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Resource-Efficient Pathways towards Greenhouse-Gas-Neutrality

Executive Summary of the RESCUE-Study

For our Environment

Umwelt Bundesamt

Imprint

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Content

1 Accepting the challenges

Humans have become an important factor influencing the biological, geological, and atmospheric processes of the Earth (Crutzen, 2006). Through economic activities such as mining, settlements and infrastructure developments, agriculture and forestry, humans influence the natural ecosystems and environmental media. To date, global economic growth is tightly coupled to the extraction and use of natural resources such as fossil fuels and other raw materials, but also land and water. This increasingly threatens our environment and livelihoods.

As a result, the use of natural resources has continuously increased in recent decades and today an estimated four out of nine planetary boundaries have been surpassed. **For example, global raw materials extraction (biomass, fossil energy carriers, metals, and non-metallic minerals) has accelerated in the last decades from around 6 Gt (billion tonnes) in 1900 to about 92 Gt in 2017** (UNEP, 2017, 2019). Given a steadily rising world population, the future demand for raw materials could further rise to more than 180 Gt by 2050 (Hatfield-Dodds et al., 2017). The extraction and processing of raw materials currently results in about half of global greenhouse-gas (GHG) emissions and more than 90 per cent of global special loss and water scarcity (UNEP, 2019).

Global GHG-emissions continue to rise despite the implementation of various climate protection measures. In 2017, fossil CO_2-emissions worldwide were with 37 Gt around 63 per cent higher than in 1990 (EC, 2019). The main cause of this is the use of fossil fuels which, in addition to the above-mentioned effects on the use of primary raw materials, influences the natural processes in the atmosphere. For example, the increase in GHG-emissions in the atmosphere leads to a rise in the global annual mean temperature. In 2016, temperatures were on average 1.1 °C higher than during the pre-industrial age (WMO, 2017). **This has adverse consequences on natural ecosystems as well as on the availability of natural resources, such as land, water, and biodiversity.**

In order to meet these challenges, the German Federal Government has committed to a number of climate and environmental targets. The Climate Action Plan defines sectoral contributions to GHG-emissions reduction by 2030 and the overarching action goal of becoming "extensively GHG-neutrality" by 2050. Nevertheless, even in the context of the international commitments made in Paris, the 2010 target corridor of an 80 to 95 per cent reduction in GHGs compared to 1990 was confirmed.

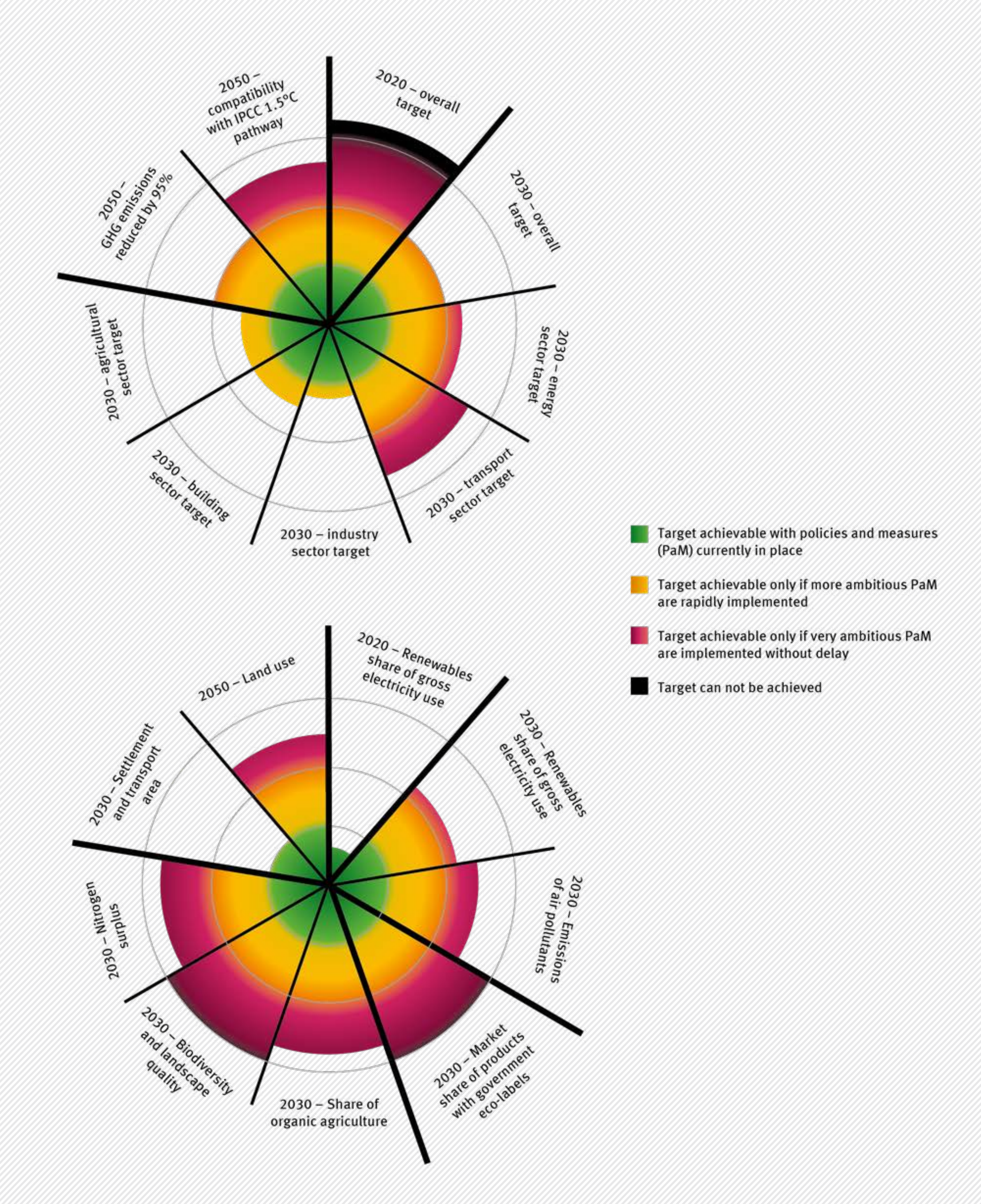
With the ratification of the Paris Climate Agreement, currently 185 of 196 parties to the Framework Convention on Climate Change (UNFCCC, 2019) have committed themselves to keep the increase in global average temperature to well below 2 °C above pre-industrial levels; and to limit the increase to 1.5 °C (UNFCCC, 2015). The German government has set "greenhouse gas neutrality" as a new environmental action target for Germany by 2050 with the "Eckpunkte für das Klimaschutzprogramm 2030" (Bundesregierung, 2019) presented in September 2019 and shows how the targets for 2030 are to be achieved. However, an increase in the level of ambition for the time window until 2030 has not been made.

Figure 1 illustrates that **reaching the climate targets of the Climate Action Plan 2050 requires substantial additional efforts and seems increasingly challenging for a number of sectors and targets initially proposed. Furthermore, other climate and environmental goals of the German government can also only be achieved if the level of ambition is increased**, such as the reduction of new land sealing which is to be reduced to net zero by 2050.

The lead indicator of German resource politics is the "Total Raw Materials Productivity" which compares the value of all goods submitted for final use (in EUR, price adjusted) relative to the mass of the raw materials used domestically and abroad for their production (in tonnes). It is a measure for the efficient use of raw materials. The Federal Government's goal is to increase total raw material productivity by an average of 1.5 per cent per year from 2010 to 2030. The average increase is currently 1.9 per cent, which is above this target. Nevertheless, the consumption of primary raw materials overall has been rising.

