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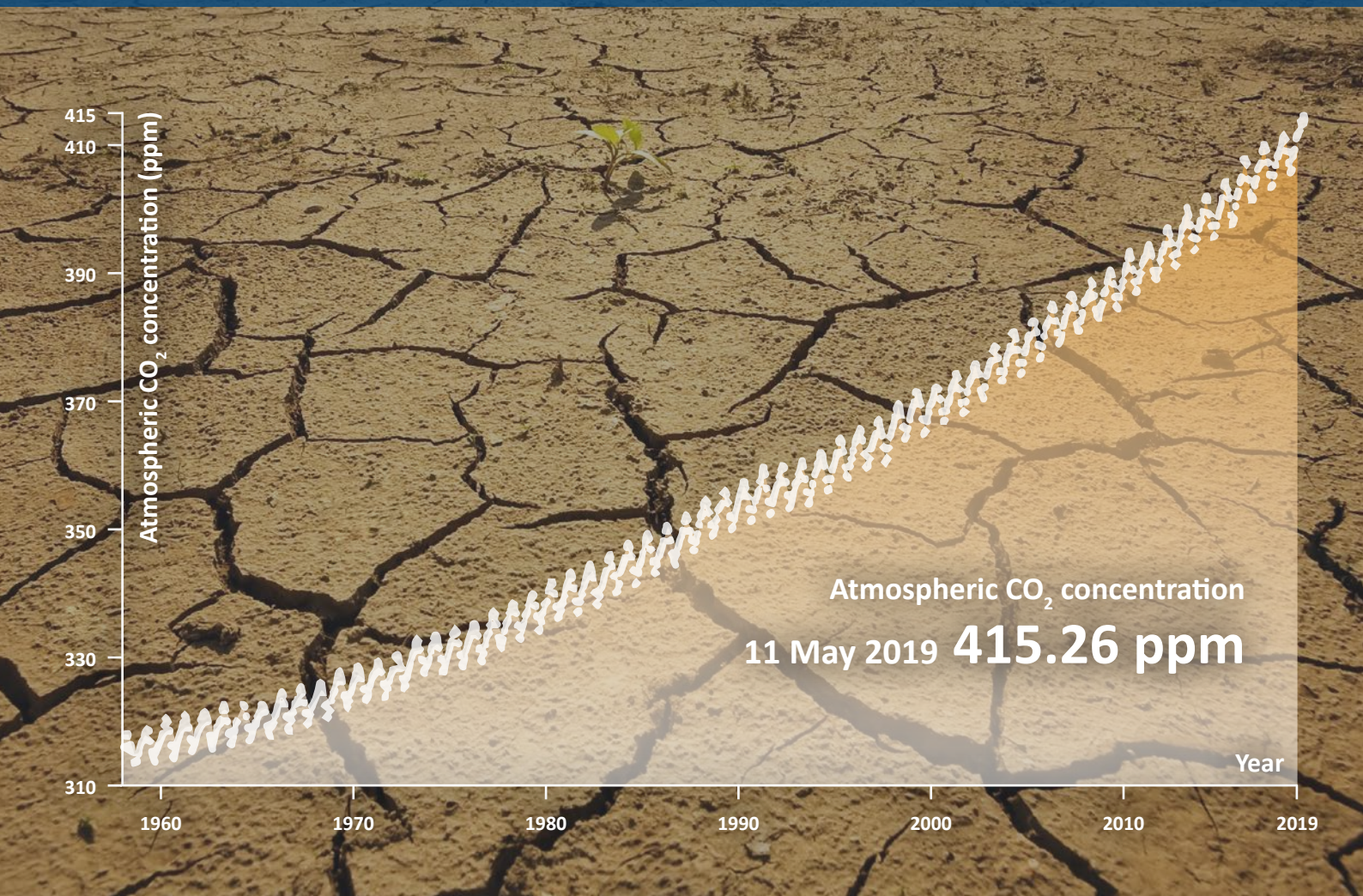
Climate targets 2030:

Towards a sustainable reduction of CO_2 emissions



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Cover
Since 1958, the content of carbon dioxide (CO_2) in the atmosphere has been measured on the Mauna Loa volcano (Hawaii, USA). This series of measurements, initiated by Charles David Keeling, is the graphical representation of the development of the mean global concentration of CO_2 in the Earth's atmosphere. With the "Keeling curve" it was possible for the first time to show the relationship between the combustion of fossil fuels and the concentration of the greenhouse gas CO_2. In the first measurement 61 years ago, the concentration was around 317 ppm (parts per million parts). In spring 2019, the concentration reached a new high of 415.26 ppm on 11 May 2019. The curve shows a characteristic, fluctuating annual course , the reason being the geography of the earth. In the northern hemisphere there is more land mass and thus more vegetation than in the southern hemisphere. During spring and summer in the northern hemisphere the global CO_2 concentration decreases because the vegetation absorbs more carbon during this time. In autumn and winter, the global CO_2 concentration increases again, as the plants in the northern hemisphere stop or strongly reduce photosynthesis. The lower vegetation in the south hemisphere cannot compensate for the increased release.

Photo: Adobe Stock; Grafik: Scripps Institution of Oceanography UC San Diego, USA; Gestaltung: Dominic Jack, Max Planck-Institut für Chemie, Mainz.

Further data and information on global CO_2 measurements: https://scripps.ucsd.edu/programs/keelingcurve/

Climate targets 2030:

Towards a sustainable reduction of CO_2 emissions

Contents

Foreword

Some 30 years from now, the European Union aims to be greenhouse gas neutral and to have reduced net emissions to zero in order to limit long-term global warming to well below 2 degrees Celsius. By declaring this goal at the 2018 UN Climate Change Conference, the European Commission claimed a leading role for the EU in climate protection. Germany and the European Union have ratified the Paris Climate Convention and must play their part. In their statement of December 2018, the German National Academy of Sciences Leopoldina, the German National Academy of Science and Technology acatech and the Union of the German Academies of Sciences and Humanities recommended a pioneering alliance between Germany and other countries to introduce a transnational minimum price for CO_2 emissions. A sufficiently high CO_2 price in all sectors would provide a financial incentive for low-emission technologies and would constitute an important step towards a greenhouse gas neutral Europe. So far, however, it has failed due to insufficient political support.

