SRU German Advisory Council on the Environment

Using the CO_2 budget to meet the Paris climate targets

ENVIRONMENTAL REPORT 2020

CHAPTER 2

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Using the CO_2 budget to meet the Paris climate targets

How much CO_2 can Germany still emit if it is to make its fair contribution to compliance with the Paris Agreement? If climate change is to be limited to the agreed level, one where it remains just about manageable, an upper limit must be set for the CO_2 emissions still globally permissible. By distributing the emissions among the community of states, it is possible to arrive at a German CO_2 budget in line with the principles of international distributive justice. The current German climate targets allow total emissions that exceed a national budget calculated in this way. In the Federal Climate Change Act, the Federal Government is supplementing existing climate targets with annual sectoral emissions limits up to 2030. This corresponds to the principle of national budgets but says too little about the level of ambition up to 2050. These emissions limits should be embedded in an overall budget up to 2050. The German Advisory Council on the Environment therefore recommends that the Federal Government should set a German CO_2 budget compatible with the Paris Agreement and tighten the climate targets accordingly. The budget should not replace existing targets but serve as an overarching basis for assessment. At the same time, it is urgently necessary to implement measures that will pave the way to climate neutrality, for example by accelerating the expansion of renewable energies. Only in this way can the use of fossil resources be quickly brought to an end. In order to keep within budget, progress on reductions must be regularly reviewed and measures must be continuously refined.

2.1 Introduction

1. With the ratification of the Paris Agreement, the Federal Republic of Germany has made a binding commitment under international law to the climate targets set out there (Deutscher Bundestag – Wissenschaftliche Dienste 2018, p. 6). According to Art. 2 of the Paris Agreement, the increase in the global average temperature is to be kept well below 2 °C above pre-industrial levels and efforts are to be pursued to limit the temperature increase to 1.5 °C. The signatory states, including Germany, have therefore committed themselves to continuously reducing national greenhouse gas emissions and to becoming completely climate-neutral by the second half of this century at the latest. A more ambitious climate policy in Germany is also increasingly being called for by the general public (Infratest dimap 2019, p. 3 and 5). Only if climate change can be limited to the agreed level will it be possible to prevent most of the elemental dangers that threaten the environment and societies of the world (IPCC 2018b). For example, the further increase in extreme weather events and their impact on infrastructure and land use would be limited (COUMOU et al. 2013) and important tipping points for the Earth's climate system would not be exceeded (SCHELLNHUBER et al. 2016).

2. But how can we determine what constitutes an appropriate national contribution to the global reduction of greenhouse gas emissions? How is it possible to assess whether the objectives of the Federal Climate Change Act (KSG) and the measures in the climate action programme together make up an appropriate German contribution to the Paris Agreement? Although Germany is responsible for determining its own contribution to reductions, it remains bound by the Paris climate targets (Deutscher Bundestag – Wissenschaftliche Dienste 2018, p. 6).

3. The CO_2 budget approach is suitable for assessing whether climate policy goals and progress in reducing emissions are Paris-compatible. This concept is based on physical climatic relationships between CO_2 emissions and global warming (WBGU 2009). The CO_2 budget describes the cumulative anthropogenic CO_2 emissions that can still be emitted from a given point in time without the resulting global warming exceeding a specified temperature threshold. The concept of the CO_2 budget is thus directly related to the Paris climate goals. It can be calculated at the global level, following which national and also sectoral levels can be derived based on normative assumptions of distributive justice.

4. In the current political debate, a large number of different goals and measures are being discussed. In addition to the temperature targets in the Paris Agreement, these include emissions reduction targets, formulated as percentage reductions up to a target year compared to a base year. Specific target years for ending emissions from a specific source, such as coal-fired power generation, are also discussed. The goal of greenhouse gas neutrality for the entire economy is pursued for a specific target year. Greenhouse gas neutrality means that there is equilibrium between anthropogenic emissions of greenhouse gases from sources and the removal of such gases by sinks.

Climate policy targets are also set at various levels: global, European, national, Federal States (*Länder*), municipal and sectoral levels. The targets vary in ambition and level of bindingness, and they are often inadequately coordinated with each other. The European climate targets are mainly operationalised in the form of greenhouse gas budgets up to 2030. German climate policy has so far been based on emissions reduction targets. The Federal Climate Change Act supplements these targets for the first time with sectoral greenhouse gas budgets up to 2030. However, a Paris-compatible transformation path up to 2050 is lacking, both at the European and the German level.

5. Many individual measures are being discussed in the various sectors, for example in electricity generation, heat supply and transport. However, an overall balance sheet is lacking. The effectiveness of sectoral strategies needs to be constantly monitored on an evidential basis to ensure that the totality of all national measures constitutes an adequate contribution to meeting the Paris climate targets.

In this chapter, the German Advisory Council on the Environment (SRU) will show how a national CO_2 budget can be calculated and what conclusions can be drawn for emissions reduction in Germany and for setting targets for individual sectors. Such a budget approach can thus provide a foundation for existing and future climate policy objectives in Germany.

2.2 The CO_2 budget as the key metric for climate protection

6. The failure of the 2009 Climate Change Conference in Copenhagen, at which no binding agreement under international law could be reached, brought about a paradigm shift in international climate diplomacy (BODANSKY 2016; SACHS 2019). Instead of binding reduction commitments, national contributions are formulated at national level and constantly adjusted (Pledge-and-Review). While the Paris Agreement itself is binding under international law, the nation states are the main players in setting their own climate targets (FALKNER 2016). These self-imposed climate policy targets are submitted as Nationally Determined Contributions (NDCs) to the Secretariat of the United Nations Framework Convention on Climate Change (UNFCCC). This approach relies for its effectiveness on the assumption that states have a vested interest in keeping to their commitments, since otherwise there is a risk of reputational damage at the international level (Naming and Shaming, see JACQUET and JAMIESON 2016, p. 644). The agreement provides for the NDCs submitted to be revised every five years and then to be subject to a Global Stocktake to assess the resulting progress in reductions (Art. 4 and 14 Paris Agreement). In this process, the Parties are obliged to continually raise the level of ambition of their contribution. This ratcheting-up mechanism (mechanism for upward revision of NDCs) is intended to ensure that the gap between the Paris climate targets and the national reduction contributions is gradually closed.

At present, the sum of national climate protection contributions is not sufficient to meet the global temperature target. In fact, even if fully implemented, the NDCs submitted so far are only sufficient to limit the global temperature increase to around 3 °C (2.4 °C – 3.8 °C) (Climate Analytics and NewClimate Institute 2019). The mean near-surface air temperature (land and oceans) has already warmed up by 0.87 °C since industrialization, over land by as much as 1.53 °C (IPCC 2019). The consequences of further warming would be disruptive to social, economic and ecological processes that are fundamental for the common welfare. A significant increase in climate policy efforts at global level is therefore necessary (ROGELJ et al. 2016a).

2.2.1 Basis for and uses of the CO_2 budget

7. Germany and the EU are obliged to make the contributions needed to achieve the Paris climate targets (see sec. 2.4.1 and 2.4.2). To this end, it is necessary to determine the contributions in detail and to review them continuously. The CO_2 budget is an appropriate approach for this purpose (see Box 2-1).

Quantitative targets and indicators in climate policy and science

8. Depending on context, climate science and policy use a range of different targets and indicators, relating either to temperature, CO_2 concentrations in the atmosphere or CO_2 emissions. The Paris climate targets were formulated as maximum warming or temperature targets. The methodological advantage of such a temperature target is that it is directly related to the consequences of global warming, because the mean temperature of the Earth is a key leading indicator for the state of the Earth system as a whole. Thus, the temperature target reflects a consensus among the international community on the level of protection to be aimed at, notwithstanding that the consequences of global warming vary greatly from region to region and are often communicated via other climate variables such as the amount of precipitation or the frequency of extreme weather events. However, in order to be able to derive guiding indicators such as the maximum permissible emission quantities at national level from a global temperature target, the level of warming needs to be converted into emitted CO_2 quantities by means of climate physics analysis.

9. There is an almost linear correlation between the total amount of cumulative all-time anthropogenic emissions of the most important greenhouse gas (CO_2) and the global temperature increase (see Fig. 2-1). A proportion of about 24 % of all anthropogenic emissions is absorbed by the oceans and about 30 % by the terrestrial biosphere (LE QUÉRÉ et al. 2018, p. 2160). The rest remains in the atmosphere for a long time, where it has a proportional effect on the mean temperature of the Earth in the medium term. This fact can be deduced, in terms of climate physics, from the relationship between atmospheric CO_2 content, atmospheric radiation balance, and the temperature, as well as from the results of numerical simulations with climate models and investigations into the course of the Earth's history. In principle, these measures are all convertible into each other, but the strength of the correlation between cumulative emissions and warming is subject to uncertainties due to the complexity of the climate system (see Fig. 2-1; ALLEN et al. 2009). Although these uncertainties have persisted unchanged since the 1970s, research has succeeded in defining in relatively precise numerical terms the measure known as climate sensitivity, i.e. the change in mean global temperature that results from a doubling of atmospheric CO_2 concentration. Defining temperature targets that are linked to the effects of climate change is therefore subject to remaining uncertainties when those targets are converted into the corresponding emissions quantities.

Box 2-1: The CO_2 budget: Definition and exclusions

Based on the current state of research, this chapter shows the maximum total amount of CO_2 that can still be emitted worldwide over the coming decades if the targets of the Paris Agreement for limiting global warming are to be met. In a second step, plausible national and European CO_2 budgets and thus corresponding emissions caps are derived from this global CO_2 budget. These calculations apply to the most important greenhouse gas, CO_2, although other anthropogenic greenhouse gases (such as methane) and aerosols also contribute to climate change (IPCC 2013). There are several reasons for this restriction. CO_2 emissions build up cumulatively in the atmosphere over long periods of time, which makes a time-spanning budget approach suitable for setting maximum total emissions. Other greenhouse gases and aerosols are often more short-lived and therefore cannot be assessed in their effect on the climate over long periods of time as a steadily accumulating total quantity, like CO_2.

This is why the Intergovernmental Panel on Climate Change (IPCC) also reports global emissions budgets as pure CO_2 budgets in its Special Report on Global Warming of 1.5° C (IPCC 2018b). The budget calculations performed in section 2.2.4 are also based on these figures. For Germany, CO_2 emissions currently represent about 88 % and thus account for the largest share of total greenhouse gas emissions ("Treibhausgasemissionen gingen 2019 um 6,3 Prozent zurück. Große Minderungen im Energiesektor, Anstieg im Gebäudesektor und Verkehr ", Joint press release of UBA and BMU, 16 March 2020). One disadvantage of this approach is that some sectors – especially agriculture – primarily emit other gases. Their contribution to climate protection cannot therefore be properly assessed using a CO_2 budget - this requires additional analysis. For shorter periods of time (e.g. a few years), the effect of other greenhouse gases can be mathematically translated into CO_2 equivalent (CO_2eq), i.e. into the amount of CO_2 which would have the same effect on the climate. In such cases it is possible to speak of a greenhouse gas budget.

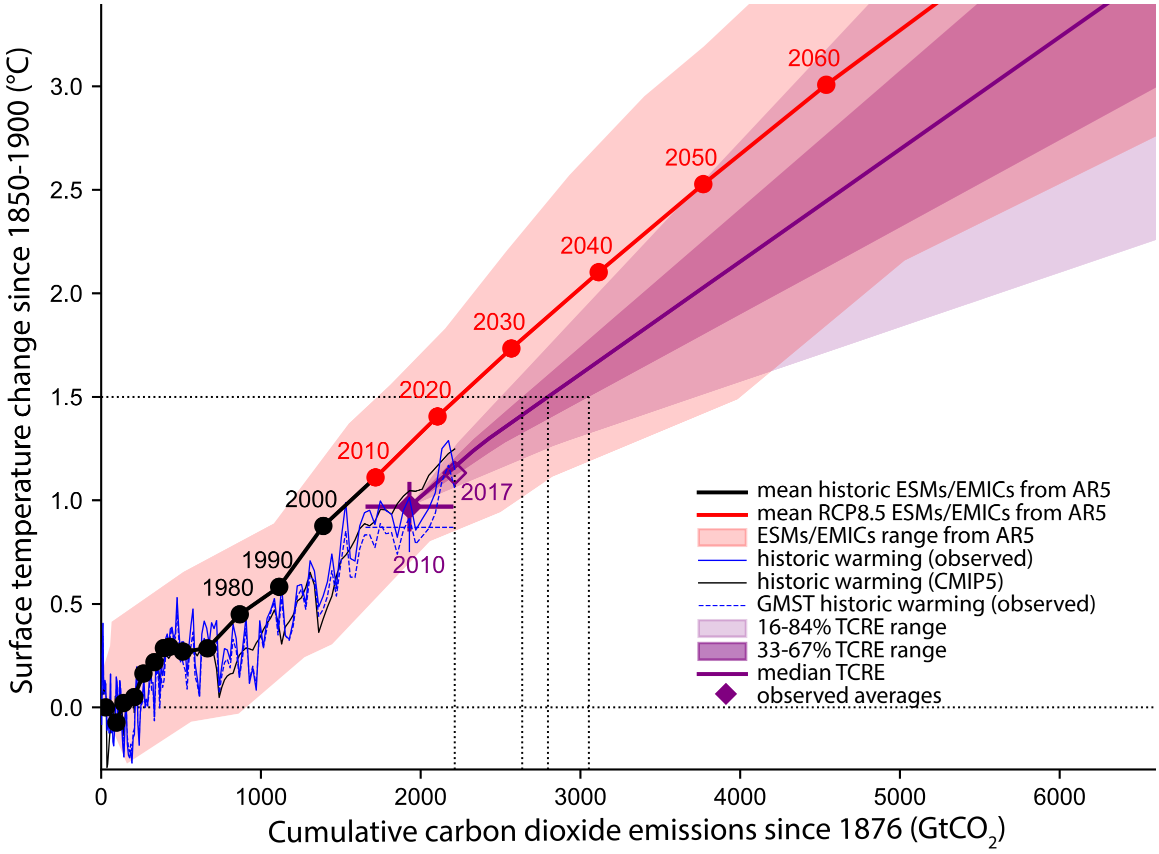
The CO_2 budgets discussed here are derived from temperature targets on the basis of climate science analysis. However, this should not be confused with politically set CO_2 and greenhouse gas budgets, which represent climate targets or are restricted by the issuing of emissions allowances. One example of this is the European Union Emissions Trading System (EU ETS), which defines annual budgets for several greenhouse gases in specific sectors and enables the trading of emissions allowances. The Effort Sharing Decision (Decision No. 406/2009/EC) and the Effort Sharing Regulation (EU) 2018/842 show annual national budgets in CO_2eq for sectors not covered by the EU ETS (item 88; UBA 2019c). In the past, German climate policy was primarily based on reduction targets for a specific year. With the Federal Climate Change Act, annual greenhouse gas budgets compatible with the European Effort Sharing Regulation were made binding for the first time and distributed among the various sectors for the period up to 2030 (item 97). The difference between a politically defined CO_2 budget and one defined by climate science – where there is one - can be described as an ambition gap. Where there is a difference between an intended budget and the real resulting budget, this can be termed an implementation gap (see Box 2-3).

Overall, climate budgets – understood as an overarching term for various budget approaches – are increasingly being used as indicators to guide political decision-making. This is a positive development, as it makes climate protection efforts more transparent and comparable. Often, however, the budget levels set are not ambitious enough to comply with the budget derived by scientific analysis from the objectives of the Paris Agreement.

10. By contrast, the atmospheric concentration of greenhouse gases, which can be converted either into emissions quantities or into temperature changes, can be measured very precisely. It is therefore, together with radiative forcing, with which it is linked, a key scientific parameter, particularly for the calculations of the IPCC (IPCC 2018b; STEFFEN et al. 2015). However, the atmospheric concentration of greenhouse gases is not only influenced by human emissions, but also by feedback effects in the Earth system that influence how greenhouse gases are absorbed and released by the atmosphere. Radiative forcing is a measure of the change in the energy balance of the Earth system in response to an external disturbance, with a positive radiative forcing leading to warming and a negative radiative forcing leading to cooling (SOLOMON et al. 2007, p. 21). An example of such a disturbance is an increase in the concentration of atmospheric greenhouse gases.

Figure 2-1

Correlation between CO_2 emissions and temperature change



The X-axis shows cumulative CO_2 emissions in Gt CO_2 since 1876, the Y-axis shows the change in near-surface air temperature (°C) since 1850 – 1900. The black line shows the warming calculated by Earth system models based on historical emissions. The red line shows the projected warming based on a business-as-usual scenario. Both projections are taken from the Fifth Assessment Report of the IPCC (AR5).

Source: IPCC 2018b, chap. 2, p. 105

From a climate policy perspective, the absolute maximum amount of greenhouse gases that can still be emitted is an appropriate parameter for assessing progress in reductions because it is based on the underlying cause (IPCC 2013; ROCKSTRÖM et al. 2017; WBGU 2009). When it is compared with the emissions in a base year or period, percentage reduction targets can be calculated.

The Paris-compatible CO_2 budget as the basis for climate policy

11. The CO_2 budget approach is based on this correlation in climate physics between cumulative CO_2 emissions and temperature increase. Since there is a linear correlation, the available CO_2 budget that will allow a temperature target to be met can be calculated and stated together with the probability of meeting the target. It can thus provide a sufficiently robust metric while allowing for the uncertainties.

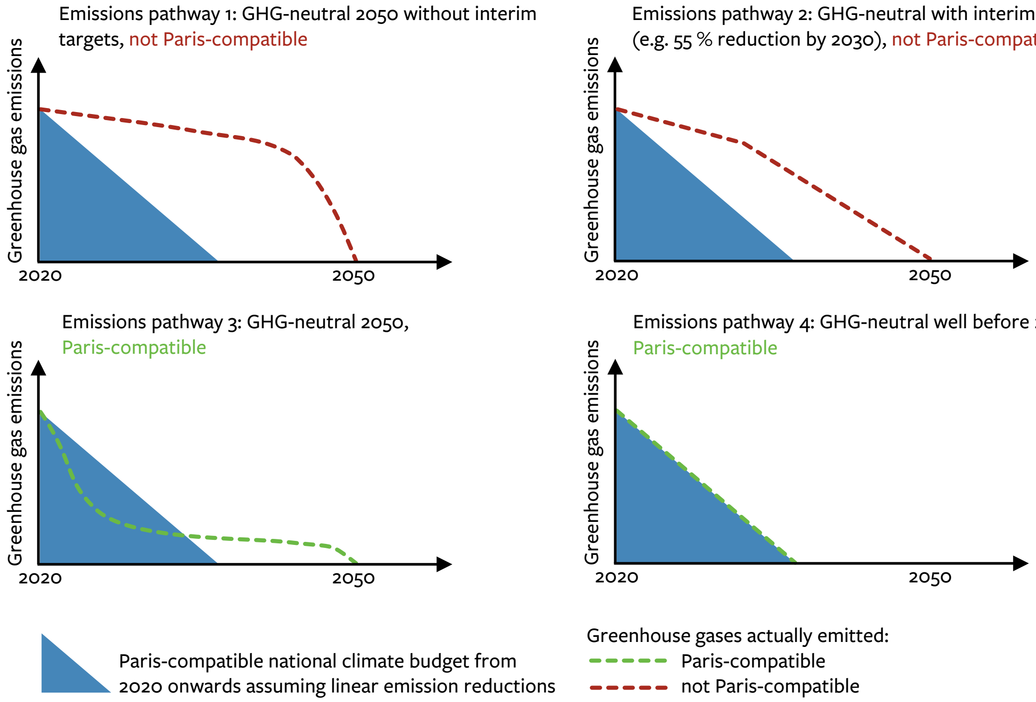
12. Greenhouse gas budgets play an increasingly important role in the formulation and operationalisation of national and European climate targets (see Box 2-1). In addition, there are percentage reduction targets for annual greenhouse gas emissions compared with a base year (e.g. 1990). At the European level, the implementation of the target of greenhouse gas neutrality by the year 2050 is currently being discussed within the framework of the European Green Deal.

Percentage reduction targets are derived from previous annual emissions levels. Like target years for greenhouse gas neutrality, however, they do not take into account the accumulated amount of future annual emissions, even if these are successively reduced. Without corresponding interim targets, these governance approaches cannot enable a proper assessment of the national or European contribution to meeting the Paris climate targets. A thought experiment can make this clear: If Germany, for example, were to begin the process of reducing greenhouse gases to zero by 2050 only in 2045, the total amount of greenhouse gases emitted would be significantly higher than the greenhouse gas budget to which Germany is entitled (Fig. 2-2, emissions pathway 1; for the German CO_2 budget, see item 33). Even a step-by-step reduction in greenhouse gas emissions would not necessarily lead to budget compliance (Fig. 2-2, emissions pathway 2). For a Paris-compatible reduction of greenhouse gas emissions within the time available (Fig. 2-2, emissions pathways 3 and 4), it is not only the date by which greenhouse gas neutrality is achieved that is decisive, but also the total amount of greenhouse gases emitted by all sectors over the corresponding period. Sector and year-specific greenhouse gas budgets, as laid down in the Federal Climate Change Act, are therefore to be welcomed in principle. However, in order to be able to assess whether the resulting emissions reduction pathways to greenhouse gas neutrality make an appropriate contribution to the Paris Agreement, a comparison with a Paris-compatible CO_2 budget based on climate physics is required.

13. In summary, European, national and regional climate policy targets should be chosen so that they are clearly aligned with the global temperature target. Against this background, the SRU recommends reviewing the targets on the basis of the Paris-compatible CO_2 budget. It can be used as a basis for climate policy at various levels (Fig. 2-3). The global CO_2 budget is based on climate physics, as the effect of emissions on global warming is known. It can be linked to existing policy instruments such as the EU ETS and the greenhouse gas budgets under the EU Effort Sharing Regulation (item 88) and the German Federal Climate Change Act (item 97) and can be scaled to any level (e.g. sectors, companies, private individuals). In addition, it is pos-

Figure 2-2

Emissions pathways for Germany compatible with the Paris climate targets (schematic)



Emissions pathway 1: GHG-neutral 2050 without interim targets, not Paris-compatible

Emissions pathway 2: GHG-neutral with interim targets (e.g. 55 % reduction by 2030), not Paris-compatible

Emissions pathway 3: GHG-neutral 2050, Paris-compatible

Emissions pathway 4: GHG-neutral well before 2050, Paris-compatible

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sible to establish reduction pathways for total emissions specified by year which cumulatively correspond to a national CO_2 budget that is compliant with the Paris climate targets. It should be noted here that the European and national CO_2 budget as well as the sectoral budgets are derived from the global CO_2 budget on the basis of normative considerations regarding fair international burden sharing and an acceptable risk of exceeding the target (sec. 2.2.2).

2.2.2 Factors in the calculation of the CO_2 budget

14. In order to determine the global Paris-compatible CO_2 budget, various methodological and normative assumptions have to be made. Complex influencing factors also play a role. To enable a better understanding, this section will provide an overview of the factors which influence the calculation and the size of the budget and which can therefore result in different budget figures (see also ROGELJ et al. 2019).

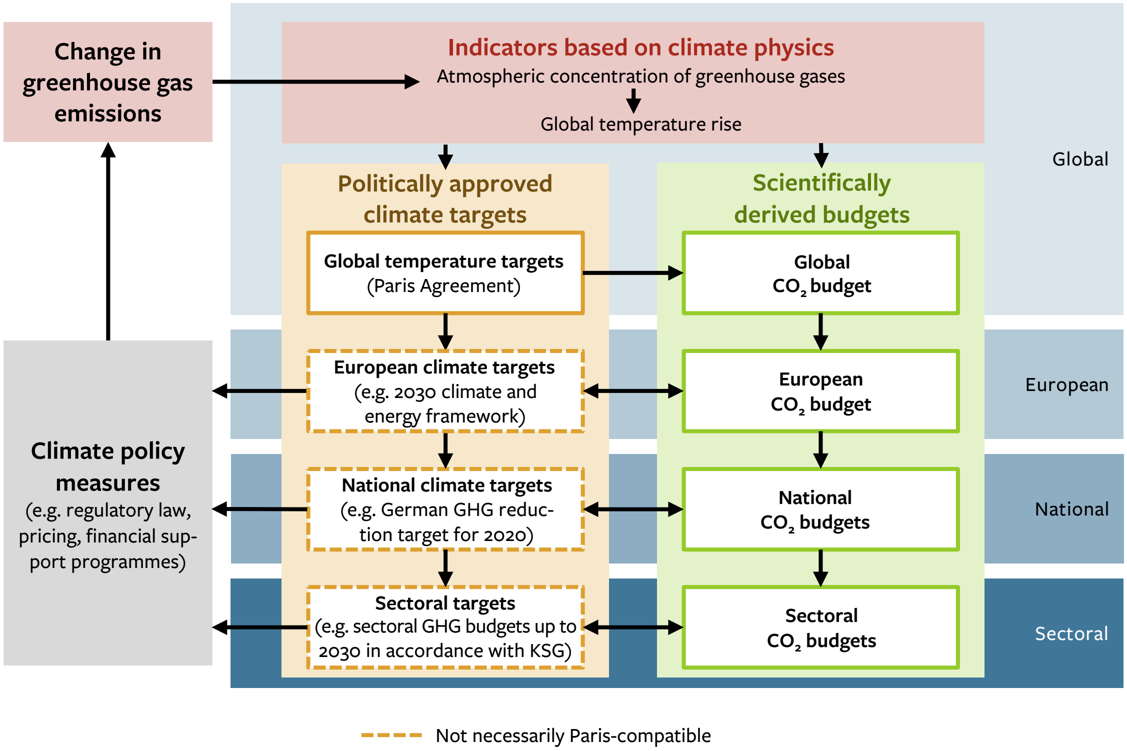
Defining the CO_2 budget

15. *Start of the period:* CO_2 budgets are based on fixed starting points, for example the pre-industrial period, or a specific year (item 29). The chosen points in time are not the same in all relevant reports, which makes it difficult to compare the resulting budget figures directly and leads to apparently different budget figures (ROGELJ et al. 2019). Furthermore, a distinction must be made between the remaining CO_2 budget from a defined point in time and the currently remaining residual budget.

