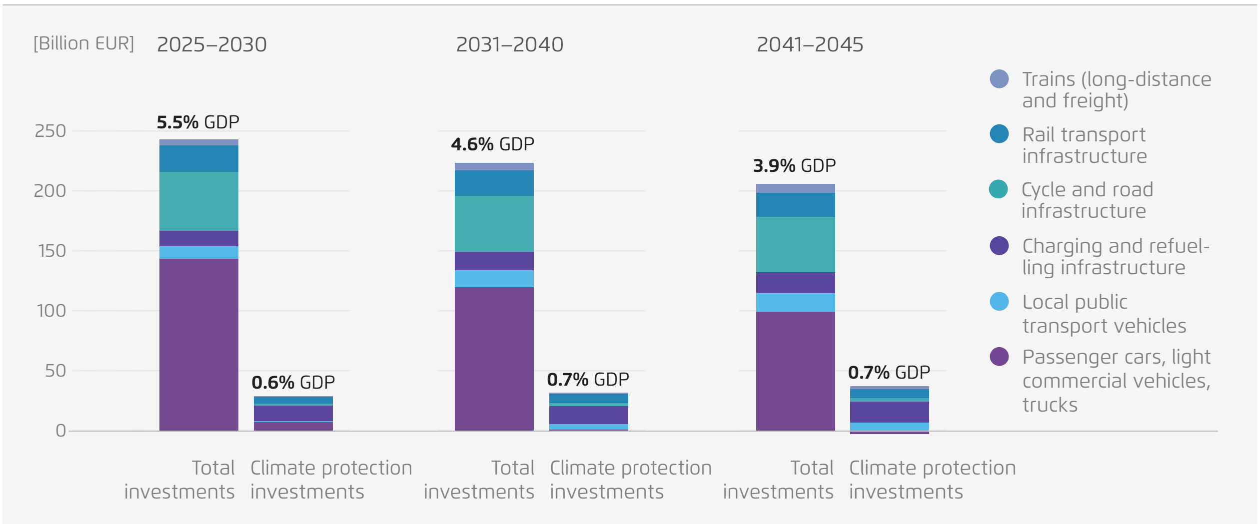
While the purchase of road vehicles accounts for most of the total investments, given their high "business-as-usual" share, climate protection investments are largely focused on developing charging infrastructure and expanding rail transport capacity (compared to the reference development in the forecasting report *(Projektionsbericht (2024))*.

The public-sector share of climate protection investments is around two-thirds. This results, firstly, from the infrastructure and the public-vehicle fleet owned directly by federal, state *(Land)* and local governments; and, secondly, from government shares in transport companies which also invest in road and rail vehicles and their associated infrastructure.

Facilitating investments

Numerous **price-based incentives** are used in the scenario to achieve climate neutrality in the transport sector. These include, for example, a more robust

Transport sector: total and climate protection investments as an annual average and their share of gross domestic product → Fig. 44



Agora Energiewende and Prognos, Öko-Institut (2024). Y-axis corresponds to the annual average during the period in billion EUR; Annotation: share of gross domestic product during each period, in real prices (2023).

increase in CO_2 pricing, harmonisation of diesel and petrol taxation (including annual inflation offsetting), vehicle tax reform (now taking effect when the car is first registered) and reformed company car taxation (enhancing the financial appeal of of zero-emission vehicles over combustion engine cars).

In order to give manufacturers investment certainty and prevent citizens and companies from being burdened with high operating costs due to a foreseeable increase in the CO_2 price, it is essential to keep the CO_2 emission limits for passenger cars as well as light and heavy commercial vehicles (all agreed at EU level).

Government has a key role to play in the area of **transport infrastructure and public transport services** as the question of how well people can switch to climate-friendly alternatives, given rising fossil-fuel prices, is also largely determined by regional public transport availability. The provision of comprehensive public transport services and expansion of safe cycle paths and footpaths are part of general public services and vital to the basic availability of mobility services (thus relieving especially the lowest income deciles). Current revenues and reserves cannot meet the investments needed in the short term to maintain and expand the federal rail network and infrastructure for local public transport. Low-interest public loans make it possible to spread repayment of the high investments over a longer period of time.

