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Policy Paper

Beyond Climate Neutrality

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Contents

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Summary

The climate crisis and the crises caused by the COVID-19 pandemic must be tackled together. Many countries are working on strategies to implement the Paris Agreement. At the climate conference in Glasgow, therefore, it will be imperative to reconcile short- and long-term goals and measures. German legislators have been obliged by the Federal Constitutional Court to plan climate-change mitigation for the long term. It should also be made mandatory at the international level to formulate and communicate long-term strategies which aim beyond climate neutrality at climate stabilization and strive for multiple benefits with other sustainability dimensions. To this end they should *first* contain a rapid and complete phase-out of fossil-fuel use. *Second,* the conservation, restoration and sustainable use of ecosystems should become a priority. *Third,* strategic preparations should be made for the removal of CO_2 from the atmosphere. To generate a strong momentum, countries at COP26 should commit to using their COVID-19 stimulus programmes in line with long-term strategies.

In the Paris Agreement, countries agreed not only on the long-term goal of climate stabilization, but also on making their financial flows consistent with the aims of climate-change mitigation and adaptation. Specific decisions on both aspects should be taken at COP26 in Glasgow: countries should use long-term strategies to orient their short- and long-term goals and measures towards climate stabilization and use the COVID-19 stimulus programmes to transform their economies in the direction of climate action.

Climate stabilization as a long-term goal of international climate policy

Climate stabilization means the permanent limitation of global warming, preferably to 1.5°C above pre-industrial levels in order to prevent dangerous anthropogenic interference with the climate system. This requires more than 'climate neutrality' – currently the stated goal of many countries. Regardless of its exact definition, climate neutrality can only be an intermediate goal. *First,* anthropogenic CO_2 emissions must be stopped very quickly; non-CO_2 emissions must be greatly reduced and the biosphere strengthened at the same time. *Second,* beyond climate neutrality, CO_2 will probably need to be removed from the atmosphere to counteract high past emissions and remaining trends towards warming. This should be anticipated by technological development paths to make this option possible.

Make mandatory long-term strategies a major topic at COP26

Long-term strategies within the framework of the Paris Agreement can become the basis for an international discussion on transformation pathways. Their formulation, communication and periodic review should be made compulsory. Countries should commit to orienting their long-term strategies towards climate stabilization and to using their COVID-19 stimulus programmes to achieve this. Minimum requirements should be defined for coherent, effective and fair long-term strategies, as well as for ensuring their measurability and comparability.

Long-term strategies provide a framework for the further development of short-term Nationally Determined Contributions (NDCs). They should incorporate the sustainability agenda and generate multiple benefits. It will also be easier to meet climate-protection goals if the world as a whole is on a more sustainable development path.

Any long-term strategy should primarily exploit national potential for climate-change mitigation. International effects should be taken into account and developing countries, especially low-income countries, supported on a partnership basis (e.g. in building and expanding value chains, social security and environmental monitoring). National expenditure on sustainability-oriented, transformative research, development and education should also be significantly increased in developing countries and emerging economies, not least to create a broad

knowledge base for a common discourse. Long-term strategies should provide guidance for reliable regulatory frameworks and financing mechanisms. A clear distinction should be made between public and private financing contributions; the envisaged role of international financing mechanisms and collaborations should be made transparent, and public funds should be pledged for longer terms.

Set priorities for long-term strategies: stop, strengthen, think ahead

Long-term strategies should set three substantive priorities for climate-change mitigation that are not mutually substitutable:

1. *Stop CO_2 emissions from fossil sources:* The WBGU recommends rapidly and completely phasing out the combustion of fossil fuels and limiting their material use to cases where no sustainable alternatives can be developed. Ending the exploration, extraction and processing of fossil resources also reduces CH_4 emissions, has considerable additional benefits for health and biodiversity, and should be negotiated multilaterally. Measures that support the phase-out (e.g. CO_2 prices, subsidy reductions and infrastructure measures) should be outlined and future energy needs estimated. The interim targets and the point in time when no more CO_2 is released from fossil sources should be based on an appropriate share of the remaining global emissions budget.
2. *Strengthen the contribution of the biosphere:* The protection, restoration and sustainable use of ecosystems on land and in the ocean should link biodiversity conservation with climate-change mitigation. The sink effect of ecosystems has already been degraded and biodiversity conservation is at risk; both can only be secured in the long term if emissions are ambitiously reduced. The diversification of farming systems (with lower CH_4 and N_2O emissions), the transformation of animal-product-heavy diets, and a responsible bioeconomy can contribute to both goals. Financial incentives, taxes and reporting requirements for companies should be geared towards strengthening ecosystem services, and long-distance ecological effects (telecoupling) should be better researched and addressed.
3. *Planning ahead for the removal of CO_2 from the atmosphere:* In order to maintain the prospects for climate stabilization even if CO_2-emission reductions are insufficient, options for permanent CO_2 removal (e.g. BECCS, DACCS, biochar) should be kept open. Technologies in which CO_2 extracted at great effort from the atmosphere is re-released within a short time (e.g. synthetic fuels) compete with long-term carbon storage and should therefore only be pursued in the absence of sustainable alternatives. Furthermore, negative impacts on other sustainability goals, e.g. caused by high biomass or land-use requirements, should be prevented. A portfolio approach could mitigate scaling-related sustainability problems of individual CO_2-removal technologies. Incentives for using technical options should only be created when there is a governance framework that ensures sustainability. However, relying on the future recovery of emitted CO_2 using technologies that are still under-researched is very risky.

All three priorities are necessary, although phasing out fossil fuels and strengthening the biosphere are fundamental. Each should have their own goals, intermediate targets and measures, and be tracked with indicators, without offsetting fossil-emission reductions, ecosystem services and CO_2 removal against each other. At the same time, interactions between the solution approaches must be taken into account to make a comprehensive transformation possible. The impacts of planned technology and transformation pathways on all dimensions of the 2030 Agenda should be assessed.