Achieving effective climate protection affects practically all sectors and falls within the purview of responsible environmental, transport, energy and health policy. The current debate revolves primarily around the costs of climate protection measures, the costs that will arise as a result of climate change are not given due consideration. These costs are already rising today, manifesting as an increase in extreme weather conditions, droughts, crop failures and forest damage. However, future generations will bear the true brunt. School climate strikes are a stark reminder of the fact that our behaviour today affects the future of all people to a worrying degree and threatens the diversity of nature and species.

In June 2019, with this in mind, the Presidium of the National Academy of Sciences Leopoldina commissioned an interdisciplinary working group to focus on measures for compliance with the climate targets 2030 in Germany as part of its science-based policy advice. In July 2019, politicians received a series of economic reports on CO_2 pricing which were also available to the working group. In September, the government will decide which measures to take to achieve the climate targets.

The present ad hoc statement presents the results of the discussions in the interdisciplinary working group. It includes information on the social and scientific debate regarding the urgency of climate protection as well as recommendations for the implementation of measures such as a CO_2 price and other innovations that can take swift effect while being socially acceptable.

We would like to express our sincere thanks to all the scientists who, as members of the working group, have shown great personal commitment. The Leopoldina sees this ad hoc statement, following the "Clean Air" statement, as a further contribution to the ongoing debate and intends to devote more attention to overarching scientific issues regarding forms of sustainable development in climate and environmental protection and nature conservation.

Jörg Hacker
President

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Executive summary

In the Paris Climate Convention of 2015, the international community agreed to limit global warming caused by human activity to less than 2°C in order to mitigate the resulting damage to humanity and nature. This goal can only be achieved if both national and international agreements are complied with immediately. Damage caused by melting snow and ice, rising sea levels, the expansion of dry zones, extreme weather conditions, and the increasing loss of biodiversity and habitats on land and in the ocean can only be mitigated by deliberate and effective efforts in the next ten years. Otherwise, large regions of the world will no longer be habitable, even if individual regions see themselves as "climate winners". In addition, there is a growing generational conflict both here in Germany and worldwide regarding the fact that we are undermining the basic conditions necessary to safeguard the livelihoods of our children and grandchildren. After all, the costs of climate change will continue to increase dramatically. Only with a resolute and swiftly implemented climate policy — nationally, with central European partners, and through worldwide cooperation — will it be possible to mitigate the catastrophic effects of climate change that are already becoming apparent.

Germany fails to meet climate protection targets

The Member States of the European Union have agreed upon specific and legally binding emission reduction targets for 2020 and 2030 and have defined country-specific targets for transport and buildings. As things stand, Germany will achieve neither the 2020 nor 2030 targets. Germany must now introduce fast-acting measures, and not only to avoid significant financial burdens on society as a result of non-compliance with the targets. Germany must pass a climate protection package that has a strong ethical foundation, is socially acceptable, and promotes innovation.

To date, the German government has defined reduction targets for individual sectors in the Climate Action Plan 2050. According to the plan, by 2030 at the latest, CO_2 emissions in Germany for all sectors combined are to be reduced by at least 55% compared to 1990. To achieve this target, national climate policy now requires a **more consistent, transparent, and rapid implementation strategy**. That strategy must give the general public, companies, and the political actors in the federal states and municipalities overall planning security and quickly create the conditions for turning away from the increasingly expensive and socially imbalanced business as usual path and onto the path of sustainable development.

Opportunities for a fundamental, science-based renewal process

The German National Academy of Sciences Leopoldina therefore emphatically calls for **an immediate, sweeping transformation**. Immediate measures are needed to achieve the 2030 climate targets. These measures should have three basic objectives: Firstly, the binding CO_2 emissions targets agreed upon at the European level should be achieved effectively; secondly, this should be done in a socially balanced manner; and thirdly, it should be done at the lowest possible economic cost. To achieve this, causing

CO_2 emissions should become increasingly unattractive, while actions that reduce such emissions should be rewarded.

With this ad hoc statement, the German National Academy of Sciences Leopoldina substantiates significant scientific guidelines and places particular focus on feasible measures that may already come to fruition between 2020 and 2030. Central to the matter is a **cross-sectoral transition** in the area of energy generation and use, which cannot succeed without an appropriate CO_2 price. Furthermore, other medium to long-term measures that are not included in this statement, such as land use, food and agriculture, coastal protection, conservation of biodiversity, the resilience of ecosystems and social systems, as well as demographic and public policy aspects, must also be considered.

Politicians must fully and clearly communicate the measures to the population — especially the opportunities and advantages of climate protection compared to the damage caused by climate change, which will increase sharply. By adopting a business as usual approach, the cost for Germany of not complying with the binding European climate targets alone is likely to have reached up to 62 billion euros by 2030.

With support rapidly increasing among the population, politicians today have the **unique opportunity** to put policy and society on the path to sustainable transformation and thus preserve the quality of life for present and future generations. The restructuring of the energy supply and use system is a project for the entire society and one to which all population groups can and must contribute. A nationally sustainable and credible climate policy is an essential step towards assuming a stronger position in the area of international cooperation and jointly preventing the looming collapse of ecological systems and civilisations.

In the past, Germany has been the driving force behind numerous innovations on an international level. The necessary investments and the resulting products and processes have sometimes laid the foundation for the high quality of life and prosperity in Germany. Climate-oriented innovations are already making an important contribution to value creation in the economy and thus also to prosperity in Germany. In consideration of future **economic and society-focused renewal processes,** a responsible policy should therefore immediately create reliable framework conditions that incentivize climate-friendly innovation and thus force back the use of fossil fuels. Jobs and a prosperous economy will not be preserved or created by the protection of obsolete technologies and economic structures.

Measures

New expert reports agree: The **most important instrument for effective climate protection is a uniform and cross-sector price for greenhouse gas emissions**. The Leopoldina supports this demand. The government must send this message as a core element of a courageous climate protection policy. In the interest of effectiveness, cost efficiency, and a socially balanced climate policy, it must also enable a significantly higher CO_2 price at the outset compared with the current price in European emissions trading of around 25 euros per tonne of CO_2. To accommodate price increases in the coming years, policy makers must politically account for the consequences of the price increase. This also applies to the implementation process regarding emissions trading, where the price is determined without further political intervention on

the market for emission certificates, and to a CO_2 tax, where the tax rates have to be adjusted regularly to the degree to which the target is missed. In the case of a tax, the less political courage there is for a high entry price, the stronger these adjustments will have to be. In any event, the CO_2 price must be recognisable as a fundamental climate policy strategy.