Figure 1

Qualitative assessment of the likelihood to reach climate and other environmental protection goals in Germany

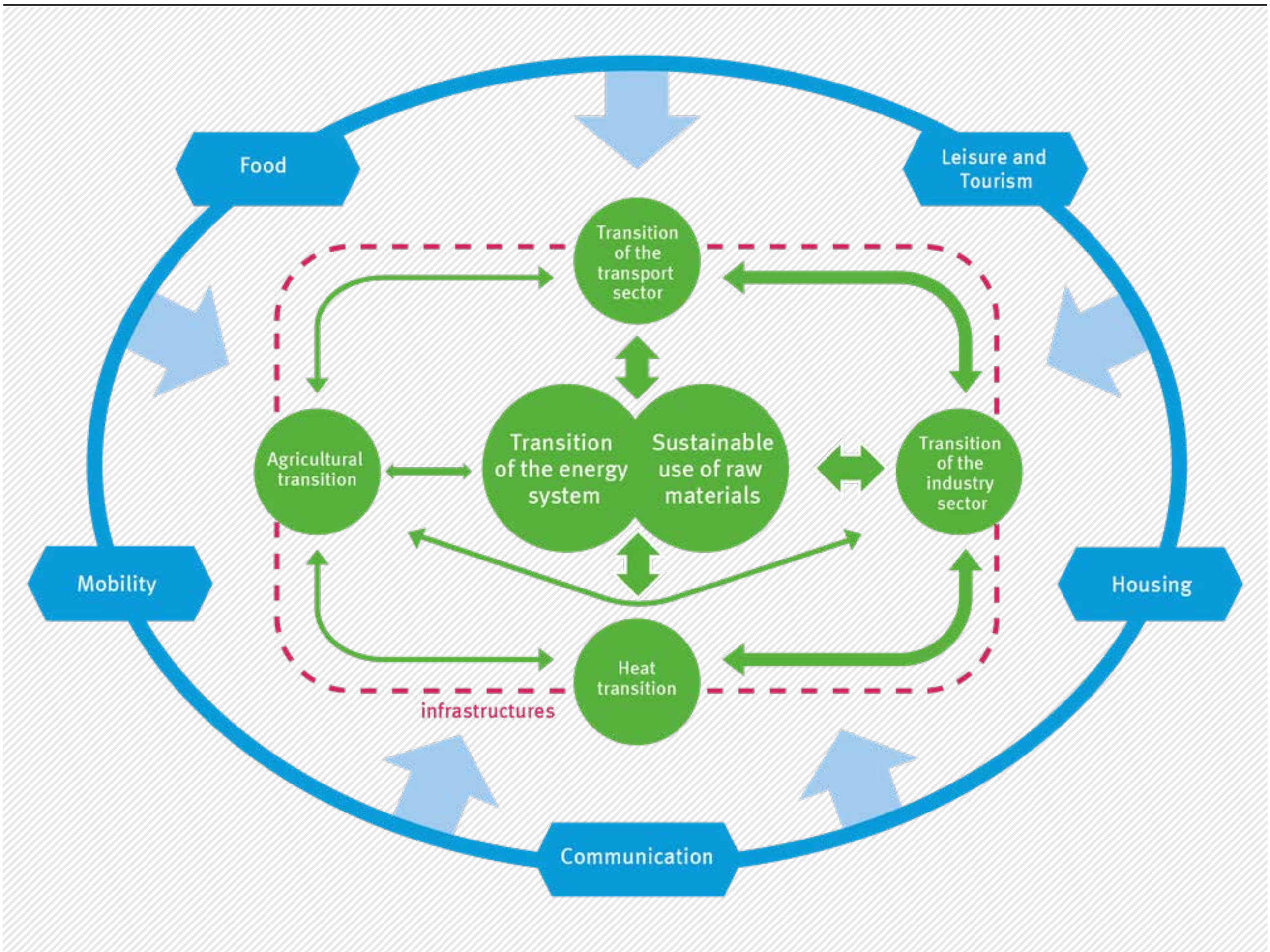


Source: German Environment Agency (Umweltbundesamt) based on Statistisches Bundesamt, 2018

A fundamental and systemic transformation of the economy and society with regards to sustainable development is urgently needed, considering also the necessary adaptations to climate change. Various interdependencies exist between the supply of energy and raw materials and the demand for these via production, infrastructure needs, and individual consumption patterns (Figure 2). **Interlinkages exist in particular between the transformation of the energy supply ("Energiewende") and underlying materials system ("Rohstoffwende") with the other changes of individual sectors and vice versa.** Overall, the transformation in all areas of application has to take place considering aspects of climate- and natural resource protection together. The speed at which such a transformation of the energy and materials system is implemented has to consider possible peaks in raw materials demands and cumulative GHG-emissions along the transformation path, and set incentives to ensure the long-term effectiveness of political measures and the readiness of necessary infrastructures and technologies.

Figure 2

Schematic illustration of the interactions between different transformation pathways for by GHG source



Source: German Environment Agency (Umweltbundesamt)

2 Identifying the solution space

To find solutions for challenges with complex and dynamic interactions, scenario studies are developed. These allow analyzing different possible "futures" and how to get there, and open up a solution space for a sustainable transformation. 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 (GHG) neutral and resource-efficient Germany in 2050. Yet Germany is not viewed in isolation, but embedded in the European Union and the world, as a producing industrial country in global trade with a modern and productive society. Climate protection, decarbonization, energy efficiency and more resource protection as a common understanding characterize the necessary social and industrial change. All Green-scenarios reach an overall GHG reduction of at least 95 % until 2050 and at least 55 % until 2030 compared to 1990 levels while raw material demand is significantly lowered. GHG neutrality can be achieved in almost all scenarios by 2050 if natural carbon sinks (within Germany) are considered. Each Green-scenario pursues all three strategies of influencing the share of GHGs 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 GHG-emissions.

Figure 3 gives an overview of the key characteristics of the six Green-scenarios. Further information may be found in the RESCUE study (UBA, 2019b).

Both the **GreenEe1** and the **GreenLate** scenarios are characterized by overall increasing production capacities and a strong export-oriented industry within Germany (see Figure 2). They differ significantly in their level of ambition, however, with regard to GHG-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 lower level of electrification and delayed action in terms of innovation and implementation. With reference to GHG-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.