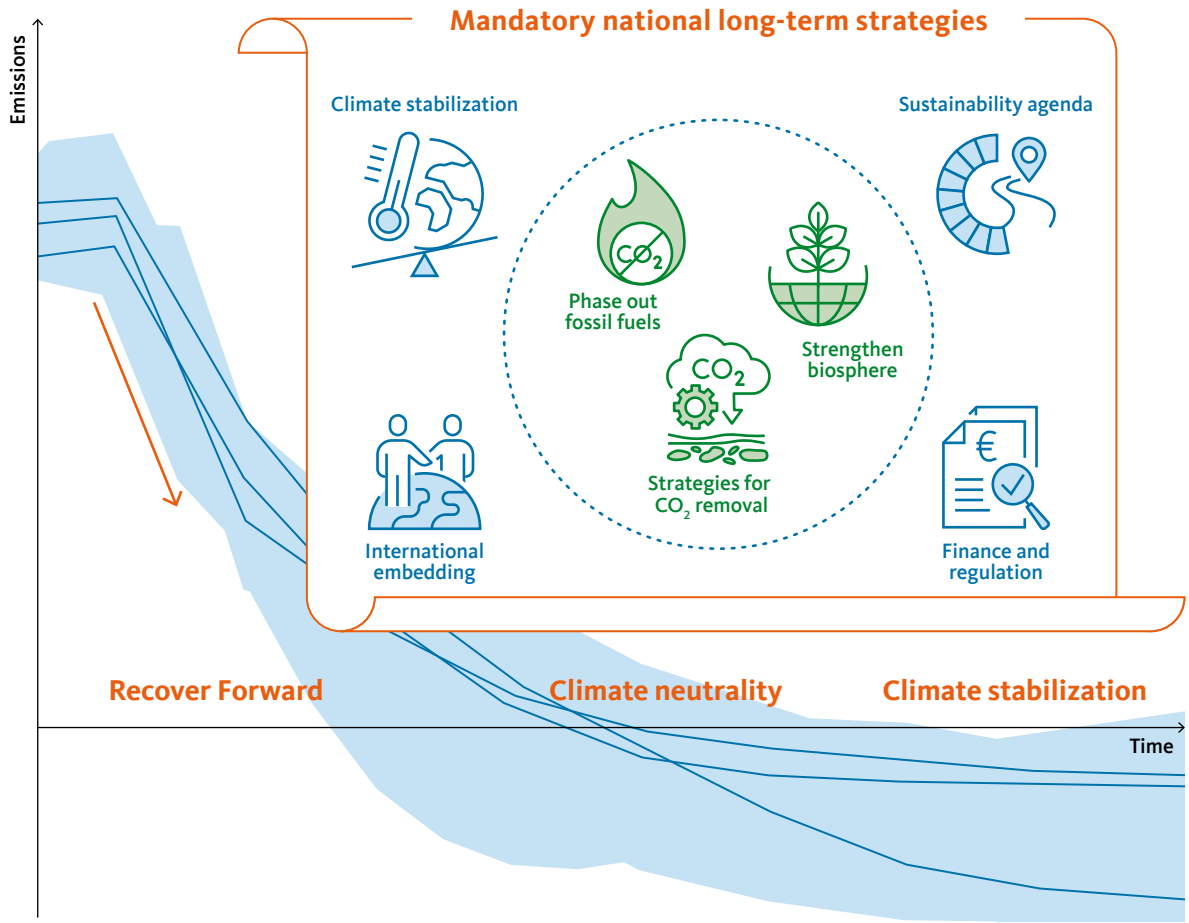
Recover Forward: using COVID-19 stimuli for climate stabilization

In response to the COVID-19 pandemic, US$16 trillion had been mobilized globally up to March 2021, representing both an opportunity and a risk for long-term climate stabilization. Around 30% of the stimulus programmes relate to environmentally sensitive sectors, but do not take sustainability concerns sufficiently into account (e.g. a negative overall effect on the environment is expected in 15 of the G20 countries). Moreover, people in South Asia and sub-Saharan Africa in particular are additionally threatened by extreme poverty as a result of the COVID-19 crisis, yet per-capita stimulus spending is about 580 times higher in high-income countries than in low-income countries. The differences in national economic capabilities thus threaten to become more entrenched and could make it more difficult to jointly tackle global challenges such as climate change, the biodiversity crisis or pandemics. The COVID-19 stimulus programmes and climate-policy framework measures should – like all forms of government support and investment – be more closely aligned with long-term strategies and be used for an ecologically and socially compatible, globally balanced transformation of economic and societal systems.

Effective climate policy requires long-term strategies

The international community faces enormous challenges in the 21st century. The impacts of climate change are increasingly being felt – with risks and damage to nature and humanity on an unprecedented scale. Add to this the COVID-19 pandemic, which has triggered a global health, economic and financial crisis.

Countries are currently mobilizing substantial sums worldwide to stabilize their economies – but are not sufficiently taking into account that what is needed is not just reconstruction but a transformative restructuring of the economy. These investments will help shape climate-change mitigation for decades to come. At the same time, many countries are working on the implementation of the Paris Agreement (PA). The priority now is to reconcile short- and long-term goals and measures to overcome both crises. The



Long-term strategies for climate stabilization
It should become mandatory for countries to formulate and communicate long-term strategies. They should gear these not only towards national climate neutrality but also towards global climate stabilization. Global emission pathways compatible with this (IPCC, 2018) are indicated in blue. COVID-19 stimulus programmes should also contribute to this ('Recover Forward'). The long-term strategies should aim for multiple benefits in the sense of the sustainability agenda, be internationally embedded and provide for reliable regulatory framework conditions and funding mechanisms. Focus topics should include phasing out the use of fossil fuels, strengthening the biosphere and strategically preparing options for the permanent CO_2 removal from the atmosphere.
Source: WBGU; graphics: Wernerwerke, Berlin

26th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC COP 26) in Glasgow opens a window of opportunity for this.

In the PA, the countries agreed on holding the increase in the global average temperature to well below 2°C and on pursuing efforts to limit it to 1.5°C above pre-industrial levels in order to prevent dangerous anthropogenic interference with the climate system (Article 2 of the PA in conjunction with Article 2 of the UNFCCC), i.e. to achieve climate stabilization. The IPCC Special Report (2018) showed that a temperature increase of 1.5°C would cause much less damage to humans and nature than a 2°C increase would. However, the nationally determined contributions (NDCs) up to 2030 that have been pledged to date are far from sufficient to achieve even a 2°C pathway.

Even the pandemic-related temporary decline in global emissions of about 6% in 2020 has not changed this: annual global emissions reductions of 7.6% would be needed to implement the PA (UN, 2020). It will very probably also be necessary to remove CO_2 from the atmosphere in order to stabilize the climate at a temperature increase of 1.5°C in the long term. This will depend, above all, on how quickly emissions of long-lived greenhouse gases (GHGs) fall in the coming years. 'Climate neutrality' is therefore in itself only an interim goal at one point in time. In the spirit of the PA and the UNFCCC, we must go beyond this and pursue permanent climate stabilization. This requires ambitious emissions reductions and the strengthening of the biosphere today, as well as strategic preparation for CO_2 removal from the atmosphere. Long-term strategies according to Article 4.19 of the PA, which are not yet mandatory, are the instrument needed here.