However, a **CO_2 price alone is not enough** to bring about a comprehensive change in behaviour: It must be complemented by other climate policy instruments and measures. **Revenues from the CO_2 price must be reinvested transparently**: as social compensation in the form of a "climate dividend", in the relative reduction of the electricity price, in climate protection and adjustments in the area of infrastructure, as well as in common goods. The overarching objective of all these approaches is to encourage economic activity and behaviour that protects the climate. If used wisely for social balance, climate protection behaviour can even lead to direct financial gain for consumers, especially among lower income groups. Wealthy citizens usually produce more CO_2 and will therefore play a correspondingly greater role in reshaping infrastructure and society. Ultimately, the whole population will benefit from modern and better infrastructure.

An effective CO_2 price will make an earlier phasing out of coal use more likely. This is technically possible in Germany with appropriate **investment in renewable energies, in a modern power grid, and in storage technologies** (power to gas, power to heat, batteries, power to liquid), especially if this is carried out together with the country's European partners. The transformation of the energy system will entail partial **decentralisation**. Examples include the local generation of renewable electricity and its storage in battery systems. However, **intelligently interlinking** the decentralised subsystems with is necessary in order to maintain the quality of the overall system.

All climate protection measures and instruments must be designed in such a way that they enable an **energy system which is open to development**. The Federal Government should, in particular, create the framework within which various climate-friendly technologies can establish themselves and not directly favour individual technologies. In order to achieve this, the transformation of the energy supply should be designed on a European basis. Due to the different weather and climatic conditions, European integration and the mix of technologies are an important advantage for the stability of the energy supply.

Different sector targets (energy, industry, transport, agriculture, buildings) should be incorporated into a **system-wide overall view of emissions**. This provides greater scope for action and is also economically sound. At the same time, all subsidies harmful to the climate must be abolished. To achieve this, the tax system must be consistently restructured to align it with sustainable goals. In order to enable the entire population to adopt climate-friendly mobility, housing, and food, long-term infrastructure investments are necessary.

Transportation accounts for around 20 % of CO_2 emissions, and the figure is rising. This applies above all to freight and passenger transport, but also to mobility in the leisure sector, as well as to shipping and air transport. A rapid reduction in transport-related CO_2 emissions can only be achieved through **massive electrification**.

Local public transport, long-distance rail transport, and freight transport by rail must therefore be considerably expanded and improved. Since railways and public transport are mainly owned by the public sector, this political decision could be implemented quickly. Prioritising public transport, cycling, and walking in cities also has a direct positive impact on health, land consumption and overall quality of life.

Intelligent mobility systems are the best replacement for private cars. Such systems drastically reduce the amount of energy and resources required for individual mobility. In motorised road traffic, **a transition to highly hybridised and battery electric vehicles is required**. To this end, a number of measures must be taken swiftly: the development of charging infrastructure for electric vehicles, the switch to electric vehicles for urban delivery and public transport, priority given to these vehicles in car parks and through reserved lanes. These and other measures have already proved their worth in other countries. Networked, **safe bicycle infrastructure** should also be massively expanded, especially in cities.

Current **transport costs do not take sufficient account of environmental impact**. They therefore often lead to large-scale relocation of production to distant countries and thus to increasing logistics services. International air and sea traffic must therefore be subject to a CO_2 price through appropriate agreements in order to reduce the quantities of goods and transport routes. Global traffic in international logistics chains must be reduced, e.g. by promoting **regional production networks**. In order to make logistics chains CO_2 neutral in the medium term, excess wind and photovoltaic electricity can be used to generate low-emission fuels using power to liquid or power to gas processes.

A consistent climate policy along these lines will have numerous positive effects: It will help to improve climate protection, environmental protection, public health, and public welfare at the national level. It will alleviate the growing generational conflict. It is the right step for a common European path towards sustainable development to also achieve global change as part of an international network. It will improve the quality of life by developing less harmful forms of mobility and production. And it will help to ensure prosperity through innovation.

1 Starting point and diagnosis

1.1 The earth and climate system is changing dramatically

The changes in the atmosphere and the ocean since the middle of the 20th century have been dramatic. The global warming of the air temperature since 1900 amounts to more than 1°C at the surface; in the ocean, it can be measured worldwide to a depth of 2 km. These changes are caused by the increase in greenhouse gases (warming of about 1.4°C) and harmful aerosols, which lead to a cooling of about 0.4°C. These substances are released into the atmosphere as waste from the combustion of coal, oil, and natural gas. The current concentration of atmospheric CO_2 of 415 ppm (measured on the Mauna Loa volcano in Hawaii, USA, see cover picture) was last recorded 3 million years ago, during the Pliocene Warm Period. At that time, the average global temperature was 2-3°C warmer. Greenland and the West Antarctic had no or significantly less ice cover. Sea level was about 20 metres higher. As a result, climate and precipitation zones were shifted and ocean currents fundamentally different.

Today, the ocean absorbs 90% of the heat generated by humans and 25% of the CO_2. Warming is causing the polar ice to melt, with far-reaching consequences for the seas and oceans and the creatures that live in them. The global death of coral reefs is also caused by ocean warming and acidification due to CO_2. Alongside these direct effects, there are indirect effects due to the fact that the greenhouse effect amplifies itself: The frozen Arctic soils will continue to thaw and release significant amounts of greenhouse gases. There will be more forest fires and droughts. Because of this, plants to store carbon. Climate change is already one of the greatest threats to the planet's biodiversity. Continuing with the business as usual approach would mean the complete and imminent loss of coral reefs as habitats.

We know from the earth's history that there are tipping points in the climate system at which abrupt and irreversible processes can occur. The melting of the Greenland ice sheet with the corresponding rise in sea level would be massively accelerated, for example, if the temperature were to rise by more than 2°C. To avoid all of this, the conditions can and must now be created to reduce global CO_2 emissions to net zero.

This requires the phasing out of fossil fuels and abandoning plans to construct new coal-fired power plants as well as closing existing plants. Then there would still be a small chance of achieving the 2-degree-Celsius goal of Paris. However, this target is at serious risk as global CO_2 emissions have risen again in the last two years. Many more coal-fired power plants are planned worldwide, which will emit more than 650 gigatonnes of additional CO_2 — a significant proportion of the remaining global CO_2 budget by continuing on this path, the internationally agreed climate targets will not be achieved.