So as to ensure a socially just transition to climate neutrality and enable access to better mobility for all, **financial support** for individuals is needed, in the form of targeted investment support for the switch to electric mobility plus compensation payments.

Public finance requirements to support investment

Public funding requirements arise from subsidies to maintain and expand rail infrastructure, for local public transport and for targeted investment support for swift electrification, both for purchasing vehicles and building up the charging infrastructure.

- → **Subsidies for rail infrastructure:** There is a need for additional investments in rail infrastructure to significantly boost rail transport performance in passenger and freight transport in the course of the mobility transition. The resulting public finance requirements to boost capacity average around 4.6 billion euros per year between 2025 and 2030, rising to an annual average of 6.3 billion euros in the subsequent period up to 2045.
- → **Subsidies for local public transport:** Besides infrastructure, subsidies are also necessary to acquire vehicles for local public transport (trains, buses), to the extent that the investments needed cannot be refinanced through ticket revenues. Based on a broadly constant cost-recovery ratio, the requirement for this is estimated to average 0.5 billion EUR per year up to 2030, increasing to 2.6 billion EUR annually up to 2045. As with rail infrastructure, this sum also refers to the additional investment in vehicles (excluding their operating expenditure), compared to the reference in the forecasting report *(Projektionsbericht 2024)*. As a general rule, expenditure on the provision of high-quality, extensive public transport services – especially in structurally weak regions – not only benefits climate protection but also general public services.
- → **Investment support for electrification:** People on low incomes living in regions without adequate local public transport coverage may be dependent on state support to purchase an electric car. The support can take the form of low-interest loans as well as premiums or income-based subsidies for leasing-models. The subsidy should, firstly, focus on affordable and energy-efficient models, and secondly, eligibility within such funding programmes should be income-based to prevent deadweight effects and a high fiscal burden. As far as the vehicles are concerned, the funding of electromobility is linked to a finance requirement of an average 3.5 billion euros per year up to 2030. But this can be met by revenues from the reformed vehicle taxes, so no explicit budgetary requirement is indicated here.
- → **Mobility Allowance:** A mobility allowance unrelated to income replaces the commuter allowance used to date, thus providing a better cushion

against cost increases caused by the CO_2 price for people on low incomes. The mobility allowance grants all employees the same financial relief for commuting to work; the amount depends entirely on the commuting distance and does not increase with tax rates and hence income – as is the case with the commuter allowance. Conversion of the commuter allowance into a mobility allowance is budget-neutral.

→ **Subsidies for expanding the charging infrastructure:** Grants totalling 0.6 billion euros per year will be provided up to 2030: to be used especially for developing an effective charging network for trucks, but also for income-related funding of private charging infrastructure plus support to develop public car-charging infrastructure, particularly in rural regions.

5.5 Agriculture and LULUCF

In order to reduce emissions in the agriculture and LULUCF sectors and to strengthen their carbon-sink capacity, public funds are mainly needed to compensate the sectors for providing public services. Funding of investments is also relevant - for example, in modernising machinery and buildings, in infrastructure and technologies to reduce greenhouse gas emissions - but it plays a lesser role compared to remuneration for public services.

There are investment needs in agricultural production (technical measures to reduce greenhouse gas emissions through modified buildings and machinery), in rewetting of peatlands, in expanding forests' CO_2 sink capacity and strengthening structurally diverse agricultural countryside. To kick-start these investments, a political framework is first needed to turn the contribution to climate protection into an economic opportunity for companies operating in the sectors and to set the right price incentives to lower emissions.

These include, for instance, an EU-wide emissions trading system for greenhouse gas emissions from agriculture and peatlands used for agriculture. Price-based incentives set price signals for more environmentally and socially acceptable economic activity, but leave it to business decisions to react to price signals.

