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Greenhouse – Gas – Neutrality in Germany until 2050

Policy Paper to the RESCUE-Study

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1 Greenhouse gas neutrality is needed!

KEY MESSAGES

- ▶ In its 1.5 °C Special Report, the IPCC estimates the consequences of global warming beyond 1.5 °C to be much more severe than previously assumed. Considering global solidarity and the precautionary principle, the global temperature rise should be limited to a maximum of 1.5 °C.
- ▶ Only if CO₂ neutrality is achieved on a global scale by mid-century, the rise in average global temperatures can be kept within the 1.5 °C limit in accordance with the Paris Agreement. Hence, global greenhouse gas neutrality or even negative net emissions should be reached by the beginning of the second half of the century.

Global greenhouse gas (GHG) emissions continue to rise despite the implementation of various climate protection measures. In 2017, CO₂ emissions from burning fossil fuels accumulated to 37 Gigatons (Gt) which means a rise of about 63 % compared to 1990 (EUCom, 2019). Already today, four out of nine planetary boundaries have been crossed (i.e., climate change, biosphere integrity, land-system change, and biogeochemical cycles (phosphorus and nitrogen)) (Rockström et al., 2009; Steffen et al., 2015). In order to face these challenges, the international community of states has – mainly conjointly – agreed on several climate and environment protection targets which have been translated into legislation, strategies, and programs within the national frameworks of the contractual states. By ratifying the Paris Agreement, to date 185 out of 196 contractual states of the UNFCCC¹ have committed to keeping the increase in global average temperature to well below 2 °C above pre-industrial levels; and to limit the increase to 1.5 °C (UNFCCC, 2015). The aim is “[...] to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century [...]” (Article 4 (1) PA, UNFCCC, 2015), i.e. greenhouse gas neutrality. Meanwhile, there is a broad consensus that Article 2 of the Paris Agreement sets a stricter temperature limit than the 2 °C limit which was agreed on during the 16th session of the Conference of the Parties (COP 16) held in Cancún, Mexico, in 2010 (Wachsmuth et al., 2018).

By adopting the Paris Agreement and establishing the 1.5 °C limit, the IPCC was asked to prepare a special report on the impacts of global warming of 1.5 °C above pre-industrial levels which was published on October 8th, 2018.

One of the key findings of the report is that the impacts of global warming beyond 1.5 °C will be much more severe than previously assumed. The impacts of a global warming by 1.5 °C will be distinctly more severe than would be expected from a linear extrapolation of the already evident impacts today of the hitherto 1 °C warming. Considering global solidarity and the precautionary principle, the findings of the report suggest that the global temperature rise should be limited to a maximum of 1.5 °C rather than to well below 2 °C.

The IPCC's special report also shows that in order to limit the temperature increase to maximum 1.5 °C, CO₂ neutrality on a global scale must be pursued by mid-century (2045–2055). By 2030, CO₂ emissions need to be lowered by 40 to 60 percent compared to 2010. Moreover, it is not sufficient to solely reach complete GHG-neutrality after 2050, but even negative net emissions are required. This means that emissions of other greenhouse gases such as methane and nitrous oxide should be reduced to the absolute minimum worldwide so they can be compensated for by removing CO₂ from the atmosphere.

¹ United Nations Framework Convention on Climate Change.

Additional CO₂ removal (CDR – Carbon Dioxide Removal) becomes necessary during the second half of the century in order to make up for the excess CO₂ emitted by then. For there is a finite global budget for CO₂ emissions. Continued emissions on today's level for ten more years would result in missing the 1.5 °C goal. Making CO₂ sinks accessible will become a needful element in reducing greenhouse gases in the atmosphere. However, such approaches are physically limited in their capacity. In addition, an increasing level of technical CDR measures will raise risks with regard to sustainability. Hence, the sooner greenhouse gas emissions are reduced, the lower the need for greenhouse gas reductions via CDR measures including related trade-offs and risks.

Compared to CO₂, the effects of other greenhouse gas emissions and the corresponding greenhouse gas effects are not linear but nonetheless to be considered in the course of limiting global warming. Besides, there are other anthropogenic effects relevant to the climate which cannot be quantified precisely given the current state of research such as non-CO₂ effects of air traffic. Therefore, a not yet quantifiable increase in reduction requirements might be necessary.

2 We need to take action now!

KEY MESSAGES

- ▶ The sooner and the more ambitiously we take action, the more degrees of freedom we have with regard to the design of the transformation path towards greenhouse gas neutrality.
- ▶ Within the next years, the course has to be set both on a global and the national scale in order to reach worldwide CO₂ neutrality by the year 2050. Failing this, a point of no return will be passed beyond which the goal of global greenhouse gas neutrality or net zero emissions by the beginning of the second half of the century can no longer be reached.
- ▶ There is a strong need to take action in order to ensure a good balance between substitution, avoidance, and sinks for greenhouse gas neutrality.

According to estimates by the IPCC, the remaining carbon budget for a 66% probability of limiting global warming to 1.5 °C equals 420 Gt. Uncertainties are substantial, however, and amount to ±400 Gt CO₂ (IPCC, 2018). Continued global emissions on today's level of 42 Gt CO₂ per year would entirely exhaust this budget within the next 10 years, approximately. This highlights and exacerbates the urgency to take action.