1.2 The tragedy of long-term climate objectives

Science has been issuing warnings for more than 40 years and international agreements have been in place for 30 years. Nevertheless, global CO_2 emissions are not declining. On the contrary: Since 1988, the year of the first climate conference and the founding of the Intergovernmental Panel on Climate Change (IPCC), emissions from fossil fuels have risen by 75%. The 2015 Paris Climate Agreement has also failed to reverse the trend so far. According to IPCC estimates, the atmosphere's ability to absorb CO_2 is down to significantly less than 1000 gigatonnes before irreversible damage occurs, which includes the loss of coral reefs worldwide, rapid loss of ice mass, a rise in sea level, and increasing extinction of species occurs. This justifies the need for immediate climate protection measures as well as long-term adjustments to avoid global warming above 2°C.

We are experiencing a "tragedy of long-term objectives". There is an ever widening discrepancy between the unfolding existential threat of climate change and repeatedly postponed political action. As evidenced by the protest movement "Fridays for Future", there is now a whole generation that is increasingly impatient and disconcerted by politics' and society's failure to act. The movement demands that the climate crisis be tackled in earnest and that long overdue action is finally taken.

Climate policy so far has been socially unbalanced in several respects: Firstly, it has not considered the effects on low-income earners, who are already responsible for less CO_2 emissions. This demographic has so far been disproportionately burdened financially. Secondly, an excessive share of climate problems is still being handed down to future generations. Thirdly, countries with the lowest per capita CO_2 emissions suffer most from the consequences of climate change. In addition, some people fear that their freedom will be restricted by the introduction of bans. A new climate change policy must address these issues.

Any failure to act or simply sticking to the status quo will incur high costs. Nature and biodiversity will certainly suffer. In many parts of the world, drought, floods, and other disasters exacerbated by climate change are forcing people to leave their habitats, with unmanageable consequences and a loss of public welfare and prosperity. Added to this are the adjustment costs, which continue to rise the longer we wait.

1.3 Good climate policy unites

Climate policy must not be stagnant. It must be equipped to overcome any existing fears of the necessary changes. It must not divide, but rather unite society in taking collective action. The conditions under which future generations will live depend on what measures are taken today: If politics and society embark on a path of sustainability, then an ecosystem open to development with various climate-friendly technologies can be achieved.

1.4 Taking a look at the big picture

Germany's current climate policy consists of a cluster of individual measures: a few additional regulations, taxes and bans, coupled with the environmentally-friendly behav-

iour of the well-intentioned. The responsibilities of the National Academy of Sciences include clearly expressing the need for a comprehensive and courageous overall renewal of the energy system and the handling of natural resources. Such a renewal should be consistently oriented towards sustainability. In the short term, the aim is to send clear signals about wide-ranging action across sectors in order to achieve already agreed climate targets and avoid the high costs of non-compliance.

1.5 A systemic challenge

The energy system is a highly complex system, which has developed at the nexus of politics, economics, society and technology. In addition to the technical structure, which combines energy sources and electricity, it is also characterized by economic and regulatory framework conditions. In addition, there are numerous interactions between actors, which is constantly rising due to the energy transition ("Energiewende"). Many decentralized energy producers increase the degree of interconnectedness and the number of interactions. Since neither Germany nor Europe are energy self-sufficient, the overall national system is closely linked to international developments at all levels (technical, regulatory, economic, social).

The large number of individual measures initiated and planned in Germany assumes that the energy supply in the various sectors can be controlled independently. However, effective measures should be designed in such a ways that they produce the desired effects and act in synergy with the system as a whole. Introducing measures becomes significantly less complex when these are applied as uniformly as possible in all sectors and when the sectors are free in their choice of technologies. The sustainability of a renewed energy system with the technical attributes of a circular economy and the social attributes of accessibility to renewable energy with fairly distributed burdens should be the guiding concept behind all measures.

1.6 Consistent, transparent, and swift action

Climate policy needs credibility. Credibility is the result of consistent, transparent, and swift action toward achieving a binding target. Climate policy must be understandable and tangible for everyone. A transparent climate policy also means openly communicating that a climate and energy transition cannot be achieved at zero cost, but that the social costs of the status quo far exceed the investment in mitigation measures. The risks and losses to nature, the common good, and quality of life inherent in the business as usual approach must be made clear. Science and state institutions have the task of contrasting these risks and losses with the comparatively moderate efforts to achieve current and future climate targets.

From a technological point of view, all the prerequisites are already in place to create an almost climate neutral energy system. From an ethical point of view, there is no alternative course of action. After all, an enlightened, modern, knowledge-based society must be committed to the responsible management of the livelihoods of future generations. This includes the preservation of healthy ecosystems. Regarding the economy, it should also be borne in mind that we are already falling short of the 2020 targets and will have to achieve an annual reduction of 25 million tonnes of CO_2 between 2021 and

2030. Should Germany fail to achieve its annual climate targets, the binding European regulation concerning burden-sharing will hit the federal budget hard: according to current estimates, costs could reach 62 billion euros by 2030 (see box).

1.7 Creating reliable framework conditions

The transition in energy and climate policy requires scope for technological creativity and investment security. Investments are usually long-term in nature and therefore require planning security. The German Renewable Energy Sources Act (EEG) has become a hindrance to the expansion of renewable energies. It needs to be reformed or abolished. More dynamism and technological competition are now urgently needed. This competition of ideas must not be restricted to Germany. The global community will only be able to overcome the global climate crisis if a rapid reduction in CO_2 emissions is achieved internationally.

Economic resources must be used worldwide for climate protection and adaptation before further rising emissions of greenhouse gases lead to considerable climate damages, which are more expensive than avoiding them. These damages weaken the economy and society, for example through declining yields in agriculture, damage to infrastructure or the resettlement of people who lose their living space. An improved risk assessment taking account of the non-linear, chaotic processes of the earth and climate system as well as of human behaviour is necessary to better assess the costs and damages of climate change.

Creating reliable framework conditions means: (a) providing incentives for the sustainability path, e.g. through a more climate-friendly tax system that sets higher prices for CO_2 emissions and environmental costs; (b) making long-term investments in infrastructure, e.g. in the resilience of the energy system and agriculture and forestry with regard to heat waves and drought, the reduction of greenhouse gas emissions or the restructuring of the transport system in order to shift transport more to railways and to consistently promote cycling.