Meeting or temporarily exceeding the climate target: Budget approaches differ with regard to whether the budget value is determined in a business-as-usual scenario for the time point at which the maximum permitted temperature rise is exceeded ("Threshold Exceedance Budgets") or whether it is derived from a pathway on which the target temperature is just reached but never exceeded ("Threshold Avoidance Budgets", see ROGELJ et al. 2016b, p. 247; PETERS 2016). Threshold exceedance budgets also include scenarios in which the temperature target is temporarily exceeded before the temperature

Figure 2-3

The CO_2 budget as the basis for existing climate targets on different levels



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drops slightly again and stabilises (RAHMSTORF 2017, p. 378 et seq.; ROGELJ et al. 2016b, p. 247). In general, budgets that allow the climate target to be temporarily exceeded are larger than those that avoid doing so.

Uncertainties and differences in the calculation of the CO_2 budget

16. *Methodological differences between the assessment models:* The models used to calculate CO_2 budgets differ in terms of underlying modelling approaches and level of detail and may lead to different budget estimations (ROGELJ et al. 2016b, p. 248). There are essentially two very different types of model to be found in the literature:

- Earth system models simulate physical and biogeochemical interactions between the atmosphere, the land surfaces of the Earth and the oceans, and the mean warming values resulting from given emissions pathways. In particular, they simulate the Earth's carbon cycle and take into account various Earth system feedback effects that influence the temperature increase caused by emissions.

- Integrated Assessment Models (IAMs) are computer models used in energy and technology economics to calculate cost-effective paths for meeting climate targets and the associated emissions reduction pathways. For this purpose, the economic models are coupled with simplified climate models, which usually have no spatial resolution, but adequately reflect the warming of the earth resulting from greenhouse gas emissions. The models are macro-economically differentiated into a number of world regions and can include individual geophysical boundary conditions in their evaluation.

In addition, data on the observed course of global warming and some other relevant Earth system parameters can also be used instead of or in addition to modelled values. In this way, the future development trends predicted by models can be narrowed down more precisely. However, since observed data also regularly exhibit uncertainties, these also have an effect on the quantification of the budget (ROGELJ et al. 2019). In particular, observed data are often not sufficiently comprehensive, or are not available for a sufficiently long period of time, to decisively reduce these uncertainties. For this reason, the inclusion of observed data does not necessarily provide better results than the analytical logic of numerical process models. Reliable budgets result from a synopsis of all findings, such as is undertaken, for example, by the IPCC in its Assessment Reports and Special Reports.

The climate cooling effect of aerosols: Aerosols are suspended particles, such as mineral dust, soot particles, sea salt or organic particles, found in different strata of the atmosphere, where they have an effect on the climate. Some of them have a warming effect on the temperature (especially soot particles), but overall they have a predominantly cooling effect (especially sulphur oxides). Aerosols emitted by humans already compensate for a proportion of global warming (RAMANATHAN and FENG 2008). Future global warming therefore also depends on future developments with regard to anthropogenic aerosol emissions. Determining the precise effect of aerosols is beset by scientific uncertainties, as is their future development, especially since it is not easy to estimate the total global volume of aerosols. These factors also contribute to uncertainties in the determination of the budget (MYHRE et al. 2017, p. 2710 et seqq.).

Feedbacks of the Earth system: Changes in the climate result in Earth system feedbacks which can increase or moderate the temperature change. One example is cloud formation; another is the carbon cycle, in which carbon is exchanged among the atmosphere, the oceans and the terrestrial biosphere, and in which the natural processes are disrupted by the burning of fossil fuels and by land use (LE QUÉRÉ et al. 2018). Since Earth system feedbacks interact with each other and involve some complex, spatially differentiated processes, it is only possible to estimate their effects on temperature change with some degree of uncertainty (IPCC 2018b, pp. 2–16). Thus, the latest IPCC Special Report on Global Warming of 1.5 °C (SR1.5) provides figures for the carbon budget for a given temperature increase. However, the report notes that Earth system feedbacks, especially from alterations to the properties of the permafrost at northern latitudes, could further reduce the actual size of the budget by about 100 Gt CO_2 (IPCC 2018b, Table 2.2).

The inclusion of hypothetical future CO_2 extraction from the atmosphere (so-called negative emissions): The size of the global CO_2 budget also depends on assumptions about the future role of so-called negative emissions technologies and practices (PETERS 2018a). Most emissions reduction pathways for meeting the climate targets foresee a large role for them (see sec. 2.3.3). Most options for negative emissions, however, are currently subject to considerable uncertainty and, for the most part, involve significant trade-offs, for example with food production and nature and biodiversity conservation, or entail significant financial or energy costs. Also, effective options are not operationally available yet (FUSS et al. 2018). For these reasons, the use of negative emissions technologies to expand the CO_2 budget plays only a minor role in this report.

Normative decisions on the level of ambition and the likelihood of meeting targets

17. *The likelihood of meeting targets and the selection of temperature targets:* The derivation of atmospheric CO_2 concentrations and of resulting global temperature changes from the CO_2 emissions emitted since a given base year is subject to uncertainties (item 9). Scientific practice therefore involves both working with mean values and identifying corridors for the remaining budget. Depending on how important it is for the target to be met, larger or smaller values must be assumed for climate sensitivity, i.e. the reaction of the climate system to changes in atmospheric greenhouse gas concentrations. This corresponds to a greater or lesser probability of meeting the target if the budget is adhered to. This is why compliance with a given maximum temperature rise is calculated and presented on the basis of probabilities. The IPCC considers probabilities of 33 %, 50 % and 67 % for temperature increases of 1.5 °C and 2 °C, respectively, for each of which a budget can be calculated, so that the combination of these targets alone results in six possible calculations (IPCC 2018b). The probability chosen for meeting a given temperature target is a normative decision. Meeting the 1.5-degree-target is usually calculated with a probability of 50 %, the 2-degree-target with a probability of 67 %, i.e. two-thirds. In both cases, there is still a considerable risk that the temperature target will be exceeded despite adherence to the budget. In the section below, CO_2 budgets are presented with a high probability of meeting the selected temperature target. This also corresponds to the constitutionally prescribed precautionary principle (SRU 2019).

18. Due to these factors, the CO_2 budget totals as calculated may vary. The scientific literature therefore shows budget ranges that reflect these influencing factors and uncertainties. For political decision-makers and for the public debate, however, a single figure is often communicated as an orientation or guideline. If this figure is used as a basis for further decision-making processes, it must always be borne in mind that the actual budget may differ because of the uncertainties. Also, new scientific insights over time can lead to adjustments to the budget figures, even if there is unlikely to be a radical revision of the existing state of knowledge. Since the remaining residual budget decreases as time passes, but the uncertainties remain the same in absolute terms, the relative impact of the uncertainties increases (PETERS 2018b; SCHLEUSSNER et al. 2018, p. 1).

2.2.3 Size of the global CO_2 budget

19. The first estimate of the global CO_2 budget to be the subject of widespread discussion was presented in 2009 in the year of the 15th Conference of the Parties (COP 15) to the UNFCCC in Copenhagen (ALLEN et al. 2009), and in the same year was also endorsed in Germany by the German Advisory Council on Global Change (WBGU 2009). The IPCC Fifth Assessment Report updated the figures in 2013 (IPCC 2013).

20. The most up-to-date calculations, in the IPCC Special Report SR1.5 of 2018, estimate a slightly larger budget in comparison (IPCC 2018b). The global CO_2 budget from the year 2018 onwards for limiting global warming to 1.5 °C is put at 580 Gt CO_2 for a 50 % probability of reaching the target and 420 Gt CO_2 for a 67 % probability of reaching the target (Table 2-1). If the temperature rise is to remain well below 2 °C with a 67 % probability (here interpreted mathematically as 1.75 °C, or halfway between 1.5 °C and 2 °C), the global budget is 800 Gt CO_2 from 2018 onwards. If the current emissions rate of around 42 Gt CO_2 per year remains unchanged, this CO_2 budget would be exhausted in 2037.

21. The increased CO_2 budgets in the IPCC Special Report on Global Warming of 1.5 °C are based on an assessment that has been modified in several respects and in some parts also expanded. In particular, observed data on the real course of global warming are now included in the evaluation in addition to the results of climate modelling. In the Fifth Assessment Report, the climate models showed a linear rise in temperature as a function of cumulative emissions, but this was higher than the observed temperature development. The Special Report therefore takes the observed temperature trend over the period 2005 to 2016 as its starting point. It is still unclear how the real temperature trend is to be incorporated into the longer-term projection, which means that the size of the remaining CO_2 budget for meeting the Paris climate targets remains the subject of scientific discussion and could be subject to further updates in the medium term (ROGELJ et al. 2019; FUJIMORI et al. 2019). However, this makes comparatively little difference to the basic findings on the scale of the CO_2 budget for meeting the Paris climate targets.

22. The size of the global CO_2 budget depends largely on the temperature target used as a starting point (item 17; Tab. 2-1). The Paris Agreement altered the earlier target of "below 2 °C" (SCHLEUSSNER et al. 2016). In Art. 2 sec. 1 lit. a of the Agreement, the parties commit themselves to limiting the rise in the global average temperature to "well below 2 °C" compared to pre-industrial levels and to pursuing efforts to limit warming to 1.5 °C. Art. 4 sec. 1 stipulates that the parties to the Agreement will aim to reach global peaking of greenhouse gas emissions as soon as possible, and to undertake rapid reductions thereafter. This is to be done in accordance with the best available scientific evidence, which suggests the use of CO_2 budgets. In the second half of the century there should be a balance between anthropogenic greenhouse gas emissions and sinks, i.e. greenhouse gas neutrality should be achieved.

The upper temperature limit that results from these specifications is not entirely clear. The formulation of the Paris Agreement as described above leads some to conclude that the 1.5-degree-target is legally binding (EKARDT 2018). In view of the wording, however, which explicitly sets a limit of well below 2 °C and (only) calls for efforts to achieve a limit of 1.5 °C, the prevailing view is that the obligations on the Parties are tiered (BODANSKY 2016; RAJAMANI and WERKSMAN 2018). Due to its vagueness, the wording of Art. 2 sec. 1 lit. a of the Paris Agreement is open to both interpretations: The 1.5-degree-target can be regarded either as an upper limit which is not to be exceeded under any circumstances, or as a long-term target to be aspired to following a temporarily permissible higher level of warming (which, however, must remain well below 2 °C) (MACE 2016). In any event, the wording makes it clear that efforts must be made to limit global warming to 1.5 °C. Furthermore, the principle of "common but differentiated responsibilities" as set out in Article 2 sec. 2 of the Paris Agreement suggests that the industrialised countries are expected to make particular efforts to limit global warming in view of the fact that they are largely responsible for it. Art. 4 sec. 1 points in a similar direction in that it recognises that developing countries still need time to reach their maximum emissions. The industrialised countries, on the other hand, should reduce their emissions without delay (Art. 4 sec. 4).

The IPCC Special Report on Global Warming of 1.5 °C provides the scientific explanation for why expected climate impacts and thus also the necessary adaptation requirements are significantly lower for global warming of 1.5 °C compared to 2 °C. It is projected that the risk of regional extreme weather events, a rise in sea levels, the occurrence of tipping points in the Earth system, risks to ecosystems, health, food security, water supply, security and economic growth will be significantly reduced if global warming is limited to 1.5 °C (IPCC 2018a). The 1.5-degree-target is also being increasingly highlighted by civil society, with the support of the scientific community (Fridays for Future 2019; HAGEDORN et al. 2019).

Considering all these arguments together leads to the following conclusion with regard to the choice of the temperature target to be used as the basis for the budget calculation. The target of "well below 2 °C", or 1.75 °C for example, must be achieved. Even if emissions pathways are followed which are likely to ensure a maximum

Table 2-1

Global CO_2 budgets as shown in the IPCC Special Report

Global warming in °C	Remaining CO_2 budget (excluding additional Earth system feedbacks) in Gt CO_2 from 01.01.2018	
	50 % probability of meeting target	67 % probability of meeting target
1.5	580	420
1.75	1,040	800

SRU 2020; data source: IPCC 2018b, Tab. 2.2

global warming of 1.75 °C by 2050, the obligation to make efforts to limit the temperature increase to a maximum of 1.5 °C remains. The 1.5-degree-target can therefore be understood as the long-term goal of the Paris Agreement (SCHLEUSSNER et al. 2016). It follows that emissions pathways that meet this target should be pursued immediately. Otherwise, there will be a temporary overshoot of the target, which can only be offset by temperature reduction measures. Both the emissions pathways to reach the 1.5-degree-target and the long-term reduction of global temperature will require large-scale negative emissions technologies and practices that are not yet available (see sec. 2.3.3).

23. All in all, there is no scientific dispute about the fact that the remaining residual budget is small and that there is only a short period of time remaining to reduce emissions worldwide to a net zero level and thus to achieve greenhouse gas neutrality (IPCC 2018b; ROCKSTRÖM et al. 2017). The pressure to act is correspondingly great. The uncertainties remaining are no justification for political inactivity (UNEP 1992, p. 3; HILLERBRAND 2009, p. 95). In view of the consequences of climate change, and taking into account the remaining uncertainties, a budget must be determined that complies with the precautionary principle and serves as a basis for political decisions, and also enables progress in climate policy to be assessed.

24. In summary, a residual global CO_2 budget, one which is based on limiting the temperature increase to a maximum of 1.5 °C, can be readily justified. For a 50 % probability of meeting the target, this amounts to 580 Gt CO_2 from 2018 onwards (item 20). For limiting global warming to 1.75 °C, with a 67 % probability of reaching the target, it amounts to 800 Gt CO_2 from 2018. This can be calculated as the maximum budget from the specifications contained in the Paris Agreement. If emissions are not reduced and 42 Gt CO_2 continue to be emitted annually, a CO_2 budget of 716 Gt CO_2 remains from the year 2020.

2.2.4 The CO_2 budget for Europe, Germany and national sectors

25. In order to calculate a national share of the available global total budget, fair and appropriate comparative international criteria for national shares must be defined.

2.2.4.1 The calculation of national CO_2 budgets for fair emissions reductions

26. The Paris Agreement requires each country to submit an NDC embracing equity and the principle of common but differentiated responsibilities and respective capabilities (Art. 2 sec. 2). At least five different interpretations can be used as a basis for the calculation of national budgets (ROBIOU DU PONT et al. 2016; IPCC 2014, p. 458; HÖHNE et al. 2014). Each leads to a significantly different result in terms of the national CO_2 budget. A national budget can be derived from the global budget on the following bases:

- Equal per capita: emissions are reduced according to the current or projected population of a country on the basis of equal remaining per capita emission rights.
- Capability: countries with higher per capita economic capacity must reduce emissions faster than those with lower economic capacity.
- Equal cumulative per capita: in addition to population size, the cumulative historical emissions of the country are included in the calculation to reflect a continuous right over time to use the atmosphere for CO_2 disposal.
- Greenhouse development rights: in order to ensure fossil-based development opportunities within the remaining global budget for countries with a hitherto lower level of development and prosperity, those countries with a high gross domestic product (GDP), high historical emissions and, under a business-as-usual scenario, continuing high emissions must reduce emissions more sharply.
- Constant emissions ratio: the current proportional distribution of greenhouse gases between countries remains constant during emissions reduction ("grandfathering"). This means that states with high emissions may continue to emit more than states with lower emissions, regardless of population size or GDP.

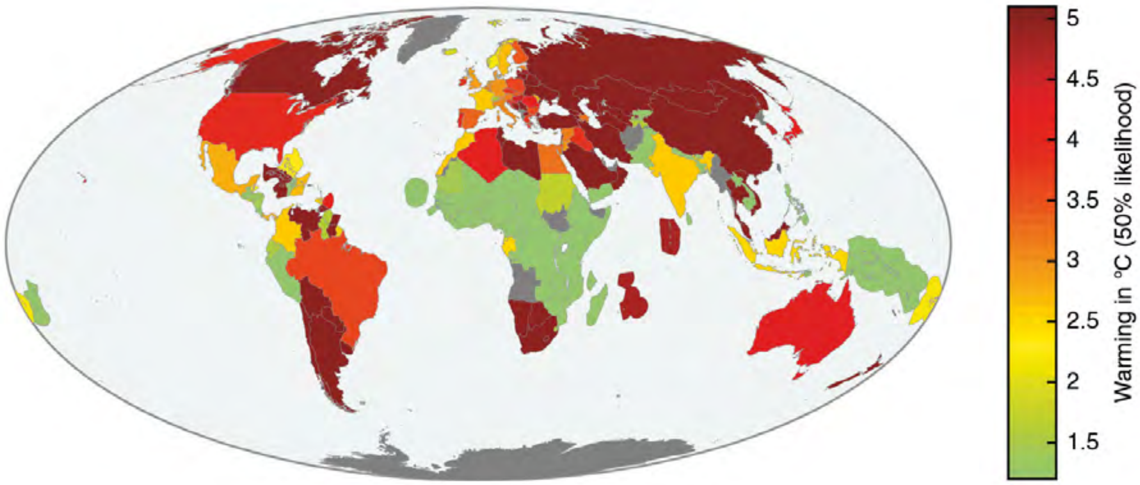
If, for example, the global CO_2 budget is distributed proportionally on the basis of 2014 emission levels, and without taking account of historical emissions, Europe would be entitled to 11 %, whereas an equal per capita distribution would result in a share of only 6 % (RAUPACH et al. 2014).

In fact, in the course of the implementation of the Paris Agreement, these differing interpretations meant that many states were able to submit an NDC that they considered least stringent for themselves (ROBIOU DU PONT and MEINSHAUSEN 2018). For example, following the logic of a constant emissions ratio, many industrialised countries, and also the EU, submitted their climate policy goals as proportional emissions reduction targets, with only a moderate level of ambition. However, if all countries were to follow the example of the EU and apply the interpretation that is most advantageous to themselves, and thus most generous, this would lead (if they use the interpretation model of the EU) to global warming of 3.2 °C (or, if the interpretation chosen by India were adopted internationally, 2.6 °C; by the USA, 4 °C; by China, 5.1 °C) (see Fig. 2-4; ROBIOU DU PONT and MEINSHAUSEN 2018). Nevertheless, each individual country will argue in each case that their national contribution to meeting the climate targets is appropriate and sufficient.

27. The reduction commitments formulated in the NDCs are currently insufficient to enable their effect on global warming to be quantified, as most NDCs are only formulated up to 2025 or 2030. Subsequently, a new and more ambitious target is to be set every five years under the Ratcheting up Mechanism of the Paris Agreement. In order to quantify the impact of current and future national reduction targets, emissions pathways must be estimated beyond 2030, as the degree of global warming depends on cumulative emissions up to the middle or end of the century or beyond (ALLEN et al. 2009). There are various ways of calculating cumulative emissions pathways that go beyond 2030 and thus making progress in the national reduction commitments visible (JEFFERY et al. 2018). In addition to modelling, for example using IAMs (item 16), the CO_2 budget approach is suitable for evaluating NDCs. If national shares of the global CO_2 budget are derived for each state, the NDCs can be measured by whether they are in line with these Paris-compatible national CO_2 budgets. A national contribution that is insufficient when measured against the overall global budget is objectively and ethically deficient in view of the binding commitment of each state to the Paris climate goals under international law. Moreover, the sum of all national budgets must be in line with the global CO_2 budget.

Figure 2-4

Global warming as a result of national interpretations of equity



The map shows global warming if all states were to follow the equity concept and ambition of a single state. Three interpretations of distributive justice are used, based on historical emissions, economic capability and equal per capita emission rights. Out of these three, each state is allocated the model that is most advantageous to it, and the map demonstrates the total global warming that would result if all other states were to adopt the same line of reasoning.

Source: ROBIOU DU PONT and MEINSHAUSEN 2018

2.2.4.2 The CO_2 budget for the EU and Germany from 2020 onwards

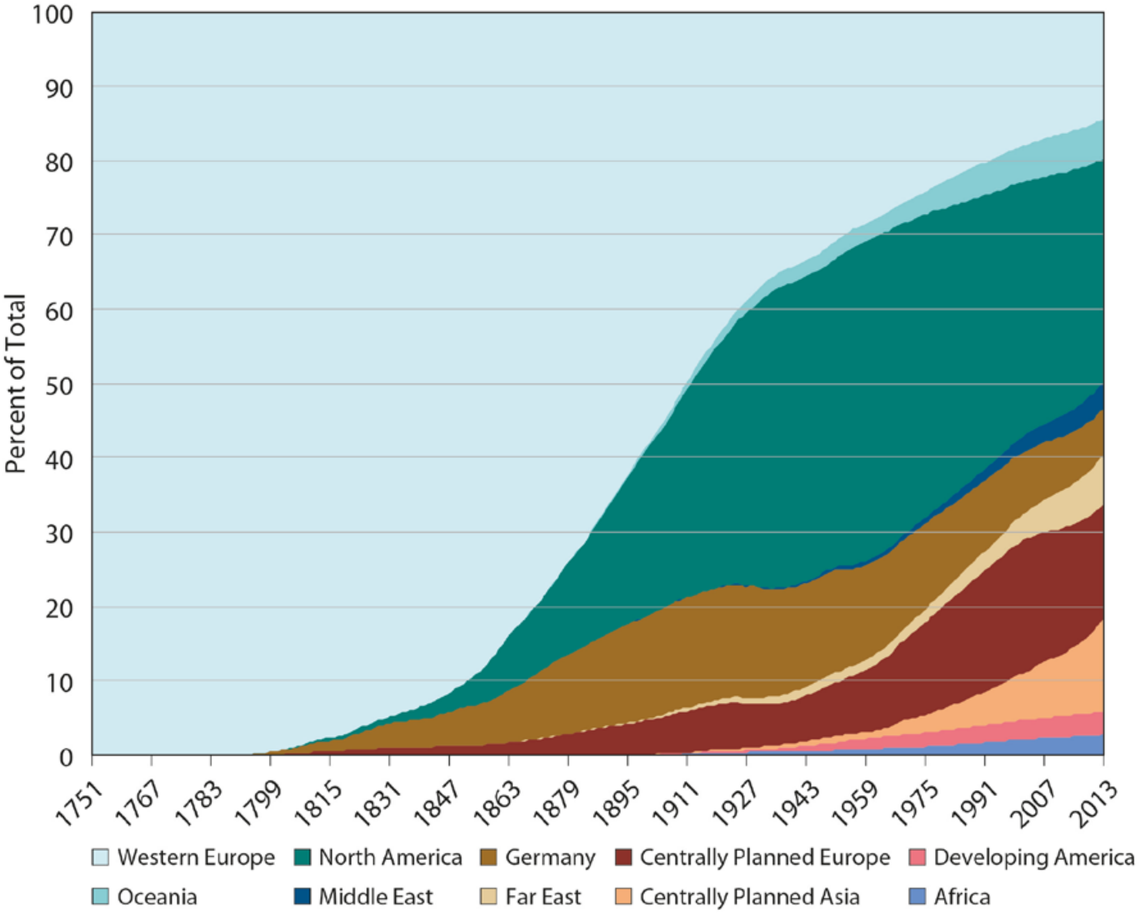
28. Both the EU and Germany have set reduction targets and measures to achieve their climate protection goals (chap. 2.4). In order to meet the obligations under the Paris Agreement and to make a fair contribution to the necessary emissions reductions, these reduction targets and measures must be consistent with the global CO_2 budget (sec. 2.2.3).

The role of historical emissions

29. Germany is responsible for a higher proportion of historical CO_2 emissions than, for example, the countries of Africa and Latin America combined (Fig. 2-5). The effects of climate change, on the other hand, are having and will have a severe impact on those regions of the world which, on the one hand, have contributed little to climate change and at the same time have only limited capacity to adapt to the consequences due to their relatively limited economic strength (World Bank 2013). As a technologically advanced industrialised country with a high GDP and high historical emissions, Germany should therefore be leading the way in transforming energy supply, achieving its national targets sooner rather than later and making an appropriate contribution to the Paris climate targets. This will give states with a lower capacity for transformation greater room for manoeuvre, and Germany, as a pioneer, will be able to demonstrate to other states the technological and economic possibilities for transition (SRU 2016b, chap. 1).

○ **Figure 2-5**

Cumulative historical CO_2 emissions from the fossil fuel burning, cement manufacture and gas flaring



Source: MARCOTULLIO et al. 2018, p. 141, based on BODEN et al. 2016

In the allocation of shares in the remaining CO_2 budget to individual states, or communities of states, the question of when the budget period begins is key (item 15). The beginning of the budget period could, for example, be the year 1990, when the first IPCC report provided the international community with the essential information on climate change. In that case, the CO_2 budgets available up to 2050 for the USA, Germany and Russia, for example, calculated on an equal per capita basis, would have been exhausted by 2009 already, even for a maximum global warming of 2 °C with a 75 % probability of meeting the target (WBGU 2009, p. 25; MEINSHAUSEN et al. 2009).

The role of imports and exports

30. Emissions are usually attributed to the country in which a product is manufactured, even if it is intended for export (territorial principle). This allows countries with a high export surplus to argue that they are at a disadvantage in emissions accounting. It is therefore useful to consider the impact of imports on emissions as well (consumption principle). For Germany, however, this impact is small: in 2015, approximately 506 Mt CO_2 were accounted for by imports and 579 Mt CO_2 by exports (Statistisches Bundesamt 2019, p. 6). This means that the two flows largely cancel each other out. It therefore makes sense to apply the territorial principle to Germany in the analysis which follows. For the EU-28, the impact is greater, but does not fundamentally change the situation either. CO_2 emissions measured according to the consumption principle are about one fifth higher than those measured according to the territorial principle (UNEP 2019a, p. 6, Fig. 2.4). For the sake of consistency, the territorial principle is also applied to the EU-28 in the following section.