Influencing the share of greenhouse gases in the atmosphere is generally possible by three different strategies:

- ▶ Avoidance of greenhouse gas-emissions as a result of reduced product consumption (through increased materials and energy efficiency, and sufficiency) or reduced activities leading to greenhouse gas emissions reductions,
- ▶ Substitution of greenhouse gas intensive technologies and products by less greenhouse gas intensive ones,
- ▶ Utilization of sinks – removal of CO₂ already emitted from the atmosphere via carbon dioxide removal (CDR).

The potential contributions by these strategies in reaching greenhouse gas neutrality are restricted, influence each other, and change over time as qualitatively shown in Figure 1. Greenhouse gas mitigation by **avoidance** is basically limited as the complete waiving of energy demand and mobility is hard to imagine in a modern society. It would be possible, however, to set the frame conditions in a way that traffic is avoided (e.g., considering short distances in urban planning) and energy efficiency enhanced (e.g., by modernizing buildings or using efficient technologies). In addition, a healthier and low-meat diet would help reduce livestock and consequently lead to lower greenhouse gas emissions. These approaches are mainly based on societal changes, individual sustainable behavior, or progressive planning² and regulation³. Therefore, they require precautionary action both in the medium and in the long term. If mitigation measures are taken too late, the potential of the respective strategy may not be fully tapped and thus its potential contribution to greenhouse gas neutrality is reduced (see decreasing green area over time in Figure 1).

The **substitution** of greenhouse gas intensive processes and products can make significant contributions to mitigation. This includes a complete shift towards renewable energy sources in the

² E.g. compact city.

³ E.g. the European Ecodesign Directive.

Figure 1

Qualitative representation of the changing room to maneuver through contributions by greenhouse gas avoidance, substitution, and carbon sinks on the path towards greenhouse gas neutrality by the middle of the 21st century



Source: Umweltbundesamt

combustibles, fuel, feedstock⁴, and power supply, for example. Research and development could yield low-greenhouse-gas process technologies and products such as alternative cement. Here it is also true, however, that late action will cut the mitigation potential with respect to greenhouse gas neutrality. In order to ensure the highest possible contribution by this strategy to greenhouse gas mitigation until 2050, it is crucial to observe several aspects: Demand for research and development needs to be identified and suitable projects be initiated early on. The required infrastructures have to be installed or existing ones fit to new requirements. The needed extension of renewable energy must be organized duly, and necessary investments be made in all sectors. This mitigation strategy by itself will not result in greenhouse gas neutrality, though. Based on today's knowledge, greenhouse gas emissions related to the use of feedstocks (e.g., chemicals) and raw materials inputs in industry (e.g., electrodes, coke as reducing agent, etc.) remain, for instance, in the glass, lime, and cement industries. Similarly, some greenhouse gas emissions from agriculture and land-use change cannot be eliminated by substitution and therefore remain.

The utilization of **carbon sinks**, both natural and technical, is limited. The potential contribution by natural sinks to greenhouse gas mitigation changes over time, e.g. due to altering age structures of forests and climatic conditions (which might themselves be altered by increasing climate change). Technical sinks such as Carbon Capture and Storage (CCS) are also limited in availability on a global scale and feature some environmental risks. Similar to avoidance and substitution measures, the use of carbon sinks requires timely action or else the potential contribution by natural sinks to greenhouse gas mitigation will decrease.

The lower the contributions from avoidance and substitution to greenhouse gas mitigation, the larger the necessary contribution by sinks. The 1.5 °C Special Report by the IPCC also states clearly that there are physical boundaries that restrict CO₂ removal from the atmosphere. Using CDR measures generally results in an increased resource demand for land, water, and energy and therefore rises uncertainty with respect to an enduring sustainable development.

⁴ The non-energetic demand of the chemical industry.

3 How to achieve this? – Green-scenarios

KEY MESSAGES

The Green-scenarios shows:

- ▶ Greenhouse gas neutrality in Germany until 2050 can be achieved via different paths requiring carbon removal from the atmosphere but without the need for technical carbon capture and storage (CCS).
- ▶ In order to limit cumulative greenhouse gas emissions, a light tightening of intermediate targets (2030) only leads to limited benefits for climate protection. Instead, rapid and ambitious action is needed.
- ▶ In the face of global challenges in limiting global warming to 1.5 °C, Germany ought to develop along a global 1.5 °C greenhouse gas mitigation path. This means that national greenhouse gas emissions should be reduced by at least 70 % by 2030 compared to 1990.

With the Climate Protection Plan 2050 the German Government defines the milestone target of a greenhouse gas emission reduction of at least 55 % by 2030 compared to 1990 and the necessary reduction contributions by the individual sectors to achieve this target whereas “extensive greenhouse gas neutrality” is stated as the overarching goal (BMU, 2016). But although Germany has entered into a stricter international commitment by ratifying the Paris Agreement (Wachsmuth et al., 2018), the Climate Action Plan 2050 merely confirms the target corridor for greenhouse gas emission reductions that was already agreed on in the Energy Concept of 2010 (German Federal Government, 2010), namely greenhouse gas emission reductions of -80 to -95 % until 2050 in comparison to 1990 levels. The German government has set “greenhouse gas neutrality” as a new environmental scope of action for Germany by 2050 with the “Eckpunkte für das Klimaschutzprogramm 2030” (German Federal Government, 2019) presented in September 2019. The level of ambition for the time frame until 2030 remains unchanged, however.