The countries must now lay down key principles for sustainable transformations and plan pathways that extend beyond 2030 or 2050. An obligation of German legislators to develop long-term strategies has recently even been derived from Germany's constitution by the Federal Constitutional Court. In line with the commitment of Article 2.1c to make finance flows consistent with the goals of climate-change mitigation and adaptation, the long-term strategies should moreover provide orientation on how the substantial financial resources of the COVID-19 stimulus packages are spent.

The COP 26 agenda hitherto includes the completion of the PA Rulebook, e.g. transparency requirements, the concretization of the rules of international cooperation under Article 6 of the PA, urgently needed increases in ambition for the NDCs, and climate finance. To date, only 29 out of 197 Parties have communicated long-term strategies to the UNFCCC Secretariat; other countries are currently developing them (Hans et al., 2020). The WBGU recommends placing long-term strategies for achieving climate neutrality and, beyond that, climate stabilization, onto the COP 26 agenda and making their creation mandatory. Long-term strategies with comparable structures and quantified targets and measures improve the possibilities of coordination and cooperation. They should include not only climate-change mitigation but also adaptation measures; the latter will not be addressed in more depth in this policy paper.

The WBGU recommends:

- Make long-term strategies one of the main issues at COP 26 in Glasgow.
- Make it mandatory to formulate and regularly review long-term strategies.
- Gear long-term strategies towards the goal of climate stabilization beyond 2050.
- Define minimum requirements for coherent, effective, socially and globally fair long-term strategies and for making them measurable and comparable.
- Countries should commit to using their COVID-19 stimulus programmes in the spirit of the long-term strategies in line with Article 2.1c of the PA. Developing countries, especially low-income countries, should be supported via multilateral cooperation formats.

Focus long-term strategies on climate stabilization

Long-term strategies under the PA have the potential to become the central basis for an international discussion on transformation pathways towards climate neutrality and lasting climate stabilization. They make resource, finance and research requirements transparent, make all actors fully aware of the need for climate-change mitigation, and reveal opportunities for cooperation, e.g. in research and development or regulation. They provide orientation for short- and medium-term decisions, for example on more ambitious NDCs, on international climate finance, and on the direction of COVID-19 stimulus programmes. The WBGU regards the following demands on long-term strategies as key:

Gear national long-term strategies towards the goal of global climate stabilization

Long-term strategies should be geared towards the goals agreed in Article 2 of the PA – inter alia towards climate stabilization, i.e. limiting global temperature rise, preferably to 1.5°C. Such a limit on global warming leads to constraints on the development of global emissions. IPCC scenarios that are compatible with the temperature thresholds specified in the PA show, in temporal sequence, first CO_2 neutrality, then greenhouse-gas neutrality and, finally, in most cases a net-negative greenhouse-gas balance – i.e. the continuous global removal of CO_2 from the atmosphere over and above what is needed to offset continuing emissions, to compensate for past high emissions and remaining warming trends (Rogelj et al., 2018). The national long-term strategies of many countries (including Germany with its Climate Action Plan 2050, adopted in 2016) have so far only aimed at 'climate neutrality', mostly by 2050 or a little later (UNFCCC, 2021). The term 'climate neutrality' is used in different ways, e.g. in the sense of CO_2 neutrality or greenhouse-gas neutrality, and should always be defined. Since, from a global perspective, it is only an intermediate balance-sheet result of a successful pathway of climate-change mitigation, climate neutrality (irrespective of the exact definition) is not adequate as the final result of national long-term strategies. There, too, it should be seen only as an intermediate goal of a transformation of economic activity that will allow long-term global climate stabilization. Therefore, strategies should also make explicit the quantities of long-lived GHGs emitted until climate neutrality is achieved (and beyond, if necessary), as well as the targeted pathway of negative emissions. Long-term strategies should explicitly declare climate stabilization in line with the temperature limits stipulated in the PA to be the long-term goal. This makes it clear that NDCs and other intermediate targets must also be formulated and pursued in such a way that they serve (or at least do not block) long-term global climate stabilization (e.g. forward-looking infrastructure development or avoiding trade-offs between CO_2 use and negative emissions, see below).

Harmonize long-term climate-policy strategies with the sustainability agenda

Climate stabilization is a central building block of sustainable development, as set out in the UN's 2030 Agenda and, at the national level, in Germany's Sustainability Strategy. Long-term climate-policy strategies should be understood as a prerequisite and opportunity for a sustainable society and used to implement and further develop the 2030 Agenda. Conversely, climate-protection targets are easier to achieve if the world as a whole is on a more sustainable development pathway (Rogelj et al., 2018).

Long-term strategies for climate stabilization should identify interrelationships and conflicts with other sustainability dimensions at an early stage and address them in such a way as to generate synergies ('multiple benefits') wherever possible. For example, approaches to reducing emissions and removing CO_2 from the atmosphere should be compatible with biodiversity conservation and biosphere protection; and changes in resource and land use, new technologies, energy and mobility systems should be in harmony with poverty reduction, civil liberties and the development of social-security systems for crisis-resistant societal cohesion.

Consider international impacts, enable development and innovation on the basis of partnership

Climate stabilization can only be achieved globally with the involvement of all countries. In their long-term strategies, countries should therefore explicitly consider the impact of their goals and measures on other countries, support other countries on the basis of partnership and open up development opportunities.

Any long-term strategy should primarily exploit national potential for climate-change mitigation. Countries should estimate and transparently present their future requirements and their potential for the production and import of raw materials and renewable energy for sustainable economic activity. On this basis, international scarcities can be taken into account in regulatory measures and in decisions on technology and infrastructure. Long-term strategies and international cooperation thus provide the necessary framework for sustainable coordination that takes appropriate account of the different regional conditions. The crediting of mitigation efforts in other countries against one's own climate targets – as is possible under Article 6 of the PA – does not effectively contribute to climate-change mitigation if it hinders early own investment in emissions reduction and the development of mitigation technologies. It should also be noted that new production and supply structures in a sustainable economy without fossil fuels could lead to considerable shifts in international value chains – shifts that are as yet hardly assessable.