Determining a Paris-compatible CO_2 budget for the EU and Germany from 2020 onwards

31. As described above, there are essentially five different interpretations of what an equitable emission reduction might look like and thus how the global budget could be allocated among states (item 26). In the past, the EU and Germany have made particularly large contributions to climate change (item 29). Among the industrialised countries, however, the position has largely established itself that historical emissions should not be taken into account in future climate protection efforts. In international discourse, however, the position is also recognised that, for reasons of distributive justice and in order to ensure development rights for developing and emerging countries, the industrialised countries should make a greater than average contribution to emissions reduction. For this reason, the approach taken by many industrialised countries of calculating their NDCs according to the logic of "grandfathering" (item 26) is strongly criticised by developing and emerging countries.

32. The following assumptions should underlie any credible and justifiable determination of a Paris-compatible CO_2 budget for the EU and Germany. If historical emissions and thus already accumulated "climate debts" towards states with lower per capita emissions are discounted in a manner that is to their own advantage, then the most ambitious budget possible should be adopted. Consequently, the probability of meeting the target should be set at 67 % instead of 50 %, and a target of 1.5 °C or a maximum of 1.75 °C should be set as the maximum warming level. A CO_2 budget based on these assumptions still implies a one-third probability that the target will not be met because the climate sensitivity of the Earth system may be greater than assumed. Furthermore, equal per capita emissions rights for every inhabitant of the Earth should be assumed; this would mean that the German share should be determined proportionally in relation to the world population on a given date. It should be noted that the share would actually decrease in future because the German population is shrinking while the world population overall is growing, which means that the budget would be smaller if aligned with demographic trends.

33. In addition, the date when the Paris Agreement was concluded is chosen here as the start point for the global budget calculation. For the sake of simplicity, the global CO_2 budget will be distributed among the states from January 2016, and the remaining budget for the EU and Germany from 2020 onwards will be derived on the basis of the assumptions described above (see Box 2-2). If historical emissions are discounted, and based on the German population as a proportion of the global population in 2016, the maximum Paris-compatible CO_2 budget for Germany is 6.7 Gt CO_2 from 2020. If 0.71 Gt CO_2 were to continue to be emitted annually, as in 2019, the available budget would already be used up in 2029. This CO_2 budget can be regarded as a well-founded Paris-compatible upper limit. For the reasons given below, the SRU recommends that an ambitious CO_2 budget should be used as a benchmark against which targets and measures for climate protection in Germany should be measured:

- Art. 4 sec. 3 of the Paris Agreement stipulates that the climate protection contributions to be submitted for each country should "reflect its highest possible ambition".

Box 2-2: Calculating a Paris-compatible CO_2 budget from 2020 onwards for the EU-28 and Germany

The maximum Paris-compatible CO_2 budget for the EU including the United Kingdom (hereinafter EU-28) is 47.2 Gt CO_2 from 2020, and for Germany 6.7 Gt CO_2. The starting point for the calculation is 2016 (reference date: Paris Agreement of the end of 2015). Historical emissions are discounted.

1st step:

- Global CO_2 budget from 2018 onwards for a 67 % probability of remaining well below 2 °C (1.75 °C): 800 Gt CO_2 (IPCC 2018b). This budget achieves the 1.5-degree-target with just over one-third probability, and a temperature rise of around 1.65 °C with 50 % probability.

2nd step:

- Global CO_2 budget from 2016 calculated by adding the CO_2 emissions for 2016 and 2017, which each amounted to 41 Gt CO_2 (FRIEDLINGSTEIN et al. 2019): 800 Gt CO_2 + (2 × 41 Gt CO_2) = 882 Gt CO_2.

3rd step:

- Paris-compatible CO_2 budget calculated for the EU-28 based on a current proportion of 7 % of the world population (Eurostat 2018): 882 Gt CO_2 × 0.07 = 61.7 Gt CO_2 (from 2016).

- Paris-compatible German CO_2 budget calculated on the basis of a current proportion of 1.1 % of the world population: 882 Gt CO_2 × 0.011 = 9.7 Gt CO_2 (from 2016).

4th step:

- Calculation of the CO_2 budget for the EU-28 from 2020 onwards: in 2016, 3.6 Gt CO_2 were emitted in the EU, and in 2017, 3.7 Gt CO_2 (EEA 2019a). For 2018 and 2019 the same emissions level as 2017 is assumed.

- CO_2 budget for the EU-28 for 1.75 °C (67 %): 61.7 Gt CO_2 – (3.6 Gt CO_2 + 3*3.7 Gt CO_2) = 47.0 Gt CO_2 from 2020 onwards.

    - If emissions remain at the same level, the CO_2 budget for the EU-28 would thus be used up during 2032 (47.0 Gt CO_2/3.7 Gt CO_2 = 12.7 years from 2020). With linear annual reductions in emissions, this budget would be used up in 2045.

The analogous calculation for a 50 % probability of reaching the 1.5-degree-target gives a CO_2 budget for the EU-28 of 31.6 Gt CO_2 from 2020, which would be used up in 2028 assuming constant emissions, and in 2037 assuming a linear reduction in emissions.

- Calculation of the German CO_2 budget from 2020: Germany emitted 801 Mt CO_2 in 2016, 787 Mt CO_2 in 2017, 755 Mt CO_2 in 2018 (UBA 2020) and probably 706 Mt CO_2 in 2019 ("Treibhausgasemissionen gingen 2019 um 6,3 Prozent zurück. Große Minderungen im Energiesektor, Anstieg im Gebäudesektor und Verkehr", Joint press release of UBA and BMU, 16 March 2020). Total emissions from 2016 to 2019 amount to 3049 Mt CO_2.

- CO_2 budget for Germany for 1.75 °C (67 %): 9.7 Gt CO_2 – 3.0 Gt CO_2 = 6.7 Gt CO_2 from 2020.

- If the emissions level remains constant, the German CO_2 budget as calculated would be used up in 2029; assuming linear reductions, in 2038.

The analogous calculation for a 50 % probability of reaching the 1.5-degree-target gives a CO_2 budget for Germany of 4.2 Gt CO_2 from 2020. If emissions remain constant, this would be used up in 2026 already; assuming linear reductions, in 2032.

Further clarifications

One gigatonne (Gt) of CO_2 corresponds to 1 billion t CO_2, one megatonne (Mt) to 1 million t CO_2. Globally, about 42 Gt CO_2 are currently emitted per year. Germany emitted 755 Mt CO_2 in 2018, which corresponds to annual emissions of 9.1 t CO_2 per capita (UBA 2020). If other greenhouse gases such as methane and nitrous oxide are also taken into account, 858 Mt of so-called CO_2 equivalent (CO_2eq) were emitted in Germany in 2018 (UBA 2020).

These figures do not take into account Europe and Germany's share of international air and sea transport. If these were included, annual emissions would be higher and the CO_2 budget would be used up earlier.

- In view of the severe consequences of climate change, it is also necessary to apply the precautionary principle. It is essential that a safety margin is maintained in order to avoid an increased risk of radical changes to the Earth system (SRU 2019).

Independently of this, the Paris Agreement gives rise to an ongoing obligation to make efforts to comply with the temperature limit of 1.5 °C. The earlier emissions are reduced, the more likely it is that the national contribution to limiting global warming to well below 2 °C will still be sufficient. Moreover, an earlier reduction in emissions also enables longer restructuring and exit pathways or budget trajectories at the sectoral level, which would seem to be necessary in view of the scale of the socio-technical transformation required (item 37).

2.2.4.3 Comparison between a Paris-compatible German CO_2 budget and a greenhouse gas budget based on the German climate targets

34. Germany has a broad range of climate policy objectives (see sec. 2.4.2). The long-term goal is greenhouse gas neutrality by 2050. Annual greenhouse gas budgets have been agreed for most sectors up to 2030. After 2030, by contrast, the reductions path is not directly linked to fixed emissions levels, but it is possible to calculate a budget for this period if certain assumptions are made. This means that it is also possible to deduce an implicit German greenhouse gas budget and to compare it with the Paris-compatible national budget. This makes possible an analysis of whether existing national climate protection policy is making the necessary contribution to achieving the global Paris climate targets.

Calculating a greenhouse gas budget up to 2050 based on national climate targets

35. In 2016, in its Climate Action Plan 2050, the Federal Government adopted so-called sectoral targets for the year 2030 for energy, buildings, transport, industry and agriculture (BMU 2019a). In the Federal Climate Change Act, these were supplemented by the sector waste and miscellaneous. The sectoral targets were confirmed in the Act and substantiated in annual budgets from 2020 to 2030 for all sectors, with the exception of the energy industry, for which annual emissions levels were set only for 2020, 2022 and 2030. Sector-specific budgets can be calculated beyond this up to 2050 using the following assumptions (see Tab. 2-2):

- According to a recent study by the Federal Environment Agency (UBA), it is possible that the energy, transport and building sectors will no longer emit greenhouse gases by the year 2050 (UBA 2019f, p. 338). However, unavoidable residual emissions will still arise in agriculture, industry, and waste and wastewater management. For these sectors, Table 2-2 shows the mean values of the scenario-dependent emissions for 2050 as calculated for the UBA study (UBA 2019f, p. 339). This leaves a residual total of 43.3 Mt CO_2eq in 2050 which must be offset by corresponding sinks in the form of negative emissions (cf. sec. 2.3.3) in order to achieve greenhouse gas neutrality. This corresponds to a reduction in emissions of around 96.5 % compared with 1990.

- Based on sector-specific CO_2 emissions in 2017, emissions will be reduced in all sectors in accordance with the Federal Climate Change Act, and the projected emission levels will be achieved by 2030, and greenhouse gas neutrality by 2050. A linear reduction path is assumed from 2030 onwards (see Fig. 2-6). In addition to those shown here, other paths or budget allocations between sectors are also possible.

- A degree of imprecision arises from the fact that the national budget derived from the Paris Agreement only covers CO_2 emissions, whereas the German climate and sectoral targets include all greenhouse gas emissions (see Box 2-1). However, since CO_2 accounted for 88 % of Germany's greenhouse gas emissions in 2017 (two-thirds of non-CO_2 emissions come from agriculture and waste management) (UBA 2018b), for the sake of simplicity the national Paris-compatible CO_2 budget is juxtaposed with the German greenhouse gas budget as derived from the German climate targets.

Comparison of the German greenhouse gas budget as calculated up to 2050 with the Paris-compatible budget

36. On the basis of historical emissions, the current climate targets for 2030, and greenhouse gas neutrality in 2050 (see Table 2-2), a budget of 15,268 Mt CO_2eq from the beginning of 2018 can be calculated. This can be compared with the Paris-compatible budget for Germany. For this purpose, recorded CO_2 emissions for the years 2016 and 2017 are deducted from the German budget determined in Box 2-2 "Calculating a Paris-compatible CO_2 budget from 2020 onwards for the EU-28 and Germany", which leaves 8,112 Mt CO_2eq for the budget from the beginning of 2018. This means that the greenhouse gas budget based on the current national climate protection targets is almost twice the size of the CO_2 budget that the SRU identifies as adequate if Germany is to comply with the Paris Agreement. Thus, meeting the national climate and sectoral targets would fall far short of what is needed for Germany's contribution to achieving the Paris climate targets. The SRU therefore reiterates with renewed emphasis that Germany urgently needs to concretise and significantly tighten up its climate protection targets (SRU 2016a, p. 4; 2016c, sec. 2; 2017b, p. 27).

The budget is divided up among the sectors in accordance with policy objectives on the basis of proportional sector shares, which are shown as the coloured areas in Figure 2-6. On this basis, from 2018, the energy sector will still account for 33 % of the remaining German CO_2 budget, industry 24 %, the building sector 13 %, transport 18 %, agriculture 11 % and waste and miscellaneous 1 %. From 2050 onwards, it is assumed that only unavoidable residual emissions from agriculture, industry and waste and wastewater management will continue to be emitted, provided they are offset by corresponding negative emissions. If the emissions in 2017 are assumed to remain constant over the next few years, a very short period of eight to twelve years would remain from the beginning of 2018, depending on the individual sector, if the Paris-compatible budget is used as the starting point. In the individual sectors, the emissions reductions would have to be almost twice as high as those currently foreseen in German climate policy. The tightening of Germany's climate targets therefore necessarily entails adjustments to the sectoral targets.

A non-linear reductions path and sectoral budget allocations

37. In addition to the linear progression shown in Figure 2-6, there are other options for how the budget (regardless of whether it is Paris-compatible or not) might be distributed over the next few years. In each case, it would need to be ensured that agreed interim targets are met at both national and European level. The SRU

Table 2-2

Emissions by sector in line with the Federal Climate Change Act and the goal of greenhouse gas neutrality for all emissions by 2050

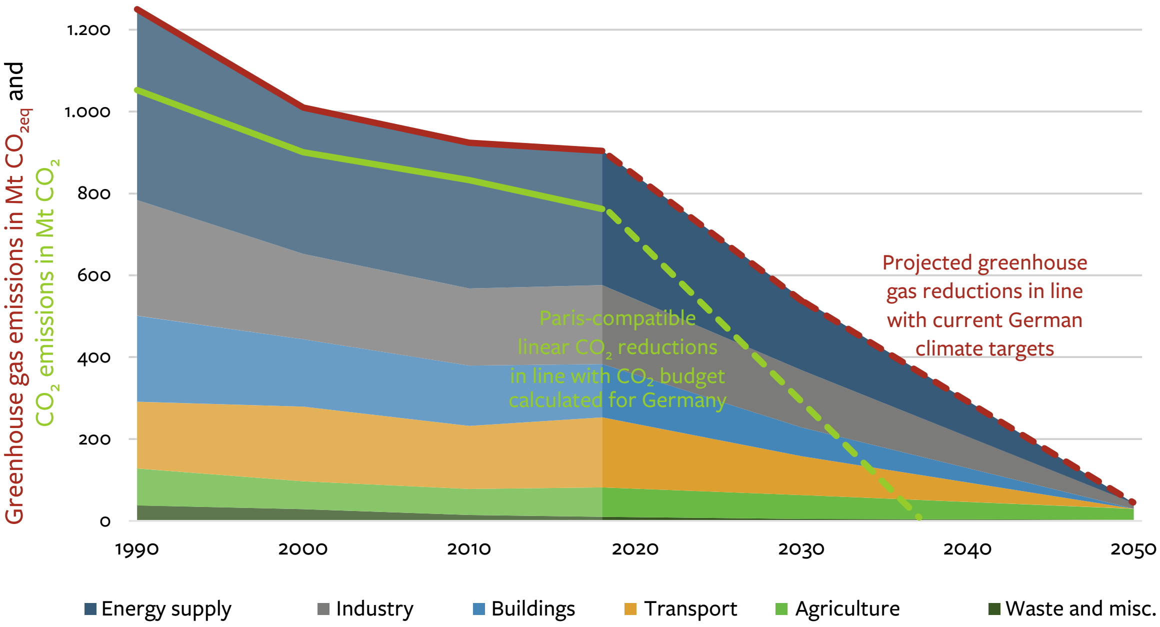
	Emissions 1990		Emissions 2017		Emissions as per KSG 2030		95 % reduction by 2050	
	in Mt CO_{2eq}	proportion	in Mt CO_{2eq}	proportion	in Mt CO_{2eq}	proportion	in Mt CO_{2eq}	proportion
Agriculture	90	7 %	72	8 %	58	11 %	27	62 %
Transport	163	13 %	171	19 %	95	17 %	0	0 %
Buildings	210	17 %	130	14 %	70	13 %	0	0 %
Industry	283	23 %	193	21 %	140	26 %	14	31 %
Energy supply	466	37 %	328	36 %	175	32 %	0	0 %
Waste and misc.	38	3 %	10	1 %	5	1 %	3	6 %
TOTAL (excl. LULUCF)	1.250	100 %	904	100 %	543	100 %	44	100 %

Totals do not always add up to 100 % due to rounding up.

SRU 2020; data source: Federal Climate Change Act, Annex 2; BMU 2019a, S. 33; UBA 2018b; 2019g, p. 339

Figure 2-6

Emissions reductions in line with national climate targets and Paris-compatible budget for Germany



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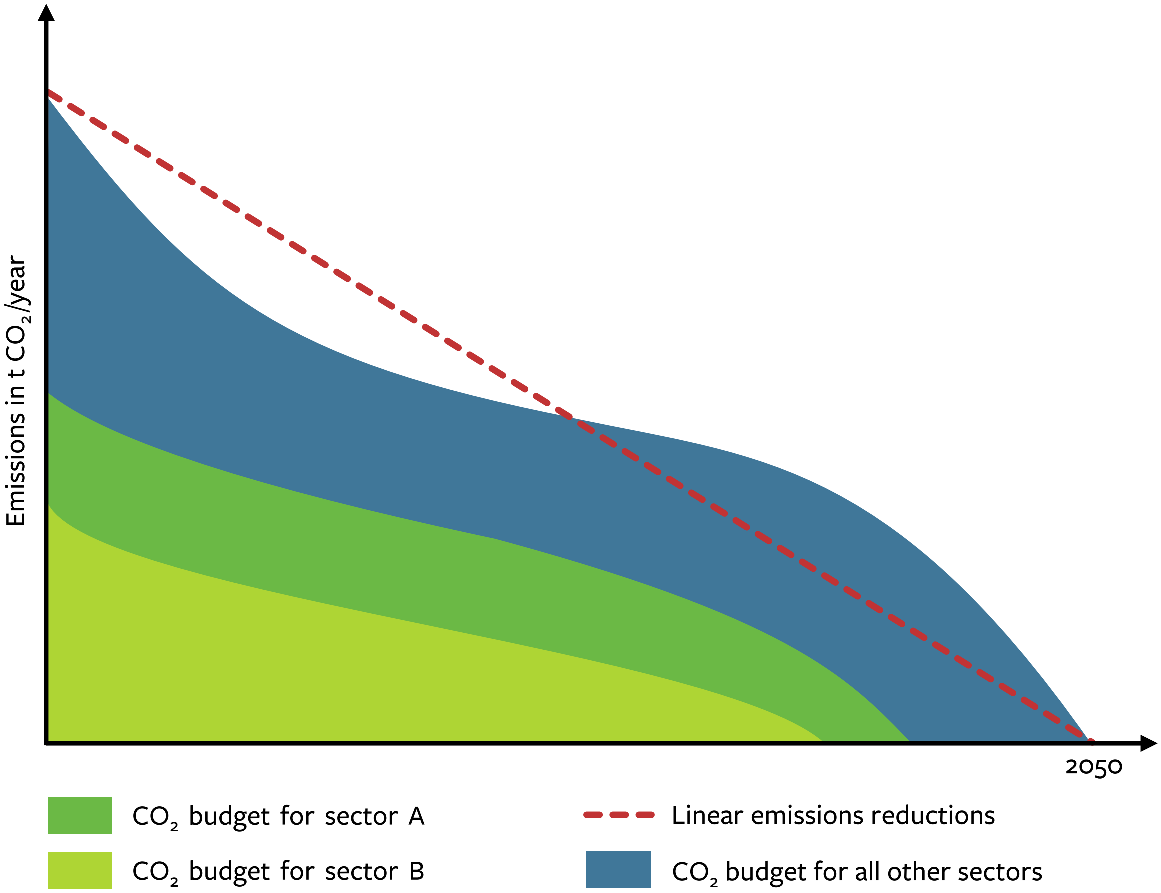
advocates making savings early on in order to reserve residual capacity for later emissions (SRU 2017a, item 10). It would be advantageous to have a trajectory which clearly undershoots the overall emissions envisaged under the Federal Climate Change Act in 2030, but which still allows the target path to be overstepped in the longer term until greenhouse gas neutrality is achieved in 2050. The reductions in emissions can be achieved with varying levels of ambition in the individual sectors, as shown in Figure 2-7. The sectoral distribution of the residual budget should be based on criteria that take into account how quickly and how far measures can be implemented in the respective sector. Sectors with a comparatively large and easily expandable mitigation potential should be given disproportionately ambitious targets, leaving more time for other sectors with greater challenges. Such a division can also follow on the basis of a consideration of macroeconomic or social impacts. The basis on which such decisions on the allocation of sectoral budgets are made should be made public. Within each sector, however, due to the urgent need for action, emissions reduction measures that can be implemented quickly must be initiated soon in any event in order to gain time for the preparation of more complex and difficult measures.

Budgets for energy sources

38. Using budgets to reduce emissions can work not only for sectors but also for energy sources. For example, budgets could be drawn up for coal, oil, natural gas, petrol and diesel, making it clear that the further use of each of these energy sources is limited. In the statement “Start coal phaseout now”, the SRU recommends that energy sources that are already easily substitutable today should be replaced as early as possible by low-emission alternatives (SRU 2017a). This would create additional time for the further use of fossil resources in those areas where replacement by climate-friendly energy sources or new technologies still requires further research and testing. In this way, energy source budgets could complement sectoral targets, which are sensible and necessary due to well-established government departments at the political level. The budgets indicate the maximum extent to which fossil energy sources can still be used, and can thereby facilitate long-term planning for energy source substitution, import strategies and infrastructure requirements. They would thus offer an additional means of measuring progress in reductions, and not only on a sectoral basis but also in terms of energy sources.

Figure 2-7

Schematic representation of an overall budget-compatible reduction path including budget allocation to sectors



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39. In summary, both a global budget and national budgets can be derived from the Paris Agreement, and these can also be allocated to sectors. If all states adhere to their respective budgets, climate change can probably be limited to the target level. Under the assumptions outlined above, the outcome for Germany is a Paris-compatible residual budget of 6.7 Gt CO_2 from 2020. This would already be used up by 2038 if emissions were reduced on a linear scale. The SRU recommends making a Paris-compatible budget the basis for German and European climate policy and avoiding a linear reduction path. A disproportionately large early reduction in the period up to 2030 will allow room for manoeuvre in the long term, but will require substantial measures to be initiated now. A slow start, in the hope of steep emissions reductions in later years, would jeopardise compliance with the budget and with climate targets.

2.3 Core principles and steps for ensuring compliance with a national CO_2 budget

40. To ensure compliance with the remaining Paris-compatible CO_2 budget, greenhouse gas emissions must now be reduced very rapidly. The exit paths needed from technologies based on fossil fuels are steep. All technologies and processes that release climate-damaging gases must now successively be replaced by ones that are virtually emission-free. This must be accompanied by measures that lead to an absolute reduction in energy consumption and/or an increase in the efficiency of current processes. The accompanying transformation of the sectors concerned represents an opportunity for economic, technological and social renewal (SRU 2016b, chap. 1).

The discussion about the course of exit paths is linked in a fundamental way to the question of how quickly alternatives can be put in place. It is important to think through entry and expansion paths for alternative procedures in conjunction that will also ensure social well-being in the future, especially the restructuring of energy, mobility and heating services. The technical and economic aspects involved are only two of many, since, for example, the social compatibility and social acceptance of climate protection measures must also be taken into account in the planning. In the following sections, the SRU recommends placing compliance with the CO_2 budget, the phasing out of fossil fuels, and the associated expansion of climate-friendly energy systems under a set of conditions. The goal is to ensure that Germany's future energy supply is based on 100 % renewable energies (SRU 2011; UBA 2019f; 2014).

2.3.1 Switch rather than exit: renewable energies instead of fossil fuels

41. Consistent measures must be taken to significantly reduce the use of fossil fuels and to accompany this by the corresponding expansion of the use of renewable energies.

Acting with foresight to end the use of fossil resources: phasing out coal, oil, natural gas, petrol and diesel

42. In view of the long investment cycles and service lives of many industrial plants and power stations, but also of similar considerations in the building and transport sectors, investment in zero-emission or at least significantly lower-emission technologies should already be being made today. More stringent climate policy measures would mean that investments in fossil applications would become uneconomical in the foreseeable future. This includes the agreed CO_2 pricing system with the pre-determined rising paths (see Box 2-5). These measures need to be taken into account in current investment decisions.

Some institutions are already addressing the issue. For example, the European Investment Bank's new lending guidelines stipulate that projects for oil and gas extraction and gas infrastructure will no longer be supported. New power plant projects have to meet much more ambitious emissions standards and should only be approved under conditions that credibly demonstrate that renewable gases will be the main source of energy in the future (European Investment Bank 2019). The SRU believes that although these requirements need to be significantly tightened, they are already moving in the right direction.

43. The Commission on "Growth, Structural Change and Employment" has drawn up a proposal for ending coal-fired power generation in Germany in order that the sectoral target for the energy industry set out in the Climate Action Plan 2050 can be met in 2030 (Kommission „Wachstum Strukturwandel und Beschäftigung" 2019). However, this alone is not sufficient to bring about the necessary reduction in emissions (SRU 2017a). The measures proposed in the Climate Action Programme 2030 are also insufficient in this respect, because although coal-fired power generation is to be phased out, no significant restrictions on other fossil energy sources such as natural gas or oil are planned. In addition, the regulations governing the expansion of renewable energies are insufficient to bring this about quickly and on the scale required. For example, the decision to lift the limit on photovoltaic subsidies up to a capacity of 52 GW (the "PV cap") will not of itself be enough to offset the already foreseeable shortfall in photovoltaic construction over the next few years.

Policymakers should strengthen planning certainty for private and commercial investment decisions by adopting far-sighted climate protection measures early on, and by gearing support and subsidy programmes towards renewable rather than fossil options. Otherwise, there is a risk of path dependencies and lock-in effects that could result in the continuing use of CO_2-intensive technologies (see also WACHSMUTH et al. 2019). The introduction of so-called bridge technologies can also create path dependencies. One example of this is the expansion of gas-fired power plants rather than directly promoting the immediate expansion of renewable energies to the required level. The same applies to infrastructure investments which may appear to make sense from a short-term perspective but will not be needed in the long term given a proper assessment of infrastructure requirements under the conditions of a greenhouse gas-neutral energy system (see ibid.).

A comprehensive overall concept is needed that enables the switch from fossil to sustainable, renewable technologies and processes to take place in a planned, regulated and coordinated manner. Pathways for the expansion of renewable energies must be developed as a prerequisite for ending the use of fossil resources. This has far-reaching implications, such as changes to infrastructural requirements (which can mean both the dismantling of existing infrastructures and the construction of new ones), changes to the patterns of import and export of energy sources, and other diverse impacts on society, the economy and jobs. The elaboration of such a policy concept is a complex matter and must be based on wide-ranging expertise from a great many disciplines.