Against this background and given the known interdependencies between climate protection and sustainable resource management, the RESCUE-study (“Resource-efficient Pathways towards Greenhouse-Gas-Neutrality”, UBA, 2019b) presented in this report analyzes six scenarios (Green-scenarios) that describe possible transformation pathways towards

a greenhouse gas neutral and resource-efficient Germany in 2050. The study outlines Germany’s potential contribution to the necessary global efforts towards climate protection and resource conservation while the scenarios focus on different levels of ambition towards achieving greenhouse gas neutrality. All Green-scenarios reach an overall greenhouse gas reduction of at least 95 % until 2050 and at least 55 % until 2030 compared to 1990 levels while raw material demand is significantly lowered. Greenhouse gas neutrality can be achieved in almost all scenarios by 2050 if natural carbon sinks (within Germany) are considered.

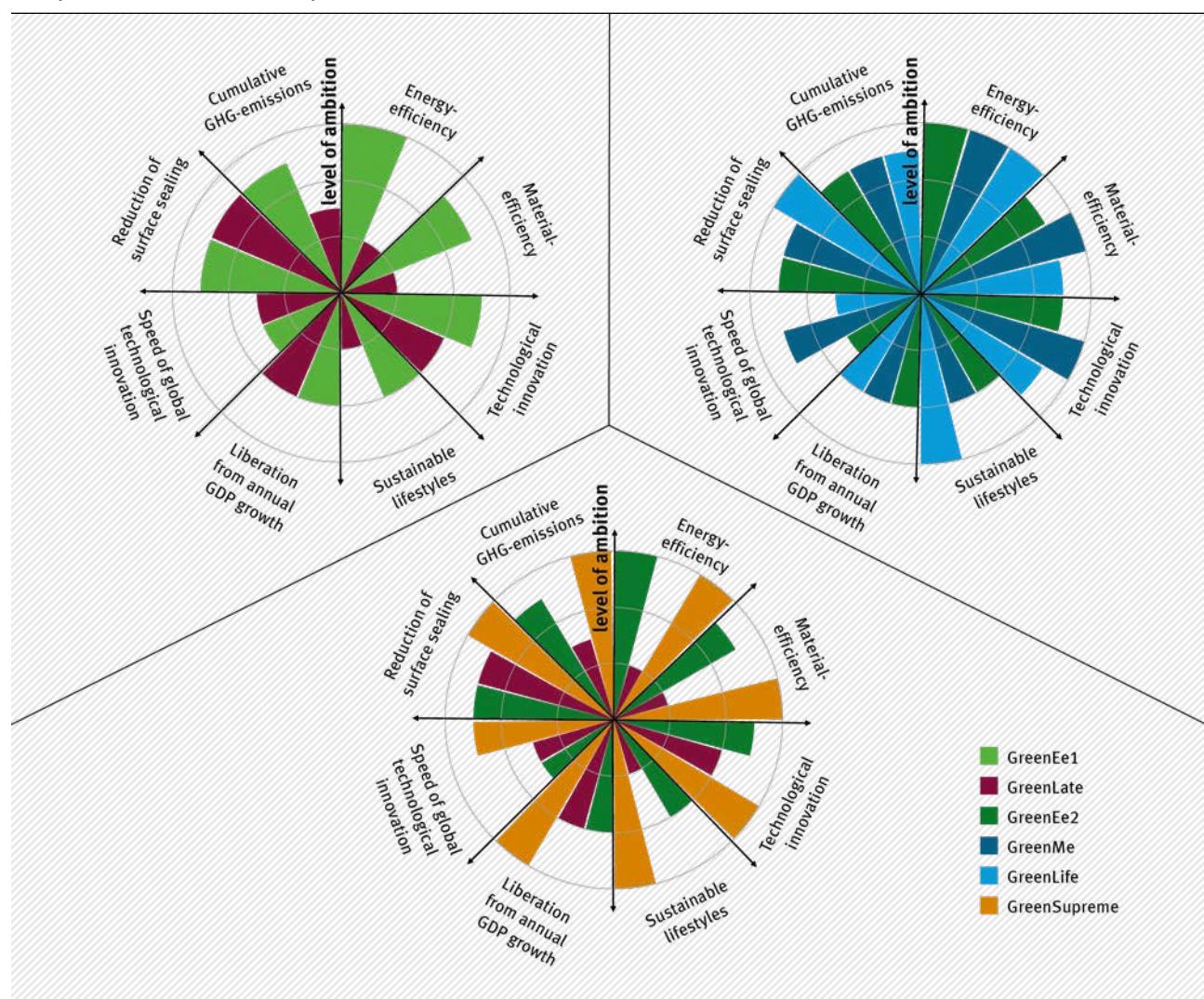
Both the GreenEe1 and the GreenLate scenarios are characterized by overall increasing production capacities and a strongly export-oriented industry within Germany (see Figure 2). They differ significantly in their level of ambition, however, with regard to greenhouse gas emissions reductions on the transformation path and both energy and material efficiency gains. In GreenLate conventional technologies such as combustion engines in heavy goods transport or gas combustion technologies in heat supply remain established in the long run. This renders GreenLate a scenario with a low level of electrification and delayed action in terms of innovation and implementation. With reference to greenhouse gas reductions, GreenLate is located at the ambitious lower edge of the German government’s target corridor, i.e., 55 % reduction

until 2030, 70 % until 2040 and 95 % by 2050. In the three scenarios GreenEe2, GreenMe, and GreenLife a more balanced foreign trade situation is assumed. Here, the effects of possible changes towards more sustainable lifestyles and measures in technical climate protection and raw material efficiency can be observed. Like GreenEe1, GreenEe2 focuses on a high level of technological innovation, integration of efficient sector coupling technologies and the tapping of energy efficiency potentials. In the GreenMe scenario further gains in material efficiency are assumed. GreenLife is characterized by a widespread implementation of more sustainable individual lifestyles, e.g., shifting towards a healthier, low-meat

diet or enhanced use of repairable, long-lasting, material-efficient products. The GreenSupreme Scenario not only combines all beneficial innovations, technical measures, and lifestyles but also assumes a significantly accelerated integration and implementation compared to the other scenarios in order to reduce cumulative greenhouse gas emissions. Thus, it makes a relevant contribution to international climate protection efforts on the path towards reaching the target of the Paris Agreement. Figure 2 gives an overview of the characteristics of the six Green-scenarios. Further information may be found in the RESCUE study (UBA, 2019b).