Furthermore, public payments for the provision of public goods are an important incentive to developing sustainable business models in agriculture and forestry. This comprises, among other things, remuneration of public services such as increased carbon sequestration in forests and on agricultural land. The necessary means can be drawn from the EU's Common Agricultural Policy funds (CAP) as well as from other budget resources. Private carbon markets can also make a contribution.

Investments are also needed, inter alia, for forest adaptation, infrastructure and hydraulic engineering measures to rewet peatlands used for agriculture. The necessary public financing needs were not quantified.

Considerably greater financial resources are needed than at present to fund an ambitious contribution by agriculture and forestry to climate protection and other sustainability goals. However, exact quantification depends heavily on the instruments and funding sources chosen. This goes beyond the remit of the current study.

6 Structuring the transport and heating transition in a socially equitable way

The transport and heating transition offers chances to improve the population's health and quality of life. A wider range of public transport and the expansion of safe cycle paths and footpaths benefit everyone; and especially those on low incomes who are also particularly often affected by traffic noise and air pollution in urban areas. The same applies to building renovation and the greening of cities, because people on low incomes are more likely to live in poorly insulated apartments in densely built-up areas and are thus particularly exposed to more frequent heatwaves in the future.

At the same time, implementation of the transport and heating transition involves considerable investments which also arise in the private sector. These mainly include expenses for renovations, installation of heat pumps or buying an electric car. For those with sufficient financial resources, a rising CO_2 price or regulatory requirements in the building sector are less of a problem; they can invest in a CO_2-free future by switching to climate-neutral technologies. The group of people continuing to rely on fossil-fuel heating and cars is therefore likely to shrink – but, without adequate support, the cost burden for them can become immense and indirectly hamper their social inclusion. To prevent this from happening, special attention at the political level and targeted support are needed here.

One political challenge in this regard is to identify the target group in the first place. This is because the question of whether there will be excessive cost burdens is determined by various factors. The most obvious factor is low income or assets. With regard to the heating transition, it is also crucial whether people own their properties or rent and what condition the building envelope and heating system are in. As for transport, the degree of difficulty is also strongly affected by regional availability of public transport and charging infrastructure, alongside individual factors such as income, household size and family situation.

These factors can reinforce or cancel each other out too – for example, a building in very poor condition combined with a very good situation in terms of income and wealth. So it is crucial to look at the whole picture when designing a mix of instruments. A systemic view of this kind requires better availability and linking of the necessary data, something that has only reached an early stage so far.

6.1 Three areas of government action for a socially equitable transport and heating transition

Here too, the policy mix in the scenario has an important function. A combination of price-based incentives, such as the carbon price and market regulation, help to redirect investments towards climate-neutral technologies. However, these incentives can only gain a widespread impact if the infrastructure required for a switch is created simultaneously, a fair distribution of costs is ensured and the incentives are accompanied by targeted investment support for people on low incomes. The study therefore proposes the following measures to guarantee that no excessive cost burdens occur and there is social inclusion for everyone:[24]

Infrastructure provision

Infrastructure provision is key to creating basic availability of mobility and energy services, thus easing the situation for the lowest income deciles in particular. Thus, the scenario includes planning

24 For similar arguments see also Zukunft Klimasozial (2024): Eine sozial gerechte und klimaneutrale Zukunft sichern.

and financing of infrastructure, for instance, climate-neutral district heating networks or regional and long-distance public transport. The framework conditions are also designed for wide-ranging expansion of EV charging infrastructure. Financial support from federal or state governments may also be necessary, depending on the capabilities of municipalities and the already existing infrastructure, which varies from region to region (Chapter 5).

Market regulation

In the scenario, minimum efficiency standards lead to a decrease in energy use and thus protect tenants from high heating costs. To avoid excessive cost burdens for individual groups, **regulations on cost sharing and price regulation for district heating networks** are also important in the building sector.