Box: Sample calculation

EU long term strategy 2050

Reduced CO_2 emissions compared to 1990

Emissions trading (ETS) targets
(industry, energy)

Reduced CO_2 emissions compared to 2005

No separate national targets

Non-ETS sectors
(transport (excluding air), buildings, waste, etc.)

Reduced CO_2 emissions compared to 2005

Reduction targets for Germany:

Reduced CO_2 emissions compared to 2005

With a business as usual approach, Germany fails to meet EU climate protection targets

Time period 2021 - 2030		Transformation of energy and climate policy * (e.g. via CO_2 pricing with climate dividends)	„Business as Usual“ **	
			Scenario 1	Scenario 2
CO_2 price in 2030	€ / t CO_2	**130**	–	–
Compensatory payments	€ / t CO_2	0	**50**	**130**
Target shortfall	Mio. t CO_2	0	361	615
Revenue	€ bn	212	**-14**	**-62**
Revenue per inhabitant	€ / p.P.	2 564	**-174**	**-745**
Paid climate dividends	€ / p. P.	1 409	–	–
Reduction of electricity tax	€ bn	67	–	–
Accompanying measures	€ bn	51	–	–

The table shows cumulated values for the period 2021-2030. CO_2 prices increase at a rate of 10% per annum. Calculations MCC (2019)

*) Based on Edenhofer at al. (2019) with exponentially interpolated values. The CO_2 price shown refers to a CO_2 tax or the CO_2 price in an emissions trading system for buildings and transport

**) The CO_2 price shown refers to the amount of compensatory payments between governments per tonne of CO_2. Scenario 1 assumes a low CO_2 price in 2030 and an interpolated emissions loophole from the Federal Government's Projection Report (2019). Scenario 2 assumes a high CO_2 price in 2030 and an emissions loophole from AGORA (2018)

Additional measures are also needed to achieve the targets, e.g.:

- Investment in renewable energies, a modern power grid, and storage technologies
- Changes in mobility (electrification, public transport, sustainable forms of transport)
- Investment in reduction of energy consumption in buildings (solar panels, heat pumps)
- Sustainable urban development
- International, particularly European, cooperation
- Funding of research and innovation

2 The restructuring process: economically efficient and socially balanced

The transformation of the national and European energy system is an enormous investment project that can only be realised with the cooperation of the general public. In order for this change to be efficient and socially balanced, it must strive for the clear and unambiguous objective of reducing climate and environmental damage by reducing and preventing emissions. Both the goal itself and the methods of and urgency for action must be communicated to the public.

The transformation of the energy system will not take place without government decisions and the contribution of civil society. The population must be able to contribute to success by changing their behaviour in the interest of greater sustainability. In order to achieve this as cost-effectively and in as socially balanced a way as possible, the state should create the framework for target-oriented decentralised action.

Different sectoral objectives (energy, industry, transport, agriculture, buildings) should be transferred as quickly as possible into a system-wide overall view of emissions in order to focus on the reduction of total emissions and thus the collective contribution to climate protection.

2.1 A price for CO_2

The most important coordination signal for effective climate protection is a uniform and effective price for greenhouse gas emissions. The government must send this message as a core element of a courageous climate protection package. In the interest of effectiveness, cost efficiency and a socially balanced climate policy, it must also keep up its decision if this CO_2 price, as is very likely, is significantly higher at the outset compared with the current price of around 25 euros per tonne of CO_2 in European emissions trading. As the price will increase from this point in the coming years, the government must account for possible consequences of this increase.

This strict condition for the credibility of climate policy action applies equally to the implementation process regarding emissions trading, where the price is determined without further political intervention on the market for emission certificates. It also applies to a CO_2 tax, where the tax rates have to be adjusted regularly to the degree to which the target is missed. In the case of a tax, the less political courage there is for a high entry price, the stronger these adjustments will have to be. In any event, the CO_2 price must be recognisable as a fundamental climate policy strategy.

A sample calculation: Assuming a CO_2 price of 25 euros per tonne of CO_2, the price of car fuel would rise by about 6 cents per litre. When coal-based electricity is supplied, approx. 1 kg of CO_2 per kW is emitted (here there is a relatively wide range depending

on the efficiency of the power plants and the quality of the coal), which currently corresponds to about 2.5 cents per kWh.

2.2 A CO_2 price must be supplemented by further climate policy instruments

A cross-sectoral uniform CO_2 price should become the leading instrument of climate policy in Germany and Europe. However, the dynamic incentive provided by a CO_2 price can be weakened by market or policy failures. Therefore, a CO_2 price should be complemented by additional sector-specific policy instruments and measures that address such failures in a targeted manner, such as investments in infrastructure, the introduction of efficiency standards, etc.

2.3 Pragmatic implementation of market-based solutions

In order to promote long-term transformation in Europe through a uniform price for greenhouse gas emissions, it would be possible to build on the existing European emissions trading system, the ETS. The ETS currently covers slightly less than half of Europe's greenhouse gas emissions by requiring parts of industry and the electricity industry to demonstrate appropriate ownership rights to this space when depositing emissions in the atmosphere.

These certificates fetch a price on the certificate market that thus represents the price for greenhouse gas emissions. This creates incentives for lower fossil fuel consumption and investment in lower-emission technologies. The price in the ETS was sometimes too low, due in part to some design errors that have since been eliminated, and thus did not fully create the intended incentives. Setting minimum prices or deleting certificates can counteract this problem.

In the future, the transport and buildings sectors must also be included in this trading system. Thus, all emissions will have a uniform price. However, there are likely to be significant hurdles to implementing this policy in Europe. For a defined transitional period approximations to the ideal of a cross-sectoral European ETS should be considered and further developed.

Politicians must quickly decide which transitional solution to pursue: A separate emissions trading system for the sectors not yet included in the ETS is associated with considerable additional bureaucratic effort and a time delay. A CO_2 tax, on the other hand, could be implemented quickly. However, considering past tax policy experience it would be difficult for politicians to credibly communicate the character of a tax as a purely transitional solution.