Figure 2

Comparison of the different parameters of the six GREEN-scenarios in RESCUE



Source: Umweltbundesamt

Each Green-scenario pursues all three strategies of influencing the share of greenhouse gases in the atmosphere: Avoidance, substitution, and natural carbon sinks. The particular extent to which the strategies are pursued differs, however, which yields a solution space encompassing all sources of greenhouse gas emissions.

The central element is the substitution of fossil related greenhouse gas emissions (see section 4). In this way, energy related greenhouse gas emissions can be completely eliminated in all six Green-scenarios. By 2050, the entire energy supply is exclusively based on renewable energy sources, i.e., the supply of electric power, combustibles, fuels, and raw materials. Furthermore, greenhouse gas intensive products such as cement are substituted by innovative products some of which still require extensive research and development to a different extent, though. The avoidance of greenhouse gas emissions (see section 5) by means of environmentally friendly mobility, sustainable consumption, repairable and energy efficient products, renovation and energetic modernization of buildings, energy management etc. is also considered in various degrees. A healthier diet following the guidelines by the German Nutrition Society and the consequent reduction of livestock likewise contribute to avoiding greenhouse gas emissions. None of the scenarios need technical carbon sinks such as CCS to reach their targets. Natural carbon sinks (see section 6) in all Green-scenarios benefit from sustainable forest management and use of wood – e.g. due to avoiding the energetic utilization of forest residues – as well as from sustainable land-use, e.g. not considering new land-take in the medium-term. Avoiding biomass cultivation for energetic use and reducing livestock lead to new land available for different purposes. In this way, an extra contribution to strengthening natural carbon sinks can be made.

By 2050, greenhouse gas reductions of 95 % in GreenLate and 97 % in GreenSupreme are achieved which considers those emissions that are also accounted for in the climate targets of the German Federal Government. The remaining greenhouse gas

emissions come mainly from agriculture with a share between 60 and 67 %. Based on today's knowledge, some raw material related industrial greenhouse gas emissions remain, too. These range between 27 % in GreenSupreme and 37 % in GreenLate and come primarily from the cement, lime, and glass industries.

If the contribution from natural sinks and the greenhouse gas emissions from land-use change are considered, the ambitious scenarios GreenLife and GreenSupreme in particular show that greenhouse gas neutrality in Germany can be achieved without technical sinks such as CCS. Even GreenLate comes close to net-zero emissions in 2050. In this respect, strengthening natural carbon sinks is essential. This may also help to tap synergies with other environmental challenges as well as with nature conservation (see section 6).