Expanding the use of renewables

44. Renewable energy sources are the core element of the decarbonisation process in Germany. When comparing the various options for electricity generation, the use of renewables is the only one that can guarantee sustainability (SRU 2011, p. 56). The SRU has already stated that for Germany "an electricity supply based solely on renewable energy sources is possible by 2050, while observing strict nature conservation requirements and avoiding other conflicts of use" (SRU 2011, p. 31). To this end, however, the demand for energy must also be significantly reduced through measures to save energy and increase efficiency. Research confirms that a German power supply system using 100 % renewable energies, supplemented by flexible elements such as possibilities for sector coupling, storage facilities and a good electricity grid infrastructure, is technically feasible and viable and can bring economic benefits (UBA 2014; 2010; HENNING and PALZER 2012, p. 5; KUNZ and KIRRMANN 2015, p. 4; WALTER et al. 2018). In addition, studies have been carried out at the European and global level which show that all energy needs can be met from renewable resources (RAM et al. 2019; 2018).

The environmental impacts of the expansion of renewable energies can be minimised through appropriate site selection, spatial planning and nature conservation guidelines and optimisation of the technology mix (SRU 2011, p. 53). The impact on nature is limited over time, usually just to the lifetime of the installation, meaning that the long-term effects are significantly lower than with the use of fossil fuels or uranium (mining, storage of radioactive waste, CO_2 storage) (ibid.). Nevertheless, there are ecological challenges associated with the expansion of renewable energies, such as impacts on the biosphere, i.e. on habitats on land and in water. These must be taken into account in planning the expansion, as must impacts on the landscape (see also SCHMIDT, C. et al. 2018a; 2018b). The interests of the climate, nature and species protection must be reconciled. A new study by the Federal Agency for Nature Conservation recommends ways of designing a nature-friendly energy supply in Germany, taking into account the need for limiting land use, for landscape protection and biodiversity conservation (WALTER et al. 2018).

45. Thanks in part to significant improvements in technological efficiency and cost reductions, renewable energy sources, such as wind turbines at locations with strong winds, can compete in cost terms with conventional electricity generation technologies (KOST et al. 2018, p. 8 et seqq.). The fact that electricity generation using conventional resources will become more expensive under the EU ETS if prices for CO_2 certificates continue to rise also plays a role. Ambitious national climate policy will not weaken the competitiveness of most sectors and companies in Germany. Energy costs are only one of many factors that affect the location of businesses; for many industrial companies, they account for only a small proportion of production costs, and there remains considerable unexploited potential for efficiency improvements. Only a few energy-intensive companies need targeted relief from possible energy price increases resulting from ambitious climate policy in order to maintain their competitiveness (see SRU 2016b, chap. 2). Whether prices will rise at all is open to question, since renewable energies usually have a price-reducing effect (OEI et al. 2019a, p. 13; Agora Energiewende 2018, p. 13). However, the price level is influenced by other factors, such as trends in the price of fossil fuels and European CO_2 allowances (Agora Energiewende 2018, p. 6; OEI et al. 2019a, p. 16). In addition, if Germany plays a leading role in the use of climate-friendly technologies, this may also have a positive impact on its international competitiveness (SRU 2016b, chap. 1).

46. However, the expansion of renewable energies must be greatly accelerated in order to achieve the climate targets. At the end of 2018, Germany had 53 GW onshore wind power capacity, 6 GW offshore and 45 GW of photovoltaic capacity installed. The expansion rates for onshore and offshore wind have fallen significantly from 6.3 GW in 2017 to 3.3 GW in 2018 (BMWi 2019c, p. 7), and even less expansion is expected in 2019 ("Halbjahreszahlen Windenergie an Land: Historisch niedriger Zubau trotz sehr guter Wachstumsperspektiven – Genehmigungsstau dringend auflösen", press release of Bundesverband WindEnergie, 25 June 2019). The reasons for this are inadequate provision of land in the Länder and protracted approval procedures as well as lawsuits and appeal proceedings against approvals already granted. By contrast, photovoltaics saw an increase to 2.9 GW in 2018 compared with 1.7 GW in the previous year (BMWi 2019c, p. 7).

Furthermore, notwithstanding general public support for the expansion of renewable energies in principle, the construction of wind energy and biogas facilities as well as electricity pylons in the vicinity of people's own homes is viewed less positively, and their willingness to pay for "green" electricity has declined (Agentur für Erneuerbare Energien 2019; FRONDEL and SUMMER 2019). As a result, local resistance to the expansion of wind energy plants and electricity grids has arisen time and again (HOEFT et al. 2017). The general public is already participating in planning procedures for the expansion of renewable energies. However, it would further promote acceptance if the interests of those affected at local level were increasingly taken into account in early-stage decision-making and planning phases, and if participation in investments were also made possible (see Chapter 7, item 655). Public acceptance is an essential prerequisite for the achievement of the national climate targets by 2030, as significantly larger annual expansion rates are required (OEI et al. 2019a; BEE 2019, p. 3; UBA 2019f, p. 34). In the Climate Action Programme 2030, the Federal Government decided to lift the cap on photovoltaic expansion and to raise the expansion target for offshore wind energy plants, but there remain regulatory framework conditions which hinder expansion (e.g. the time required for approval procedures, the way tendering procedures work, delays to the expansion of the grid) (BMU 2019b). The decisions currently being taken do not do justice to the demands and necessities arising from advancing climate change. The Federal Government is likely to miss the climate targets it has set itself for 2030 in its Programme of Measures by a wide margin (OEI et al. 2019b, p. 10). Amendments to the measures adopted are urgently needed to meet the national targets, which are not even Paris-compatible. Additional and further efforts will be needed to make a proportionate contribution to the Paris Agreement. To this end, a joint strategy is to be drawn up by the Federal Government and the Länder, which will focus not only on the expansion of renewable energies but also on emissions reductions in the building and transport sectors. With increasing sector coupling, cross-sectoral measures must also be initiated, for example to better coordinate the expansion of renewable energies and electricity grids with electricity requirements in the different sectors.

47. A rapid expansion of renewable energies goes hand in hand with rising demand for a number of raw materials for the production of the necessary technologies. Exactly which raw materials are needed when depends on the planned expansion paths and on technological developments, for example due to competition for raw materials between different products (World Bank 2017; ANGERER et al. 2016; see also SRU 2017b, chap. 3.5). Since the raw materials required are not available in sufficient quantities as secondary raw materials, it is necessary to extract primary raw materials. Here it should be noted, firstly, that extraction and processing generally lead to considerable environmental and health impacts and often exceed local and regional environmental pollution limits (CHAHOUD et al. 1999; ERICSSON and SÖDERHOLM 2010; MUDD and WARD 2008; UNEP 2019b; OECD 2019; see also SRU 2017b, sec. 2.3.2). Moreover, the availability of raw materials may be limited due to insufficient mining capacity and to supply risks, whether due to economic or political factors, leading to price increases. In general, research suggests that a sufficient supply of raw materials is possible, but temporary supply bottlenecks are to be expected (ANGERER et al. 2016; BLAGOEVA et al. 2016; BGR o. J.; BUNGE and STÄUBLI 2014; FRONDEL et al. 2006; Öko-Institut 2017; BUCHERT et al. 2019). These can be countered by technical measures such as improving material efficiency, substitution of raw materials or switching to other technologies. However, an expansion of mining capacity may also be necessary. Growing global demand for lithium and cobalt can be expected, for example, due to increasing numbers of electric vehicles. The demand for platinum will rise if fuel cell technology is used more extensively and the quantity that becomes available because of the decline in the use of catalytic converters is not sufficient to meet that demand (MARSCHEIDER-WEIDEMANN et al. 2016, p. 263 et seqq.). According to BLAGOEVA et al. (2016), bottlenecks for various raw materials are possible in the EU if timely adaptation measures are not taken. These include indium and silver for photovoltaic modules and rare earths such as dysprosium, neodymium and praseodymium for wind turbines. In both cases, however, demand depends on the specific technology being used. For example, indium is only required for so-called CIGS photovoltaic modules; the silicon and cadmium telluride-based technologies predominantly used so far do not need indium. Silver, on the other hand, is required for all types of photovoltaic modules. In the case of wind power plants, there are technologies available both with and without the use of rare earths.

For the sake of clarity and transparency with regard to the environmental impacts and possible supply risks attendant on the decarbonisation of energy supply, the demand for raw materials should therefore be taken into account when drawing up decarbonisation paths. It is important to examine which paths involve the lowest possible environmental impact. If it is necessary to increase raw material extraction, the framework conditions for this should be designed in such a way that high environmental and social standards are ensured. Since a large part of the necessary raw materials is obtained abroad, this must form an integral part of both foreign trade and development policy (SRU 2012, sec. 2.4.4).

In addition to the extraction of raw materials, the question of recyclability must also be considered. Only high-quality recycling can reduce the demand for primary raw materials. This means that the course has to be set now to ensure that the materials used are recyclable and that the corresponding infrastructure for these materials is available in the future. The prerequisite for this is that appropriate regulations are created.

The switch to renewable energies must not be undertaken from an energy perspective alone, but must be linked to the question of the management of material flows in society and of the environmental impacts caused by them (see also SRU 2019, item 362). The goal is to ensure that neither local, regional nor planetary boundaries are exceeded in the course of global decarbonisation (see, for example, VIDAL et al. 2013; HERTWICH et al. 2015; GIBON and HERTWICH 2014; UBA 2019d).

2.3.2 No return to nuclear energy

48. The pressure for action on climate policy has led to a revival of the public debate on the use of nuclear energy. Its proponents see it as an option for a rapid reduction in emissions alongside the expansion of renewable energies, as it enables climate-friendly power generation with low CO_2 emissions. In France, the 50 % reduction in electricity generation from nuclear power plants originally envisaged by 2025 has now been postponed by ten years to 2035 because the expansion of renewable energies has not taken place on the scale required (SCHNEIDER et al. 2019, p. 69). At the European level, the Clean Energy Package stated that a share of around 15 % for nuclear power, together with renewable energies, should form the backbone of a CO_2-free European electricity system in 2050 (European Commission 2018b, p. 10). The European Investment Bank also continues to provide loans for nuclear projects (European Investment Bank 2019). For Germany, the SRU categorically rejects the idea that it makes sense to ascribe a role to nuclear energy in the future electricity supply (SRU 2011b, sec. 2.4.2). Rather, Germany should abide by the nuclear phase-out already decided on and now being implemented, and should demonstrate that a transition to a renewable energy system without the use of nuclear energy is possible in order to send a signal at global level. In this context, “nuclear energy” refers to all electricity generation technologies that use nuclear fission to generate energy.

The risk of accidents and the unresolved issue of final disposal

49. The use of nuclear energy poses a danger to many millions of people in the event of even just a partial release of substances hazardous to health and the environment, and entails the risk that entire stretches of land could become uninhabitable for very long periods (WBGU 1998, p. 70). Numerous incidents – especially the catastrophic accidents at Chernobyl and Fukushima – have demonstrated that the use of nuclear energy involves considerable risks. Renewable energies offer alternatives that make nuclear energy superfluous. It is thus possible to avoid the high safety risks that arise in particular from the effects of such accidents (Ethikkommission Sichere Energieversorgung 2011, p. 10).

50. After use, safe, sealed storage of the radioactive waste must be ensured for a million years or more. Disposal is linked to other issues, such as where and how it can be stored, how this is financed and how the interests of future generations can be taken into account with respect to the final storage or disposal (ECKHARDT and RIPPE 2016). Out of consideration for the well-being of future generations, the precautionary principle requires that risks should be minimised as early as possible (risk prevention). In addition, people living both now and in the future must be protected as far as possible from any harm, including damage to the environment and to human health (SRU 2019, sec. 2.2.2.1.2). For these reasons, the SRU believes that the continuing operation of nuclear power plants beyond the agreed exit path would not be justifiable.

51. The call for an extension to the operating lives of existing nuclear power plants must also be viewed critically from a safety perspective. Longer operating times and the associated wear and tear on components increase the safety risk, which is difficult to assess due to a lack of experience with such long operating times (MATTHES and KALLENBACH-HERBERT 2006, p. 61). Retrofitting and upgrading the safety components of existing nuclear power plants to the highest safety levels required for new reactors is expensive and not economically viable (Greenpeace 2014, p. 5). In addition, there is currently no technically mature facility anywhere in the world for the permanent storage of highly radioactive waste (BESNARD et al. 2019, p. 75; BRUNNENGRÄBER 2019, p. 18). The Federal Company for Radioactive Waste Disposal has the task of finding a site by 2031 that offers the safest storage over millions of years (BGE 2019). It will take further years or even decades until this site is approved and made operational. The search for a repository in Germany will therefore continue to be long and arduous. The German public is also sceptical towards nuclear energy. The accident in Fukushima led to an increase in the proportion of people in Germany with reservations about safety and a negative attitude towards nuclear energy (Frankfurter Allgemeine Zeitung 20.04.2011). An extension or renewed use of nuclear power plants and the associated search for additional final disposal options therefore hold enormous potential for conflict.

Economic inefficiencies

52. The construction of nuclear power plants does not make sense from an economic perspective either. From a global perspective, investments in renewable energies are more cost-effective than investments in nuclear power plants (SCHNEIDER et al. 2019, p. 213; LAZARD 2018, p. 2; MENDELEVITCH et al. 2018; KEMFERT et al. 2017; 2015). This is due, among other things, to significantly increased specific investment expenditures for new nuclear power plants, increasing operating costs, unresolved issues concerning dismantling and final disposal, and the continuing impossibility of insuring against nuclear accidents (KEMFERT et al. 2015; SCHNEIDER et al. 2019, p. 214). Higher safety requirements result in cost increases for construction and dismantling and for storage of radioactive waste, all of which are difficult to estimate (KEMFERT et al. 2015, p. 1065). So-called fourth-generation nuclear power plants and small modular reactors are also technically difficult to manage and are not expected to be economically viable (WEALER et al. 2019, p. 516). Due to higher safety requirements, extensions to the operating life of nuclear plants mean additional costs for retrofitting and are often not cost-effective (SCHNEIDER et al. 2019, p. 238). Retrofitting at European nuclear power plants following accidents has so far been poorly implemented, which is also due in part to reasons of cost-effectiveness (Greenpeace 2014, pp. 5 and 12).

53. In Germany, the decision in 2011 to phase out nuclear energy marked a political consensus on ending the use of nuclear energy by 2022. Globally, however, nuclear energy continues to play a role. This is shown by the fact that its share in global electricity supply is no longer declining but has stagnated at a level of just over 10 % in recent years, with new power plants being built in China in particular (SCHNEIDER et al. 2019, p. 32). The fact that nuclear power plants are being built despite a lack of economic viability is due to political incentives in the form of subsidies (WEALER et al. 2019, p. 518). In scenarios drawn up by the International Energy Agency (IEA), the IPCC and the EU, it is still assumed that nuclear energy will play a role in achieving the climate target despite a lack of economic viability (IEA 2018, p. 22; IPCC 2018a; European Commission 2018b, p. 10). Since two-thirds of the world's nuclear power plants are over thirty years old (IAEA - PRIS 2019) and will therefore have to be replaced in the foreseeable future, it is especially important when these investment decisions are made to replace nuclear energy by increasing the use of renewable energies, which makes sense in both economic and safety terms.

2.3.3 The role of negative emissions – limiting the use of CCS in Germany

54. In addition to the need to reduce CO_2 emissions, the increasing pressure to act on climate change is also prompting a discussion on whether and to what extent practices for CO_2 capture or extraction of CO_2 from the atmosphere are needed.

2.3.3.1 Negative emissions

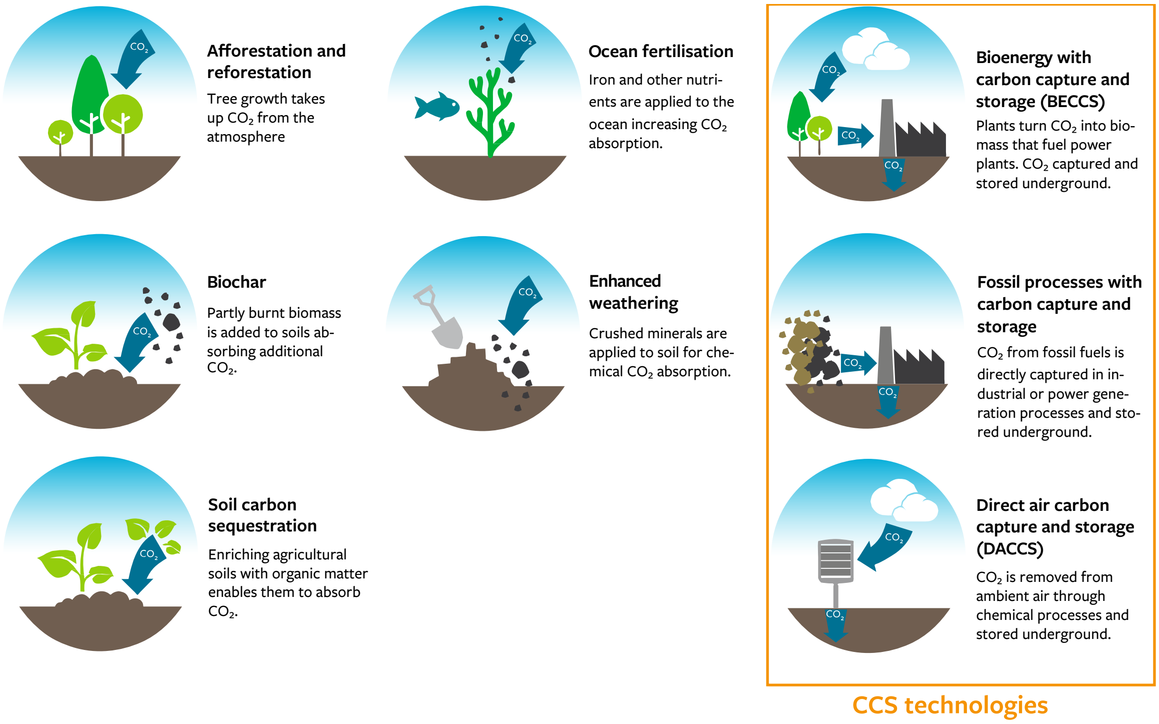
55. Today, more than half of all CO_2 released is offset by natural processes, i.e. via terrestrial and ocean sinks (LE QUÉRÉ et al. 2018, p. 2160). The term negative emissions refers not only to such natural processes but also to additional practices carried out by humans that remove CO_2 from the atmosphere or prevent its release into the atmosphere (IPCC 2019; 2018a; MINX et al. 2018, p. 3; MORROW et al. 2018). The IPCC Special Report on Climate Change and Land identifies a number of possible land-based practices for generating negative emissions (IPCC 2019, p. 28 et seq.). Among them are some that, in addition to carbon sequestration, have a positive impact on other indicators such as adaptation to climate change, desertification and land degradation, and food security. Depending on the particular circumstances, this may apply, for example, to afforestation and reforestation, the production of biochar and its use in soil, or soil carbon sequestration. Other negative emission practices are also under discussion, such as ocean fertilisation, enhanced weathering, and artificial alkalisation of oceans, as well as various methods of carbon capture and storage (CCS). CCS includes combinations with fossil power plant and industrial processes or with bioenergy (bioenergy with carbon capture and storage – BECCS), but also direct air carbon capture and storage (DACCS) (see Fig. 2-8; MINX et al. 2018).

In view of the inadequate results achieved so far in emissions reductions, these processes represent an attempt to limit climate change through other large-scale interventions in key components of the Earth system. These approaches, which are discussed under the umbrella term geoengineering, are tempting because they hold out the prospect of a technical solution which requires society to change its behaviour only slightly or not at all (UBA 2011, p. 41). Research and development of processes for generating negative emissions makes perfect sense. However, for ecological, technological, political and ethical reasons, they represent an option in the debate on emissions budgets which should be viewed critically and which, from today's perspective, is often no more than speculation (UBA 2011). Many detailed questions would still have to be clarified before any large-scale deployment (SPP 1689 2019, p. 65).

56. The Paris Agreement states that an emissions balance needs to be achieved in the longer term, i.e. remaining sources of CO_2 are to be offset by corresponding additional sinks. However, negative emissions are not to be used to increase the size of the budget in mathematical terms (see item 16). The reason for this is that the large-scale availability, environmental compatibility in use and long-term reliability of negative emissions practices are all uncertain. However, the expan-

Figure 2-8

Processes covered by the term "negative emissions"



Source: MCC 2016, modified and translated sion of negative emissions practices can increase the probability of compliance with the budget, since the size of the budget is linked to the probability of achieving the target.

The role of negative emissions in scientific modelling

57. A large proportion of the cost-optimal climate scenarios as assessed in IPCC SR1.5 involve a not insignificant contribution from negative emissions to achieving climate targets where global warming is well below 2 °C (FUSS et al. 2018; IPCC 2018a; ROCKSTRÖM et al. 2017; ROGELJ et al. 2018). These scenarios envisage less rapid reductions in emissions than would be the case if negative emissions were not taken into account. It is very likely that residual emissions that are difficult or impossible to reduce, such as those from industrial processes or from land use, land use change and forestry (LULUCF), will persist and will have to be offset in the long term (DAVIS et al. 2018; LUDERER et al. 2018; UBA 2014; 2019f, p. 50 et seq.). A recent UBA study for Germany shows that natural sinks, i.e. sustainable agricultural and forestry land management, can offset these unavoidable emissions and that greenhouse gas neutrality will be achieved by 2050 without the need for CCS (UBA 2019g, p. 32). In contrast, other energy technology modelling assume only limited potential for non-CCS applications, which means that a very large contribution from CCS is needed to meet climate targets in the remaining time frame. Thus, the IPCC's Fifth Assessment Report envisages a significant global expansion of bioenergy in combination with CCS (IPCC 2014). What is often not taken into account, however, is that an expansion on this scale would entail far-reaching changes to land use and land consumption that could not realistically be achieved within the limits of the planetary boundaries.

CCU as an option for the utilisation of CO_2

58. A distinction needs to be made between negative emissions and processes that involve the downstream use of CO_2 (carbon capture and utilisation – CCU) (Deutscher Bundestag 2018, p. 15 et seq.). In such processes, CO_2 is captured and subsequently utilised for other purposes. Fields of application include the chemical industry, but also the production of synthetic hydrocarbons, such as liquid fuels and methane. If the CO_2 is subsequently released into the atmosphere, the positive contribution to climate protection over the entire process chain depends crucially on the form of energy use that is substituted, the resources required to capture the CO_2, and whether renewable energies were used in the process. A subsequent capture and utilisation (which may be thought of as a carbon cycle, which however may not be kept closed, see UBA 2014, p. 72) or subsequent storage (carbon capture utilisation and storage – CCUS) involve a high energy input and will only make sense if sufficient electricity from renewable energies is available. Moreover, the state of development of systems for CO_2 separation from the air is still limited. So far, only few and relatively small plants have been built and only a few companies are active in this field (e.g. RUB 2019). There is therefore still a great need for further research. Synthetic hydrocarbons are likely to be required in the future, especially in shipping and aviation, to reduce emissions, and the use of CCU processes would be an option here. In general, however, the use of synthetic fuels should be limited to those processes in which alternatives such as the direct use of electricity are not feasible (see also SRU 2017b, p. 15).

2.3.3.2 Use of CCS in Germany

59. As a potential carbon sink, CCS repeatedly plays a role in climate policy debates. The reasons that speak against the use of CCS in Germany are in particular the safety risks, the limited storage potential and the lack of public acceptance and cost-effectiveness, as explained below (see also SRU 2009).

Safety and storage capacity for CCS

60. CCS does not involve the avoidance of emissions, but merely storing them away as safely as possible underground. Research activities in recent years have produced technical and scientific knowledge on the separation, storage and transport of CO_2 (Deutscher Bundestag 2018, p. 51). Worldwide, only 18 CCS projects are in operation, of which 14 use CCS in combination with tertiary oil recovery (Enhanced Oil Recovery - EOR), in which CO_2 is forced into a borehole under high pressure in order to drive oil out (Global CCS Institute 2018, p. 18). In EOR, a large proportion of the CO_2 remains underground, but stricter regulatory requirements must be met in order for EOR-CCS projects to be approved (ZALUSKI et al. 2016). Since the primary objective of EOR is oil extraction, the experience gained with monitoring and storage security in EOR-CCS projects is not always directly applicable to pure CCS applications.

Research and development into CCS is being pursued intensively, particularly in Australia, Canada, the USA, Japan, China and some Arab states. The only two European projects currently underway are both in Norway, though the British government is planning a first project for CO_2 storage and use to begin around 2025 (Deutscher

Bundestag 2018, pp. 20 and 49; Department for Business, Energy & Industrial Strategy of the United Kingdom 2018). Although no major problems have been identified in projects implemented to date with regard to the technical feasibility and safety risks of storage, the results are not universally transferable to other potential sites (NETL 2019; MARKEWITZ et al. 2017, p. 27). The scale of the environmental risks associated with storing CO_2 in the seabed is difficult to estimate (UBA 2008, p. 322). One experiment showed relatively low risks from leakage (VIELSTÄDTE et al. 2019). However, there is no experience with CO_2 storage which is designed for centuries or millennia (ROST 2015, p. 13). Although the "state of the art in research and technology seems to justify further experiments with demonstration projects in Germany" (Deutscher Bundestag 2018, p. 15), deployment beyond the demonstration phase is not a realistic prospect in the near future.

Many of the larger-scale CO_2 storage projects are also located in sparsely populated regions with relatively lax monitoring of possible leaks which does not meet the safety requirements in densely populated regions in Central Europe. The resolution accuracy of the monitoring technologies is also limited, so the measurements are subject to uncertainty (ibid. 2018, p. 12). Geological formations that appear suitable for the permanent storage of CO_2 are distributed differently around the world (ROST 2015, p. 57). The storage potential in Germany is severely limited (SRU 2009, p. 9). It would also be necessary to examine the geographical relations between CO_2 sources and storage sites, as well as ensuring the establishment of suitable transport infrastructure (ESKEN et al. 2010, p. 17). In addition, there is some competition with other possible uses, for example the storage of compressed air as an electricity storage or for hydrogen (SRU 2009, p. 34).