The collection of taxes and charges that has grown over time in the individual sectors, especially in transport and buildings, must be corrected as it stands in the way of a cross-sectoral energy transition. The recommendations for reform that are made here — separate emissions trading or tax as possible transitional solutions — are an important step in the restructuring of the energy tax system.

2.4 Easing the burden of undesirable distribution effects on private households

Revenues from the CO_2 price must be reinvested transparently: as social compensation in the form of a "climate dividend", in the relative reduction of the electricity price, in climate protection and adjustments in the area of infrastructure as well as in common goods. The objective is to encourage economic activity and behaviour that protects the climate. Climate protection behaviour will then even lead to a financial gain for consumers.

The transformation of the energy supply system triggers distribution effects. Low-income households typically spend more of their income on energy and therefore bear a relatively higher burden for conversion requirements. The revenues from emissions trading or CO_2 taxation would enable a social climate policy, e.g. through infrastructure made available to the general public (improved public transport, bicycle infrastructure) or a (partly) flat-rate reimbursement, which would benefit lower-income households in accordance with their income. Part of the income must also be used for targeted measures with a positive impact on the climate.

2.5 Easing the burden of undesirable distribution effects on businesses

Companies that use energy as part of their production incur higher production costs. They can often pass on a significant portion of such cost increases to their customers. If this is not possible, for example because they compete on international markets with companies from other economies that are not subject to the same price for greenhouse gas emissions, then domestic value creation falls behind or threatens to migrate ("carbon leakage"). This would work against the intention of climate policy.

It is therefore economically and ecologically necessary to compensate for these disadvantages. In the existing European Emissions Trading System (ETS), this has been achieved by the free allocation of emission certificates. This could also be done in an ETS extended to other sectors. However, there is likely to be less frequent cause for this in these sectors. Imports subject to a border-adjusted carbon tax corresponding to the implicit emission content can have a similar protective effect, but could be a politically sensitive measure, especially for an open economy like Germany.

2.6 The public must be able to contribute to success

Fiscal and legislative measures can provide effective incentives for technologies and practices that reduce CO_2 while penalising those that emit CO_2. However, such approaches will only be successful if the general public is convinced of the necessity of such a climate policy and is therefore prepared to change its behaviour so as to reduce the carbon footprint. Climatic changes and their consequences will only unleash their full force on the coming generations. Therefore, a change in the behaviour of today's generations can best be set in motion by rational, analytical insights and less by the immediate experience of positive or negative consequences. Scientific education must therefore promote a realistic and science-based perception of problems in all population groups. Selected measures to steer individual behaviour in the "right" direction (nudging) or to support individual decisions through education (boosting) can contribute to this.

All measures must take account of the fact that people are more likely to act in pursuit of obtaining short-term benefits or to avoid short-term losses. On the other hand, spatially and temporally distant benefits and existential threat scenarios do little in the way of motivation. In addition, positive incentives for sustainable changes in behaviour are more successful in the long term than punishments or negative moralistic approaches. With regard to all fiscal and other regulatory measures, direct positive incentives for environmentally oriented action must therefore be recognisable and clearly communicated.

2.7 Focus on research and development

As technology progresses, the costs of transformation decrease. In this respect, a CO_2 price fulfils a dual function. On the one hand, it creates the framework within which innovations can be successful on the market. In modern innovation systems, the state has a highly demanding task regarding industrial and innovation-related policy: State support should primarily intervene where the social return on an activity exceeds the private return.

On the other hand, political efforts must be integrated with the activities of research institutions and companies in research and development in the sense of a well-understood industrial policy that remains open to technology and maintains competition.

3 The energy system in Germany and Europe

Energy supply is a basic prerequisite of a functioning and evolving society. Therefore, the user groups (individuals, households, companies, organisations, regions) are at the centre of the system. They are linked to the technical energy system via a further subsystem of regulations, economic factors and legal framework conditions. The technical system consists of energy carriers (fossil, nuclear, renewable), transport and storage infrastructure, basic applications (heat, electricity, mobility) and end uses (production, domestic use, information and communication technologies, mobility, industry, trade, services, agriculture, and forestry). Strong links exist between all elements.

3.1 Germany is part of a Europe-wide, complex energy system

Today, the German energy system is often linked to other countries via technical and regulatory institutions. The power grid is one example. At times of peak demand, electricity is imported. Excess energy is absorbed from abroad via interconnectors. This currently works without any problems. In order for this international balance to continue to be possible, it is necessary to restructure the energy system at the national, European, and international levels in close coordination with neighbouring countries.

Since the turn of the millennium, Germany has been a substantial exporter of electricity with a net electricity export of around 10% of production, but still imports 64% of its energy requirements in the form of coal, oil, gas, and uranium from abroad. It is therefore unlikely that Germany alone can eliminate this import dependency, even if the conversion losses in an electricity-based energy system are significantly lower and energy-saving measures have not yet been exhausted.

In the medium term, importing renewable energy from regions with favourable climatic conditions for producing energy (e.g. North Africa, the Middle East), could become an option for the European energy network. If the freedom is obtained to optimise the balance between electrical and non-fossil material energy carriers, maximum efficiency can be achieved throughout the system.

3.2 Centralised-decentralised: no contradiction

Users of the energy system have different demands regarding the quality and volume of the energy supply. As of yet, the energy system in Germany has been centralised. It functions well and will thus be needed in the future. This centralised energy system must be accompanied by a decentralised energy framework. The latter could ensure the supply of individual buildings with electricity and heat generated by solar panels and heat pumps or the electricity supply of computer and data centres. Locally generating renewable energies, e.g. for buildings, and local storage in battery systems can signif-

icantly reduce the burden on the centralised infrastructure. Intelligent networking is needed to maintain the quality of the system. Any decentralisation requires the existence of powerful, secure digital communication and control systems. The infrastructure for this is still largely lacking and must be set up immediately.

3.3 Material energy carriers of the future

Material energy carriers such as gases and liquid fuels will continue to be necessary for some industrial applications and to compensate for fluctuations in the availability of renewable energies in the electricity grid. The use of regenerative fuels (green fuels) entails considerable losses both in their production and in their conversion back into electricity. For example, it is not advisable to transform biogas into electricity. Therefore, instead of a much larger electrical subsystem, a much more intelligent and thus more efficient system should be created — one which makes the joint production of chemical energy carriers economically possible and reduces the regeneration of electricity to the minimum necessary for grid stabilisation. The direct use of green fuels in heat and mobility applications is recommended.