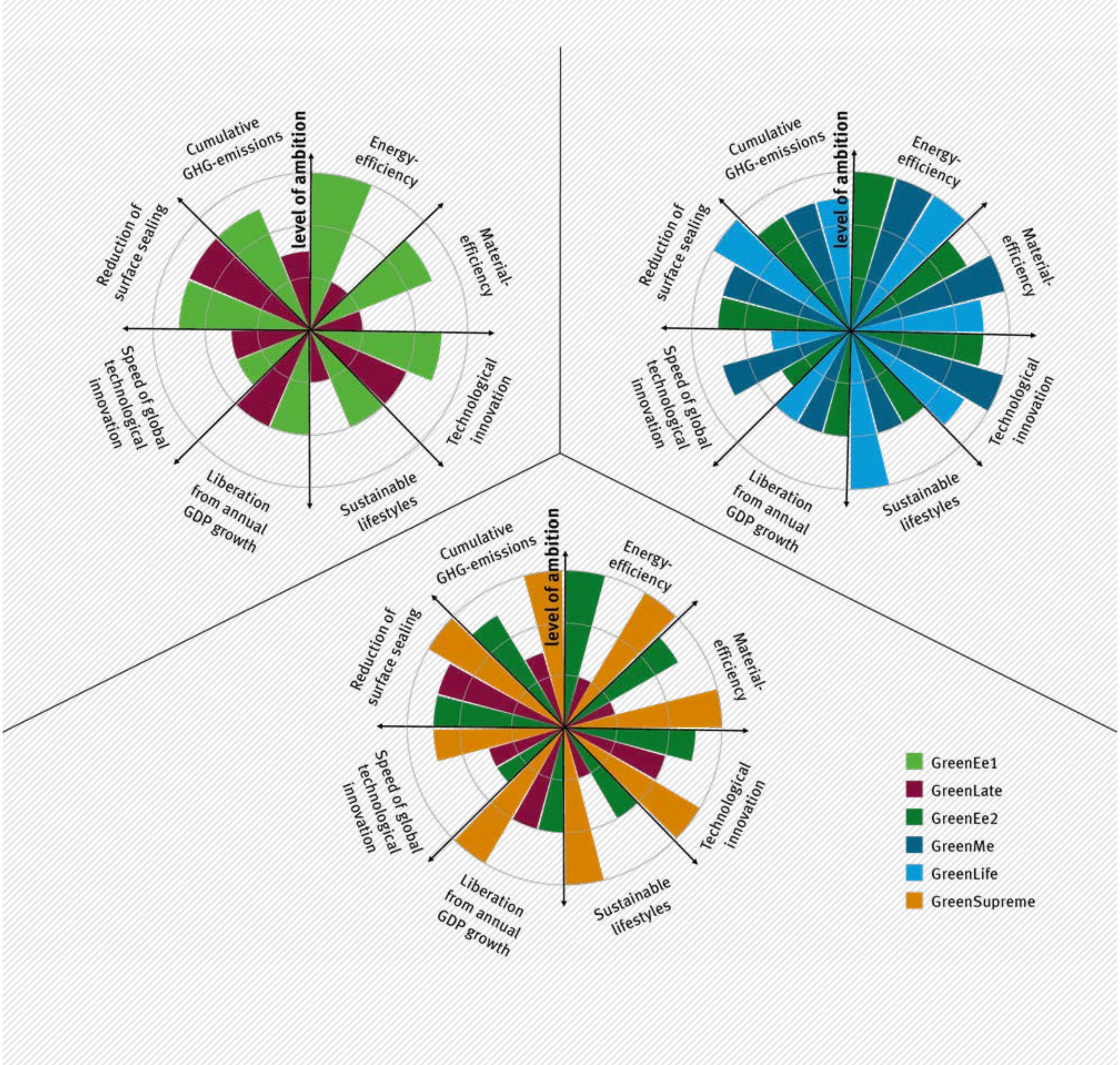
In the three scenarios **GreenEe2, GreenMe**, and **GreenLife** a more balanced foreign trade situation is assumed. Here, the effects of possible changes towards more sustainable lifestyles and measures in technical climate protection and raw material efficiency can be observed. Like **GreenEe1, GreenEe2** 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, and 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 GHG-emissions. Therefore, not only the phase-out of coal-fired power generation will be initiated in the short term, but also the phase-out of general coal use. By 2030, coal will no longer be used for electricity generation and by 2040 the complete phase-out of coal use will have been achieved. Also, in contrast to all other scenarios, a stronger exemption of overall economic growth[1] is assumed.

1 In GreenSupreme, there will be an average zero growth in Germany's overall economy from 2030 onwards, just as in Japan in recent years, but the per capita gross domestic product (GDP) will continue to rise compared to today as the population decreases slightly until 2050.

Figure 3

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



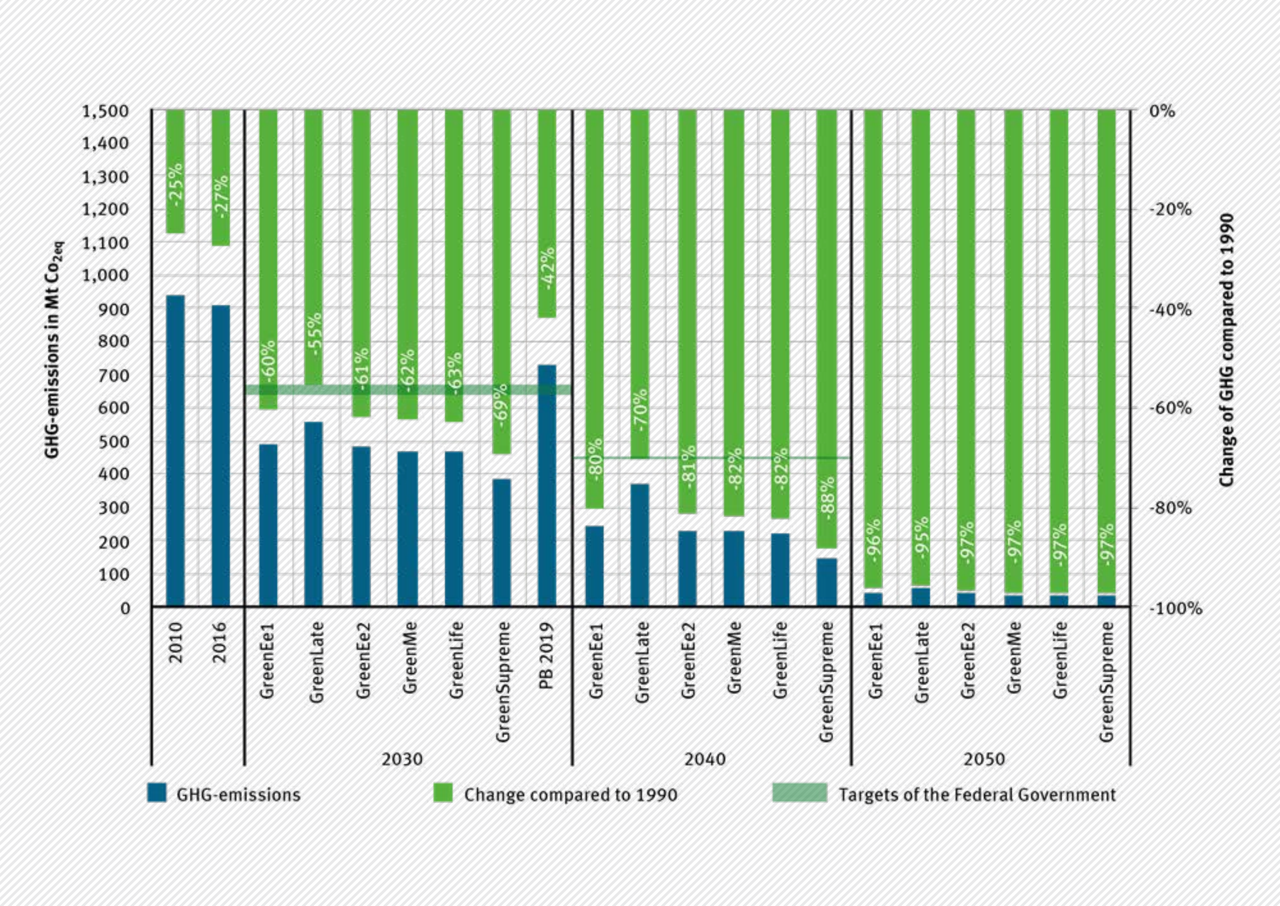
Source: German Environment Agency (Umweltbundesamt)