Moreover, not all countries have the technological, economic and institutional capacity to implement ambitious long-term strategies. Most developing countries need support both in their contributions to long-term climate stabilization and biosphere protection and in their basic crisis resilience and adaptability. High-income countries should therefore earmark corresponding international support in their long-term strategies – which is also in line with the principle of common but differentiated responsibilities and respective capabilities (Article 2.2 of the PA). In doing so, they should not limit themselves to climate finance, unilateral technology transfer and capacity building (Articles 9, 10 and 11 of the PA). Instead, offers should also be made in the areas of economic, scientific and development cooperation, also using existing bilateral and multilateral instruments. More specifically, countries should be enabled to develop their own research and development capacities, e.g. for exploiting renewable energy sources or for diversified agricultural systems. In Germany and the EU the strengthening of ecological and social standards in supply-chain laws can increase the incentives for decarbonizing transregional supply chains. Furthermore, as part of their long-term strategies, high-income countries should also support the expansion of social-security systems, resilient health systems, education systems and environmental monitoring, as well as of disaster control to deal with climate risks in developing countries, especially low-income countries.

Finally, long-term strategies require profound technical and social innovations and a broad knowledge base as a prerequisite for a common discourse. However, transformative research for sustainability has hitherto only played a minor role in many national science and education systems and should be strengthened in a targeted manner. Large emerging economies such as India and Indonesia spend only 0.65% and 0.23% of their GDP respectively on research and development (UIS, 2021). Only a few countries and alliances formulate spending targets. For example, India is aiming at 2% by 2022, the African Union at 1% and the EU at 3% (EAC-PM, 2019; UNECA, 2018; EU Commission, 2020). Interdisciplinary sustainability, environmental and climate research should be mentioned explicitly in the long-term strategies. Strengthening them can improve strategy development in many countries as well as international coordination.

Improve planning security: secure funding for long-term strategies

Long-term strategies should also show how the necessary change and innovation processes in society and the economy can be financed. In order to meet global investment requirements – in the energy system alone about US$830 billion (2010) per year will be needed up to 2050 compared to a business-as-usual scenario (Rogelj et al., 2018:154) – existing capital flows and the strong short-term boost from the COVID-19 stimulus packages must be brought in line with the long-term climate-policy goals, and further private and public funds must be mobilized. Planning security for investors and funding recipients is key for this; at the same time an openness to technological or societal change must be maintained.

This firstly requires reliable climate-policy frameworks, including financial incentives, e.g. via CO_2 pricing, which influence investors' expectations on long-term returns, especially if such pricing is coordinated globally, as proposed by Germany's Chancellor at the 2021 Petersberg Climate Dialogue. The public sector

can also send credible long-term signals via concrete infrastructure plans backed up by reliable financing.

In addition, private investment can be mobilized or redirected, firstly by improving the compatibility of investment strategies with long-term climate goals, e.g. through transparently structured financing instruments such as green bonds or sustainability-linked bonds. Secondly, government support and financing instruments can reduce barriers to investment resulting from uncertain future climate-policy conditions. One example is financing instruments that transfer all or part of the risk of uncertain CO_2 prices to the state. Equally important is long-term government promotion of high-risk research and development, e.g. for disruptive springboard innovations. Thirdly, greater transparency on climate risks can be created, e.g. by means of the extended reporting obligations for companies under EU taxonomy rules.

Greater planning security and the mobilization of private funds are also necessary in international climate finance. Short-term and unreliable financing pledges inhibit investment by developing countries in the transformation and decarbonization of their social and economic systems as part of long-term strategies. Following the likely failure of high-income countries to meet the US$100-billion-per-year contribution target agreed in Copenhagen (Bhattacharya et al., 2020), confidence in international cooperation needs to be restored. To this end, countries should set out their contributions and the way these are to be developed further in their long-term strategies and thus also specify the distribution keys of multilateral financial mechanisms. In this context, they should distinguish between public and envisaged private funding. Furthermore, they should clearly identify bilateral and multilateral channels and levers such as grants and concessional loans, through which their pledges are to be implemented and private investment mobilized in developing (and especially low-income) countries. The mechanisms of Article 6 of the PA can make a contribution to mobilizing private investment if clear frameworks ensure the ecological integrity of markets and their compatibility with long-term climate-policy goals.

The WBGU recommends:

- Set out explicitly in long-term strategies how appropriate national contributions to achieving the global goal of climate stabilization can be made and how NDCs can be further developed;
- strive for multiple benefits for the Sustainable Development Goals (SDGs), thereby inspiring the further development of the sustainability agenda beyond 2030; also
- take into account the international implications of national policies and provide for partnership-based support to developing countries in their contributions to climate stabilization and in addressing climate risks.
- Significantly increase national spending on sustainability-oriented research, development and education, especially in low-income countries and emerging economies.
- Make regulatory frameworks and financing mechanisms an integral part of long-term strategies; make them reliable and strategically oriented in order to increase planning security and to promote the provision of private capital. Clear distinctions should be made between public and private financing contributions, as well as between grants and concessional loans; the envisaged role of international financing mechanisms and cooperative approaches (e.g. under Articles 6 and 9 of the PA) should be made transparent, and public funding should also be pledged for the longer term.

Set priorities: stop, strengthen, think ahead

Stopping and, if possible, reversing the accumulation of long-lived greenhouse gases in the atmosphere, especially CO_2, is central to climate stabilization. When carbon from fossil deposits (coal, oil, natural gas) is released into the atmosphere in the form of CO_2 or CH_4, this increases the total amount of carbon circulating between the atmosphere, the oceans and the terrestrial biosphere. This 'fast' domain of the carbon cycle is mainly governed by natural (biological and chemical) processes. Measures within this cycle (such as reforestation) cannot offset the ongoing carbon input from fossil deposits. The additional fossil carbon is the primary driver of climate change, including ocean acidification.

In designing their long-term strategies, therefore, the Parties should set three strategic priorities with a view to climate stabilization. First, the use of fossil resources, especially as energy sources, should be completely avoided as soon as possible. Climate-friendly alternatives – such as expanding renewable energies and raising energy efficiency – would be strengthened in return. The second focus of long-term strategies should be the conservation and restoration of ecosystems and the sustainable use of the biosphere. These are not only indispensable 'allies' for climate-change mitigation as they sequester carbon, they are also crucial for human life as a whole because of the many ecosystem services they provide. However, climate-change-mitigation measures in the biosphere essentially modify the 'fast' carbon cycle and cannot reverse the additional input of carbon from fossil sources caused by humans. Third, strategies must therefore be developed to enable CO_2 to be removed from the atmosphere in a sustainable manner in the future – beyond the limited absorption capacity of natural (in some cases restored) and managed ecosystems.