To ensure that CO_2 prices also have an incentive effect and do not weigh excessively on tenants, the CO_2 Cost Sharing Act, which regulates the CO_2 cost allocation between tenants and landlords, should be evaluated and, if necessary, modified. In order to shield tenants from sharp price increases after efficiency measures, financial investment support for landlords (combined with requirements on rent levels) plus a reform of the modernisation levy are also options.[25]

Price regulation of district heating networks ensures that no excessively high prices are charged, despite the power imbalance between suppliers and buyers due to a natural monopoly.

In the transport sector, regulatory measures such as CO_2 emission-reduction targets and a speed limit help to reduce the specific energy consumption of vehicles, resulting directly in lower operating costs. The consequent reduction in greenhouse gas emissions is also accompanied by decreased demand for CO_2 certificates, which in turn puts downward pressure on CO_2 prices.

Financial support

Targeted investment support can take the form of low-interest loans, the state taking on loan risks as well as grants or subsidised leasing models (for example, for EVs). Eligibility criteria which are income-related or that address particularly affected groups are useful for all instruments. Debt financing is particularly suitable where households get by well financially and where the climate-friendly alternative is more cost-effective over its whole lifespan than the fossil-fuel reference, but where there are temporary liquidity hurdles. Grants make particular sense for households facing more financial challenges and as start-up financing for climate-friendly technologies which are not yet competitive. To avoid deadweight effects and a heavy fiscal impact, eligibility within the funding programmes should be linked to availability of financial resources and, in the transport sector – if administratively feasible – to the regional availability of public transport too.

The study initially estimates 17 billion euros annually for the buildings sector, rising to 20 billion euros from 2030, being available for heating system replacements, building envelope renovations, programmes to create housing in existing buildings and financial compensation measures. An annual average of 3.5 billion euros is earmarked for investment support to purchase EVs up to 2030.

Both investment support programmes and the expansion of climate-neutral infrastructure lead to a permanent reduction in emissions. However, both types of measures tend to have an impact only in the medium to long-term. Since excessive cost burdens are driven by various factors, it is also scarcely possible to prevent every conceivable hardship scenario through targeted funding programmes. Therefore, it is also sensible – at least temporarily – to use financial **compensation measures**, such as direct

25 Öko-Institut (2024): Sozialgerechte Förderung für energetische Sanierungen im Mietwohnbereich

payments. Energy costs, which are rising due to climate policy measures, can thus be broadly mitigated in the transitional period. General government subsidies to reduce energy costs for everyone play a lesser role from the viewpoint of social redistribution. The assumption here is a climate allowance that, for administrative reasons, is initially a universal payment which is later increasingly income-related. Furthermore, a mobility allowance not linked to income replaces the commuter allowance used so far. So as to provide sector-specific relief, boosting the heating-cost component in housing benefit or subsidised public transport tickets would also be conceivable as alternatives.