3 Solution options – climate protection

The Green Scenarios focus on options for achieving GHG-neutrality to the greatest possible extent or complete GHG-neutrality by 2050. For this, the scenarios show different transformation pathways across all emission source groups. **Despite the fact that some of individual sectoral climate protection targets are not met, the overall GHG-reduction target for 2030 is reached in all Green scenarios.** Only the GreenLate-scenario remains within the target range of the Climate Action Plan (reduction of 55 % compared by 2030 compared to 1990). However, the other scenarios go well beyond this target. For example, in GreenEe1 a reduction in GHG-emissions of 60 % is achieved compared with 1990 levels. In GreenEe2, GreenMe, and GreenLife, GHG-emissions are reduced by around 61 to 63 % compared to 1990. **Furthermore, given its higher level of ambition, in GreenSupreme a reduction of 69 % in 2030 can be observed. The GHG-reductions are dominated by the initiated phase out of coal-fired power generation. And in GreenSupreme, the phase-out of coal-fired power generation has already been completed by 2030.** Across all Green-scenarios, the energy sector contributes a disproportionately high share to the GHG-reductions and the sectoral target for 2030 is safely achieved. Also, the sectoral targets in industry and agriculture are achieved with high probability in all scenarios. In the context of the phase-out of energetic biomass use and the rapid

Figure 4

Greenhouse-gas (GHG) mitigation in the Green-scenarios until 2050 by individual sectors



Note: Only GHG-emissions are shown that are included in the targets of the German Federal Government.

Source: own illustration based on (UBA, 2020a, 2020b, 2020c, 2020d, 2020e) and (BMU, 2019b) abandonment of decentralized biomass heating systems, the target in the building sector can only be achieved in GreenSupreme. However, by 2035 at the latest, all Green-scenarios will achieve the sectoral GHG reduction target for 2030, even with the phase-out of decentralized biomass use. As a result of slow action, GreenLate clearly misses the sectoral climate protection target in the transport sector by 2030. The two GreenEe scenarios only narrowly miss the sectoral target in the transport sector, while GreenMe meets the target with high probability. With GHG reductions of 42 % (GreenLife) and 51 % (GreenSupreme) both scenarios even exceed the sectoral targets of the climate protection plan in 2030.

This highlights that emissions reductions above the existing target laid out by the German Federal Government can be achieved, but only if additional and even more ambitious measures are implemented. As a result, this should also be defined and put into action in the context of Germany's international and European obligations.

By 2050, GHG-reductions of 95 % in GreenLate and 97 % in GreenSupreme are achieved which considers the GHG-emissions that are also accounted for in the climate targets of the German Federal Government (Figure 4)**. In this way, energy related GHG-emissions can be completely eliminated. By 2050, the entire energy supply is exclusively based on renewable energy sources, i.e., the supply of electric power, combustibles, fuels, and chemical feedstock[2].** In spite of healthy and low-meat eating styles and a reduction in animal numbers in Germany, 60 to 67 % of the remaining GHG-emissions are caused by agriculture. According to the current state of knowledge, not all GHG-emissions can be avoided in industry either. In 2050, between 27 % (GreenSupreme) and 37 % (GreenLate) of GHG-emissions are still generated by industry. The main sources are the cement, lime, and glass industries.

All Green-scenarios show that (almost complete) GHG-neutrality can be achieved. However, the different transformation paths result in varying cumulative emissions between 2010 and 2050. In GreenSupreme, almost half of the GHG-emissions emitted between 1990 and 2015 are released again in the period 2015-2050. **Especially a rapid phase-out of coal use, also going beyond a renewable electricity supply, can limit the cumulative GHG-emissions.**

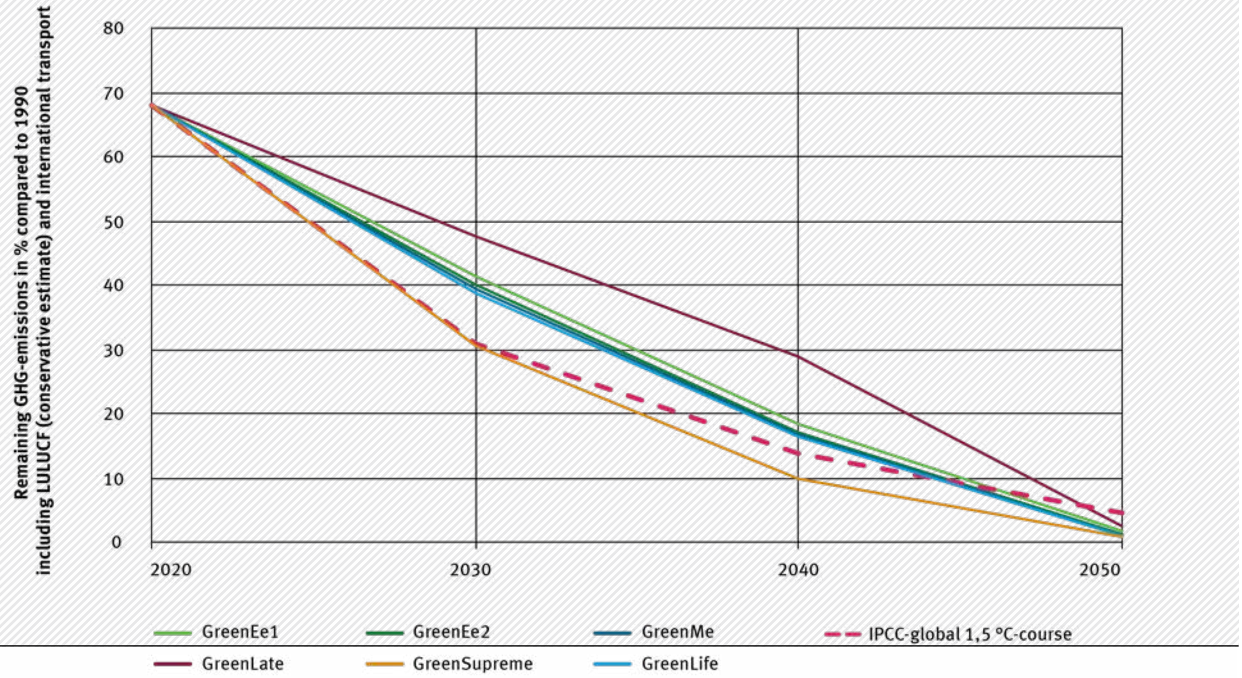
The impacts of a delayed transformation are visible in GreenLate where around 37 % more GHG-emissions are emitted than in GreenSupreme. In the other scenarios, emissions until 2040 are equal to emissions in GreenSupreme until 2050. **This highlights that in order to limit cumulative GHG-emissions, a light tightening of intermediate targets (2030) only leads to limited benefits for climate protection. Instead, rapid and ambitious action is needed.**

Furthermore, GHG-emissions, which are counted towards the goals of the Federal Government, are only a part of the nationally caused emissions. For land use and land-use changes (LULUC), forest management, and national international transport (i.e., the transport of national consumer goods by sea and air), further GHG-emissions must be considered. Especially important are the natural sinks in connection with sustainable forest management, wood use, and land use. Natural carbon sinks in all Green-scenarios benefit from sustainable forest management and use of wood (e.g., avoiding the use of forest residues for energy purposes) 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 leads to new land becoming available for different purposes. In this way, an extra contribution to strengthening natural carbon sinks can be made. In this study, no ecosystem accounting was carried out and the reduction potentials of natural carbon sinks could only be estimated on the basis of available literature. In this way, a corridor of possible GHG-reductions was defined from the literature using both conservative and optimistic assumptions for the scenarios. **The scenarios show that through sustainable agriculture and forestry**