Each of these three priorities is necessary in its own right; they are not substitutable. National long-term strategies should specify targets, measures and financing mechanisms for each of these priorities separately and not set them off against each other in an overall balance target (e.g. climate neutrality).

This differentiation should also be taken into account in international cooperation. Article 6 of the PA, for which a Rulebook is to be adopted at COP26, contains on the one hand the framework for voluntary market-based cooperation (bilateral or multilateral or centrally coordinated by a UNFCCC body, Articles 6.2-3 or 6.4-7). In particular, such cooperation makes it possible to credit climate-change mitigation efforts in partner countries towards national NDCs (internationally transferred mitigation outcomes, ITMOs) or to create international carbon markets. On the other hand, a framework is to be established for non-market-based instruments (Article 6.8, e.g. coordinated incentive systems for energy-efficiency improvement). One focus of the current negotiations is to avoid the double counting of ITMOs towards NDCs. For climate-change mitigation to be effective and successful in the long term, however, it is equally crucial that the long-term strategies describe how international cooperation under Article 6 of the PA contributes to each of the priority areas.

Within each component, care must be taken to ensure that solutions are integrated into a strategic roadmap and evaluated according to the following criteria:

- *Contribution to target achievement:* the contribution of long-term strategies to climate stabilization depends crucially on the effectiveness of the measures they contain. Not all approaches are equally effective and should therefore not be treated equally.
- *Orientation towards multiple benefits:* climate-change-mitigation measures should be selected in such a way that they simultaneously also contribute to other (sustainability) goals and thus generate multiple benefits, for example for biodiversity conservation and human well-being, as well as for other areas of the 2030 Agenda.
- *Operationalizability and systemic embedding:* long-term goals should be underpinned by milestones and concrete measures that can be implemented. At the same time, attention must be paid to systemically embedding the solution approaches to enable forward-looking transformations and avoid undesirable path dependencies.

The implementation of the long-term strategies should trigger a transformative process that has positive effects and multiple benefits beyond climate-change mitigation.

The WBGU recommends:

- Long-term climate-stabilization strategies should include three priorities:
  1. *Stop:* rapidly and completely phase-out the burning of fossil fuels and limit their material use to cases where no sustainable alternatives can be developed.
  2. *Strengthen:* link biodiversity conservation and climate-change mitigation through the conservation, restoration and sustainable use of ecosystems.
  3. *Think ahead:* develop strategies for the sustainable removal of CO_2 from the atmosphere.
- All three priorities are necessary, although phasing out fossil fuels and strengthening the biosphere are fundamental. The three priorities are not mutually substitutable. They should each have their own goals, intermediate targets and measures, and be tracked with indicators.
- The differentiation between the priorities should also be reflected in market mechanisms and other international collaborations under Article 6 of the PA. Offsetting between contributions from different priorities should be urgently avoided in international market mechanisms.
- Measures for the individual priorities should be evaluated and selected according to their effectiveness for achieving climate goals and their orientation towards multiple benefits with regard to other sustainability goals.

Stop CO_2 emissions from fossil sources

In order to halt climate change, only a limited amount of anthropogenic CO_2 emissions can be allowed to enter the atmosphere in total (IPCC, 2018:14f.). The focus here is on phasing out CO_2 emissions from the use of fossil fuels as quickly as possible. Countries should link this to interim targets which are then taken up in the NDCs. The interim targets and the point in time at which no more CO_2 from fossil sources will be released should be based on an appropriate share of the remaining global emissions budget.

Shape the phase-out of fossil fuels

The WBGU recommends that the long-term strategies should stipulate a complete phase-out of fossil fuels (coal, oil, natural gas) for energy generation and restrict their material use (e.g. in the petrochemical sector) to applications for which no sustainable (renewable) alternatives can yet be developed. As for the remaining non-energy uses of fossil resources, it is important that the stored carbon is not re-released, e.g. by combustion or decomposition at a later date. Moving away from fossil-fuel use as quickly as possible should be the yardstick for the implementation of efficiency or demand-side measures, the rapid development of renewable energy and mobility systems, and the restructuring of industry.

This shift to renewable energy and raw materials could not only reduce CO_2 emissions from fossil-fuel combustion from currently about 80% of global anthropogenic CO_2 emissions to zero (Friedlingstein et al., 2020), but also massively reduce the methane emissions associated with the extraction and processing of fossil resources, which account for about 35% of global anthropogenic CH_4 emissions (Saunois et al., 2020). In addition, considerable health effects can be achieved in the sense of multiple benefits. Lelieveld et al. (2019) estimate the global excess mortality rate (i.e. preventable deaths) due to air pollution from fossil-fuel use at about 3.6 million per year. Other sustainability dimensions can also benefit: the exploration and extraction of fossil resources often directly threatens and destroys valuable and fragile ecosystems (e.g. the Yasuní National Park), while petrochemical products also lead to global problems beyond climate change, for example in the form of microplastics.

Strategies that rely on end-of-pipe solutions for emissions reduction, such as the use of carbon capture and storage (CCS) in combination with the continued use of fossil fuels, can achieve only some of the above-mentioned multiple benefits and therefore do not fit as well into a comprehensive transformation towards sustainability. Furthermore, the WBGU continues to strongly advise against relying on nuclear energy, especially because of the still far-from-negligible risk of severe accidents, the unresolved problem of final storage and the risk of uncontrolled proliferation.

Design technology pathways systemically; aim for multiple benefits

Long-term strategies should not only formulate the targets for reducing CO_2 emissions and the use of fossil resources, but also strategically indicate which (development) pathways should be followed to achieve these targets, while taking other sustainability goals into account. The objective is adapted technical and societal development pathways that pursue climate stabilization in harmony with the broader sustainability agenda and which in this sense are explicitly geared towards synergies and multiple benefits.

With a view to climate stabilization, it should be ensured that fundamental technological and infrastructural decisions do not undermine or diminish the possibilities of removing CO_2 from the

atmosphere. Technologies that actually release CO_2 into the atmosphere should therefore be avoided as far as possible, even if they are regarded as climate-neutral because the CO_2 was removed from the atmosphere beforehand (whether by photosynthesis or technical processes). This applies in particular where alternative technologies are available, e.g. in the case of biofuels and synthetic C-based fuels in the transport sector. This is because the options for removing CO_2 from the atmosphere are limited and often involve risks for other sustainability dimensions, such as food production or biodiversity conservation (WBGU, 2021:51ff.). Secondly, the limited potential for the safe storage of CO_2 must be taken into account. Although the geological storage potential is considered to be large, there are open questions with regard to societal acceptance and the permanence of storage, which depends not only on geological conditions but also on management (WBGU, 2021:54). Technology pathways that avoid the generation of CO_2 from the outset are therefore superior to pathways that plan for the limited storage potential over a long term and on a large scale. Countries' strategies should therefore clearly state (also quantitatively) which role they assign to individual technologies.