Annex

Annex 1 – Key results and framework data

→ Table A1

Category	Indikator		Statistics	'Climate-neutral Germany' implementation		Comparison with 'Climate-neutral Germany' 2021	
			Start year[1)]	2030	2045	2030	2045
Framework data	Population [million] (2022)		84	85	85		
	GDP [billion euros 2015 prices]		3 262	3 534	4 155		
	ETS-I prices (2022 prices) [Euro / tCO_2]		81	132	194		
	ETS II Prices/BEHG (2022 Prices) [Euro / tCO_2]		30	124	188		
	Crude Oil [Euros 2022/Barrel]		96	69	66		
	Fossil gas [Euros 2022/MWh(Hs)]		76	28	20		
	Hard coal [Euros 2022/MWh(Hs)]		37	12	9		
	Hydrogen price – green [Euros 2022/MWh(Hs)]			125	100		
GHG emissions [million t CO_2eq] [2)]	Total[3)]		674	433	-31 (40)	-18	-18
	Energy sector		205	98	-3.3 (2.4)	0.1	15
	Industry		155	115 (117)	-19 (11)	-8.3	11
	Buildings		102	72	0.8	7	-2.2
	Transport		146	89	0.6	0	0.6
	Agriculture		60	57	23	-1.4	-18
	Waste		5.5	3	1.9	-2	-0.1
	LULUCF		3.6	-11	-35	-13	-24
Hydrogen	Hydrogen demand [TWh]			45	268		
	Domestic hydrogen production [TWh]			29	84		
	Hydrogen imported [TWh]			16	184		
Biomass	Biomass supply [TWh] (2020)		286		294		
	Biomass demand [TWh] (2020)		330		327		
Energy	Gross electricity consumption [TWh]		525	727	1267		
	Energy sector		52	76	100		
	Installed capacity [GW]	Onshore wind	61	98	180		
		Offshore wind	8	26	73		
		Photovoltaics	82	215	469		
		Large-scale storage [4)]	7	30	102		
		Dispatchable generation	83	65	72		
Industry	Final energy consumption [TWh] (2022)		665	671	617		
Buildings	Heat pumps [millions]		1.7	6	15.7		
	Final energy consumption [TWh]		943	863	700		
Transport	Stock of all-electric passenger cars [millions] (2022)		1.2	12.6	37.8		
	Transport capacity rail freight transport [billion tkm] (2022)		131	177	182		

1) The start year is normally 2023. Other years were chosen if 2023 statistics were not available in time. In this case the start year is noted after the core indicators.
2) Values in brackets without CCS and negative emissions
3) Statistical year (2023); 2030: without LULUCF according to § 3 (1) KSG, 2045: with LULUCF according to § 3 (2) KSG
4) Incl. vehicle-to-grid, excl. home storage

Annex 2 – Public finance needs to support investments annual average [billion EUR_{2023}]

→ Table A2

	2025–30	2031–45	Impact on budget
Energy sector	17.6	12.4	
Renewable energies electricity generation	13.1	4.0	yes
System flexibility (battery storage)			a)
Hydrogen production and infrastructure	2.8	4.6	b)
H_2 levy portion	0.0	3.7	no
Portion having a budgetary impact	2.8	0.9	yes
District heating generation, storage and networks	1.7	3.7	yes
Electricity grids			c)
CO_2 infrastructure			d)
Industry	6.7	5.7	
Carbon contracts for difference e)	2.4	2.1	yes
Heat pump expansion in industry	0.7	0.3	yes
Electricity price compensation	3.6	2.0	yes
BECCS/DACCS expansion	0.0	1.3	yes
Accelerated depreciation			f)
Grid charge reductions			g)
Buildings	17	20	
Support for renovations and heating replacements	17	20	yes
Heat pump electricity charges			h)
Transport	9.1	8.9	
Electromobility	3.5	0	i)
Charging infrastructure	0.6	0	yes
Subsidy for rail infrastructure	4.6	6.3	yes
Subsidy for local public passenger transport	0.5	2.6	yes
Mobility allowance			j)
Reform of company car taxation			k)
Agriculture & LULUCF	0.8	0.9	l)
Natural climate protection	0.8	0.9	yes
Market value of emission certificates used	28.5–41.2	19.3	m)
Compensation payments and hardship support	10	10	yes
Total budgetary needs	57.8	54.1	
Total after deducting CO_2 revenues	16.6–29.3	34.8	

See following page for footnotes

Footnotes to Table A2

Agora Energiewende (2024), these are federal-level funding programmes, unless stated otherwise. In the sector of local public passenger transport, the subsidies are partly paid out by states *(Länder)* or municipalities.

a) There is financing for storage via the electricity market and thus no additional subsidy requirement.

b) Hydrogen use in power plants is supported financially by a levy on the electricity price. This levy does not have an impact on the budget. The market ramp-up of hydrogen production requires start-up financing which has a budgetary impact.

c) Public equity investments in financing the electricity grids can save 5 billion euros per year. At the same time, public financing in the context of a financial transaction would have a neutral impact on the 'debt brake' *(Schuldenbremse)*.

d) This item was not quantified in the study.

e) The scope of the carbon contracts for difference will be expanded, including steam generation in particular.