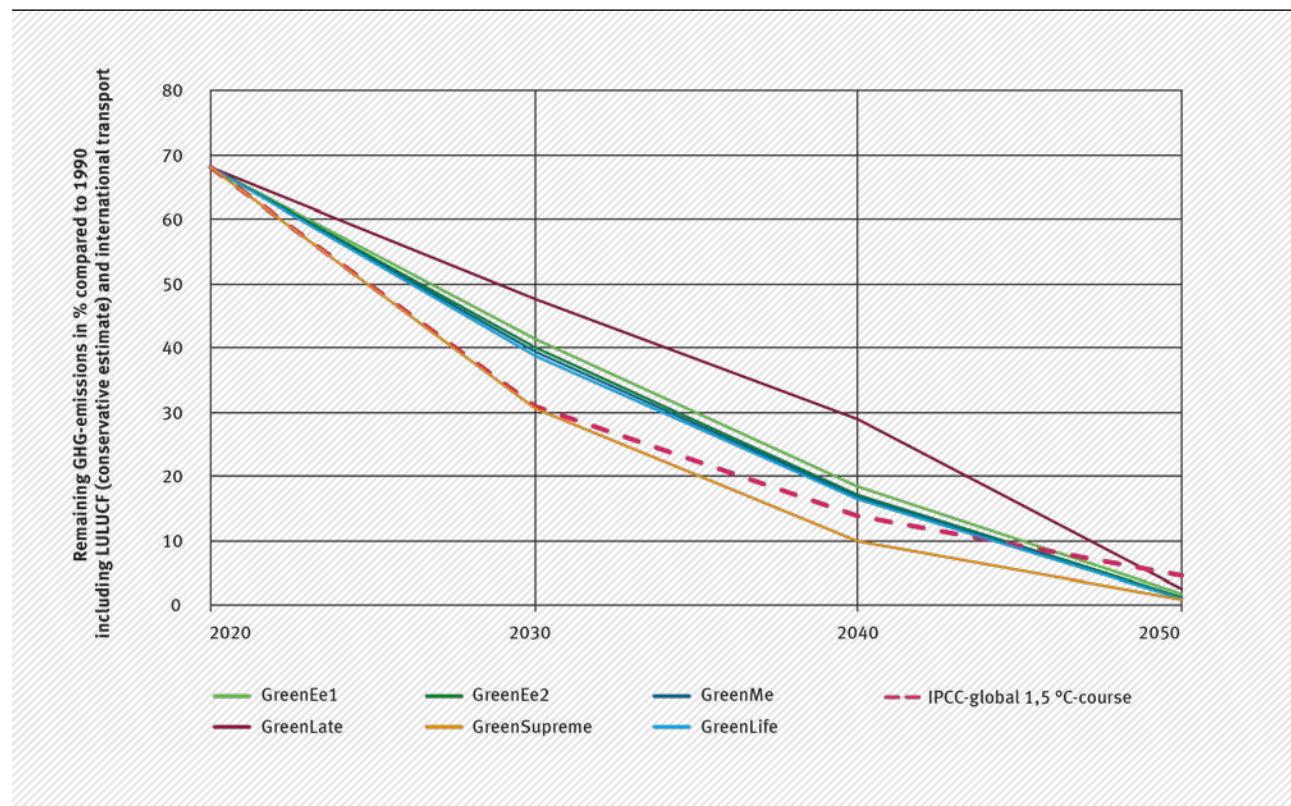
Against the background of the global challenges related to climate change and international commitments the chosen path towards greenhouse gas neutrality is pivotal. The GreenSupreme scenario complies best with the respective requirements as shown in Figure 3 in comparison to a 1.5 °C compatible global mean pathway (IPCC global 1.5 °C course). The mean IPCC global 1.5 °C course (IIASA, 2019) is based on different global 1.5 °C compatible paths and represents a median transformation path along which the global community and the overall anthropogenic greenhouse gas emissions must move. This does not mean that every single nation must exactly stick to this path, however. According to the Paris Agreement, affluent countries such as Germany play a prominent role in climate protection (compare Article 4 (1) PA, (UNFCCC, 2015)). Taking into account that Germany's prosperity and economic performance rely on greenhouse gas intensive technologies and fossil energy sources, Germany should make an ambitious contribution to limiting anthropogenic greenhouse gas emissions compared to other countries. Surveys show that from an equity point of view Germany should reach greenhouse gas neutrality already before 2035 (Climate Analytics, 2018; Höhne et al., 2019). The assessment of an equitable effort sharing between

all parties is the particular task of politicians. In order to best approach a globally adequate contribution by Germany, not only the extensive and fast implementation of national climate protection

measures is necessary – as in GreenSupreme – but also ambitious international cooperation as well as funding and implementation of climate protection measures outside Germany (see section 7).

Figure 3

Development of the remaining GHG-emissions in the Green-scenarios taking into account LULUCF (conservative) and the CO₂ emissions of international transport



Source: own illustration based on (UBA, 2020a, 2020b, 2020c, 2020d, 2020e) and (IIASA, 2019)

The Green-scenarios demonstrate that greenhouse gas neutrality in Germany becomes feasible through a fundamental transformation in the sense of a sustainable development. This concerns all areas of day-to-day actions and economic activities.

The question is no longer whether or when particular contributions need to be made and developments tackled. It rather becomes obvious that we must act now and that each and every contribution by both the production and the consumer sides is important.

4 How to achieve this? – Substitution

KEY MESSAGES

- ▶ The complete phase-out of the use of fossil fuels should be realized by 2050 at the latest.
- ▶ The phase-out of coal-fired power generation must be implemented quickly and should be realized until 2030.
- ▶ The phase-out of coal use across all economic sectors should be realized until 2040.
- ▶ The annual gross expansion of onshore wind energy must be increased to at least 4 GW per year and preferably to 5.5 GW per year.
- ▶ The annual gross expansion of photovoltaics must be increased to at least 3.5 GW per year and preferably to 4.8 GW per year.

Global greenhouse gas emissions increased from 27 Gt CO₂eq to 51 Gt CO₂eq between 1970 and 2015 (Climate Action Tracker, 2018). Emissions from the burning of fossil fuels and from industrial processes contributed 78 % to total greenhouse gas emissions between 1970 and 2010. The territorial greenhouse gas emissions of Germany were reduced from 1,251 million tons (MT) in 1990 to 907 MT in 2017 – a reduction of 28 % (UBA, 2018). National greenhouse gas emissions are also mainly caused by stationary and mobile combustion of fossil fuels. These caused about 88 % of the carbon dioxide emissions in 2017. As a result of using fossil fuels, the cumulative consumption of primary raw materials is rising steadily.

The complete phase-out of fossil fuels across all sectors of the economy is inevitable in order to reach greenhouse gas neutrality and a sustainable resource management. In order to reduce cumulative emissions to the atmosphere and thus meet our international obligations the phase-out of coal-fired power generation must be implemented quickly until 2030 and must be extended fast until 2040 to a phase-out of coal use across all economic sectors. The substitution of fossil fuels by renewable energy is technically feasible to a large extent. Remaining

technical challenges should be solved quickly through research and development. Renewable energy must be used in a sustainable and efficient way, however, and demands for new technology-critical materials (e.g., metals) carefully monitored to avoid potential burden shifting.

Therefore, the sustainable energetic use of biomass is limited. Crop biomass is associated with competition for land (also as a potential carbon sink) and negative impacts on water, soil, biodiversity, and nature conservation (UBA, 2013). The energetic use of residual forest wood must be balanced against the increase in carbon sinks, biodiversity, and other environmental and nature conservation benefits.