In order to achieve synergies with other sustainability goals, the comparison of different solutions should, as a matter of principle, include all external costs as far as possible, so that climate-change-mitigation technologies, for example, are also assessed with regard to different impacts on health, ecosystems and biodiversity. For instance, IPCC analyses show that suitable measures to reduce the demand for energy also have a positive impact on other sustainability goals (Roy et al., 2018:448). The WBGU therefore recommends conducting systematic impact assessments of envisaged technology pathways for the sustainability dimensions set out in the 2030 Agenda.

Consider international dimensions; embed resource strategies sustainably and in a spirit of solidarity

It is also very important to explore the international implications and requirements of national strategies and to make them transparent. In this context, long-term strategies should include national energy-carrier and raw-material strategies for the phase-out of fossil resources. In this way, they can help to ensure the consistency of different national strategies, for example with regard to the international availability of key raw materials and renewable energy carriers. In order to establish appropriate markets and supply chains, especially low-income countries should be supported in developing local production and supply capacity. Sufficient local investment and, where necessary, the transfer of technologies should therefore be provided for at an early stage, and support given for the adaptation and expansion of existing infrastructure. In particular, SDG 7 (affordable and clean energy) should also be kept in mind: around 789 million people worldwide still lack access to electricity (UN, 2020) and billions of people rely on solid fuels for cooking – with considerable health consequences. Long-term strategies in all countries should contribute to overcoming this energy poverty and certainly not exacerbate it.

Identify research needs; launch a transformative research offensive

In some respects, a complete phase-out of fossil-fuel use goes beyond the limits of what is technically feasible today or, from today's perspective, requires societal innovations and an increased use of certain technologies that have not yet been tested – or at least not on a large scale. It is therefore of great importance for long-term strategies to also address strategic research and development needs, taking into account socio-economic framework conditions. Among others, the following topics are highly relevant:

- *Green hydrogen as a future energy carrier:* development of new, non-critical materials for electrolysis and fuel cells, as well as socio-technical system approaches for production, efficient consumption and distribution, and their application on a broad scale.
- *Bioeconomy:* biogenic raw materials as a substitute for fossil-based resources and appropriate regulatory and incentive systems to secure their sustainable production.
- *Intelligent sector coupling:* increased efficiency and flexibility in the supply and use of energy from renewable sources with a view to achieving a fully renewable energy supply. These include, for example, drive technologies for means of transport that are difficult to electrify, as well as demand-side measures.

The WBGU recommends:

- *Strive to phase-out the use of fossil resources:* Clear pathways should be developed for exiting the use of fossil resources for energy generation and, where possible, for material uses; they should be based on the still available CO_2 budgets.
- *End the exploration and extraction of fossil resources:* The termination of extraction and exploration of fossil resources should be negotiated and decided multilaterally. Countries should set out in their long-term strategies how they will contribute to this.
- *Seek multiple benefits; institutionalize impact assessment:* The phase-out of fossil fuels should be used as an opportunity to make progress in other sustaina-

bility dimensions. For this purpose, assessments of the national and international impacts of planned technology and transformation pathways on all dimensions of the 2030 Agenda should be made standard. Possibilities for the resource-saving conversion of existing infrastructure should be examined.

- *Countries should use long-term strategies* to outline their current and planned measures and policies (e.g. carbon pricing, reduction of fossil subsidies, transitional use of international mechanisms, infrastructure development, efficiency and other demand-side measures).

Strengthen the biosphere's contribution

Climate-change mitigation and biodiversity conservation are two highly important – but also very different – sustainability goals that interact with each other. Biodiversity and ecosystem services form the basis of a functioning biosphere and are among humanity's indispensable natural life-support systems. Nevertheless, ecosystem services are under severe threat, above all from land-use changes, the overexploitation of ecosystems and, increasingly, climate change. And yet these scientific insights are being translated into action far too slowly. The preservation of the biosphere is not only indispensable but also highly urgent for sustainable development. Long-term climate stabilization cannot be achieved without an intact and resilient biosphere.

In a sustainable stewardship of the biosphere, climate-change mitigation and biodiversity conservation can be synergistically linked. This applies both to terrestrial ecosystems and to marine and coastal ecosystems. To achieve this, it is crucial to put a stop to the destruction of natural ecosystems and the overexploitation of biogenic resources as quickly as possible. In addition, 'nature-based solutions' can make an important contribution to climate-change mitigation as well as to other goals of sustainable development. However, the climate-relevant effects of nature-based solutions are not only limited but also reversible. Site-specific reforestation, for example, takes decades, but the stored CO_2 can be released back into the atmosphere within hours by a climate-change-induced forest fire.

The WBGU has outlined *multiple-benefit strategies* for the fast carbon cycle (WBGU, 2021) that allow positive effects to be generated both on land and in the ocean, both for climate-change mitigation and for biodiversity conservation.

1. *Synergize CO_2 removal through restoration:* Restoring degraded ecosystems not only removes CO_2 from the atmosphere, it also promotes biodiversity and ecosystem services. The rewetting of peatlands, the site-specific reforestation of degraded forest land and the restoration of marine and coastal ecosystems (e.g. mangroves, seagrass beds and kelp forests) are promising approaches that can achieve synergistic effects for several sustainability goals. The focus in this context should definitely be on the restoration of species-rich, near-natural ecosystems and not on the creation of plantations. Storing CO_2 by means of ecosystem restoration can have a climate-stabilizing effect over long time scales if emissions are successfully reduced, but it can in no way replace ambitious emissions reductions and cannot, therefore, be set off against them. The WBGU furthermore recommends significantly expanding the targets laid down in the Bonn Challenge.
2. *Expand and upgrade protected-area systems:* Natural terrestrial and marine ecosystems already store large carbon stocks. At the same time, they continue to act as CO_2 sinks. Both services are threatened by the ongoing destruction and overexploitation of natural ecosystems and by climate change. Ecosystem protection thus serves not only biodiversity conservation but also climate-change mitigation. In order to exploit this synergy, protected-area systems should be expanded and upgraded. The WBGU recommends expanding protected-area systems to cover 30% of the land and ocean areas. In addition to the Convention on Biological Diversity (CBD), the UNFCCC should also support this target. The quality criteria agreed internationally in the CBD should be consistently applied; improved cooperation between nature conservationists and climate protection activists should be sought at all levels.
3. *Diversify agricultural systems:* Industrial agriculture contributes significantly to climate change and biodiversity loss through the encroachment of agricultural land into natural ecosystems, by soil degradation and the use of agrochemicals. In the long term, this also has a negative effect on the sustainability of food production. To reverse these trends and harness synergies between agriculture and climate-change mitigation, the WBGU recommends a fundamental shift towards ecologically intensive, multifunctional production systems in which efficiency gains are primarily achieved by promoting ecosystem services. This could not only improve CO_2 uptake in soils, but also reduce CH_4 and N_2O emissions from agriculture.
4. *Promote the transformation of animal-product-heavy diets:* Dietary habits with a large share of livestock products generate much more GHG emissions than a predominantly plant-based diet due, among