2 This refers to the non-energy needs of the chemical industry in the form of hydrocarbons for chemical production.

Figure 5

Development of the remaining GHG-emissions in the Green-scenarios taking into account LULUCF (conservative) and the CO_2 emissions of international transport



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

management the more ambitious GreenLife- and GreenSupreme-scenarios are able to achieve net zero emissions by 2050, and even GreenLate comes close to this result. **Achieving country-level GHG-neutrality is therefore possible without the use of CCS** (Carbon Capture and Storage)**, but instead through fostering natural carbon sinks. This in turn also provides synergies with other environmental goals such as biodiversity protection.**

The GreenSupreme scenario represents the transformation path with GHG-emissions being closest to international commitments. The Green-Scenario in comparison to a 1.5 °C compatible global mean pathway (IPCC global 1.5 °C course) are shown in Figure 5. The mean IPCC global 1.5 °C path (IIASA, 2019) is based on different global 1.5 °C compatible paths and represents a median transformation pathway along which the global community and the overall anthropogenic GHG-emissions must move. However, this does not mean that every single nation must exactly stick to this path. Considering that Germany's prosperity and economic performance rely on GHG-intensive technologies and fossil energy sources, Germany should make an ambitious contribution to limiting anthropogenic GHG-emissions compared to other countries. **Results from the scenario modeling highlight that the high level of ambition reflected in GreenEe1, GreenEe2, GreenMe, and GreenLife (especially until 2040) does not meet the requirements of the IPCC's average global 1.5 °C emissions pathways.** However, it should also be noted that this global 1.5 °C course does not reflect in any way considerations of global equity. According to the Paris Agreement, affluent countries such as Germany play a prominent role in climate protection (compare Article 4 (1) PA, (UNFCCC, 2015)). Surveys show that from an equity point of view Germany should reach GHG-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.** Furthermore, other climate-relevant emissions generated as a result of human activity and which cannot yet be quantified clearly from a scientific perspective (e.g., the non-CO_2 effects of air traffic) should also not be ignored. **Simply considering the precautionary principle therefore requires rapid action to sufficiently tackle the global challenge of limiting global warming to 1.5° C.**

4 Solution options – Sustainable Resource Use

The transformation towards a largely GHG-neutral Germany has considerable effects on the demand for **raw materials** (i.e., biomass, fossil energy carriers, non-metallic minerals, and metals). In RESCUE, the headline indicator for raw materials use is the **RMC (Raw Material Consumption)[3] which represents the primary raw material use for domestic consumption and investments.** RMC can be reduced through the phase-out of fossil energy carriers when transitioning towards a renewable energy system. Other important leverage points include, e.g., structural policies that reduce the number and size of new settlement areas, increased energy savings, enhanced use of secondary materials, optimization of manufacturing processes via substitution and increases in material efficiency, and life-style changes. In all scenarios, continuous improvements in materials efficiency and in the technological development in Europe and the rest of the world (RoW) are assumed.

In 2010 (base year), Germany's RMC equals 1.37 Gt and is dominated by non-metallic minerals and fossil fuels (Figure 6).

The largest reduction of RMC is associated with the phase-out of fossil energy carriers in all scenarios. Already in GreenLate it is assumed that energy efficiency potentials across all sectors are unlocked and an ambitious sustainable resource policy is implemented (with a time delay compared to the other scenarios). This includes the increased use of secondary materials and material substitution as well as changes towards more sustainable life-styles[4]. As a result, the **RMC decreases in GreenLate already by -56 % until 2050 compared to 2010 levels.**

Additional measures to increase energy efficiency supplemented by additional sustainable life-styles changes[5] in **both Green-scenarios allows for a reduction of RMC of about -61 % to -62 % until 2050. Implementing additional measures to increase materials efficiency (GreenMe) are capable of reducing RMC by -68 % in total until 2050.** This include, e.g., tapping into the full recycling potentials for materials, additional material substitutions, and the use of innovative materials such as textile-reinforced concrete and timber constructions. In addition, it is assumed that at global-scale efforts towards increased materials efficiency (similar to Germany) also take place and this is reflected in the lower material footprint of imports.

Further life-style changes (i.e., a reduction of per-capita living space compared to today and consumer preference for more durable goods offered within the framework of a sharing economy) of the **GreenLife-scenario results in a reduction of RMC of -63 % in 2050 compared to 2010.** Furthermore, in **GreenSupreme a more ambitious transformation of the energy system and the liberation from annual economic growth are capable of reducing RMC by -70 % until 2050.**

In all scenarios, raw materials use decreases between 2010 and 2050. At the same time, a continuous economic growth of about 0.7 % per year (all scenarios except GreenSupreme from 2030[6]) leads to an increase of the gross domestic product (GDP) and thus of the total raw material productivity[7]. With an **annual average increase of total raw material productivity of 2.3 % to 3.0 % across all scenarios, the observed trend is above the target of ProgRess II (BMUB, 2016)**

3 RMC (Raw Material Consumption) is composed of domestic raw material extraction and imports minus exports. In order to calculate indirect imports (raw material equivalents (RME)) use is made of input-output and linkage tables from URMOD (https://www.ifeu.de/methoden/modelle/urmod/) together with data on imports and exports in the German economy. RME represent conversion factors to express a unit of product traded into the amount of material extraction needed, anywhere in the world, to produce the traded product.

4 Since the GreenLate scenario focuses on technical/technological measures, only a few aspects of more sustainable lifestyles are included. This includes, e.g., less meat consumption and changes in the transport system through avoidance and relocation. However, it is assumed that these measures are implemented with a delay compared to the other scenarios.