It is essential to expand wind energy and photovoltaics. In order to limit their demand and the associated challenges and environmental impacts, e.g., with regard to land consumption, raw material demand, etc., energy efficiency measures must be consistently implemented and an effective sector coupling is required. Sector coupling enables the use of electricity across all fields of application (i.e., for electricity, fuels, and raw materials/feedstocks). Efficient sector coupling means that renewable electricity is directly used wherever possible.

Renewable fuels should only be used where they are technically necessary, e.g., in air traffic, the chemical industry or a few industrial processes. To achieve this, a fast switch in the energy supply to an energy system entirely based on renewables is necessary. At the same time, the raw material requirements of the technologies during expansion and their global transferability must also be taken into account.

Recommendations for action in the sectors

In addition to the points made in the key messages, the regulatory and economic framework conditions (including effective CO₂ pricing) required for the substitution of fossil fuels and the use of greenhouse gas neutral and low-greenhouse gas technologies for all fields of application must be created. This will enable the following steps in the sectors to be taken (for further details see the RESCUE full report (UBA 2019b)):

- ▶ The climate-friendly integration of Power-to-X technologies should be the top priority given their substitution potential and effective greenhouse gas reduction.
- ▶ Germany should rapidly intensify sustainable partnerships with other countries on research and development (R&D), knowledge transfer, and implementation related to PtG/PtL production sites. Already at an early stage, globally favorable locations for the expansion of renewable energy systems and renewable fuels based on electricity need to be determined and developed.
- ▶ No new oil heating systems should be installed. From 2030 onwards no new gas heating systems should be installed, either.
- ▶ As far as technically possible, fossil fuels should be substituted by the direct use of renewable electricity (e.g., for process heat generation).
- ▶ The phase-out of fossil carbon in the chemical industry must be prepared quickly through research and development projects. Against the background of long life-times and increased recycling rates, durable products in the chemical industry must soon be replaced by renewable energy sources.
- ▶ The fossil-based hydrogen economy in Germany (possibly with a short-term focus on petrochemicals) should be restructured starting from 2030 onwards towards the use of renewable energy through the integration of hydrogen electrolysis.
- ▶ In order to efficiently achieve the climate targets, at the very latest from the year 2040 new cars entering the market should only be electric cars. In on-road freight transport the implementation of battery-electric drive trains for light goods vehicles and lorries up to 12 GVW must be paramount. For lorries over 12 tons GVW the implementation of overhead catenary hybrid lorry and overhead catenary battery-electric lorry systems is needed and requires the rapid installation of the respective infrastructure alongside highly-frequented sections of motorway.
- ▶ Alternative low or zero-carbon products for the substitution of conventional products associated with high greenhouse gas emissions (e.g., cement production) should be developed and put on the market.

5 How to achieve this? – Avoidance

KEY MESSAGES

- ▶ Society needs to find new ways of thinking in all areas in order to establish environmentally conscious behavior on both the demand and the supply sides. For this purpose, it is necessary to create a regulatory and economic framework and to take measures with regard to education policy.
- ▶ Each individual needs to develop a greater awareness of their own responsibility in day-to-day behavior in order to effectively reduce the consumption of energy and greenhouse gas intensive products.

Mitigation of greenhouse gas emissions is more than just a technical issue. Although both the substitution of fossil energy carriers and alternative technological solutions for greenhouse gas emissive industrial processes (e.g. steel production) bear a high potential to limit greenhouse gas emissions, these approaches are not sufficient. Reductions in greenhouse gas emissions in agriculture and land-use in particular are only possible to a limited extent by technical means. Thus, the strategy of avoidance is crucial in order to comply with international obligations and environmental challenges in a sustainable manner.

Each individual generates certain demands driven by his or her desires and consumer behavior in all areas of life, i.e. leisure, housing, communication, mobility, and nutrition. These demands affect the development of the respective service and production sectors. Sustainable supply and behavior have positive effects on the consumption of greenhouse gas intensive products and the substitution of fossil fuels by renewable energy. For example, a healthier diet based on the guidelines by the German Nutrition Society could lower the demand for meat products and hence reduce livestock, greenhouse gas emissions, and associated further demands for water and fertilizers.

Final energy demand significantly accounts for the greenhouse gas emissions on the transformation path. This includes the required amount of renewable energy sources substituting for fossil fuels and raw materials, the dependency on energy imports, and the demand for resources such as land. Energy efficiency measures across all sectors make substantial contributions in this respect. This helps

reduce greenhouse gas emissions and integrate renewable energy on the transformation path in particular.

Recommendations for action in the sectors

This greenhouse gas mitigation approach in particular shows that climate protection is a challenge for society as a whole. A fundamental transformation of both society and the economy in the sense of a sustainable development is needed – see key messages.

Similar to substitution, avoidance requires a regulatory and economic framework which promotes a fast rethinking process in all areas of our day-to-day actions and economic activities⁵:

- ▶ Phasing out environmentally harmful subsidies is very important in order to successfully manage the transition to sustainable production and consumption patterns.
- ▶ Ambitious measures to increase energy efficiency must be taken quickly across all economic sectors considering also the associated raw material demands. Both regulatory measures and support schemes for energy efficient technologies and an effective energy management must be implemented.

⁵ For further information see RESCUE full report (UBA 2019b).