Public acceptance of CCS

61. CCS projects in Europe have been introduced more slowly and on a smaller scale than was expected at the beginning of the century. Their implementation failed in most cases due to high costs and a lack of public support (Deutscher Bundestag 2018, p. 49). Another factor was that some storage sites are located underneath residential areas and residents protested against CCS projects because of safety concerns.

In Germany, only one out of four planned CCS projects resulted in the storage of CO_2. Here, too, the main obstacles were high costs and a lack of acceptance. The fact that a project in Ketzin was temporarily put into operation can be attributed both to the comparatively small storage capacity and the involvement of the local population in a participatory way (DÜTSCHKE et al. 2015, p. 242). In addition, the project was designated as purely for research and was set up for a limited period from the beginning.

Economic inefficiencies of CCS

62. An evaluation report of the Federal Government assumes that for CCS plants, "for the first European projects, but probably also for the foreseeable future, the entire technology path consisting of capture, transport and storage does not suggest the likelihood of profitability" (Deutscher Bundestag 2018, p. 50 et seq.). The IEA notes that, given the small number of existing and planned CCS projects in Europe, the costs will probably only go down if state support is increased (IEA 2018, p. 350). In addition to these aspects, which apply to the economic viability of all CCS applications, further aspects are discussed below, differentiated by procedure.

Economic aspects of CCS in power generation

63. Modelling shows that investments in CCS coupled with fossil power plants are currently very cost-intensive and in most cases uneconomical. The construction and operation of CCS plants makes existing power plant technology more expensive, and the additional costs cannot be recovered through the existing price range for emissions allowances (SUSSAMS 2018). Greenhouse gas emissions from CCS power plants can be reduced, but not completely cut out (ESKEN et al. 2010, p. 17). At the same time, due to the energy required for capture, the efficiency of the power plant decreases, by a proportion dependent on the capture process (BONGARTZ et al. 2015, p. 81), which increases the fuel demand. This is in stark contrast to the goal of increasing energy efficiency and reducing energy consumption.

64. In the energy sector in particular, cheaper alternatives are increasingly available (see also item 45). The average electricity generation costs of photovoltaic systems and onshore wind energy plants in Germany are already equal to or below those of newly constructed conventional power plants using lignite, hard coal or natural gas (KOST et al. 2018, p. 2). Especially in the long term, investments in renewable energy sources and their operation are more economical than fossil alternatives which would have to be operated in combination with CCS (ibid., p. 3 et seq.; HAINSCH et al. 2018, p. 25). Moreover, an energy system operating entirely on renewable energy sources is technically feasible in Germany, as shown in section 2.3.1 above. Overall, therefore, the

SRU believes that the use of CCS in electricity generation in Germany remains unadvisable, both for economic reasons and in view of risks and ecological side-effects.

Economic aspects of CCS in industrial processes

65. Most existing CCS projects are designed to capture CO_2 released in industrial processes, such as natural gas processing, fertiliser production or hydrogen production from methane (Deutscher Bundestag 2018, p. 9). In Germany, about 38 % of industrial emissions are non-energy-related and are attributable to production processes in primary industries, such as lime, cement and steel production and basic chemicals (BMU 2019a, p. 57). The majority of these processes should be made emission-free through further technological innovations, or the goods produced should be replaced by alternatives. For the remaining residual emissions, which should be as small as possible, the use of CCS could be the only available option to prevent the release of emissions. However, CCS is currently not economically viable for industrial plants and, if the plant location is a long way from the storage site, it may require the construction of potentially costly new infrastructure (Deutscher Bundestag 2018, p. 43). CCS should therefore only be considered by industry as a last resort and should not inhibit research and development into zero or low emissions products or processes in the industrial sector.

Economic aspects of BECCS

66. The combination of bioenergy use with CCS in theory offers the advantage that a plant-based, renewable raw material is used for energy production, and the resulting emissions are captured and stored by CCS, so that the overall emissions balance can be negative. It is often assumed that bioenergy is always CO_2-neutral, because only the amount of CO_2 absorbed during the growth of the plant is released. However, this depends on the type of biomass (see sec. 2.3.4). Whereas, for example, in the case of wood from residual and waste materials, essentially only emissions from transport and sometimes from processing have to be accounted for, in the case of cultivated energy crops a considerable amount of auxiliary and operating energy has to be expended on their provision, processing, conversion and use. This leads to emissions. In the cultivation of bioenergy crops, the greenhouse gas emissions of agricultural production must also be taken into account, especially of greenhouse gases other than CO_2 (ARNOLD 2015, p. 493; cf. also sec. 2.3.4).

Another problem is that the cultivation of bioenergy crops is land intensive. According to the findings of climate economy models, in order to achieve large-scale negative emissions through BECCS, huge areas of land would be required for the cultivation of biomass as well as enormous resources of transport and storage (GEDEN and SCHÄFER 2016, p. 2). The potential for sustainable biomass is limited and the proportion suitable for bioenergy production is further reduced by competition over its use (UBA 2019f, p. 28; 2013a, p. 52 et seqq.; 2013b, p. 7; ARNOLD 2015, p. 501). The costs of bioenergy generation also rise significantly through CCS, although the fuel properties and thus the costs vary greatly depending on the type of biomass (FINKENRATH et al. 2015, p. 595; ARNOLD 2015, p. 500).

While for certain regions and applications and small-scale BECCS systems, sustainability and climate benefits may be possible, this is unlikely to be the case at the global level for large-scale use. On account of its limited potential in Germany alone, socially and environmentally sustainable use of BECCS on a large scale is not possible here, and should not be pursued.

Economic aspects of DACCS

67. Compared with processes coupled to fossil or biogenic sources, separating CO_2 from the air requires enormous technical and energy resources due to the lower CO_2 content, and this is reflected in correspondingly high costs. The process is currently still in the development stage. For cost and efficiency reasons, there are thus clear arguments against using DACCS while coal, gas and bioenergy continue to be used on a significant scale without CCS (WIETSCHEL et al. 2018, p. 65 et seq.). Whether and when DACCS will reach technical and economic commercial viability is currently an open question.

Interim conclusions on CCS applications and negative emissions

68. CCS cannot be recommended for Germany for the foreseeable future due to high costs, unfavourable geological storage conditions and the risk of the unintended release of CO_2 over time. Avoiding emissions, which is possible both by reducing consumption and by substituting emission-free processes for fossil fuels, has top priority and is as a general rule preferable to the capture and storage of CO_2. In particular, the use of CCS should be avoided in electricity generation (see also SRU 2011, p. 50). In the long term, and in the absence of any alternatives, CCS could become necessary in order to offset residual emissions. Storage potential should be preserved for these processes. Extensive use of BECCS is not advisable if sustainability and environmental protection criteria are to be met, on account of the limited potential alone. If BECCS applications are considered, their net environmental and climate impacts must be calculated and assessed, for example with regard to material cycles and transport chains.

69. Negative emissions are already part of the debate on ways to limit climate change, a debate that is likely to become even more intense if global climate protection measures remain inadequate. It is therefore necessary to critically examine the ecological, technological, political and ethical aspects of these techniques through further research and testing. Any expansion of negative emissions should be dependent on the results of this research and should not already be decided on today as a substitute for mitigation and adaptation measures.

2.3.4 The need for regulation of the use of stemwood for energy

70. An expansion of the use of wood as an energy source to replace fossil fuels is a recurrent topic of discussion in the context of the energy transition (e.g. KLEPPER and THRÄN 2019; Committee on Climate Change 2018). In the private sector, it mainly concerns the use of pellet heating systems for buildings; at municipal level, smaller biomass plants for combined heat and power generation; and in terms of large-scale plants, the potential conversion of wood biomass into electricity in former coal-fired power plants. Overall, however, none of these options currently plays a prominent role in energy supply, and their use has so far been largely limited to individual applications.

71. However, the appeal of using wood biomass to generate energy could grow strongly in the course of an accelerated energy transition in line with ambitious climate targets, and the number of such plants could increase. The plans being made by European energy companies alone to switch from coal to biomass require roughly as many wood pellets as are currently being produced worldwide (Sandbag 2019). This would require a forest area half the size of the Black Forest every year (ibid.), even if the plans initially favour the use of wood from thinnings and plantations. Because the available volume of wood biomass from residual and waste materials is limited, the likelihood is that this would in future include higher proportions of stemwood harvested specifically for use as fuel (AGOSTINI et al. 2014; SEARCHINGER et al. 2018). Since the potential for this in Germany and Europe is limited due to effective regulations, this could be a considerable threat to the world's forests in the long term, because their economic use would become attractive on international markets. So far, this market has been largely left untouched by effective regulation (SCHLESINGER 2018).

72. This development can also be expected to accelerate if the price of greenhouse gas emissions allowances from fossil sources increases the pressure on energy producers to switch to alternative energy sources for economic and legal reasons. Operators of fossil power plants may hope to make the transition to a renewable fuel by burning wood biomass, which would allow power plants to continue operating. Such an expansion of the use of wood biomass, including from stemwood, is all the more likely because many existing regulatory systems currently classify it as virtually greenhouse gas neutral and thus make it eligible for the fulfilment of climate targets (STERMAN et al. 2018). This applies, for example, to the Renewable Energy Directive 2018/2001, which was amended at the end of 2018. This directive assumes that the use of wood chips from stemwood to generate heat or electricity can in many cases be assumed to be virtually climate neutral.

73. Significantly greater use of global forests for energy in the future conflicts with respecting the planetary boundaries and with efforts towards forest protection and reforestation around the world. In order to avoid significant adverse developments with serious environmental risks, an early, targeted and effective political regulation of the use of wood biomass, in particular from stemwood, is required. This must be done before the widespread use of biomass for energy generation and a corresponding market has established itself due to inadequate regulation (REID et al. 2020).

In the following section, we will look closely at two subsidiary aspects of a problem which overall is much broader in scope and which has to be assessed in detail on a differentiated and case-specific basis. Firstly, we will consider the sources from which the additional volumes of wood biomass required might come, and whether from an environmental and social perspective these are available on a sustainable basis. Secondly, we will examine whether the use of wood biomass from stemwood for energy production is really as climate friendly as is claimed (BRACK 2017).

Limited availability of ecologically sustainable biomass from stemwood

74. It is not possible to deduce from individual current examples of the use of wood biomass from stemwood for energy that such use can be scaled up to much larger volumes on a sustainable basis. There is a danger that sharply increasing demand will be met by the international biomass market, as existing sustainability criteria limit the volumes available from German and European production. The international market already plays an important role in today's comparatively small-scale use. From a global perspective, North America is a major producer of wood pellets, while Europe is globally significant in terms of consumption (THRÄN et al. 2019).

A well-known example for the import and extensive combustion of wood pellets is the Drax power station in Great Britain. There, several coal-fired power plant units were first converted to co-firing and then to the exclusive use of biomass. In 2017, Drax imported 59 % of its pellets from the USA and 24 % from Canada (Drax Group 2018). This encouraged the commercial exploitation of forests and plantations, especially in the USA (DALE et al. 2017). Pellets produced in the southern USA are also made from stemwood (WALKER et al. 2015, p. 21). New wood fired power plants are also under construction in other countries such as France, Belgium, Denmark and the Netherlands, and existing coal fired power plants are being converted for co-firing of wood biomass (OSTERATH 2017; REID et al. 2020, p. 7).

Against this background, an insufficiently regulated expansion of the use of wood biomass from stemwood for energy production must be carefully scrutinised, even if some of the actors involved describe it as sustainable because of its plant origin. Both the volumes that can realistically be made available on a sustainable basis and the national, European or global sources that can be used for this purpose must be scrutinised. Likewise, the overall ecological effects and the criteria to be applied must be carefully examined.

75. Sweeping references to sustainability criteria in the regulation of the wood biomass supply chain are often not helpful with regard to the global market. Existing sustainability criteria are often not sufficient to effectively regulate ecological and social conditions of production. This is particularly the case where there are strong economic incentives to use biomass. This can make suitable land areas into an increasingly attractive economic resource. As the example of the demand for palm oil from the European food industry shows, negative impacts resulting from international demand often cannot be prevented in spite of numerous regulations. The draft of the new Renewable Energies Directive was also criticised by the scientific community on the grounds that the sustainability criteria used fall short of those in the old Directive. This applies above all to the consideration of nature conservation issues in the use of wood biomass from forests (SEARCHINGER et al. 2018; HENNENBERG et al. 2018). The new sustainability criteria also contain only weak provisions regarding the climate impact of biomass use.

Carbon balance of the use of wood biomass for energy

76. The use of wood biomass for energy in the interests of climate protection is often predicated on the assumption that it is partially or largely emissions-neutral, because combustion emits only as much CO_2 as the plant has already absorbed during growth or will absorb in the future during regrowth (HABERL et al. 2012). However, these intuitively plausible considerations often fail to stand up fully to more detailed scientific analysis (NORTON et al. 2019). They are usually justified in the case of highly productive crops with a short rotation period, or when residual and/or waste wood is used (TER-MIKAELIAN et al. 2015; BOOTH 2018). However, with regard to the use of freshly cut stemwood from forests or slow-growing plantations, the net carbon balance generally looks different. This is due to several factors which are frequently not sufficiently taken into account in carbon accounting.

77. It can be stated as a general principle that wood is a much more inefficient energy source than coal, gas or oil. When electricity is generated in a biomass power plant, 50 % more CO_2 is emitted per unit of energy produced than is typically the case with coal, and approximately as much CO_2eq as with natural gas (SEARCHINGER et al. 2018, based on LAGANIÈRE et al. 2017 and IPCC 2006, chap. 2, Tab. 2.2). Therefore, when biomass is burned, more CO_2 initially escapes into the atmosphere at the chimney than would be the case with a comparable fossil fuel plant. The postulated mitigation effect thus relates in its entirety to the net carbon balance and to the expectation that the emitted quantity of CO_2 is removed from the atmosphere either beforehand or afterwards.

However, the fact that biomass has grown through absorbing CO_2 before it is burned, and that vegetation acts in this way as a natural carbon sink, does not necessarily mean that this carbon represents CO_2 credit that can be accounted for as climate-neutral energy production. The natural sink function of global vegetation has already been taken into account in models for the projected evolution of global warming and thus in the formulation of climate targets, more specifically in the sensitivity of the climate system to emissions (item 9). Only additional anthropogenic sinks created over and above natural sinks (sec. 2.3.3.1) constitute new CO_2 credits for potential use. The mere presence of a sink is not a sufficient criterion.

The use of wood biomass for energy production at a given location therefore usually means initially taking on a "carbon debt", which is only subsequently redeemed by the regrowth of the forest or plantation. However, it can take decades before the CO_2 emissions caused by the use of stemwood are subsequently removed from the atmosphere. Depending on the type of plantation, it can take between a decade (in the case of fast-growing plantations) and a century (in the case of forests in temperate zones) until the debt is paid off. Over a number of decades, therefore, the use of stemwood harvested from existing forests specifically for the purpose of energy production can actually lead to an increase in greenhouse gases in the atmosphere compared to the use of fossil fuels. Greenhouse gas savings will only be achieved after several decades or even centuries (AGOSTINI et al. 2014; SEARCHINGER et al. 2018). The scientific term for this is the "carbon payback time" (STERMAN et al. 2018). Only after this period can a positive net balance be achieved, under favourable circumstances. However, counting this as a credit today means drawing up the balance sheet well before the debt is actually redeemed.

78. Furthermore, it is often argued that coupling the use of biomass for energy with CCS, as may be possible in future, would lead to a significantly more favourable net carbon balance. Here, too, questions arise as to the ecological compatibility of the quantity of biomass needed and of the CCS technology to be used, which has not yet been successfully deployed on a large scale (see sec. 2.3.3). Using biomass to produce pyrolysis products such as biochar which can be applied to soil is certainly the most attractive option from a climate and environmental point of view. However, the associated problems mean that detailed and precise assessments are needed (SCHMIDT, H.-P. et al. 2018).

79. Moreover, the net carbon balance should not include the absolute size of an anthropogenically produced sink, but only the difference to an alternative use of the land. This applies especially to the alternative of the retention of existing non-utilised biomass, which can sometimes have a greater sink effect than utilisation for energy. In Central Europe in particular, forests are often far below their maximum possible carbon content due to centuries of use. So they continue to sequester CO_2. Although a forest that is renewing following logging grows at a faster rate, it contains less carbon overall. It is not the sink effect of a new plantation that is decisive, but the difference between that and the previously existing vegetation. Figure 2-9 illustrates that the carbon content of an area of forest that is regularly harvested is lower than that of an unmanaged forest (HOLTSMARK 2012).

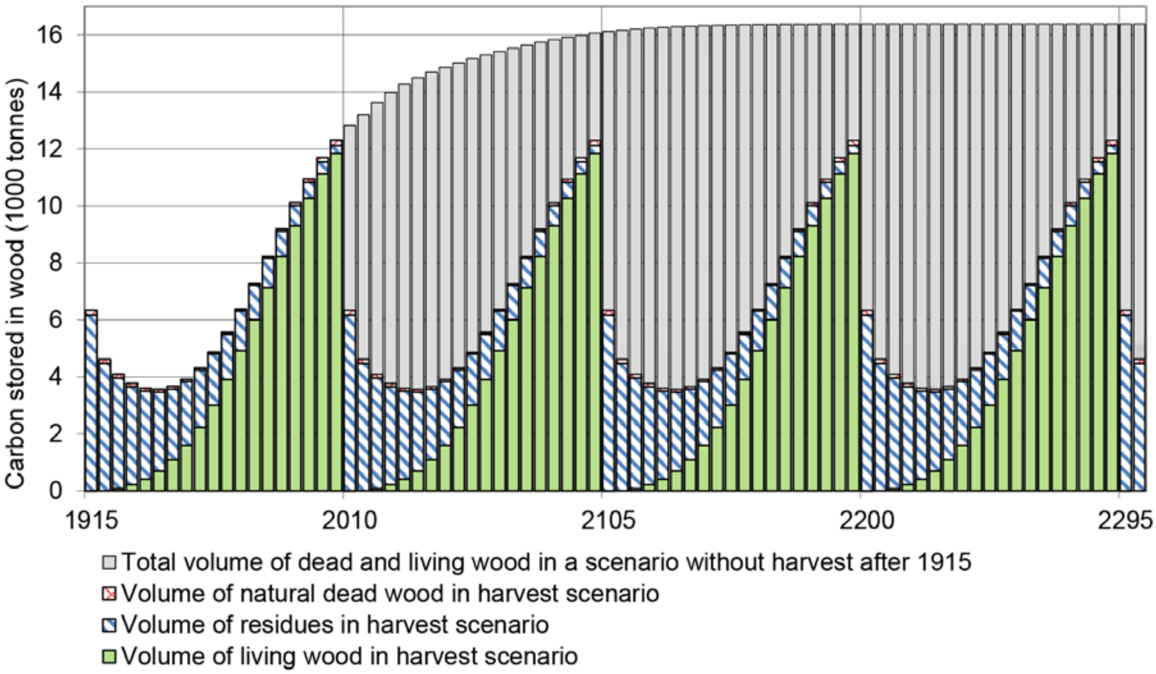
However, if the harvested wood is used, a positive net greenhouse gas balance can still be achieved in principle. For example, a positive net greenhouse gas balance can exist for long-lasting wood products which replace energy- or greenhouse gas-intensive products, even though the forest's carbon stock has been reduced by logging (LIPPKE et al. 2010; JOHNSTON and RADELOFF 2019). This calculation depends both on how much CO_2 is stored in the wood products and on their substitution effect, i.e. on which raw material or product the wood replaces (HENNENBERG et al. 2019). In the case of the use of stemwood for energy, however, carbon storage does not occur because of their combustion. With the CO_2 storage balance approach, alternative use scenarios can be included in the net carbon balance of wood products. This approach calculates the amount of CO_2 per cubic metre of harvested wood that is additionally stored or not stored due to forest management and the use of wood in products (HENNENBERG et al. 2019).

80. Another argument often put forward is that the balance sheet must be drawn up for multiple logging sites in a country, or for the whole country: if timber is felled at one site, it is already being replaced elsewhere. For managed forests, however, this simply means that after a carbon debt is incurred in one place, another debt is incurred later in another place, even if the original carbon debt is possibly partially redeemed. Repaying a carbon credit by taking out another credit means that, in the overall balance sheet, a debt remains, that is, a reduced total amount of carbon stored on the land surface. If no logging is carried out, the carbon stock is maintained (HOLTSMARK 2012).

81. Another factor that is often inadequately reflected in net carbon balances is the spatial displacement effects that can result from the use of land for the production of wood biomass for energy. As demand for wood biomass increases, this option becomes econom-

Figure 2-9

The carbon content of forests as a function of their management



The figure shows the amount of carbon stored in dead and living wood biomass on an area where clear-cutting takes place in 2010, 2105, 2200 and 2295 (green, blue and red bars), and with no logging after 1915 (grey bars).

Source: HOLTSMARK 2012

ically more attractive and may displace other forms of use, such as food production in other parts of the world, because large areas are needed for biomass plantations. Due to the growing world population, the demand for agricultural products will increase. If areas on which wood biomass is grown for energy are no longer available for food production, other areas will be used to supply the market, possibly also in other regions of the world. Investigations show that taking into account the carbon balances of all the relevant sites, including spatial effects and assuming constant demand for products, can lead to significantly different, often significantly worse net CO_2 balances than the overly narrow but common practice of considering each site individually (SEARCHINGER et al. 2018). This is a direct consequence of the fact that land is a limited resource and that differently managed or uncultivated land areas sometimes represent a natural CO_2 sink or may hold a higher carbon content. These sinks should be protected as part of wider climate protection strategies.

82. However, greenhouse gas accounting for the use of wood biomass for energy often fails to take into account the above-mentioned aspects of forest management and thus the emissions from the harvesting of wood, or does not do so sufficiently (HENNENBERG et al. 2019; NORTON et al. 2019; SEARCHINGER et al. 2018). Since the coming years and decades are crucial for meeting the Paris climate targets, the use above all of stemwood from existing forests which is harvested specifically to be used for energy should generally be considered counterproductive and ecologically harmful from the perspective of reducing greenhouse gas emissions (MITCHELL et al. 2012).

In particular, however, the use of wood biomass from stemwood for energy stands in blatant contradiction to other objectives of environmental and sustainability policy, which aim to protect the integrity of the biosphere as an important climate regulating component of the Earth system. Recycling and the sparing use of paper and cardboard products are long-established measures for the protection of forests. Campaigns to reduce the use of disposable coffee cups and other packaging and cardboard products aim to encourage the sparing use of wood as a resource. The international efforts to protect and renew forests are in the service of climatic, ecological and social goals. These would be undermined if the harvesting of stemwood for energy use were at the same time being enabled or even encouraged in the name of climate protection and sustainability.

83. It is beyond dispute that the use of stemwood in addition to waste and residual biomass can also be an environmentally friendly form of energy production in small quantities, in some local and regional contexts and under managed conditions. However, when it is scaled up to the quantities required for effective climate change mitigation, there is a risk of depletion of the Earth's often poorly protected forests. This is in contradiction to the strict observance of planetary boundaries. If demand increases in the course of the energy transition, wood biomass could become a highly sought-after and economically attractive resource. As the overuse of land is already the main reason for the progressive loss of habitats today, this would be a dangerous development, especially in view of the simultaneous growth of the world population and of efforts to increase using biomass for a future bio-economy. Although biomass is a renewable resource, the Earth's forests and their associated ecosystems should not become the next case study in the over-exploitation of the Earth.

2.4 Governance: the key to remaining within the CO_2 budget

84. Although there is broad political agreement that the Paris Agreement forms the foundation of German climate policy, there is a large discrepancy between this and its implementation at national level. For example, the German climate targets, which were already set before the adoption of the Paris Agreement, are not Paris-compatible in terms of a fair distribution of the global climate budget (see item 36). Even though the level of ambition of the existing targets cannot be considered sufficient, they will not be met. For example, Germany is likely to fail to make a fair contribution to the European climate targets in 2020 and possibly also to meet its own national climate target of reducing greenhouse gas emissions by 40 % compared to 1990. German climate policy thus suffers from both an ambition gap and an implementation gap (for the distinction, see Box 2-3).

85. Chapter 2.2 showed why credible climate protection contributions by the signatory states are a prerequisite for the success of the Paris Agreement. The key to better compliance with the targets and better implementation of climate protection contributions is climate governance. This is understood here to mean the totality of the rules and institutions that ensure the implementation and monitoring of climate policy commitments. Climate and energy policy, which are linked, operate in a multi-level system involving international, supranational (or European) and national levels. Climate policy is thus a typical example of multi-level governance (JÄNICKE 2017, p. 110 et seq.). For Germany, the climate and energy policy of the EU is of particular importance. Germany's climate targets and climate policy can also only be understood in the context of the European regulatory framework. The following sections will therefore first describe European and then national climate governance. Based on this, proposals will then be made as to how the latter can be improved in such a way that it provides greater support for ensuring compliance with the Paris climate targets.

2.4.1 EU climate governance

86. The EU decided to submit a joint European climate protection contribution under the Paris Agreement. As the member state responsible for the largest proportion of European emissions (around 21 %), Germany bears a considerable responsibility for ensuring that the European reduction contribution can be achieved.