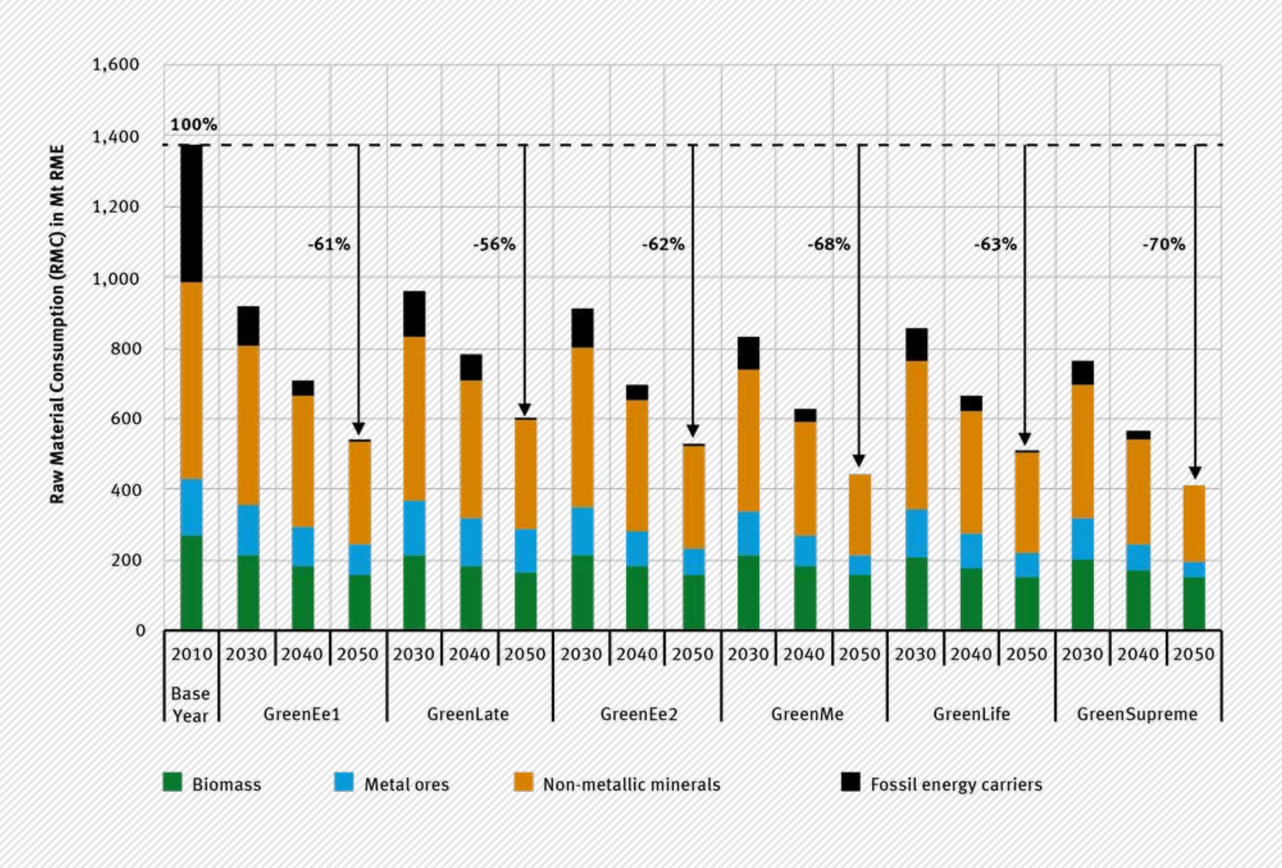
5 This includes, e.g., a lower per-capita living space or changes in personal mobility when compared to GreenLate.

6 In GreenSupreme there is essentially a qualitative growth of individual branches and sectors. However, this is compensated by declining developments in other sectors. This means that from 2030 onwards there will be an average zero growth of the overall economy, but the per capita gross domestic product will continue to increase compared to today.

7 Total raw material productivity = (GDP + imports)/RMI, with GDP: Gross Domestic Product and RMI: Raw Material Input. In the indicator, imports are taken into account not only by weight of imported goods but with the associated total primary raw material inputs (Raw Material Equivalents = RME).

Figure 6

Raw material consumption (RMC) by raw materials category for all Green-scenarios



Note: All numbers expressed in raw material equivalents (RME)

Source: own compilation based on UBA, 2020a, 2020b, 2020c, 2020d, 2020e

and the German Sustainability Strategy (Bundesregierung, 2018).

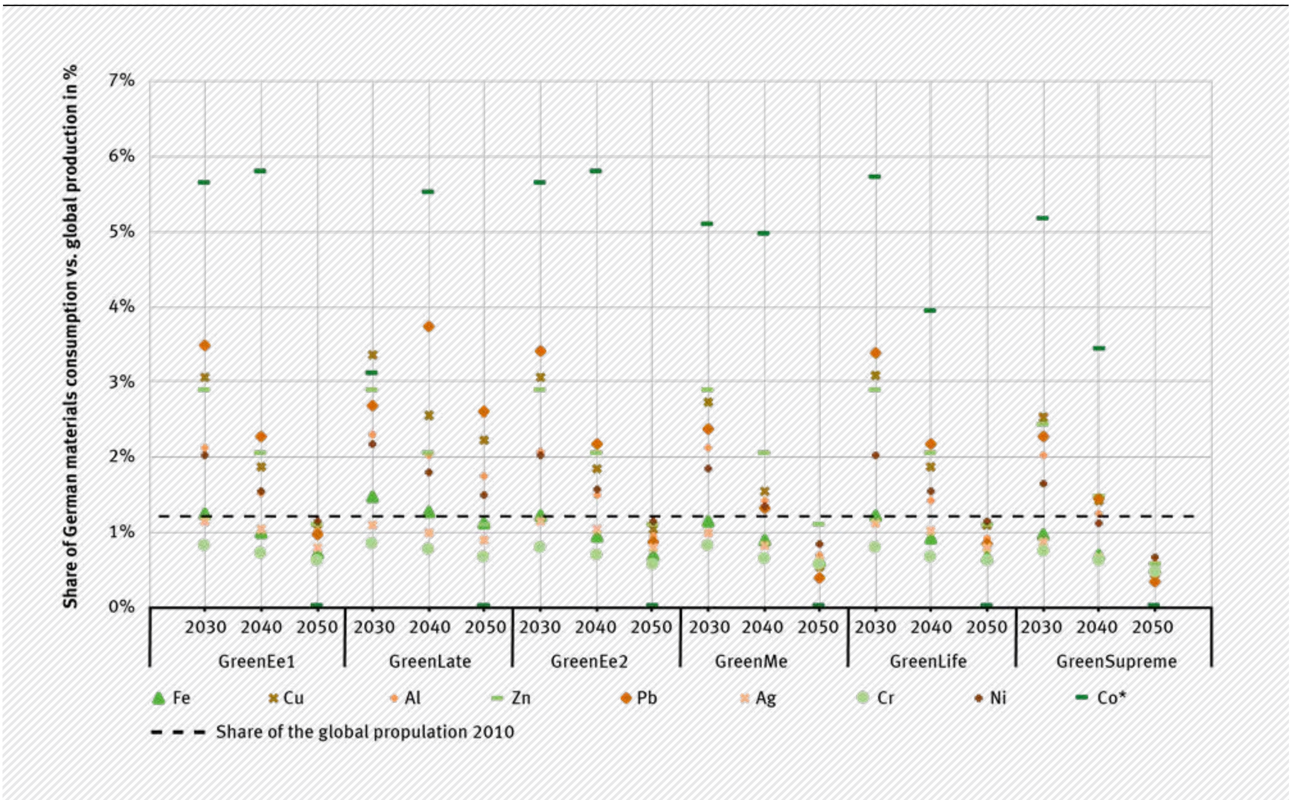
Non-metallic minerals use (e.g., sand, gravel, limestone) decreases in all scenarios. In particular, assumptions with regard to the development of living space and the reduction of land take from settlements and transport in all scenarios to 0 ha/day by 2050 (BMU, 2016) influence the amounts of non-metallic minerals use. Furthermore, assumptions with regard to the share of secondary materials, material substitution (e.g., wood for non-metallic minerals), and increasing material efficiency affect the demand for non-metallic minerals.

Dietary changes such as reduced meat consumption combined with reduced animal numbers, as well as a decline in population and the assumption that no biomass is used for energy purposes after 2030 all contribute to the decline in **biomass use** until 2050. In contrast, increasing wood construction in all Green scenarios except GreenLate and the substitution of abiotic materials by wood (e.g. insulating materials) increase the biomass demand (especially in GreenMe and GreenSupreme). However, this effect decreases continuously after 2030 due to the assumed living space developments.