In order to avoid greenhouse gas emissions, the following steps are required in the different sectors:

- ▶ The reduction of livestock plays a key role in effective climate protection in agriculture and land use. A reduction in domestic livestock is only possible, however, if human nutrition patterns change at the same time and the consumption of animal products is reduced to a healthy level in accordance with recommendations by the German Nutrition Society.
- ▶ In the short term, the building renovation rate must be increased to at least 2.5 % per year compared to the current level of 1 %.
- ▶ Already today, the requirements for new construction, refurbishment and modernization should largely meet the requirements of the existing building stock in 2050.
- ▶ Energy efficiency in industry can and must be increased through the use of energy-efficient technologies, energy management, the optimization of processes and procedures, and the consistent use of waste heat over all fields of application.
- ▶ In order to achieve a sustainable mobility, traffic avoidance and a shift towards environmentally sustainable traffic concepts must be stimulated soon. This includes structures for short distances.
- ▶ Freight traffic should be shifted towards railways and inland waterways wherever possible. This can be promoted through enhancing the attractiveness of road alternatives on the one hand and through making freight traffic on roads more expensive by adding charges for environmental costs.
- ▶ Tax privileges of air traffic should be eliminated while the railway network needs to be expanded in order to significantly improve the accessibility of and interconnection between areas of high population density and thus avoid domestic flights.

6 How to achieve this? – Strengthen natural sinks

KEY MESSAGE

- Sustainable land-use in agriculture and forestry facilitates carbon removal from the atmosphere by natural means while synergies with other environmental challenges such as biodiversity protection can be tapped.

In addition to substitution und avoidance, the removal of carbon dioxide from the atmosphere (CDR – Carbon Dioxide Removal) is required to reduce the atmospheric carbon content. All 1.5 °C compatible scenarios in the IPCC's 1.5 °C Special Report include carbon sinks in order to remove CO₂ from the atmosphere to at least compensate for unavoidable greenhouse gas emissions from other sectors such as industry or agriculture.

If greenhouse gas mitigation by means of substitution and avoidance progresses too slowly, the resulting pressure on carbon sinks may create or increase conflicts. This is because CDR measures usually demand land and, to varying degrees depending on the measure, other resources such as water or energy. Most technical CDR measures with subsequent storage currently under discussion, such as sea fertilization and BECCS (bioenergy with carbon capture and storage), bear risks for the environment and a sustainable development based on today's knowledge (UBA, 2019a). Therefore, sinks cannot replace substitution and avoidance but appear to be a necessary complementary measure.

Already today strengthening natural carbon sinks is a feasible option to sustainably remove CO₂ from the atmosphere. This can be accomplished by sustainable land use, e.g. soil-conserving and humus-enhancing land management, protection and rewetting of moors, grassland conservation, and sustainable forest use. Although sinks are limited, their potential to remove CO₂ is relevant on the national level and significant on a global level. In addition, this contributes to adaptation to the consequences of climate change and to the achievement of global sustainability goals such as the protection of biodiversity.

In Germany, forests as a natural carbon sink can be conserved and strengthened by the increased conversion towards mixed forests and by increasing the share of protected forests to around 7 %. In addition to the forest sink, the storage in wood products can be enlarged by an increased cascading use. Taking these options into account, a carbon sink potential of at least 32 million tons of CO₂ is possible according to the recent "nature conservation scenario" simulated using the Forest Development and Timber Resource Model (WEHAM) (Oehmichen et al., 2018). This was taken as a conservative estimate for natural sink potentials in the Green-scenarios because no modelling of the eco-system was performed for the RESCUE project and the greenhouse gas emissions from wood products calculated in the WEHAM scenarios are likely to be much larger than in the Green-scenarios (UBA, 2019b). In combination with all measures from the other sectors this could allow Germany's greenhouse gas emissions in GreenSupreme to be reduced by as much as 99.2 % until 2050 as illustrated in Figure 3. A more optimistic estimate is provided in the study "Forest Vision Germany" by Öko-Institut commissioned by Greenpeace Germany (Greenpeace, 2018). According to this study up to 12 % of the forests should be designated as conservation areas leading to a forest based net carbon sink potential of 90 million tons of CO₂. This could render reductions in greenhouse gas emissions of 103.8 % in Germany by 2050 possible, see Figure 3. The overall assumed measures in the Green-scenarios, and in GreenSupreme in particular, go beyond those in the "nature conservation scenario" (Oehmichen et al., 2018) while falling short of those in the "Forest Vision Germany" study (Greenpeace, 2018).

Figure 4

Greenhouse-gas mitigation in 2050 considering LULUCF



Note: LULUCF – Land Use, Land-Use Change and Forestry; HWP – Harvested Wood Products; Also the energy-based GHG-emissions of international transport are considered in the base year.

Source: own illustration based on (UBA, 2020e) and (Greenpeace, 2018)

Another possible potential for natural carbon sinks lies in waiving both biomass cultivation and the energetic use of forest wood residues. The energetic use of biogenic flows should rather be restricted to such applications which are beneficial in terms of climate protection such as slurry fermentation.

Recommendations for action in the sectors

Natural carbon sinks can compensate for unavoidable greenhouse gas emissions from other sectors. At the same time there are synergistic effects with other environment policy domains such as biodiversity protection. These natural potentials should be tapped in addition to substitution and avoidance measures while they cannot replace those (for further information see RESCUE full report (UBA 2019b)):

- ▶ A sustainable and active transformation of forest cultivation is urgently necessary. The current high share of coniferous forest monocultures makes forests and, thus, the provided carbon reservoir vulnerable to direct and indirect consequences of climate change. In contrast, mixed deciduous forests show an increased resilience.
- ▶ The rewetting of drained moors and their conversion into paludiculture should be accomplished by 2050 at the latest.
- ▶ In order to strengthen the environment, nature, and biodiversity the energetic use of cultivated biomass should be phased out in the medium term and the energetic use of residual forest wood should be phased out in the long term.