2020 and 2030 climate targets and European climate protection commitments

87. With the Climate and Energy Package 2020 (European Commission 2008) and the framework for climate and energy policy up to 2030 (European Council 2014) based on it, the EU set itself what are for the most part binding Europe-wide climate and energy targets. For example, greenhouse gas emissions are to be reduced by at least 40 % by 2030 compared to 1990 levels, a figure that is expected to rise significantly to between 50 % and 55 % under the European Green Deal in summer 2020. Furthermore, the proportion represented by renewable energies in gross final energy consumption is to be at least 32 % by 2030 according to decisions already taken. Gross final energy consumption, as a measure of energy efficiency, is

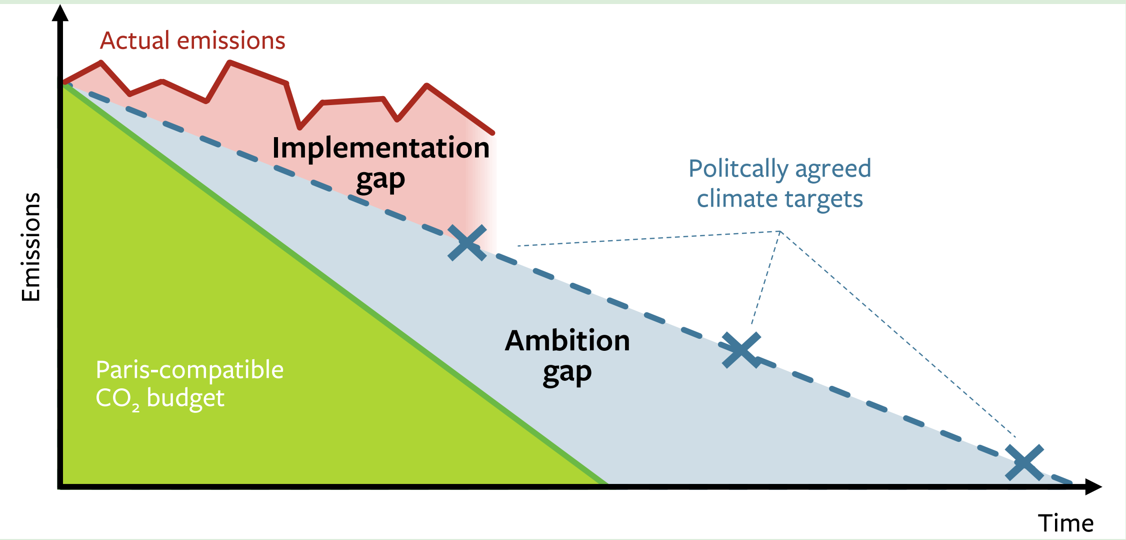
Box 2-3: The ambition gap and the implementation gap in climate policy

The effectiveness of climate governance can be assessed on the basis of two criteria (see Fig. 2-10):

- Ambition level or ambition gap: Are the existing goals ambitious enough, and are interim goals defined that will help make their achievement likely? Is there continuous monitoring of the compatibility of national climate protection targets with a CO_2 budget derived principally from the Paris Agreement?
- Target achievement or implementation gap: Are the agreed climate targets properly taken into account in political decision-making, and are the necessary climate protection measures adopted? Are there political mechanisms in place to respond to an imminent or actual (partial) failure to meet targets?

Figure 2-10

Schematic representation of the ambition and implementation gaps in climate policy



SRU 2020

In terms of the level of ambition of its climate and energy policy, Germany was formerly one of the leading states. However, there is an ambition gap vis-à-vis the Paris Agreement, which is why the climate targets urgently need to be amended (sec. 2.2.4.2; see also SRU 2016a, p. 4 et seq.; 2016c, p. 4 et seqq.). To this end, the carbon budget should be used as a measure of the Paris compatibility of the climate targets (item 109).

to be reduced in parallel by at least 32.5 % by 2030 compared to the reference scenario (see Table 2-3 on the EU's climate policy objectives for 2030). The European Commission is currently planning to adapt the energy-related targets and directives to the revised climate target in 2021 (European Commission 2019b, p. 5).

88. The EU is already operationalising its climate target for 2030 as a binding greenhouse gas budget to ensure that a 40 % reduction in greenhouse gas emissions compared to 1990 is achieved by that date. Legally, this is done via the Effort Sharing Regulation and the EU ETS. This also has consequences for the climate policy obligations of the member states. Separate regulations apply to emissions from LULUCF, but not to those from agriculture. The LULUCF Regulation (EU) 2018/841 stipulates, among other things, that starting in 2021 the LULUCF sector must be greenhouse gas neutral by the end of the decade. The section that follows will focus primarily on emissions excluding land use.

For major emitters, i.e. mainly power stations and industrial plants as well as EU air traffic, the EU ETS is the central climate policy instrument. It defines annual emis-

Table 2-3

Selection of EU climate and energy policy targets for 2030

	2018[1)]	**2020 targets**	**2030 targets (in line with informal trilogue agreement)**	**Notes**
Greenhouse gas emissions				
Greenhouse gas reductions **(vs. 1990)**	23,2 %	at least 20 %	at least 40 %	binding
Greenhouse gas reductions within EU ETS **(vs. 2005)**	29 %	21 %	43 %	binding
Greenhouse gas reductions in non-ETS sectors **(vs. 2005)**				
EU overall	11,3 %	10 %	30 %	binding
Germany	7,7 %	14 %	38 %	binding
Renewable energy				
Share of renewable energy in gross final energy consumption				
EU overall	18 %	20 %	at least 32 %	binding
Germany	16,7 %	18 %	no country-specific targets, but instead national target contributions which must add up to the binding EU target	binding
Efficiency and consumption				
Reduction in energy consumption				
EU overall	10,1 % reduction in primary energy consumption vs. 2005	by 20 % (amounts to a 13 % reduction in primary energy consumption vs. 2005)	by at least 32,5 %	indicative for 2020, not defined for 2030
in individual EU member states		indicative national contributions to meeting the targets	no country-specific targets, but instead national target contributions which must add up to the binding EU target	indicative
		additional cumulative final energy savings of 1.5 % per year	additional actual cumulative final energy savings of 0.8 % per year	binding

Source: BMWi 2019a, p. 31, adjusted; 1) preliminary figures as per EEA 2019b sions ceilings applying to emitters. Tradable emissions allowances ensure that the contribution of these sectors to the greenhouse gas reduction target is achieved in an economically efficient manner across Europe. Consequently, there are no fixed national contributions to this target, since the location where emissions are reduced depends, among other things, on the specific abatement costs. Around 42 % of EU-wide emissions are covered by the EU ETS, and those emissions in the current target system are to be reduced by 43 % by 2030 compared to 2005.

Emissions from small point sources are not covered by the EU ETS. This relates in particular to transport, agriculture and buildings, but also, for example, to smaller industrial facilities. For these emission sources, hereinafter referred to as non-ETS sectors, the EU has adopted binding national annual ceilings for greenhouse gas emissions for the period 2013 to 2020 under Effort Sharing Decision No. 406/2009/EC and for the period 2021 to 2030 under the Effort Sharing Regulation or Climate Action Regulation (EU) 2018/842. The European target of a reduction of 30 % by 2030 compared to 2005 was divided up among the individual member states. The economically stronger member states will have to meet more ambitious reduction targets than the weaker ones.

German obligations within the framework of European climate policy

89. Of the European climate targets for 2020 (see Table 2-3), Germany can probably only meet the renewable energy target. Emissions in the non-ETS sectors are likely to exceed the reduction target and budget (see Box 2-4). The efficiency target for 2020 will not be met either.

The Effort Sharing Regulation for the period up to 2030 currently requires Germany to reduce greenhouse gas emissions in the non-ETS sectors by 38 % by 2030 compared to 2005. Binding emissions allocations are determined annually in line with a reduction path, from which a cumulative binding greenhouse gas budget for the German non-ETS sectors can also be calculated for the period from 2021 to 2030. Since the starting point of this path from 2021 is determined using the final greenhouse gas inventories for the period 2016 to 2018, the budget can only be calculated conclusively in the second half of 2020 when the full data are available. Based on the provisional German greenhouse gas emissions figures for 2018 (EEA 2019b, p. 92), it should be around 3,645 Mt CO_2eq (authors' calculation based on the emissions figures in EEA 2019b, p. 92; 2018, p. 86).

Under the Federal Climate Change Act (see item 95), emissions in 2030 across all sectors are to be around 543 Mt CO_2eq (see Table 2-2). If it is assumed that 90 % of emissions from the energy sector and around 75 % of emissions from industry are covered by the ETS (analogous to the calculations in Agora Energiewende and Agora Verkehrswende 2018, p. 34), the emissions from the non-ETS sectors could amount to around 280.5 Mt CO_2eq in 2030 in accordance with the permissible annual emissions in the Federal Climate Change Act. This would be only slightly less than the annual emissions allocation of 296.2 Mt CO_2eq under the Effort Sharing Regulation (EEA 2019b, p. 94). For the remaining period from 2021 to 2030, the total annual emissions from the non-ETS sectors under the Federal Climate Change Act are also not far from the maximum binding annual emissions allocations under the Effort Sharing Regulation.

90. The level of ambition of the Federal Climate Change Act is thus compatible with existing European commitments up to 2030, provided that climate targets and annual emissions levels are met. This assumes, however, that there is no implementation gap. According to an estimate which takes into account the measures in the Climate Action Programme 2030, emissions in the non-ETS sectors will be reduced by around 27 % by 2030 compared with 1990, leaving a gap of around 11 percentage points (HARTHAN et al. 2020). For this reason, the successful implementation of adequate programmes of measures for the individual sectors is of central importance.

Governance Regulation

91. In December 2018, the Governance Regulation No. (EU) 2018/1999 for the Energy Union and Climate Action was adopted. This creates reporting and monitoring obligations with respect to the climate and energy targets of the member states. Like the Paris Agreement, the European Commission is relying here on the effectiveness of naming and shaming. The logic behind the governance system and the reporting obligations on the nation states can therefore broadly be compared to the NDCs at the international level (SCHLACKE and LAMMERS 2018, p. 426).

The greenhouse gas reduction target or budget is made legally binding on the individual member states via the combination of the Effort Sharing Regulation and the EU ETS. However, the states bear joint responsibility for achieving the European expansion target for renewable energies in 2030 (SCHLACKE and LAMMERS 2018, p. 425). The national contributions to this target are initially determined by the member states themselves.

The energy efficiency target for 2030 is only indicative (ibid.). As there are no binding targets with respect to renewable energy or energy efficiency for member states, the adoption of appropriate measures and the achievement of the European target depend to a large degree on possible monitoring and evaluation procedures. Only in this way can it be determined whether the sum of national efforts will be sufficient to achieve the European targets.

92. The core instrument of the Governance Regulation are the National Energy and Climate Plans (NECPs), which are to be drawn up by the member states on a mandatory basis. These are drawn up for a period of ten years. The first planning period is from 2021 to 2030, and the final plans were to be submitted by the end of 2019. Through the NECPs, the Governance Regulation implements detailed monitoring and reporting obligations for the member states, and provides for progress in energy and climate policy to be assessed and monitored by the European Commission (PAUSE and KAHLES 2019, p. 11). This should first of all ensure the coherence and compatibility of national strategies and the attainability of the European targets for 2030 (Leopoldina – Nationale Akademie der Wissenschaften et al. 2018, p. 26). By means of a so-called gap-filling mechanism, the European Commission aims to ensure that the common objectives can be achieved even if there is a lack of ambition in the NECPs or poor implementation. Among other things, the European Commission will be able to make recommendations to the member states for the achievement of the renewable energy or energy efficiency target in the event of an implementation gap. Options for sanctions by the European Commission vary depending on the objective. However, infringement proceedings would only be conceivable if clearly inadequate measures were being taken to achieve the renewable energy target (SCHLACKE and LAMMERS 2018, pp. 433-435).

In Germany, the Federal Ministry for Economic Affairs is currently responsible for drawing up the NECP, and in doing so it aggregates the existing national energy and climate policy goals and measures. The first draft NECP was submitted to the European Commission at the end of 2018, and the Commission delivered a preliminary assessment of the member states' drafts in June 2019. It deemed the measures contained in Germany's draft NECP to be insufficient to guarantee that the greenhouse gas reduction targets for 2030 would be met (European Commission 2019a). However, it was inevitable that the German NECP draft would remain vague, because at the time of publication the Federal Government and the Bundestag had not yet reached agreement on the Federal Climate Change Act and the Climate Action Programme 2030.

In future, the Governance Regulation will require the submission of a progress report on the achievement of the targets by the member states every two years from 2023 onwards. In addition, the NECP can be updated, and its level of ambition can be raised, in 2023, on a one-off basis.

The EU's long-term strategy up to 2050, and the agenda of the new European Commission

93. The EU's target up to now has been to reduce greenhouse gas emissions by 80 to 95 % by 2050. The long-term strategy up to 2050 is currently being negotiated at EU level (UBA 2018a). This is to be adapted to the requirements of the Paris Agreement, and in particular the 1.5-degree-target, for which the current target corridor of 80 to 95 % is insufficient (European Commission 2018a, p. 17). The European Council decided in December 2019 to support the goal of greenhouse gas neutrality by 2050 (European Council 2019, p. 1). The government of Poland has not yet been able to agree to these Council conclusions, which is why the issue will be raised again at the Council summit in June 2020. The aim is to reach a final agreement by late summer 2020 so that the long-term strategy can still be included in the renewed European NDC 2020. A further differentiation of climate change commitments could also be envisaged as a political compromise for the purpose of achieving a binding EU-wide target of greenhouse gas neutrality by 2050. For example, Poland could be allowed to achieve greenhouse gas neutrality only after 2050, while Western European countries in the vanguard would be required to reach a negative emissions balance before 2050 in order to balance sinks and emissions (GEDEN and SCHENUIT 2019, p. 3).

With the European Green Deal, the new European Commission has set ambitious climate protection at the heart of its political agenda. In addition to greenhouse gas neutrality in 2050, it has set itself the task of raising the level of ambition of the climate protection targets for 2030. This includes increasing the greenhouse gas reduction target to 50 to 55 %. As a result, the EU ETS and the Effort Sharing Regulation would probably need to be revised accordingly. It can be assumed that German emission allocations under the Effort Sharing Regulation will also decrease. This would mean that the German climate target for 2030 and the sectoral targets derived from it would not only be incompatible with the Paris

Agreement, but would probably also have to be revised to comply with European law (see item 89). The Federal Climate Change Act stipulates that in such an event the annual sectoral emissions levels would have to be adjusted (see item 96). However, if correspondingly ambitious climate protection measures are not taken in time, there is a risk that the target will again be missed, with corresponding financial consequences (see Box 2-4).

The draft European climate law presented by the European Commission could also incorporate mechanisms for raising the level of ambition in future in line with the Paris Agreement, as well as increased independent monitoring (MEYER-OHLENDORF and MEINECKE 2018, p. 26).

2.4.2 National climate governance

94. With the Integrated Energy and Climate Programme 2007 (Bundesregierung 2007), the Federal Government set itself the goal of reducing greenhouse gas emissions by 40 % by 2020 compared to 1990. This goal was confirmed in the Energy Concept 2010 (BMWi and BMU 2010) and recognised by all subsequent federal governments.

As a result, a differentiated architecture of climate and energy targets (see Table 2-4) and monitoring has developed in Germany. The Climate Action Plan 2050 adopted by the German government in 2016 is of particular importance in terms of climate policy. It specifies the German climate protection targets, identifies strategic fields of action and defines sectoral emissions targets for 2030 (see sec. 2.2.4.3). The Climate Action Plan is to be reviewed and updated regularly. In addition, the plan will be monitored and supported by experts, for which purpose the steering committee for the Climate Protection Science Platform was set up in 2019.

In its annual climate protection report, the Federal Government provides information on its progress towards achieving its greenhouse gas reduction targets. In addition, it submits a projection report every two years as part of its European obligations. This report contains scenarios for the future evolution of greenhouse gas emissions and evaluates the effectiveness of climate protection measures already adopted and planned. Despite this, policy in Germany has repeatedly suffered from implementation gaps (see also Box 2-4). The weakness of German climate policy has so far been attributed in part to inadequate governance, commitment and involvement on the part of the legislator. For example, the energy and climate targets within the 2010 Energy Concept were adopted by the government but not passed into law. The lack of parliamentary approval and the lack of involvement of societal stakeholders has made it difficult to implement targets and adopt the necessary climate protection measures (DUWE et al. 2017, p. 5). Overall, the German climate targets have provided insufficient legal and planning security (RODI 2017, p. 753). For this reason, numerous actors have pointed out already that the adoption of a national climate protection law could help to strengthen the currently weak governance of German climate policy (DUWE et al. 2017; von LÜPKE and NEUHOFF 2019; RODI 2017; SRU 2013, p. 132).

The Federal Climate Change Act as a milestone in German climate policy

95. With the Federal Climate Change Act, which was passed by the German Bundestag in November 2019, climate policy in Germany will for the first time have a legally binding basis. The Climate Action Programme 2030 adopted by the Cabinet, which consists of numerous sectoral measures together with the national Fuel Emissions Trading Act (BEHG), is intended to ensure that the greenhouse gas reduction target of 55 % by 2030 is achieved (BMU 2019b; for the relationship between the budget approach and climate protection instruments, see Box 2-5). The SRU emphatically welcomes the adoption of the Federal Climate Change Act. The Act brings the importance of climate targets, clear responsibilities for implementation and regular monitoring of progress in reductions into the centre of the political debate. Climate protection laws can help to make the goals, planning and monitoring of climate protection more binding. In this way they can contribute to the professionalisation of governance (DUWE and STOCKHAUS 2019, p. 11).

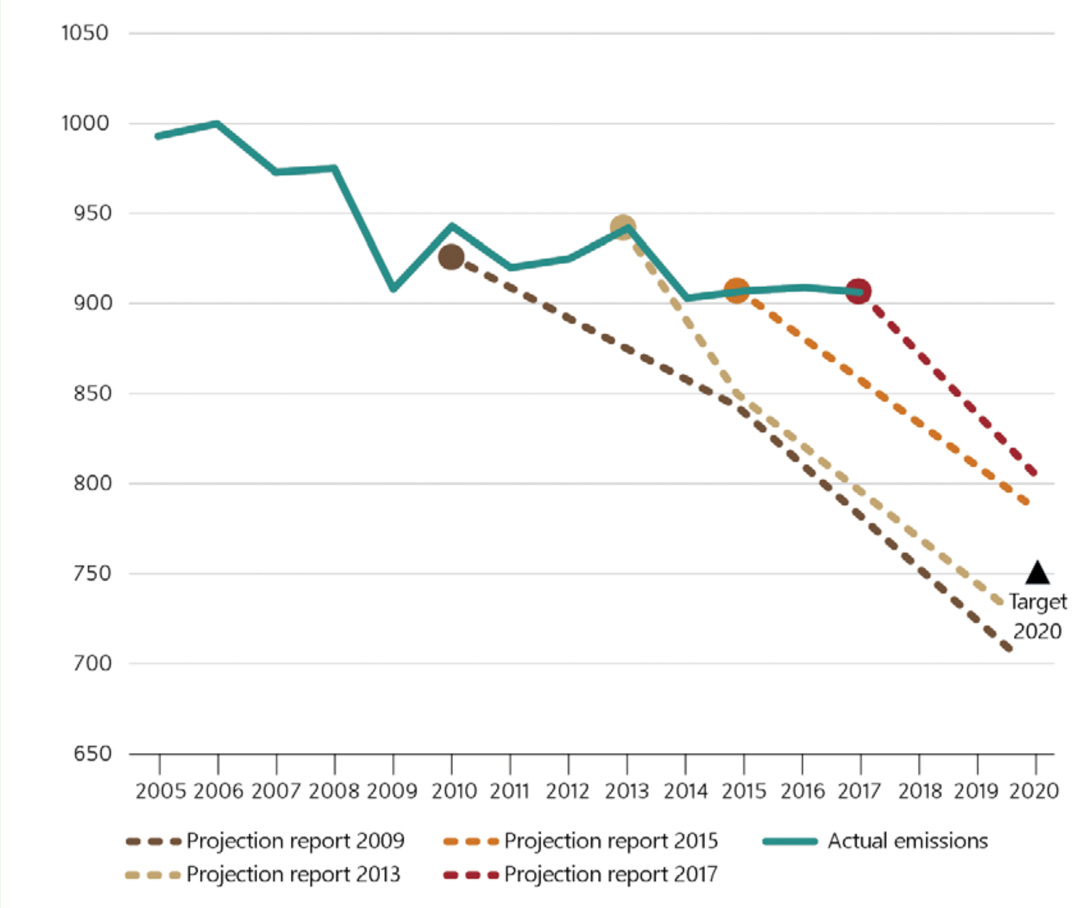
The Federal Climate Change Act brings together the Climate Action Plan and the climate protection programmes. The government's own Climate Action Plan 2050 takes a long-term perspective and outlines the framework and goals of future climate policy. The Federal Climate Change Act, on the other hand, primarily regulates the medium-term operationalisation of these targets, currently up to 2030. This ensures that appropriate and sufficient climate protection measures are taken in the form of climate protection programmes in order to achieve the reduction target of 55 % by 2030 and to meet European climate protection obligations. These measures are to be adopted both after the climate protection plan has been updated (§ 9 of the Climate Change Act) and after any implementation gap has been identified (emergency

Box 2-4: Germany's failure to meet climate policy targets and the resulting financial consequences

German climate policy suffers from an implementation gap. For example, Germany will probably fail to meet its national climate target (Table 2-4) of reducing greenhouse gas emissions by 40 % by 2020 compared with 1990. Germany will also fail to meet its European obligations (item 89). Although there was no lack of public political commitments to the German and European climate targets for 2020, there was no adequate response to a looming failure to meet the target which was both foreseeable from an early point and indeed repeatedly forecast, and adequate additional measures were not taken (DUWE et al. 2017, p. 27). This reflects the gap in climate policy between the abstract commitment to planetary boundaries as the guard rails for political action and the concrete level of ambition of political strategies and programmes, a gap which is also visible in other areas of environmental policy (SRU 2019, item 256).

Figure 2-11

Actual and projected greenhouse gas emissions in Germany taking into account agreed climate policy measures (in Mt CO_{2eq})



Source: von LÜPKE and NEUHOFF 2019, p. 78, translated

Since 2015, the projection reports produced by the German government (BMUB 2015; 2017, p. 32) have concluded that the 2020 reduction target of 40 % will probably not be met (see Fig. 2-11). Even so, some commentators criticised the scenarios on which the projection reports were based and their underlying assumptions as too optimistic. As a result, the tendency was to underestimate the climate protection gap (Agora Energiewende 2017), and actual emissions have in fact regularly exceeded those in the projection reports (von

LÜPKE and NEUHOFF 2019, p. 77). In addition, the expert commission for the monitoring process entitled "Energy of the Future" set up by the German government repeatedly pointed out the danger that the target might not be met (LÖSCHEL et al. 2019, p. Z-14). The Federal Government acknowledged the implementation gap for the first time in the coalition agreement (CDU, CSU and SPD 2018, p. 142), but no immediate measures were taken to close it by 2020. From the analysis of how this implementation gap has come about, conclusions can be drawn with regard to the appropriate allocation of departmental accountability and monitoring which should be laid down in the Federal Climate Change Act (see sec. 2.4.3).

The consequences of missing the target from a budget perspective, and possible financial risks

An implementation gap that prevents the achievement of a point target such as the 2020 greenhouse gas reductions target has significant consequences. For example, it results in a substantial increase in the annual reduction rate compared to the last decade (LÖSCHEL et al. 2019, p. Z-11). Average greenhouse gas reductions between 2010 and 2017 amounted to only about 5 Mt CO_2eq per year, a rate that must be increased roughly fivefold if the Federal Government's climate targets for 2030 are to be met (authors' calculation, based on emissions figures in UBA 2019a).

Particularly in view of budgetary considerations, the identification of an implementation gap also demands additional tightening or even the overfulfilment of future targets: if a large proportion of a possible Paris-compatible budget has already been used up in the past, an even more ambitious reduction will be necessary in the future in order to ensure that it is still met. Given the limited effectiveness of climate policy over the past decade and the failure to meet the interim targets, the already limited scope for making the necessary decarbonisation and the associated wider transformation as socially acceptable and economically efficient as possible has been yet further reduced (item 37).

While the failure of the German government to meet its national climate targets will not initially have any direct legal consequences, the situation is different with regard to the European climate protection obligations. As things stand at present, Germany is failing to make its contribution to the Effort Sharing Decision because annual emissions in the non-ETS sectors exceed the European provisions. Despite overfulfilment in the early years, Germany will probably not be able to meet either the total budget of permitted emissions for the period from 2013 to 2020 or its European greenhouse gas reductions target for 2020 (EEA 2019b, p. 34). If this happens, Germany will be obliged to purchase emissions allocations from other member states that have overachieved their reductions target for the same period. According to some estimates, this could entail costs of in the hundreds of millions by 2020 (GORES and GRAICHEN 2018).

Since the European Effort Sharing Regulation also defines binding annual emissions budgets for the non-ETS sector for the period 2021 to 2030 (item 88), there is a clear risk that this too will be missed by a substantial margin if the Climate Action Programme 2030 does not achieve the hoped-for and necessary reductions, as has been forecast (HARTHAN et al. 2020).

For Germany, only the crediting of surpluses from the LULUCF sector, which is limited to 22.3 Mt CO_2eq under Annex III of the Effort Sharing Regulation, and the purchase of emission allocations from other member states can be considered as flexibilities. However, the LULUCF sector in Germany could turn from a greenhouse gas sink into an emitter over the next decade (BMU 2019c, p. 190). The primary flexibility option should therefore be seen in the purchase of surplus emission allocations from other member states. However, it is unclear how many surplus allocations will be available and at what price other member states would be willing to transfer. It is also conceivable that climate-policy pacesetters will retire their surplus emission allocations, as Sweden has already done in the past (APPUNN 2019). Statements regarding the possible costs of acquiring emission allocations therefore entail a high degree of uncertainty, but they have been estimated (excluding measures under the Climate Action Programme 2030) to amount to up to EUR 62 billion for the period 2021 to 2030 (Agora Energiewende and Agora Verkehrswende 2018, p. 28). This means that they also represent a risk for the federal budget.

In order to reduce the risk of costly climate policy implementation gaps, departmental accountability has been strengthened in the Federal Climate Change Act, as have the annual emissions quantities provided for there up to 2030. Strengthening the Council of Experts on Climate Change could also help to prevent implementation gaps from arising in the future (see sec. 2.4.3).