other factors, to greater land consumption. Diets worldwide should be oriented towards the Planetary Health Diet (Willett et al., 2019). Not only is this healthier than animal-product-heavy diets, it also helps achieve other global sustainability goals. The WBGU therefore recommends the consistent further development of framework conditions, sustainability-oriented standard-setting (e.g. food guidelines) and the creation of corresponding incentives for business and consumers. Furthermore, the potential for avoiding food losses and food waste should be exploited.

5. *Shape the bioeconomy responsibly and promote timber-based construction:* The use of biomass can replace emissions-intensive processes and fossil resources and thus ease the transition to long-term climate stabilization. However, the resulting increase in the demand for land intensifies competition with food security and biodiversity conservation, thus limiting the sustainable potential of biomass. For a bioeconomy based on sustainable land use, the WBGU therefore recommends that the state should lay down framework conditions for the supply and use of biomass. Within this framework, particularly sustainable construction with timber from site-specific sustainable forestry should be strengthened, since it offers an alternative to the far more climate-damaging conventional construction methods using steel and concrete.

There are corresponding options for action with multiple benefits for marine and coastal ecosystems. Undisturbed marine sediments store about twice as much organic carbon as terrestrial soils (Atwood et al., 2020). The WBGU therefore recommends strengthening marine CO_2 storage via sustainable fishing and aquaculture. This would also secure an important contribution to the supply of protein for humanity in the future (WBGU, 2013). The sustainable use of marine biomass also offers opportunities for the bioeconomy, which should be increasingly researched.

Such an integrated approach to the biosphere – in the sense of thinking about the land and the oceans together and treating protected goods and different claims on use in an integrated way – can help to identify sustainable future pathways in a holistic manner. For this to happen, humanity's approach to its stewardship of the biosphere must change fundamentally. Ambitious and resolute decisions by all Conferences of the Parties to the three Rio Conventions – the UNFCCC, the CBD and the Convention to Combat Desertification (UNCCD) – are needed to initiate a transformative change in the way we treat the biosphere. The WBGU adds the following recommendations to promote concrete implementation at the instrumental level.

The WBGU recommends:

- *Gear financing mechanisms to goals in a differentiated way:* Ecosystem services are commons and require special protection. Contributions to the conservation and restoration of ecosystems should be embedded in a broadly based system of payments for ecosystem services. Financing instruments and mechanisms for climate-change mitigation and biosphere protection thus differ in terms of complexity and time horizons and should be kept separate according to their respective objectives. Tax and subsidy systems and corporate reporting obligations should take impacts on ecosystem services into account.
- *Gear managed ecosystems to biodiversity and ecosystem services:* In order to avoid long-term GHG emissions, conserve biodiversity and ensure food security, it is essential to make agriculture, forestry, fisheries and aquaculture sustainable and to diversify them. Subsidies should be based on the contribution to the common good and ecosystem services, including CO_2 sinks.
- *Make international trade and supply chains sustainable:* Current world trade is decoupled from its relations with ecosystems. The negative long-distance ecological effects (telecoupling) of value-creation and supply chains should be reduced and, where possible, prevented; research on appropriate governance should be strengthened.

Thinking ahead about CO_2 removal from the atmosphere

Scenarios on climate development show that even if greenhouse-gas emissions are rapidly reduced, it is very likely that the additional removal of CO_2 from the atmosphere will be necessary to achieve the mandatory climate goals laid down in the PA. The WBGU therefore recommends making greater efforts to prepare for such scenarios within the long-term strategies, sounding out the sustainable potential of different approaches to removing CO_2 from the atmosphere, strategically exploring implementation options, and creating a corresponding governance framework.

Initially, the protection and restoration of the biosphere play the main role here, including the aim of strengthening its ability to sequester CO_2. Since CO_2 sequestration in the biosphere is itself affected by ongoing climate change, the main emphasis should be on reducing emissions. At the same time, restoration measures should be implemented that can ensure both biodiversity and carbon storage and, in the longer term,

support climate stabilization through CO_2 uptake from the atmosphere. Owing to the vulnerability of the biosphere, the WBGU urgently advises against lowering reduction ambitions by setting off ecosystem-based CO_2 sequestration against emissions reduction at an early stage – rather, restoration should be fully exploited as a complementary measure. The more ambitious the emissions reduction, the more restoration measures can contribute to climate stabilization.

However, strengthening the sink function of natural and managed ecosystems alone will probably not be enough to achieve climate stability. Therefore, other methods of CO_2 removal must also be considered. Industrialized countries have a particular obligation because of their CO_2 emissions that have accumulated in the atmosphere to date. They should use their financial and technological capabilities to develop viable ways of removing CO_2 from the atmosphere – ways that are consistent with the broader sustainability agenda, perhaps also through long-term international cooperation.

Strategically examine options for CO_2 removal and close knowledge gaps

The targeted removal of CO_2 from the atmosphere can be achieved by a wide range of approaches that differ fundamentally in terms of the permanence of storage, stage of development, the desired and undesired side effects, and public acceptance. There are also major regional differences in each case.

Ecosystem-based approaches such as restoration or improved agricultural management methods are seen as uncritical and well-tested, with potentially high co-benefits for biodiversity conservation. As discussed above, the WBGU therefore recommends implementing these approaches at an early stage with a view to generating multiple benefits (WBGU, 2021:79; Sala et al., 2021). In these methods, the carbon is stored in biomass or in soils; the weak point as regards their climate impact is therefore the permanence of storage, particularly in view of the anticipated further impacts of climate change. Further research is needed on this and on the question of global and regionally explicit sustainable potential.