7 Acting beyond Germany!

KEY MESSAGES

- ▶ The successful transformation towards greenhouse gas neutrality within Germany depends on both a European and global development in line with the Paris Agreement.
- ▶ Greenhouse gas neutrality in Germany until 2050 and the reduction of greenhouse gas emissions along a global 1.5 °C path are prerequisites and still only one part of an equitable contribution by Germany to fighting global climate change.
- ▶ In addition to increased climate action at the national level, Germany needs to act internationally to ensure that other countries also become greenhouse gas neutral by 2050 at the latest while setting significantly higher intermediate targets in terms of climate protection.
- ▶ A credible, responsible German climate protection policy includes substantially stronger impulses for European cooperation and target-oriented international collaborations in order to promote the effective implementation of climate protection measures outside Germany. The focus here should be on phasing out fossil energy carriers, eliminating environmentally harmful subsidies, and the protection and extension of natural carbon sinks.

An extensive transformation of the German economic system and way of living towards greenhouse gas neutrality as proposed in the Green-scenarios is embedded in both the European and the global development. The Paris Agreement serves as a guideline for the design of sustainable national, international, and global efforts in climate protection. This means that overall all contracting parties need to plan their development along a 1.5 °C compatible path. Given the current state of knowledge, however, the required transformation is projectable only to a certain extent both on the national and the international level. According to the Paris Agreement, affluent countries such as Germany play a prominent role in climate protection, though (compare Article 4 (1) PA, (UNFCCC, 2015)). This can be justified by such countries' economic prosperity, technological capacity, and the historic development of greenhouse gas emissions. Industrial countries such as Germany have to date caused disproportionately high greenhouse gas emissions since the industrial revolution compared to less developed countries. The assessment of an equitable effort sharing between all parties remains the particular task of politicians, though.

With regard to the above-said, the Green-scenarios of the RESCUE project (UBA, 2019b) basically reveal the following: Achieving greenhouse gas neutrality in Germany by 2050 while reducing greenhouse gas emissions along a sustainable and 1.5 °C compatible path (compare section 3) is ambitious yet feasible. Such a path can merely be the base for an equitable contribution by Germany to the fight against climate change, though. In addition to the transformation on the national level, Germany should assume more responsibility in proactively promoting the European and global transformation with particular regard to the strategic guidelines of substitution, avoidance, and strengthening natural carbon sinks.

In accordance with the Paris agreement the 1.5 °C Special Report by the IPCC suggests that the European Union (EU) reviews its existing long-term targets as the present economic and technological potentials would allow for much higher contributions to greenhouse gas mitigation than previously determined (Wachsmuth, Denishchenkova et al., 2019). Moreover, by its proposal "A Clean Planet for All" (EUCom, 2018) the European Commission has opened the discussion about the goal of action

“Climate Neutrality in 2050” among the heads of states and governments (EUCoun, 2019; UBA, 2019c). An integrated European and national climate protection policy is inevitable in order to achieve greenhouse gas neutrality within Germany which is the national economy with the highest performance within the EU currently accounting for approximately 20% of the EU’s total greenhouse gas emissions (EEA, 2019). This interlocking (between EU and domestic policies) must be based on concrete measures on a priority strategic level enabling larger greenhouse gas reductions in the medium term and greenhouse gas neutrality in the long term. As a first step in this direction Germany could adopt a progressive attitude towards raising the EU’s 2030 climate targets to make them compatible with a sustainable 1.5 °C compatible global mean path. For that purpose, Germany must be willing to make a significant contribution and to actively strive to enlarge the number of EU member states supporting greenhouse gas neutrality and an increased reduction target for 2030. Furthermore, in the short term Germany should explore possibilities among member states to adjust the contributions by the emissions trading scheme and by the non-ETS sectors as well as the applicable legislative framework and instruments early and effectively along the strategic guidelines of substitution, avoidance, and strengthening natural carbon sinks.

On the international level Germany should advocate the tightening of mitigation-relevant instruments of the United Nations Framework Convention on Climate Change (UNFCCC) such as the strengthening of the Green Climate Fund, the definition of robust and

environmentally upright regulations for market mechanisms under Article 6 of the Paris Agreement, and promotion of additional efforts in climate protection outside Germany. Further levers could be increased investments in both the Bonn Challenge for REDD+⁶ and the “4 per 1000” initiative⁷ in order to save and expand natural carbon sinks worldwide. Germany should also push the implementation of taken decisions such as the phase-out of environmentally harmful subsidies (G20, 2016) among the G20 and other country groups and strive towards partnerships for directed sector-specific global measures such as a global coal phase-out. A socially acceptable and fair transition and hence a high level of acceptance can only be achieved if all relevant stakeholders are involved (importers/exporters).

Beyond that, Germany must support other countries in tightening and implementing their Nationally Determined Contributions according to the Paris Agreement within the frame of the International Climate Initiative. In addition, Germany should plead for every trade agreement between the EU and other countries to be in line with climate and resource protection and to particularly support trading resource efficient and greenhouse gas neutral products.

⁶ Funding mechanism for the reduction of emissions caused by deforestation and forest degradation in developing countries.

⁷ International initiative launched by France on 1 December 2015 at the COP 21 inviting all partners to state or implement some practical actions on soil carbon storage.

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