Due to the additional demands for **metals** for restructuring the economy and the energy system, the decrease in the consumption of metal ores equals only -4 % to -29 % until 2030, whereas a reduction of -16 % to -53 % can be achieved by 2040. In GreenLate, the transformation of the economy is delayed and does not pick up speed until after 2030. **However, the restructuring of the German economy as described in the Green Scenarios is also associated with an interim increase in the use of individual raw materials,** such as cobalt, lead, copper or lithium (Figure 7) (see also the full RESCUE study). These metal demands are significantly higher than Germany's current share of the global population (dotted line in Figure 7). **Against the background of a globally fair use of raw materials, the most ambitious transformation path possible similar to GreenSupreme should therefore be pursued.**

Figure 7

Final demand of selected raw materials in 2030, 2040, and 2050 as a share (%) of global primary production in 2015/2016.



* Estimate only for batteries used in transportation.

** Germany's population in 2010 was 81.75 million people and the global population equaled 6.96 billion people (81.75 million people / 6.96 billion people = 1.17 %).

Source: own compilation based on: (UBA, 2020a, 2020b, 2020c, 2020d, 2020e). Global production estimates were taken from the US Geological Survey for the latest year available (USGS, 2019). For chromium, the production data from chromite was used and a metal content of 30 % assumed.

5 Successful implementation of climate and natural resource protection

In order to come close to both an appropriate German contribution to limiting the global temperature increase to 1.5 °C and a globally equitable use of raw materials, major national efforts in line with the GreenSupreme scenario are necessary. In order to achieve this successfully, the following three basic strategies for climate and resource protection must be pursued in a balanced way:

- **Substitution:** Replacement of GHG- and resource-intensive technologies and products (those with a high RMC) with substitutes displaying both lower material- and carbon footprints or which are even GHG-neutral.
- **Avoidance:** Reducing the consumption of products and processes and avoiding other unsustainable activities through efficiency, sufficiency, and consistency in order to lower GHG-emissions and primary raw materials use (as well as wider natural resource requirements).
- **Natural carbon sinks:** The removal of CO_2 already emitted from the atmosphere by carbon sinks (carbon dioxide removal CDR) to reduce GHG-emissions.

The substitution of GHG- and resource-intensive processes and products can contribute significantly towards a GHG-neutral and resource-efficient Germany in 2050. Substitution is largely characterized by technical measures. These include, e.g., the complete transition toward renewable energies for the supply of fuels, power, and chemical feedstocks ("raw materials"). For this, the necessary investments and still required research and development (R&D) of renewable technologies must be ensured across sectors. R&D can also lead to the development of low-GHG process technologies and products, such as alternative building materials (e.g., alternatives for conventional concrete). The fundamental challenge here, however, is that delayed action reduces the potential of substitution strategies to contribute sufficiently to GHG-neutrality until 2050. Therefore, it is important that necessary R&D is initiated at an early stage, the necessary infrastructures are expanded in time, and the expansion of the renewable energy system including related investments are carried out in time to ensure the highest possible reduction contribution of the substitution strategy by 2050. Global partnerships for knowledge and technology transfer are needed to promote the required technological progress and ambitious transformation steps also outside Europe. The recommendations for action underlying the GreenSupreme scenario are summarized in Figure 8.

However, GHG-neutrality cannot be achieved by substitution alone as a mitigation strategy. According to the current state of knowledge, some GHG-emissions remain from the industry sector, e.g., from the glass or cement industry. Similarly, GHG-emissions from agriculture and land-use changes cannot be fully avoided through the substitution strategy. Furthermore, each individual person also generates demands via their needs and consumption behavior in leisure, living, communication, mobility, and nutrition, which in turn has an effect on the development of the various production and service sectors. By transforming toward more sustainable life-styles, the demand for GHG-causing and resource-intensive products can be reduced. At the same time, making more durable and less resource-intensive products more widely available can help changing consumer demands.

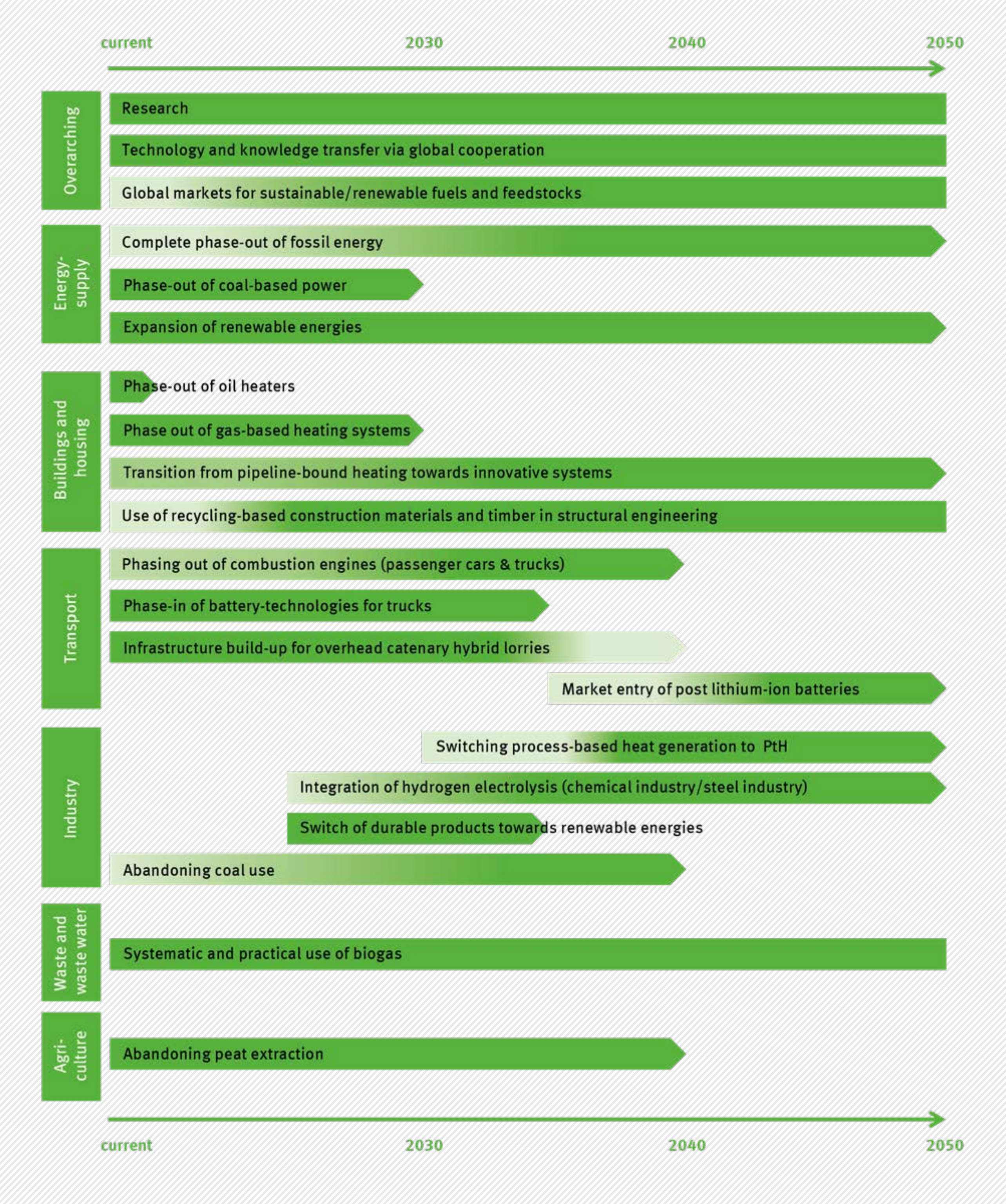
Avoidance therefore **considers both the supply and demand sides** of products, processes, and services. Related demand-side changes are based primarily on a societal transition towards more environmentally conscious life-styles of each individual person and can be supported by suitable planning[8] and regulatory[9] measures. This requires medium and long-term planning and action. If mitigation measures are taken too late, the potential of the avoidance strategy cannot be fully exploited by 2050 either, and the potential contribution to GHG-neutrality is reduced.