f) This item was not quantified in the study. Accelerated depreciation does not represent a direct budgetary expenditure but a reduction in government revenues.

g) A tax reform provides grid charge reductions for companies. There are no direct budgetary outlays for this.

h) A grid charge reduction for heat pumps does not cause any direct requirement from the budget. The electricity tax reduction leads to a decrease in tax revenues which were not quantified in detail in this study.

i) Funding for the vehicle aspects of electromobility can be covered by revenues from the revised vehicle taxes so that no explicit need arises here.

j) Conversion of the mileage allowance into a mobility allowance is budget-neutral.

k) The reform of company car taxation, whereby purchasing zero-emission vehicles becomes more financially attractive than passenger cars with combustion engines, was not quantified.

l) Not all of the funding requirements needed in this sector have been quantified.

m) For the period up to 2030, a range is presented from the 'Climate and Transformation Fund' finance plan and the market value of the emission certificates used, as quantified in the study.

References

Agora Energiewende and Agora Industry (2024): *Low-carbon-hydrogen in the EU.* Available online at https://www.agora-energiewende.org/publications/low-carbon-hydrogen-in-the-eu; last checked on 11.10.2024.

Agora Energiewende and Agora Industry (2024): *Wasserstoffimporte Deutschlands.* Available online at https://www.agora-energiewende.de/publikationen/wasserstoffimporte-deutschlands; last checked on 11.10.2024.

Agora Energiewende and Agora Verkehrswende (2023): *Der CO_2-Preis für Gebäude and Verkehr.* Available online at https://www.agora-energiewende.de/publikationen/der-co2-preis-fuer-gebaeude-und-verkehr; last checked on 11.10.2024.

Agora Industry (2023): *15 insights on the global steel transformation.* Available online at https://www.agora-industry.org/publications/15-insights-on-the-global-steel-transformation; last checked on 11.10.2024.

BDI (2024): *Transformationspfade für das Industrieland Deutschland.* Available online at https://www.transformationspfade.com/home/downloadbereich; last checked on 11.10.2024.

Castro et al. (2020): *A review of agent-based modelling of climate-energy policy.* Available online at https://www.researchgate.net/publication/339999881_A_Review_of_Agent-based_Modelling_of_Climate-Energy_Policy; last checked on 11.10.2024.

Deutscher Bundestag (2024): Unte*rrichtung durch die Bundesregierung. Klimaschutzbericht 2024. BT-Drucksache 20/12760.* Available online at: https://dserver.bundestag.de/btd/20/127/2012760.pdf; last checked on 11.03.2025.

Öko-Institut (2024): *Sozialgerechte Förderung für energetische Sanierungen im Mietwohnbereich.* Available online at https://www.oeko.de/news/pressemeldungen/sanierungen-von-mietwohnungen-sozial-gerecht-foerdern/; last checked on 11.10.2024.

Pfeiffer et al. (2023): *Referenzszenario der Holzverwendung and der Waldentwicklung im UBA-Projekt BioSINK.* Öko-Institut Working Paper 4/2023. Available online at: https://www.oeko. de//fileadmin/oekodoc/WP-Referenzszenario-Bio¬SINK.pdf; last checked on 11.10.2024.

Prognos, Öko-Institut, Wuppertal Institut (2021): *Towards a Climate-Neutral Germany by 2045. How Germany can reach its climate targets before 2050. Executive Summary conducted for Stiftung Klimaneutralität, Agora Energiewende and Agora Verkehrswende.* Available online at https://www.agora-energiewende.org/publications/towards-a-climate-neutral-germany-by-2045; last checked on 11.03.2025

Safarzynska (2017): *Integrating behavioural economics into climate-economy models: some policy lessons.* Available online at https://www.researchgate.net/publication/316091418_Integrating_behavioural_economics_into_climate-economy_models_some_policy_lessons; last checked on 11.10.2024.