Table 2-4

Selected climate and energy policy goals for Germany

	Status Quo (2018)	2020	2030	2040	2050
Greenhouse gas emissions					
Greenhouse gas emissions (vs. 1990)	– 30,8 %1)	at least – 40 %	at least – 55 % in the form of annual sectoral emissions totals in the KSG	at least – 70 % (Climate Action Plan 2050)	Greenhouse gas neutral (KSG) – 80 to – 95 % (Climate Action Plan 2050)
Renewable energy					
As proportion of gross final energy consumption	16,7 %2)	18 %	30 %	45 %	60 %
As proportion of gross electricity consumption	37,8 %2)	at least 35 %	at least 50 % EEG 2017: 40 to 45 % by 2025	at least 65 % EEG 2017: 55 to 60 % by 2035	at least 80 %
Efficiency and consumption					
Primary energy consumption (vs. 2008)	– 7,9 %3)	– 20 %			– 50 %
Gross electricity consumption (vs. 2008)	– 3,9 %3)	– 10 %			– 25 %
Final energy productivity (2008–2050)	1,0 % per annum (2008–2017)	2,1 % per annum (2008–2050)			

Source: BMWi 2019a, p. 16, adjusted; 1) „Klimabilanz 2018: “4,5 Prozent weniger Treibhausgasemissionen“, Joint press release of UBA and BMU, 2 April 2019; 2) UBA 2019e; 3) BMWi 2019b; AGEB 2019

programme pursuant to § 8 of the Climate Change Act). It is unclear, however, why the updating of the Climate Action Plan, which is also scheduled on a regular basis, is not explicitly mentioned and prescribed in the Federal Climate Change Act, especially since the Federal Government is already behind schedule in this regard.

96. The Federal Climate Change Act initially stipulates that greenhouse gases must be reduced by 55 % by 2030 (§ 3 sec. 1 KSG). However, the commitment to pursue greenhouse gas neutrality by 2050 is only mentioned as one of the aims of the law and is not further specified. The Act provides for the possibility of tightening up national climate protection targets in future if this is necessary to meet European or international targets (§ 3 sec. 3 KSG). As explained, this is already necessary today, since the previous German climate targets cannot be considered Paris-compatible (see chap. 2.2). The raising of the European greenhouse gas reductions target for 2030 as envisaged would entail an adjustment of the European Effort Sharing Regulation, which would reduce the emissions budgets for the non-ETS sectors provided for there (see item 90). From this perspective, too, a swift and ambitious revision of the German climate targets seems necessary.

Box 2-5: The CO_2 budget as a benchmark for political climate protection measures

Irrespective of which policy measures are chosen for the implementation of the Paris Agreement at national and European levels, they should be in line with the CO_2 budget, which is based on natural science but also takes into account aspects of distributive justice. In order to check whether implementation is Paris-compatible, the CO_2 budget should also be used as an additional assessment basis for political instruments even if other targets or benchmarks are already in place at national or European level (see sec. 2.5). With the Paris Agreement, the Federal Republic of Germany committed itself in 2016 to align national policies in different areas and sectors with the agreement.

In the current climate policy debate, instruments for more robust CO_2 pricing play an important role. The introduction of CO_2 pricing can indeed be a climate policy instrument, although other instruments exist and even ambitious pricing alone would not be sufficient. It would have to be flanked by other measures that take into account not only climate policy objectives but also other sector-specific objectives, such as the promotion of energy efficiency improvements or the expansion of public transport infrastructure (BACH et al. 2019a). Through the integration of different sector-specific policies, wider social objectives such as improving the quality of life or road safety can be achieved jointly with climate policy objectives. Nevertheless, pricing is important, since the current system of charges and levies is neither consistently oriented to the CO_2 emissions resulting from use nor to the energy content of the energy sources (SRU 2019, p. 122; KEMFERT et al. 2019a). Heating and motor fuels, for which fossil fuels are predominantly used, would accordingly have to be priced higher (KEMFERT et al. 2019a; 2019b; BACH et al. 2019a; SRU 2019). Up to now, the building and transport sectors have made only a small contribution to climate protection compared with the electricity sector (for a comparison of percentage and absolute emissions levels, see BMU 2019a, p. 8). Achieving the sector targets by 2030 is unlikely without further measures for the buildings and transport sectors (BACH et al. 2019a, p. 32 et seq.).

CO_2 pricing is basically possible via emissions trading or taxation. Both instruments pursue the goal of reducing emissions in order to achieve climate policy goals. However, there are theoretical and practical differences between them (KEMFERT et al. 2019b; 2019c; BACH et al. 2019a). The basic advantages of emissions trading lie in its ecological target accuracy and static economic efficiency. The ecological accuracy results from the control it provides over quantity: the reduction targets can be achieved with a high degree of certainty by correctly determining the quantity of allowances (the cap) for the sectors concerned, which follows the same quantity logic as budgets. The static economic efficiency (cost efficiency) is a result of emissions trading being a market mechanism: free trade establishes a uniform price for each tonne of greenhouse gas emitted and covered by the trading system. This enables a cost-efficient internalisation of the external effects of emissions (FEESS 2007, p. 125), since only those emitters whose marginal abatement costs are below the price of additional allowances will reduce emissions. All other emitters will buy additional emissions rights on the market instead of carrying out their own reductions (FISCHEDICK et al. 2012, p. 123). Moreover, emissions trading is distinguished in economic theory by a high dynamic innovation effect (dynamic efficiency). This is the ability to stimulate advances in environmental technology (ENDRES 2013, p. 158). In a static analysis, the marginal abatement costs are given, whereas in a dynamic analysis learning curve effects are factored in. This means that the marginal costs of a technology can decrease due to increasing use and technological advances (FEESS 2007, p. 185; FISCHEDICK et al. 2012, p. 124).

However, implementation deficits in emissions trading can lead to inefficiencies in practice, as illustrated by the EU ETS, which is currently the main instrument for pricing greenhouse gas emissions within the EU (SRU 2015; BACH et al. 2019a). For emissions trading to be effective in terms of climate policy and ecologically accurate, an ambitious cap is an essential prerequisite. This should be based on the size of the CO_2 budget (GRONWALD and KETTERER 2009, p. 25; SRU 2017b, p. 125). Due to political enforcement difficulties, the EU ETS has suffered since its introduction in 2005 from over-allocation, and thus from prices that are too low, because the cap was set too high. Empirical observations suggest that the high dynamic efficiency that the EU ETS ought to be able to generate in theory has not yet in practice provided the incentives for radical innovations that are necessary for the achievement of the long-term climate policy goals (MATTHES 2010, p. 40).

Furthermore, extending the EU ETS to the buildings and transport sectors may lead to further inefficiencies, for example due to differences in abatement costs. These are very high in the transport sector (between 200 and 400 euros per tonne). For a sufficient incentive effect, the price of allowances would therefore have to rise dramatically (GERBERT et al. 2018; Cambridge Econometrics 2014; KEMFERT et al. 2019c). The inclusion of these sectors would initially accelerate the decarbonisation of the energy sector instead of bringing about significant reductions in the transport sector. Long-term price signals, which the EU ETS is not good at providing, are also needed for urgently needed energy efficiency improvements in the building sector. A sharp increase in the price of allowances could in turn lead to carbon leakage effects in industry, which would require protective measures to be taken to prevent emissions being shifted abroad (NEUHOFF et al. 2019). The introduction of separate emissions trading schemes for the heating and transport sectors would also entail the risk of legal and economic implementation problems (for further discussion of this see BACH et al. 2019a; KEMFERT et al. 2019c).

In contrast to the quantity-oriented system with emissions trading, taxation is a price instrument. Setting the CO_2 price results in a volume reduction, which, however, cannot be predicted precisely ex ante. In order to reduce this uncertainty, the price path can be adjusted depending on the emissions reductions actually achieved. This would result in less planning certainty for market participants, but a higher degree of ecological accuracy. The price level would thus be adapted to the ecological effects achieved, as is envisaged in the Swiss pricing system, for example (BACH et al. 2019a; KEMFERT et al. 2019a). In order to provide actors with sufficient planning certainty, the rising trajectory of price paths can be made as foreseeable as possible (SRU 2016b, p. 173). Taxation can thus offer the advantage of greater price stability and planning certainty through appropriate price setting. Long-term price signals can be set in order to counteract the price fluctuations inherent in trading and to create incentives for investment in more climate-friendly technologies (UBA 2019b). In particular, long-term dynamic incentive effects can be created. If tax rates are gradually increased on a fixed path, this creates planning certainty for private households and companies in their consumption and investment decisions (BACH et al. 2019a).

Financial compensation for low-income households could be implemented more easily and with lower transaction costs within a wider reform of the tax system – for example, by redistributing revenues via a climate bonus or by reducing levies and charges on the electricity price. This can also promote public acceptance for CO_2 pricing. However, such financial compensation must not be offset against the “basic provision for jobseekers” provided under Book II of the German Social Security Code (SGB II) in order to avoid negative distribution effects, which would in turn require changes to the law (KEMFERT et al. 2019c).

With the Federal Climate Change Act adopted by the German Bundestag on 15 November 2019, the permissible emissions levels for all sectors will be legally prescribed, up to 2030 initially (item 97). In addition, at the beginning of October 2019, the Federal Cabinet adopted the Climate Action Programme 2030, including measures for its implementation. A key element is the introduction of pricing for the heating and transport sectors from 2021, which is to be implemented through the Fuel Emissions Trading Act. A fixed price of 25 euros is to be set for emissions allowances at the beginning of 2021, rising to 55 euros in 2025 (see Box 6-3). However, it is unlikely that these low prices are ambitious enough to align with a Paris-compatible CO_2 budget. A higher CO_2 price is needed to ensure that the steering effects are sufficient (BACH et al. 2019a; 2019b; FÖS 2019, p. 3; Agora Energiewende and Agora Verkehrswende 2019). Moreover, the planned fixed prices mean that there are considerable constitutional concerns which need to be addressed (KLINSKI and KEIMEYER 2019; ANTONI et al. 2019). In order for fixed prices to be introduced, there can be no upper limit on the total quantity of emissions allowances available, as this is not compatible with fixed prices. This would then not create a situation of scarcity. However, in its decision on the EU ETS in 2018, the Federal Constitutional Court stated that the total quantity of available emissions must be limited by a cap in order to force up prices through scarcity (KLINSKI and KEIMEYER 2019). The Climate Action Programme 2030 also contains measures for the building sector. In addition, at the end of 2019 the Federal Cabinet adopted the draft of the Building Energy Act (GEG-E), which transposes the amending Directive (EU) 2018/844 to the Building Efficiency Directive into German law (see chap. 7, item 624). Furthermore, § 72 GEG-E specifies the prohibition of the installation of new oil-fired heating systems from 2026 onwards, as provided for in the Climate Action Programme 2030. However, this important step towards achieving an almost climate-neutral building stock, which is cited as a goal in the reasoning to the GEG-E, is weakened by exemptions. For example, hybrid systems which are combined with solar thermal energy will continue to be permitted and financially supported beyond 2026.

To ensure that the national policies adopted are in line with the commitments under the Paris Agreement, the CO_2 budget can serve as an (additional) baseline for measurement. A Paris-compatible CO_2 budget can be used in this way as an assessment tool to enable national climate policy to be checked for any gaps in ambition or implementation.

97. The allocation of areas of policy responsibility between different departments can lead to environmental and climate issues being seen primarily as a task for the Ministry of the Environment (SRU 2019, i.a. p. 165). However, emissions are ultimately generated in sectors for which other ministries are responsible. This tends to create little incentive for the other ministries to achieve the targets, as is also evident from the example of the sustainability strategy and its objectives (ibid., p. 168). The failure to meet the national greenhouse gas reduction target for 2020 and the financial risks of failing to meet the European climate targets, as shown in Box 2-4 “Germany’s failure to meet climate policy targets and the resulting financial consequences”, reflect the failure of individual sectors to take sufficient climate policy responsibility for their emissions. For example, through the purchase of emissions allocations, the overall federal budget would bear the consequences of any shortcomings in sectoral climate protection policy instead of those costs being passed on to the responsible sectors and departments in accordance with the polluter-pays principle.

Seen from this perspective, the division of the greenhouse gas reduction target for 2030 into sectoral annual emissions quantities (§ 4 KSG) in the Federal Climate Change Act and the crucial political innovation that the Act represents are to be welcomed. The annual emissions quantities in the Federal Climate Change Act thus correspond to greenhouse gas budgets up to 2030 (see sec. 2.2.4.3) and for the first time transpose the approach of politically binding budgets to the national level. They are based on the sectoral targets in the Climate Action Plan 2050 and define exact year-by-year emissions pathways for the individual sectors. The exception to this is the energy industry, for which annual emissions quantities are only defined for 2020, 2022 and 2030. It means that for the first time the individual departments are responsible for the implementation of the corresponding sectoral strategies and measures (§ 4 sec. 4 sentence 1 KSG). If a sector exceeds its annual emissions quantity, the difference is set off against the emissions budget for the coming years. In the past, there were no mechanisms in place which would enable further sectoral measures to be taken if agreed climate protection measures proved to be inadequate. The Federal Climate Change Act now stipulates that the responsible ministry must submit an emergency programme for adoption by the Federal Government within three months of the identification of any implementation gap (§ 8 sec. 1 KSG). This is a step in the right direction. In this context, however, the proposed option of transferring annual emissions volumes between sectors (§ 8 sec. 2 KSG) does not seem particularly sensible. The flexibility given by the introduction of such a redistribution of annual emissions quantities must not be at the expense of sectoral accountability and the effectiveness of sectoral targets. There is a danger that a false incentive will be created for departments to repeatedly fail to meet targets in the hope or expectation that greenhouse gas budgets will be reallocated.

98. From a procedural and participatory point of view, the political process of drawing up the Federal Climate Change Act and the Climate Action Programme 2030 is open to criticism. Originally, an action programme containing sectoral programmes of measures for the achievement of the 2030 target was to be adopted by the end of 2018 (BMU 2019a, p. 78 et seq.; CDU, CSU and SPD 2018, p. 142 et seq.). In practice, however, there have been repeated delays. This was one of the reasons why an independent review of the effectiveness of proposed measures to be commissioned and undertaken by research institutes did not take place as planned (Der Spiegel 13.09.2019; BMVI 2019). The political delays also had consequences for the involvement of civil society and for European reporting obligations. For example, the period for the planned participation of voluntary associations in several legislative projects within the climate action programme was less than one day, which would make meaningful participation impossible (Tagesspiegel Background Mobilität & Transport 07.11.2019). By the end of 2018, the German government was to have outlined to the European Commission in the draft NECP how Germany’s contribution to the European climate targets was to be achieved. However, a failure of political decision-making meant that the impact assessment on the consequences for the climate of the measures planned was not provided. This meant that the European Commission was also unable to make a full evaluation of the German draft NECP. The online consultation on the draft German NECP carried out in the summer of 2019 had to take place without covering measures which were only later adopted by the German government as part of the Climate Action Programme 2030. Whether the responses submitted in the consultation on the NECP were conversely taken into account in the political decision-making process that led to the Climate Action Programme 2030 cannot be clearly established in retrospect. The deadline for submission of the final German NECP at the end of 2019 was also missed. Ultimately, it remains unclear to what extent the catalogue of measures in the Climate Action Plan 2050, drawn up with the aid of an elaborate participatory process, was taken into account by the Federal Government in the formulation of the Climate Action Programme 2030 with its sectoral measures. The mixed system chosen for CO_2 pricing, the Fuel Emissions Trading Act, did not take into account the recommendations of the German Council of Economic Experts regarding the possible advantages of a separate emissions trading system and a pure CO_2 tax (Sachverständigenrat zur Begutachtung der gesamtwirtschaftlichen Entwicklung 2019, p. 110). Nor did the Federal Government take up the report's proposals on socially balanced redistribution options. Finally, the Climate Action Programme 2030 has been widely criticised because the measures it contains are unlikely to be sufficient to achieve the national climate target for 2030 (EDENHOFER et al. 2019; HARTHAN et al. 2020). This also puts at risk the fulfilment of European obligations. This makes it all the more important to integrate scientific expertise, to monitor effectiveness and to regularly update the programmes of measures.

2.4.3 The Federal Climate Change Act in the context of the Paris Agreement

99. Regular monitoring of progress towards the achievement of targets and updating of targets and measures are of particular importance for climate policy. In these respects, the Federal Climate Change Act could be further improved in the future, and the budget approach for ensuring a level of ambition commensurate with the Paris Agreement could be more firmly embedded. One way of doing this would be to strengthen the relevant knowledge-based institutions. With the Council of Experts on Climate Change, the Federal Climate Change Act (§§ 11 and 12 KSG) provides for a body which, thanks to the interdisciplinary composition of its five members, is ideally suited to fulfil these tasks. However, this body could be integrated even more effectively into climate governance. The aim should always be to provide the Federal Government and the Bundestag with the necessary expertise required to facilitate knowledge-based decisions on decarbonisation. In countries with appropriate advisory bodies, they contribute in this way to a comprehensive public debate (DUWE and STOCKHAUS 2019, p. 28).

100. The Federal Climate Change Act essentially defines a number of tasks for the Council of Experts on Climate Change. One of them is to verify the accuracy of emissions data for the various sectors as published by the UBA (§ 12 sec. 1 KSG). Their analysis is then submitted to the Federal Government. The added value of this review remains unclear. The implementation gap to date arose in part from overly optimistic projection reports (see Box 2-4). There was no doubt regarding the technical quality of the emissions data for past years. The data can only be used ex post to check whether the sectors have complied with their annual emissions ceilings. If this is not the case, the German government commits itself to adopting an emergency programme (§ 8 sec. 1 KSG) in order to comply with the annual emissions limits in future. The Council of Experts examines the assumptions regarding the greenhouse gas reduction impacts of the measures contained in the emergency programme (Art. 12 para. 2 KSG).

In addition, the Federal Government should obtain a statement from the Council of Experts on the reduction impact before it transfers annual emissions quantities between sectors, adopts a climate action programme or updates the climate action plan (§ 12 sec. 3 KSG). The primary task of the Council of Experts is thus to document sectoral emissions reductions retrospectively and to check the plausibility of the impact of the Federal Government's own climate protection measures.

Level of ambition and climate targets

101. International comparisons show that a dedicated panel of climate policy experts could be assigned a more active role in assessing the level of ambition and proactively preventing implementation gaps. The mandate of the Committee on Climate Change (CCC) in the UK has also proven to be effective in terms of the level of ambition. On the basis of its analyses, the CCC proposes carbon budgets for a period of five years to the government, which are then debated in the British parliament and, as a rule, adopted into law without any major deviations (DUWE et al. 2017, p. 59). In this way, the work of the CCC proactively addresses the level of ambition as well as any possible ambition gap in British climate policy and supports the political decision-makers in reducing it. Since the CCC's proposal forms the basis for the political debate, the legislature and the government have to provide more justification in advance if they want to deviate from the budget as mandated by the science.

102. It has been demonstrated that the German climate targets are not sufficient to meet the Paris Agreement. There is therefore a need to make greater use of scientific expertise to proactively address the ambition gap by making a fair, Paris-compatible CO_2 budget the basis for the appraisal of climate targets. As part of this, the Council of Experts could advise the government on how large such a Paris-compatible CO_2 budget might be. In section 2.2.4.2, the calculations behind such a Paris-compatible budget were presented. The Federal Government should declare a CO_2 budget as a transparent basis for evaluating the level of ambition of the climate targets. The Council of Experts could then make recommendations for adapting the German climate targets to the government's own CO_2 budget.

The question of whether climate targets are best formulated as annual sectoral budgets or by keeping them as point targets cannot be answered conclusively. Politically agreed binding greenhouse gas budgets represent a relatively straightforward way of operationalising the scientifically determined Paris-compatible CO_2 budget. In respect of the European targets, too, which also define annual emissions ceilings for the EU ETS and the non-ETS sectors, a budget-based target system seems the logical choice. However, in some cases point targets can create stronger political dynamics (Committee on Climate Change 2017, p. 11) and offer more flexibility on the way to achieving the targets (Danish Council on Climate Change 2019, p. 18). This flexibility between sectors can help to ensure that climate targets are achieved more cost-effectively or with greater consideration of distributional effects (see sec. 2.2.4.3). With increasing sector coupling and the associated electrification, the difficulty of accurately allocating emissions to individual sectors will also increase in future. As the implementation gap of recent years has shown, a target system using point targets alone entails the risk on the other hand that emissions reductions may be postponed into the future (Danish Council on Climate Change 2019, p. 18).

In practice, a mixed system seems the best way to combine the certainty of meeting the targets with flexibility along the way. The Federal Climate Change Act takes a step in this direction by supplementing the point target for 2030 with permissible annual emissions quantities on the path towards it, thus making the sectoral targets of the Climate Action Plan 2050 binding. The advantages of both target systems could be further combined in the future by defining interim targets (e.g. for 2025 etc.) and supplementary qualitative indicators, or by creating additional accounting and incentive structures for the (over)fulfilment of sectoral targets.

Monitoring and implementation

103. In the past, reductions scenarios in the Federal Government's projection reports have proven to be too optimistic (von LÜPKE and NEUHOFF 2019, p. 78). The Federal Climate Change Act obliges the Federal Government to have the greenhouse gas reduction assumptions checked for plausibility by the Council of Experts before the adoption of programmes of measures. However, the German Council of Experts on Climate Change may not take independent action. It may, however, be commissioned by the Bundestag or the Federal Government to prepare a special report (§ 12 sec. 3 sentence 2 KSG). Furthermore, it has no mandate either to evaluate proposed measures except in terms of their emissions reduction impacts, or to formulate its own proposals.

In other countries, comparable bodies can work independently on climate-related issues and thus contribute to the political debate. The Swedish Climate Council, for example, is able not only to evaluate the effectiveness of climate policy measures, but explicitly also to examine the totality of the government's actions for their climate policy consequences (BRUHIN et al. 2018, p. 14). It presents an annual report in which, in addition to the general reporting, it focuses on areas of climate policy action which are considered urgent. The British CCC also regularly evaluates whether climate policy measures already adopted are sufficient to meet the five-year carbon budgets, and which additional measures could narrow the implementation gap. The government is obliged to respond to these reports (von LÜPKE and NEUHOFF 2019, p. 78). By this means, potential implementation gaps in climate policy can be proactively addressed.

104. In order to be able to pre-empt shortfalls in emissions reductions and thus avoid further implementation gaps, the Council of Experts should therefore be given a mandate to consider future emissions trends and independently to propose programmes of measures (EDEN-

HOFER et al. 2019, p. 13). It is conceivable, that the Council of Experts could be entrusted with the development of such future programmes. In addition, the Council could review the Federal Government's projection reports. Its findings could then be passed on to the Federal Government and the Bundestag, which could use them as a guide to the effectiveness of various measures and as a basis for the political formulation of the climate protection programme. A parliamentary debate on the expert reports could contribute to an informed public debate and to transparency, something which already happens in other countries (DUWE et al. 2017, p. 60).

Integration in the consultation and advisory landscape

105. In addition to the Council of Experts on Climate Change, Germany already has a differentiated network of scientific bodies and actors, one which however has not yet been able to command sufficient political attention. The Expert Commission on the Federal Government's "Energy of the Future" monitoring process was created to support the energy transition. The Climate Action Plan 2050 also makes provision for a scientific monitoring process for the revision and updating of targets and measures (BMU 2019a, p. 79), which was institutionalised in 2019 in the form of the steering committee of the Science Platform for the Climate Action Plan 2050. For the future, it would seem to be crucial to pay more attention to the structural interrelations between the various advisory bodies, their roles and resources (EDENHOFER et al. 2019, p. 14). It is conceivable, for example, that the expertise of the existing advisory bodies could be pooled on suitable issues, especially in order to take account of the close links between issues of energy and climate policy. It can also be assumed that a council of experts with the appropriate resources and the additional institutional status and weight described here would be better able to make itself heard by both political decision-makers and the general public.

Updating, policy cycles and European integration

106. The Federal Climate Change Act provides for the determination in 2025 of annual sectoral emissions levels beyond 2030. For these concrete future sectoral targets, the Council of Experts on Climate Change could be commissioned to draw up various decarbonisation scenarios as well as to outline the technological and economic developments required in each sector. All of this should be submitted to the Federal Government and the Bundestag. This is the only way to assess whether sectoral emissions reductions represent an appropriate distribution of the overall reduction efforts. This can help to ensure that the sectoral targets create the most cost-effective and socially acceptable path towards decarbonisation and avoid misdirected investments.

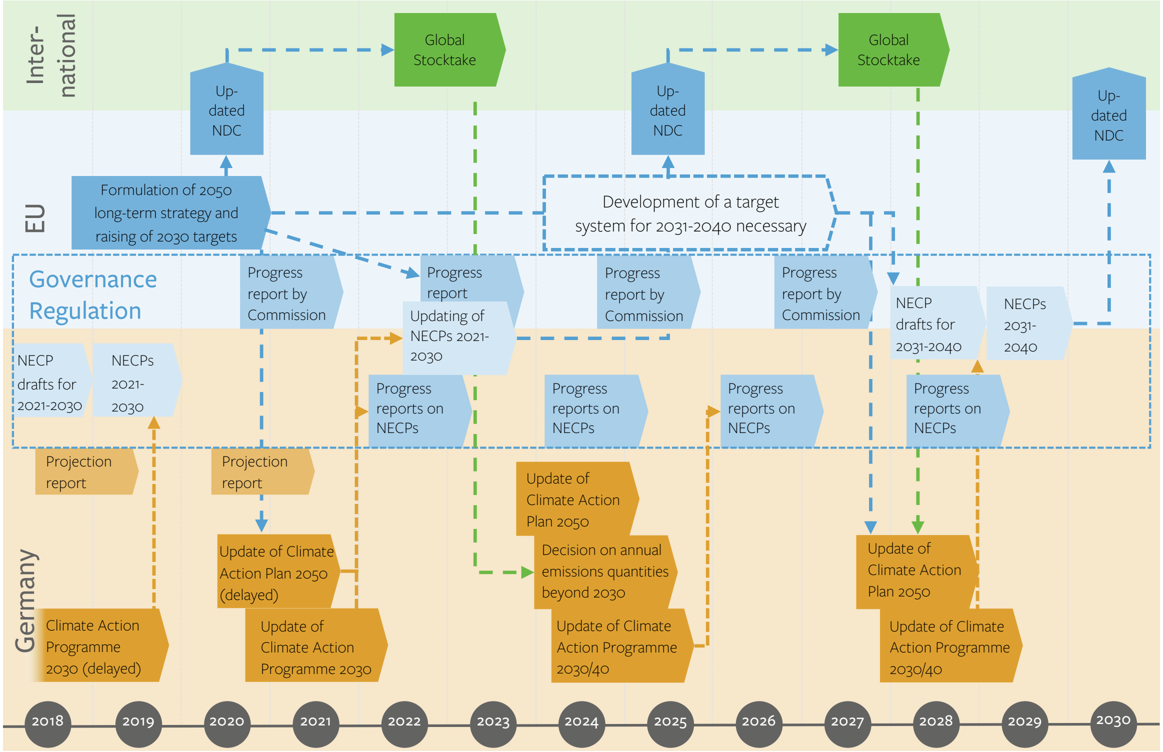
107. Finally, it would be important to align German climate governance more closely with existing European and international policy cycles and requirements. It was described above how the delays in the formulation of the Climate Action Programme 2030 impacted on both European reporting obligations and participation processes. Currently, there is a risk of overlap and confusion between the various revision and updating cycles and the detailed content of the Climate Action Programme 2030, the regular but already delayed revision of the Climate Action Plan, the NECP reporting, the upgrading of the European climate targets for 2030 and the European long-term target. It would therefore make sense to align the requirements of the Federal Climate Change Act and the government's own climate- and energy-related strategies even more closely with existing European reporting obligations and cycles (see Fig. 2-12; SCHLACKE and LAMMERS 2018). The updating of the Climate Action Plan is not mentioned in the Federal Climate Change Act. One way of contributing to this might be to revise the Climate Action Plan (and therefore also the Climate Action Programmes) according to fixed cycles linked to the projection reports and the European progress reports.