The greatest possible savings in CO_2 emissions could be achieved by quickly phasing out the use of coal and oil. Due to its high hydrogen content, gas is an attractive energy carrier and can be relatively easily replaced by its “green” variant (power to gas technology).

3.4 Swiftly initiate a mobility turnaround

Looking at the central sectors of the energy system in terms of their contribution to CO_2 emissions, it is obvious that mobility plays an important role. For Germany, it is of great importance not only in terms of environmental policy, but also industrial policy.

Transport accounts for around 20% of CO_2 emissions in Germany, and the figure is rising. Road traffic today is still almost exclusively powered by fossil fuels. However, conventional combustion engines are less efficient than electric engines and emit CO_2. Regarding passenger and freight transport, only 19% and 25% respectively are accounted for by environmentally friendly means of transport, such as electrified rail transport. All forecasts indicate that mobility will continue to rise, in terms of both freight and passenger transport. This makes these areas particularly difficult to transform. Global production networks lead to increasing logistics services. The reduction of CO_2 emissions in the transport sector should be tackled on three fronts: reduction, relocation, and increased efficiency:

- **Reduce traffic:** Current transport costs do not take sufficient account of environmental impact. They therefore often lead to large-scale relocation of production to distant countries and thus to increasing logistics services. Global traffic in international logistics chains must be reduced, e.g. by promoting regional production networks.
  Shipping and air traffic are increasing dramatically worldwide. These transport systems are particularly harmful to the climate and the environment: Ships usually still run on heavy fuel and do not have the usual exhaust gas purification equipment

that road traffic has; aeroplanes emit their exhaust gases and large amounts CO_2 at great heights. International air and sea traffic must therefore be subject to a CO_2 price through appropriate agreements in order to reduce the harmful effect on the environment.
In order to make logistics chains CO_2 neutral, excess wind and photovoltaic electricity can be used to generate fuels that are as low-emission as possible (power to liquid or power to gas). Urban delivery traffic is increasingly causing emissions in cities. Traffic can be reduced through optimised logistics concepts, polycentric shopping areas, trade and services connected via local public transport, and improved bicycle infrastructure. Urban development must be adapted to people's changing lifestyles and mobility habits in order to reduce individual short-distance traffic, in particular, in the medium to long term, without at the same time restricting mobility requirements. A bicycle- and pedestrian-friendly infrastructure is still the best remedy against climate-damaging emissions, harmful particulate matter and nitrogen oxide pollution as well as urban land consumption.

- **Relocate traffic:** In principle, a relocation of traffic from road to rail and, in urban areas, to public transport and bicycles is necessary. Local public transport, long-distance rail transport, and freight transport by rail must therefore be considerably expanded and improved. Massive efforts must be made to increase the small share of more environmentally friendly means of transport in the overall traffic volume, with a particular focus on achieving more rail transport. In addition to the expansion of public infrastructure, these changes require effective incentives to permanently alter the behaviour of users. Since railways and public transport are mainly owned by the public sector, this political decision could be implemented quickly. Prioritising public transport, cycling, and walking in cities also has a direct positive impact on health, land consumption and overall quality of life.

- **Make traffic more efficient:** In motorised road traffic, a transition to highly hybridised and battery electric vehicles is required. To this end, a number of measures must be taken swiftly: the development of charging infrastructure for electric vehicles, the switch to electric vehicles for urban delivery and public transport, priority given to these vehicles in car parks and through reserved lanes. These and other measures have already proved their worth in other countries. Acceptance by the general public can be promoted by measures that make the use of such vehicles and infrastructure more convenient and affordable. Networked, safe bicycle infrastructure should also be massively expanded, especially in cities. A rapid reduction in transport-related CO_2 emissions can only be achieved through massive electrification. However, electrification in the area of transport only makes sense in conjunction with an increasingly renewable energy sector.
  Fuel cell systems could become an alternative technology in the long term: They can be operated with "green" hydrogen, produced by electrolysis with electric current and from water, although this currently requires 2 to 2.5 times more primary energy than battery electric vehicles. Storage facilities for gaseous hydrogen are already available today. Alternative liquid-based storage systems are being tested, such as promising LOHC technology ("Liquid Organic Hydrogen Carrier", a liquid storage material for hydrogen). The production of renewable fuels from biomass and biogenic processes should only be increased if it is possible to use residues as resources in an economically and ecologically compatible way or to successfully advance completely new semi-synthetic processes.

When new vehicles are registered, stricter requirements should apply immediately in order to reduce the CO_2 emissions of the entire fleet of vehicles. The conversion of public-sector vehicle fleets should set a positive example.
"Smart metering" allows end consumers to directly access the electricity market. This means that if there is a high supply of wind and solar power, the electricity for controllable devices such as electrified building heating systems and vehicle batteries can be offered at a favourable price and the burden on the electricity grid can be relieved. At the same time, the consumer has cost advantages. For example, Consumers "refuel" their e-cars more cheaply when the sun is shining and there is excess electricity capacity. For this purpose, the vehicle communicates directly with the energy provider.

3.5 Making the right investments in building technology

In Germany, buildings account for around 35% of final energy consumption and around 30% of CO_2 emissions. The main sources of CO_2 emissions are the combustion of fossil fuels (oil and gas), inefficient circulating pumps in heating systems, and heat loss. The most effective means for cutting emissions in the near future are heat pumps powered by renewable energy, low-loss lighting technology, walls, roofs and windows with strong insulating properties, ventilation systems with efficient heat recovery and high fan efficiency, use-related room heating through improved temperature control, and biogas-powered monovalent CHP systems. Only about half of the population owns a home and only a part of this group has the necessary financial means for energy-oriented renovation in order to be able to react to rising heating costs caused by a CO_2 price. Therefore, specific incentives must be found for the reduction of building-related CO_2 emissions for the many rented apartments and less affluent home owners.

3.6 Climate protection is health protection

All measures in the energy sector that serve to protect the climate are at the same time measures to promote air pollution control and thus health. Reducing the emission of CO_2 and other greenhouse gases generally also leads to a reduction in harmful substances, in particular fine particulate matter. However, there are exceptions: For example, retrofitting internal combustion engines with catalytic converters leads to the reduction of NO_2, but also to increased CO_2 emissions.