8 For example: compact city or city of short distances.

9 For example: eco-design guidelines.

Figure 8

Recommendations for action to implement the "substitution" strategy



Note: The different arrows indicate the time period of the recommended action. The different shades stand for the urgency of implementation. The end of each arrow indicates the successful and completed implementation of the recommended action.

Note: more detailed information can be found in Chapter 7.1 of the RESCUE study UBA, 2019.

Source: German Environment Agency (Umweltbundesamt)

Figure 9

Recommendations for action to implement the "avoidance" strategy

Note: The different arrows indicate the time period of the recommended action. The different shades stand for the urgency of implementation. The end of each arrow indicates the successful and completed implementation of the recommended action.

Note: more detailed information can be found in Chapter 7.1 of the RESCUE study UBA, 2019.

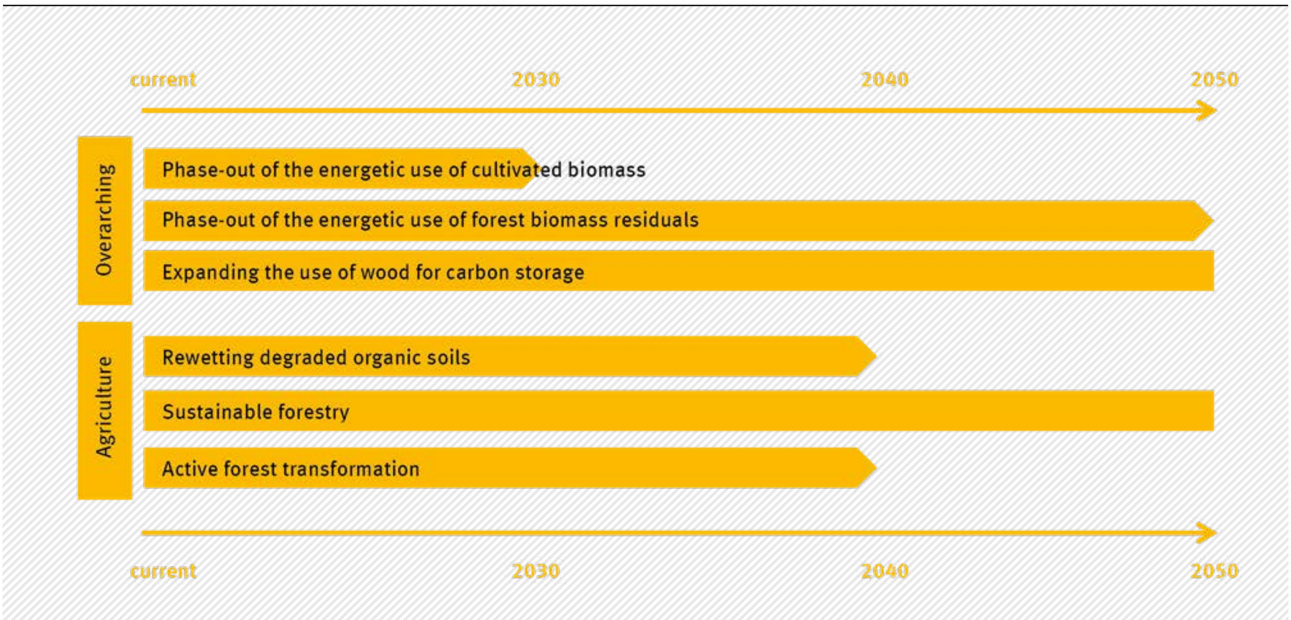
Source: German Environment Agency (Umweltbundesamt)

The avoidance strategy is, however, only of limited use for climate and natural resource protection because the complete avoidance of energy and mobility is difficult to imagine in a modern society. Nevertheless, an avoidance strategy is necessary in order to achieve long-term climate protection goals and to enable a globally fair demand for natural resources. For all sectors (with the exception of agriculture and forestry) only substitution and avoidance strategies can be implemented and must be combined in an economically targeted manner. The recommendations for action on avoidance in the individual areas on which the GreenSupreme scenario is based are summarized in Figure 9.

Making increased use of carbon sinks supports climate protection and also provides overlaps with natural resource conservation, and can create synergies within other areas of environmental protection. Sinks represent a further option for influencing GHGs in the atmosphere by removing carbon dioxide from the atmosphere (CDR – Carbon Dioxide Removal). In the IPCC 1.5 ° special report, all underlying scenarios that limit the global temperature increase to 1.5 °C include the use of carbon sinks. It should be noted that at least those GHG emissions that cannot be avoided by the two previous reduction strategies must be removed from the atmosphere by additional measures. Nevertheless, CDR measures are physically limited in their capacity and are prone to additional risks. In contrast, strengthening the natural carbon sinks already offers the possibility of sustainable CO_2 removal from the atmosphere. While natural carbon sinks are also limited, they are available at a relevant scale nationally and at a significant scale internationally. **Sinks are therefore no replacement for the substitution and avoidance of GHG-emissions as highlighted above, but are still essential for successful climate protection.** The faster GHG-emissions are reduced via the first

Figure 10

Recommendations for action to implement the “carbon sinks” strategy



Note: The different arrows indicate the time period of the recommended action. The different shades stand for the urgency of implementation. The end of each arrow indicates the successful and completed implementation of the recommended action.

Source: German Environment Agency (Umweltbundesamt)

Note: more detailed information can be found in Chapter 7.1 of the RESCUE study UBA, 2019.

two strategies, the lower the potential conflict of objectives and risks associated with CDR measures. The recommendations for carbon sinks on which the GreenSupreme scenario is based are shown in Figure 10.

In addition, overarching measures are needed to ensure GHG-neutrality in a cost-effective and resource-efficient manner. Economic instruments such as energy taxation and CO_2 pricing of fossil-based energy, the promotion of research and its implementation, and the reduction of environmentally harmful subsidies represent key considerations for future technical and social innovations, investments in infrastructure, location decisions by industry, and for individual energy consumption. A long-term oriented policy avoids structural breaks and creates long-term planning for all players in society through clear legal regulations. Furthermore, **a global, common understanding of joint climate and natural resource protection should be developed in the short term. Only by doing so can climate and natural resource protection be successful and national efforts and investments in Germany be carried out in an economically sensible manner.** This also requires the rapid introduction of GHG-neutral technologies, production systems, and products with a low material footprint on a global scale through accelerated technical development and international knowledge and technology transfers.

Even if the RESCUE study appears ambitious against the background of current trends, political decisions, and social discussions, it shows that GHG-neutrality in Germany and a more sustainable level of raw materials use are still possible through ambitious action. However, the question no longer arises whether and when individual contributions should be made and developments need to be addressed. Instead, it becomes apparent that action must be taken now and every contribution (both from a production and consumption standpoint) must be seriously considered and utilized.

The ambitious national targets can only be achieved if they are embedded in corresponding European and international developments and are oriented towards the Paris Agreement and Agenda 2030. The right course needs to be set within the next few years at the global, European, and international level.

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