It would also be advisable for climate policy to be more tightly interlinked with other policy areas. This applies in particular to energy policy. The SRU has already made proposals for the embedding of sustainability policy in all government departments and for greater scrutiny of all political programmes and strategies for their sustainability (SRU 2019, p. 166 et seqq.). Analogous requirements for any proposals with potential impacts on the climate would be conceivable.

Currently, a further enlargement of the implementation gap is threatened by the raising of the 2030 targets proposed by the new European Commission. It would seem sensible to raise the existing German climate and sectoral targets for 2030 soon and to align them more closely with a CO_2 budget compatible with the Paris Agreement. Besides the fact that raising Germany's climate targets is necessary in any case with the CO_2 budget in mind, this would have two advantages. Firstly, it would give Germany a more credible basis for negotiations and would enable it to advocate more effectively for raising Europe's 2030 targets in the forthcoming European Council negotiations so as to make them compatible

Figure 2-12

German, European and international climate policy cycles



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with the Paris Agreement. Secondly, it would avoid a purely reactive and belated adjustment of the German sectoral targets and the Climate Action Programme 2030. If there is a delay in raising the German sectoral targets for 2030 to meet the new higher European requirements, there is a risk that the non-ETS sectors will again fail to meet their targets and that additional costs may be incurred because of the need to purchase emissions rights from other countries (see Box 2-4).

2.5 Recommendations for action

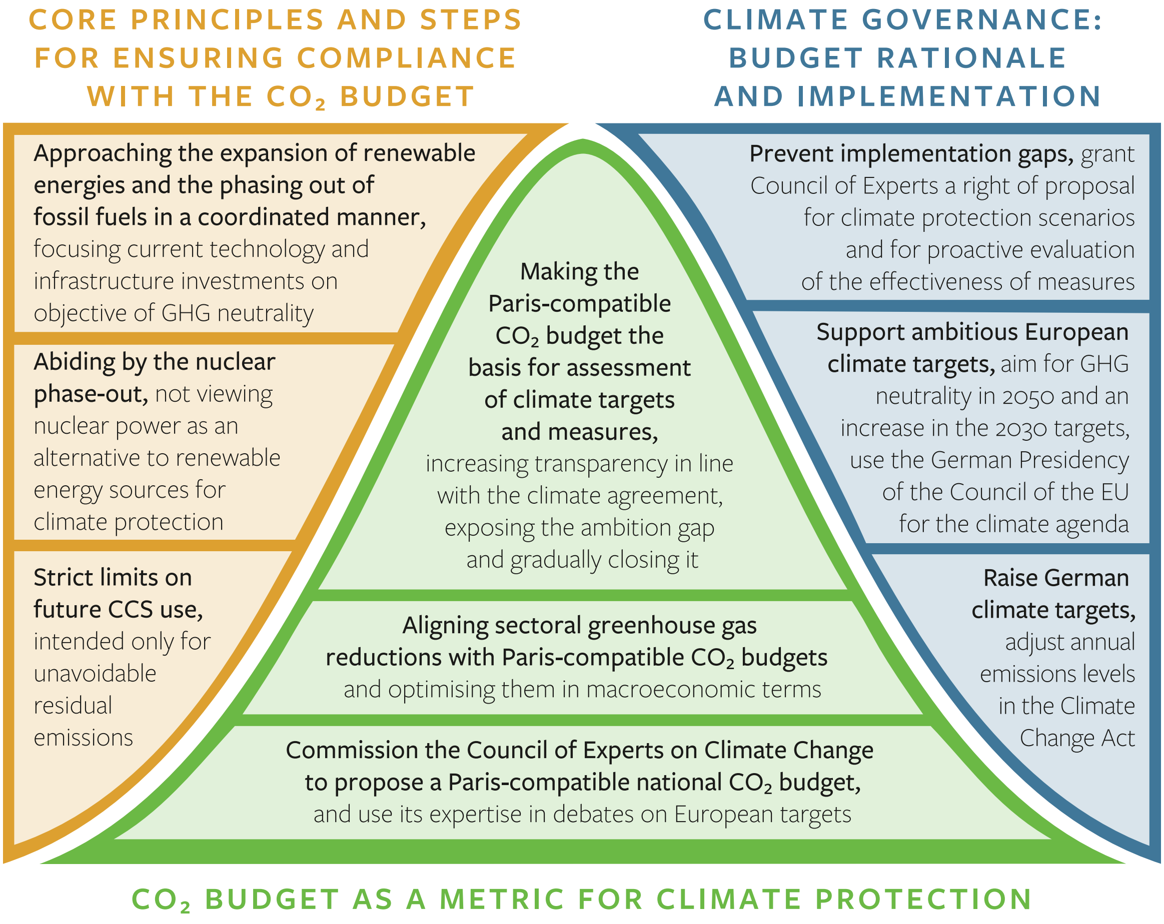
108. The SRU recommends to the Federal Government and to other decision-makers involved the following core principles and steps for a climate policy that will ensure that Germany's contribution to the fulfilment of the Paris Agreement is fully compliant with the requirements of both climate science and international equity (see Fig. 2-13).

Using the CO_2 budget as the key metric for climate protection

109. *Aligning climate targets and measures with a Paris-compatible CO_2 budget.* At the European level, the Effort Sharing Regulation and the EU ETS already contain climate protection targets that define annual emissions quantities and thus greenhouse gas budgets. The Federal Climate Change Act also contains sectoral budgets up to 2030. In addition, there are still percentage reduction targets for annual greenhouse gas emissions compared to a given base year. Global warming depends largely on the cumulative total of emissions affecting the climate. This is why an upper limit on total emissions must be observed, as expressed in the CO_2 budget as a simplified version of the climate budget. Regardless of the form in which targets are formulated for specific years or sectors and of how emissions reductions are achieved and regulated, the effectiveness of national and European climate protection measures and the level of ambition of reduction targets should therefore be measured against the CO_2 budget.

Figure 2-13

Recommendations for the introduction, implementation and observance of the CO_2 budget



CORE PRINCIPLES AND STEPS FOR ENSURING COMPLIANCE WITH THE CO_2 BUDGET

Approaching the expansion of renewable energies and the phasing out of fossil fuels in a coordinated manner, focusing current technology and infrastructure investments on objective of GHG neutrality

Abiding by the nuclear phase-out, not viewing nuclear power as an alternative to renewable energy sources for climate protection

Strict limits on future CCS use, intended only for unavoidable residual emissions

Making the Paris-compatible CO_2 budget the basis for assessment of climate targets and measures, increasing transparency in line with the climate agreement, exposing the ambition gap and gradually closing it

Aligning sectoral greenhouse gas reductions with Paris-compatible CO_2 budgets and optimising them in macroeconomic terms

Commission the Council of Experts on Climate Change to propose a Paris-compatible national CO_2 budget, and use its expertise in debates on European targets

CLIMATE GOVERNANCE: BUDGET RATIONALE AND IMPLEMENTATION

Prevent implementation gaps, grant Council of Experts a right of proposal for climate protection scenarios and for proactive evaluation of the effectiveness of measures

Support ambitious European climate targets, aim for GHG neutrality in 2050 and an increase in the 2030 targets, use the German Presidency of the Council of the EU for the climate agenda

Raise German climate targets, adjust annual emissions levels in the Climate Change Act

CO_2 BUDGET AS A METRIC FOR CLIMATE PROTECTION

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110. *Establishing the current size of Germany's remaining CO_2 budget at an official level and monitoring it on an ongoing basis.* The German government should commit itself to a CO_2 budget and make it the benchmark for its future climate policy. It can instruct the Council of Experts on Climate Change to establish up-to-date values for the national and European CO_2 budgets (see item 118) and should follow the scientific advice. Despite uncertainties, the size of the national CO_2 budget can be derived with sufficient robustness from the IPCC studies on the global CO_2 budget, provided that a suitable principle of international distributive justice has been agreed upon. If the core budget were to decrease due to new findings, climate policy would have to be tightened up. If it were to increase, the achievement of the target would be made easier.

111. *Recommendation on the size of the national CO_2 budget.* In this chapter, the SRU demonstrates how a national CO_2 budget can be calculated. The SRU's recommendation is based on the temperature targets in the Paris Agreement. The CO_2 budget calculated here is based on warming of 1.75 °C, and is supplemented by a budget based on warming of 1.5 °C. If historical emissions are disregarded, and if the principle of equal per capita emissions rights for today's world population is applied, then the resulting CO_2 budget remaining for Germany from 1 January 2020 amounts to 6.7 Gt CO_2. If emissions were to continue at today's level, this budget would be fully used up in 2029. Assuming linear annual reductions in emissions, the budget would last until 2038. The goal of greenhouse gas neutrality in 2050 will require very steep cuts in the next few years in order to enable continuing emissions at low levels until the middle of the century. There is also a very good case for limiting global warming to 1.5 °C, and efforts to achieve this are provided for in the Paris Agreement. The remaining CO_2 budget for 1.5 °C would be significantly smaller, at 4.2 Gt CO_2 from 1 January 2020, and greenhouse gas neutrality would have to be achieved sooner. Linear emissions reductions towards greenhouse gas neutrality in 2050 would require Germany to keep a disproportionately large share of the global CO_2 budget until the middle of the century. This runs counter to the assumption of globally equal rights to the use of the atmosphere.

Including key principles and steps for compliance with the CO_2 budget

112. *Phase-out of coal, oil, natural gas, petrol and diesel.* Due to the deficiencies in climate policy to date, the remaining CO_2 budgets are now noticeably reduced in size and require the use of fossil resources to be ended relatively quickly. A rapid end to coal-fired power generation as early as 2030 would open up budgetary leeway. The SRU welcomes the fact that the coal phase-out is being implemented in Germany. However, it also recommends that the necessary phase-out of fossil oil and natural gas should be tackled immediately in both political and planning terms in order to avoid wasteful investments in further fossil-based technologies and to initiate the necessary transformations. Accordingly, for climate policy reasons, the use of petrol and diesel should be phased out in stages.

113. *Understanding the rapid expansion of renewable energies in systematic terms as a counterpart to the phasing out of fossil energy production.* Whether an exit path based on the CO_2 budget is feasible depends among other things on the deployment rate for alternatives. The discussion on phasing out the use of fossil resources should therefore be conducted together with the switch to renewable energies and questions of sector coupling and the availability of raw materials. The SRU recommends that the target of 100 % renewable energy should be set in a timeframe that corresponds to the phase-out path enabling the Paris-compatible CO_2 budget to be met. Today's investments in technology and energy infrastructure are crucial for mid-century emissions levels. Today's investments must therefore be compatible with an economy that is greenhouse gas neutral by the middle of the century. Lock-in effects and path dependencies due to bridging technologies which may work in the short term but make it difficult to achieve climate targets in the medium to long term must be avoided. Government support programmes should be more strongly oriented towards renewable energy sources and decarbonised technologies, and the promotion and subsidising of fossil technologies should be ended.

114. *The switch to 100 % renewable energies should take into account further key aspects of environmentally sound implementation.* As a general principle, the expansion of renewable energies must have as little adverse impact as possible on environmental protection, landscape conservation and (on a larger scale) biosphere protection. Questions of land and water consumption, fertiliser use, landscape structure, biodiversity and water conservation and of competing uses should be taken into account in planning. In addition, the expansion should be carried out under the following general conditions:

- The total phase-out of nuclear energy in Germany by 2022 must be adhered to; the grounds for avoiding fundamental risks to the environment and health, widely accepted by the general public, remain just as valid as the economic reasons which also clearly argue against the use of nuclear energy across the globe.

- Wood biomass should only be used to produce energy if a positive climate effect of its use is proven and if it comes from carefully controlled, sustainable production, ideally from residual and waste materials. This makes regionally differentiated use possible, but excludes a comprehensive expansion on a large scale. In particular, the import of wood biomass for energy use is only justifiable under strict criteria. The growth of the market must be closely monitored and undesirable trends must be countered at an early stage. In addition, the Federal Government should draw up an integrated comprehensive strategy for the use of biomass. Although there are analytical and political approaches which could make possible greater use of biomass in future, there is a risk of adverse developments, especially in relation to imports. With regard to climate protection, there should be a thorough and systematic analysis of how much biomass the different sectors plan to use in order to reduce emissions, and a realistic overall strategy should be drawn up.

- Due to the environmental impacts associated with extraction and production, and the fact that recycling is never 100 % possible and also involves adverse environmental impacts, the demand for raw materials should always be minimised as a general principle. In addition to energy-saving and material efficiency measures, decarbonisation paths must therefore as a matter of necessity include the greatest possible reduction of overall energy demand and must develop appropriate measures.

- Renewable energy sources have material limitations, because the extraction of the raw materials required for the new technologies involves considerable environmental pollution. For this reason, raw material requirements, including environmental impacts and recycling, must always be taken into account in the design and development of decarbonisation paths (see also SRU 2017b, sec. 3.5).

115. *The potential use of CCS should be limited to offsetting small, unavoidable residual emissions quantities, subject to strict conditions, in the interests of achieving full greenhouse gas neutrality in the medium term.* Methods for extracting CO_2 on a large scale from the atmosphere or directly from industrial processes are currently largely speculative in nature, and are often energy-intensive (e.g. DACCS), consume important environmental resources (e.g. BECCS) and in addition enjoy little public support. These emerging technologies should therefore not be part of strategic plans for achieving the necessary emissions reductions. They must not be used in calculations to increase the national CO_2 budget through negative emissions. The goal of greenhouse gas neutrality means reducing emissions as much as possible in all sectors and – especially in the energy and transport sectors – avoiding them to the greatest extent possible. The quantity of negative emissions that can be achieved in future through organic carbon storage methods such as sustainable forest and soil management is highly uncertain and depends on climatic conditions. However, an expansion of natural sinks can increase the likelihood of staying within budget. Although the potential contribution of negative emissions should not be part of strategic planning at present, further scientific research and technological development is appropriate.

Embedding budgetary thinking and ambitious implementation of climate protection measures in climate governance

116. *In view of the limited CO_2 budget, the German long-term target for 2050 and the European debates, the German climate targets for 2030 and 2040 need to be significantly more stringent.* A political debate about raising Germany's climate targets and adopting further climate protection measures should therefore be conducted sooner rather than later, and should be followed up on an ongoing basis. The Federal Climate Change Act explicitly provides for the possibility of raising targets should this become necessary to meet European or international climate protection goals. The calculation of a Paris-compatible CO_2 budget has shown that this is indeed the case. The level of ambition of the climate targets should therefore be measured against this CO_2 budget and any possible ambition gap should be openly discussed. For this purpose, it is not necessary to rely solely on greenhouse gas budgets to guide policy in the future. Instead, the reduction targets should be designed so as to be consistent with a Paris-compatible CO_2 budget.

As the new European Commission has set itself the goal, in the European Green Deal, of raising the level of ambition of the climate targets for 2030 and aiming for greenhouse gas neutrality by 2050, the German climate targets also need to be adjusted. If Europe raises its greenhouse gas reduction target for 2030 to between 50 and 55 %, as proposed by the European Commission, and lowers the annual emissions allocations under the Effort Sharing Regulation, the Federal Republic of Germany will face considerable costs due to the need to purchase additional emissions allowances from other member states over and above those already projected.

117. *The Federal Climate Change Act is a step in the right direction. It should subsequently be geared towards consistently and systematically closing both the ambition and the implementation gap.* In the Federal Climate Change Act, the national climate targets are enshrined in law for the first time. Permissible annual emissions quantities contribute to a higher degree of departmental accountability and help to avoid future implementation gaps. For the LULUCF sector, a binding compensation system for emissions and sinks from land use is planned in European law for the next decade. Since the departmental accountability principle applies here as well, land use could be given the status of a separate sector for permissible annual emissions quantities with an annual budget based on the European provisions.

The existing Climate Action Programme is unlikely to be sufficient to ensure compliance with the annual emissions levels set in law. The implementation gap in climate policy is becoming a risk to the national German budget, but the costs will not be borne by those responsible for them. If the costs of acquiring additional emissions rights from other member states were to be transferred to the corresponding departmental budget, this would be in line with the polluter-pays principle. A sector-specific adjustment to the CO_2 price, or an increase in the price of CO_2 allowances under the national emissions trading system, as a consequence of the failure to meet sectoral targets would also be conceivable. This would generate additional revenue for the acquisition of the necessary emissions rights and have a dampening effect on emissions trends in the relevant sector.

118. *The integration and consideration of scientific expertise in setting climate policy targets and in the design of measures and the evaluation of their effectiveness should be strengthened.* In the Council of Experts on Climate Change, established by the Federal Climate Change Act, there will in future be a body with comprehensive scientific expertise in the fields of climate science, climate policy and climate economics. Considering this, its mandate is relatively small.

In the future, the Council of Experts is to document the evolution of emissions as well as any possible implementation gap and will be consulted by the government when Climate Action Programmes are adopted to confirm greenhouse gas reduction impacts. Its mandate is thus largely limited to evaluation. Effective monitoring, however, entails additional aspects. In order to identify implementation gaps early on and to facilitate an informed public debate on climate protection measures, the mandate of the Council of Experts on Climate Change should therefore be enhanced.:

- The Council should evaluate the level of ambition of Germany's climate targets and recommend amendments where necessary. In addition, the size of any ambition gap should be identified and clearly communicated. A Paris-compatible CO_2 budget, to which the German government should commit itself, would provide a suitable assessment benchmark. Should the latest scientific findings on the size of the remaining global CO_2 budget change, the Council of Experts can, if necessary, recommend that the Federal Government adjust its national budget.

- The Council of Experts should be able on its own initiative to propose emissions reduction measures, write expert reports and draw up decarbonisation scenarios, instead of merely checking the plausibility of the Federal Government's proposals. The scientific expertise at its disposal could be used to draft alternative, cost-optimised and socially acceptable sectoral scenarios for budget-compatible greenhouse gas reduction paths, to facilitate public debate and to provide policymakers with a realistic foundation for making decisions on how to achieve their goals. Only in this way can the risk of further implementation gaps be minimised from the outset.

119. *The German government should commit itself to ambitious climate protection throughout Europe in the course of implementing the European Green Deal and in line with the long-term strategy.* With the German EU Council Presidency in the second half of 2020, the Federal Government has an opportunity to embed Paris-compatible climate targets and the budget approach in the European climate law and in the updated European NDC 2020. The European Commission is also proposing to raise the medium-term EU greenhouse gas reduction target for 2030 from 40 % to 50–55 % compared to 1990 (European Commission 2019b, p. 5). The Federal Government should support this plan in the European Council. Since both the EU ETS and the Effort Sharing Regulation can be used as a basis for calculating emissions volumes up to 2030, both the existing targets and possible future targets and their implementation can be reviewed for their Paris compatibility in line with the budget approach.

120. *German climate policy should be better aligned with EU goals and processes.* The failure to prepare the programmes of measures in good time and to revise the Climate Action Plan in accordance with the schedule (BMU 2019a, p. 78) both had repercussions on the European reporting obligations. In future, the revision of the Climate Action Plan and Climate Action Programmes should be carried out in such a way that they meet the European reporting obligations under the Governance Regulation and ensure adequate public participation. Germany must submit an updated NECP by 30 June 2023. By that date at the latest, an update of the Climate Action Plan with a higher level of ambition that is as far as possible Paris-compatible, a corresponding tightening of the annual emissions levels up to 2030, and an update to the Climate Action Programme 2030 must all be agreed in order to ensure that the targets are met.

2.6 Conclusion

121. The dramatic consequences threatened by unchecked climate change have long been well documented by the scientific community. In recent years, the first effects have been felt in Germany, too. Not least as a result of this, climate policy is once again becoming the focus of public debate. While Germany was often considered a climate policy leader in the past, this is no longer the case. Since the impact of climate policy measures still falls far short of what is needed, climate policy goals such as the greenhouse gas reduction target for 2020 are likely to be missed. In view of this situation, the

Federal Government has initiated a Climate Change Act as well as the Climate Action Programme 2030, but the precise impact of these initiatives remains to be seen. It is likely, however, that the climate protection measures introduced will not be sufficient overall to meet Germany's climate targets up to 2030, let alone make an appropriate contribution to meeting the requirements of the Paris Agreement. In view of these shortfalls, two projects should be pursued with determination and resolve. Firstly, the current implementation gap between existing climate targets and the actual development of emissions should be quickly closed by means of appropriate measures. At the same time, the level of ambition of Germany's climate targets should be reassessed and raised in order to align them with the requirements of the Paris Agreement.

122. In the view of the SRU, the CO_2 budget is an appropriate basis for the assessment of the German climate targets and measures in terms of their contribution to meeting the requirements of the Paris Agreement. The global CO_2 budget is a scientifically calculable figure that specifies the maximum quantity of CO_2 emissions that can still be emitted before greenhouse gas neutrality is achieved. The global temperature increase must not exceed the maximum value of well below 2 °C as stipulated in the Paris Agreement. When a remaining global CO_2 budget is determined, scientific uncertainties resulting from the complexity of climate reactivity in the Earth system must be taken into account. It is nevertheless possible to determine a robust budget, which is what is reported by the IPCC. The global CO_2 budget can then be divided up among the community of states so that national remaining budgets are defined. Since neither binding national reduction targets nor criteria for the division and distribution of the global budget were defined in the Paris Agreement, different options are conceivable, which, however, reflect different conceptions of distributive justice and of the relative strengths and capacities of the individual states.

The SRU recommends that both the existing implementation gap and the remaining ambition gap between national and global climate policy goals should be reported on clearly and transparently by the Federal Government. Building on this, the Federal Government should use a national CO_2 budget to quantify and substantiate the national obligation which it believes arises from the Paris Agreement. The SRU proposes a method of deriving a German CO_2 budget from the global one. This calculation identifies the upper limit of a national budget which is scientifically robust and in accordance with both international law and the principles of global distributive justice. In particular, Germany's historical emissions and economic strength as well as the risks associated with global warming above 1.5 °C all constitute strong arguments for committing to an ambitious residual budget.

123. Regardless of the details of the specific CO_2 budget committed to, in view of the fact that emissions are currently falling too slowly the need for further measures is urgent. Long-term investment cycles, the fact that fossil fuels can be replaced by renewable energy sources, and the need for research and development work must all be taken into account when planning climate protection measures using a budget perspective. Decarbonisation paths should involve the lowest possible raw material requirements, including their environmental impacts, and should take into account options for recycling. In order to make the necessary exit paths from fossil energy sources a reality, a corresponding expansion of renewable energies is essential. Without such a two-pronged approach, the use of coal, oil, natural gas, petrol and diesel cannot be reduced and then phased out in time. For economic, ecological and security policy reasons, nuclear energy is not an option for climate-friendly power generation. The SRU recommends that the use of CCS technologies, all of which are still in the development stage, with ecological consequences which are still a matter of dispute, should be restricted to processes with long-term unavoidable residual emissions, and subject to strict conditions. In this context, biomass, too, should be used only to a limited extent, and the large-scale use of stemwood harvested for energy generation should be avoided altogether. The climate protection contribution of biomass must be carefully assessed in terms of its CO_2 impact and possible further potential. It should be effectively regulated, especially when sourced from international markets, so that only sustainable, climate-friendly use can be guaranteed.

124. With the agreement on a Climate Action Programme 2030 and the Federal Climate Change Act, the Federal Government is taking a first step towards putting climate policy on a legally binding basis and achieving greater verifiability of the progress on reductions. However, in order to rapidly reduce the existing implementation gap and to take proper account of the budget approach, sectoral responsibility and the monitoring and evaluation of climate policy should be effectively strengthened. A significant enlargement of the mandate of the Council of Experts on Climate Change would contribute to this. The Council should gather up-to-date scientific information on the size of the remaining global CO_2 budget. If necessary, it should recommend that the Federal Government adjust the national CO_2 budget, the benchmark for the climate targets, in line with the new findings. The Council's mandate could also include proactively advising the Federal Government on adjusting the annual emissions levels in the Federal Climate Change Act, raising existing reduction targets, and providing ongoing support for their implementation. To this end, the Council should not only document the implementation gap, but also propose to the Federal Government alternative, budget-compatible decarbonisation paths for different sectors based on the current state of research.

125. As part of the European Green Deal, the European Commission is currently in negotiations over raising the European climate targets for 2030 and achieving climate neutrality by 2050. It is thereby acknowledging that current European climate targets are not sufficiently ambitious to make a fair contribution to limiting the rise in temperature in line with the Paris Agreement. A rapid alignment of the German climate targets with the Paris Agreement is therefore also sensible and necessary from a European policy perspective.

2.7 List of relevant publications

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Secretariat of the German Advisory Council on the Environment

Luisenstraße 46, 10117 Berlin, Germany
Tel.: +49 30 263696-0
info@umweltrat.de
www.umweltrat.de

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