3.7 What needs to be done now in terms of energy supply?

The systemic character and primacy of sustainability must guide the transformation of the energy supply. The restructuring must be hierarchical and encompass the three levels of political action: local, national, and European or international. A transformation path must be defined and regularly adjusted to this end. This path may not be embarked upon equally quickly by all nations at the same time. However, all measures must be compatible with the path.

The restructuring requires regulatory guidelines that are valid throughout the system. They are designed to have long-term validity and create reliable economic conditions.

They are open to different technologies. The involvement of the general public as well as supporting information and awareness-raising work are indispensable.

The central challenge in transforming the energy system is the comprehensive rapid development of the remaining renewable energies and the establishment of European systems for their transport. This must be paired with a system of negative reinforcement for the use of fossil fuels as well as with citizen-oriented communication.

Industry is a central partner when it comes to transforming the energy system. However, there is currently no single branch of industry that can perform this task. Cross-industry dialogue is therefore necessary. This process and the mobilisation of the considerable capital required are tasks that policy makers must now shape directly. Otherwise, the conversion process may not move beyond test facilities. A current example of this weak dialogue between various industries was the discussion on e-mobility.

4 Climate targets 2030: Instruments and measures for immediate climate protection

Now, we need a transformation boost, which is based on innovation. The transformation to a carbon neutral economy is a great challenge, while also offering great potential for economic growth. Germany must now begin this transformation while also helping to design all measures on a European level. With ambitious and long overdue new regulations on sustainable climate protection, politicians can carry their share of responsibility for the future. The general public should be able to actively participate in the dialogue on climate protection. The transformation of the energy system will only succeed if the government leads the way.

Recommendations

1. A **uniform CO_2 price** for all sectors (energy, industry, transport, buildings, others) should become the **guiding instrument of climate policy**. In the medium term, **European emissions trading should apply to all sectors**. At present, certificate trading is only used in the industrial and energy sectors. This sectoral approach must be overcome. However, there are likely to be significant political hurdles to establishing an emissions trading system that covers all sectors equally. For this reason, a CO_2 price should be implemented immediately for a transitional period in areas that are not regulated by emission certificates.

2. This **transitional solution** can be implemented either through a CO_2 tax or through a separate **emissions** trading scheme. The government must quickly send this message as a core element of a courageous climate protection package. In the interest of effectiveness, cost efficiency, and a socially balanced climate policy, it must also enable a significantly higher CO_2 price at the outset compared with the current price in European emissions trading of around 25 euros per tonne of CO_2. To accommodate price increases in the coming years, policy makers must politically account for the consequences of the price increase. The mechanism of CO_2 price fixing must be explicitly designed as a learning system.

3. At the same time, **energy taxes and charges should be reformed.** The collection of taxes and charges that has grown over time in the individual sectors, especially in transport and buildings, must be corrected as it stands in the way of a cross-sectoral energy transition. This includes the abolition of all (even disguised) subsidies for CO_2-intensive technologies and modes of transport. If the EEG is not abolished, the costs for the EEG should also be apportioned to the heat and fuel sector in order to facilitate the substitution of fossil fuels by CO_2-free electricity for electric mobility and heat pumps.

4. The **introduction of a CO_2 price must be supplemented by further climate policy instruments and measures** in order to achieve legally binding cli-

mate targets. The dynamic incentive effect of a CO_2 price can be weakened by market or policy failures, among other things. Therefore, where these problems arise, the guiding instrument of the CO_2 price should be complemented by sector-specific complementary policy instruments and measures that specifically correct failures, such as investments in infrastructure, efficiency standards, etc.

5. The energy transition and new climate policy must be **socially balanced, designed with reliable framework conditions,** and able to minimise the burden of unwanted distribution effects. **Revenues from the CO_2 price must be reinvested transparently**: in social compensation in the form of a "**climate dividend**", in the relative reduction of the electricity price, in infrastructure that is low in carbon emissions, or in common goods. The objective is to encourage economic activity and behaviour that protects the climate. Thus, even lower income groups, which usually spend a larger proportion of their income on energy, would not be burdened disproportionately and would potentially even have their burden **reduced**.

6. **Existing technological solutions for this new energy and climate policy must be implemented quickly.** Renewable energy sources will become a central component of the energy system. In order to bridge fluctuations, the support of flexibly operable gas-fired power plants is needed first. This reserve capacity should be gradually replaced by network services and large-volume storage or transformation of excess energy into fuels. In the **buildings sector**, technical solutions (e.g. heat pumps, windows with good insulating properties, solar panels and ventilation systems) and thermal insulation are efficient measures. Concerning architecture, new incentives should be created for climate-neutral construction, and especially for the use of sustainable materials (e.g. wood). "Smart home" technologies should be expanded while simultaneously taking digital security into account.

7. The envisioned energy and climate transition requires **scope for technological creativity** and investment security. More dynamism and technological competition are now urgently needed. The Federal Government should **continue to promote** the research and development of **new technologies**. In doing so, it creates the framework within which various climate-friendly technologies can prevail. No single technology should be given preference.

8. In the short term, reduction in **transport-related** CO_2 emissions can only be achieved through **massive electrification**. Measures that have been successful elsewhere include the rapid expansion of charging infrastructure for electric vehicles, the conversion of urban delivery and public transport vehicles to electric vehicles, priority given to these vehicles for parking spaces and in the form of reserved lanes. More resources must be made available for **local public transport, long-distance transport, freight transport by rail and urban bicycle transport** in order to increase quality and quantity significantly and quickly. Networked, safe bicycle infrastructure should be massively expanded, especially in cities.

9. There should be **incentives for the reduction of greenhouse gas emissions in industrial processes and agriculture**. In principle, an appropriate CO_2 price will also stimulate change; as in the mobility sector, accompanying measures can have an additional supportive effect.

10. **Urban development** must be adapted beyond 2030 to people's changing lifestyles and mobility habits. The focus here lies particularly on the question of how traffic can be reduced over short distances without restricting people's desire to be mobile. The far-reaching effects of successful climate protection on quality of life and health should be actively communicated.

Appendix

Further literature

Statements and analyses of the Academies' Project "Energy Systems of the Future"

The German Academies of Sciences have been supporting the transformation of the energy system in Germany and Europe for around 10 years with science-based statements, above all in the joint project "Energy Systems of the Future" (ESYS). The extensive statements and analyses are available at https://energiesysteme-zukunft.de/ .

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