Zukunft Klimasozial (2024): *Eine sozial gerechte and klimaneutrale Zukunft sichern.* Available online at https://zukunft-klimasozial.de/#publikationen; last checked on 11.10.2024.

Publications by Agora Energiewende

In English

The carbon price for buildings and road transport
A concept for the transition from national to EU emissions trading

Boosting the clean heat market
A policy for guiding the transition of the EU heating industry

Climate-neutral Germany (Executive Summary)
From target-setting to implementation

Enabling a just coal transition in Kazakhstan
Opportunities, challenges and strategic pathways

Investing in the Green Deal
How to increase the impact and ensure continuity of EU climate funding

EU climate policy between economic opportunities and fiscal risks
Assessing the macroeconomic impacts of Europe's transition to climate neutrality

Low-carbon hydrogen in the EU
Towards a robust EU definition in view of costs, trade and climate protection

9 Insights on Hydrogen – Southeast Asia Edition

12 Insights on Hydrogen – Brazil Edition

The benefits of energy flexibility at home
Leveraging the use of electric vehicles, heat pumps and other forms of demand-side response at the household level

EU policies for climate neutrality in the decisive decade
20 Initiatives to advance solidarity, competitiveness and sovereignty

Modernising Kazakhstan's coal-dependent power sector through renewables
Challenges, solutions and scenarios up to 2030 and beyond

The roll-out of large-scale heat pumps in Germany
Strategies for the market ramp-up in district heating and industry

All publications are available on our website: www.agora-energiewende.org

Publications by Agora Energiewende

In German

Kurs auf Zielerreichung
Weichenstellungen für die Klima- und Energiepolitik der 21. Legislaturperiode

Factsheet Grüngasquote
Einordnung für die 21. Legislaturperiode

Factsheets Klima und Energie
Einordnung für die 21. Legislaturperiode

Ein neues Investitionsinstrument für Wind- und Solaranlagen
Wie marktliche Anreize und staatliche Absicherung den Weg in ein klimaneutrales Stromsystem ebnen können

Die Energiewende in Deutschland: Stand der Dinge 2024
Rückblick auf die wesentlichen Entwicklungen sowie Ausblick auf 2025

Klimaneutrales Deutschland
Von der Zielsetzung zur Umsetzung – Vertiefung der Szenariopfade

Investitionen für ein Klimaneutrales Deutschland
Finanzbedarfe und Politikoptionen

Klimaneutrales Deutschland
Von der Zielsetzung zur Umsetzung

Wärmenetze: klimaneutral, wirtschaftlich und bezahlbar
Wie kann ein zukunftssicherer Business Case aussehen?

Meer-Wind für Klimaneutralität
Herausforderungen und notwendige Maßnahmen beim Ausbau der Windenergie auf See in Deutschland und Europa

Serielle Sanierung
Effektiver Klimaschutz in Gebäuden und neue Potenziale für die Bauwirtschaft

Wasserstoffimporte Deutschlands
Welchen Beitrag können Pipelineimporte in den 2030er Jahren leisten?

Der Sanierungssprint
Potenzial und Politikinstrumente für einen innovativen Ansatz zur Gebäudesanierung

All publications are available on our website: www.agora-energiewende.de

Agora Energiewende Agora Industry Agora Agriculture Agora Verkehrswende

Publication details

About Agora Think Tanks
Agora Energiewende, Agora Industry, Agora Agriculture and Agora Verkehrswende develop scientifically sound and politically feasible strategies for a successful transformation to climate neutrality – in Germany, Europe and internationally. The organisations which are part of the Agora Think Tanks work independently of economic and partisan interests.

Agora Think Tanks
Anna-Louisa-Karsch-Straße 2
10178 Berlin | Germany
P +49 (0) 30 7001435-000

www.agora-thinktanks.org
info@agora-thinktanks.org

Translation: Paul Wardle
Typesetting: Theo Becker | Elser Druck GmbH
Title picture: Chris Gray | Unsplash

362/01-S-2025/EN
Version 1.0, April 2025

This publication is available for download under this scan code.