Further approaches to CO_2 removal should be examined in detail to determine how and to what extent sustainable implementation is possible in each region, and what framework conditions would be necessary to ensure sustainability. Research and development should not only focus on the development and testing of individual approaches, but also consider how they can be systemically embedded in the overarching sustainability agenda and how they relate to each other in the sense of a portfolio approach. Here are a few examples:

Many methods (like restoration) are based on first capturing CO_2 from the atmosphere through photosynthesis (i.e. by plants). This applies, for example, to bioenergy in combination with carbon capture and storage (BECCS), large-scale afforestation and the use of biochar. What they have in common is that they have potentially large negative impacts on biodiversity and food production because of their large land and/or biomass requirements. Water and nutrient cycles can also be affected. The aim here, therefore, is to estimate land-area potential or the sustainably available biomass potential that is realistic in each region, and to develop criteria for weighing up the options (e.g. afforestation vs. biomass cultivation for BECCS).

In the case of technological options for CO_2 sequestration that do not rely on photosynthesis by plants (e.g. direct air carbon capture and storage, DACCS), energy consumption and costs are an issue, as are possible problems with waste materials. Common to both BECCS and DACCS are unresolved questions regarding the potential and long-term governance of CO_2 storage facilities, which may also be in demand as a result of the continued use of fossil fuels in combination with CCS. Other methods under discussion, such as enhanced weathering or ocean alkalinization, are based on the application of very large amounts of material, so that both the effects of material extraction and the impacts on ecosystems must be assessed here. In 2008, the CBD adopted a *de facto* moratorium on ocean fertilization as long as there was no adequate scientific basis, risk assessment or global regulatory mechanism. In 2011, a similar but weaker resolution was passed opposing climate-related geoengineering that influences biodiversity.

Limit the future need for CO_2 removal, but prepare for its use

The extent of the technological removal of CO_2 from the atmosphere needed to stabilize the climate depends primarily on the speed with which fossil fuels and resources are phased out. This must be a priority in order to limit the removal of CO_2 because of its potential adverse side effects. In view of the current state of climate-change mitigation, however, the Parties can no longer ignore the possible future role and necessary development needs in the field of CO_2 removal. The WBGU therefore recommends developing a strategy on the application of CO_2-removal measures for long-term strategies that is oriented towards sustainability criteria and the precautionary principle.

First, the strategic option of CO_2 storage must be kept open. To this end, for example, lock-ins in CO_2 usage should be avoided – e.g. in the case of 'CO_2 recycling', which removes CO_2 from the atmosphere, but releases it again later. This competes with the long-term

biological and geological storage of CO_2 removed from the atmosphere. Excessive use of geological CO_2 storage for CCS combined with the use of fossil fuels could also limit future possibilities for permanent CO_2 removal from the atmosphere.

Second, strong governance mechanisms should be created based on scientific expertise for assessing the potential and risks of technologies; these should enable the use of methods for removing CO_2 from the atmosphere in the longer term without encouraging the uncontrolled development and application of technologies. In addition to safeguarding the climate impact, it is important to prevent in particular negative impacts on other dimensions of sustainability, e.g. on biodiversity and nutrition. The recommended separation of the three priority areas of long-term strategies addresses this. In addition, international cooperation should work towards ensuring that CO_2 removal and storage take into account geographical, economic, institutional and social prerequisites, as well as the global distribution of responsibility.

The WBGU considers it highly risky to rely on the future recovery of emitted CO_2 because technologies in these areas are still young and often poorly researched. This underlines all the more clearly the priority of mitigation strategies in the sense of the complete phase-out of fossil fuels described above. It must also be ensured that the Parties clearly separate their climate-policy targets for emissions reductions from those for removing CO_2 from the atmosphere, particularly with regard to timetables, financing and crediting.

The WBGU recommends:

- Countries should address the development of strategies to remove CO_2 from the atmosphere at an early stage; in particular, they should also create a suitable, internationally effective governance framework aimed at preventing negative impacts on other areas of sustainability.
- In particular, approaches to atmospheric CO_2 removal that go beyond enhancing CO_2 sequestration in the biosphere should not be encouraged with incentives until an appropriate governance framework is established.
- Technologies should be assessed on the basis of their systemic integration in broader sustainability and their interaction. In the sense of a portfolio approach, different methods should be considered that would make a flexible reaction to new challenges and findings possible. In this way, substantial amounts of CO_2 could be removed from the atmosphere if necessary while sustainability problems of individual technologies caused by scaling could be kept within limits (e.g. in the case of land use).
- The WBGU urgently warns against scaling down ambitious measures to avoid emissions and restore the biosphere in reliance on future CO_2 removal and storage technologies, or reducing them by offsetting them against restoration measures.

Recover Forward: using COVID-19 stimuli for climate-change mitigation

In response to the COVID-19 pandemic, immense financial resources are being mobilized which, in addition to short-term economic stabilization, also have a structural effect and represent both an opportunity and a risk for long-term climate stabilization. These expenditures and parallel climate-policy frameworks should be more closely aligned with long-term strategies. The marked international disparity of the pandemic impacts and stimulus programmes must be addressed in order to jointly solve global challenges.

Stimulus packages worth US$16 trillion were put in place globally in the period up to March 2021 (UN, 2021). These funds are being used primarily to stabilize the economic and social systems (e.g. short-time-working allowances) and to boost innovation and modernization; for the most part, however, they do not take sustainability concerns into account. The G20 countries and ten other major economies are spending about US$14.9 trillion, of which US$4.6 trillion or 30% is being spent directly in sectors that are particularly climate-relevant (energy, industry, transport, agriculture and waste management); of this, only US$1.8 trillion can be classified as 'green', and a negative overall effect on the environment is expected in 20 of these countries (Vivid Economics, 2021). For example, G20 countries have pledged around US$300 billion to support fossil fuels, but only US$230 billion for clean energy sources (Energy Policy Tracker, 2021). 37% of the 'Next Generation EU' recovery plan (worth €750 billion or US$830 billion) is allocated to environmentally sustainable initiatives, but EU member-state programmes also include environmentally and climate-damaging subsidies and infrastructure investments, as well as bailouts without environmental requirements (Vivid Economics, 2021).

The large sums spent are accompanied by an additional global public debt of 15% (UNDESA, 2021), which will further limit future generations' scope for dealing with climate, biodiversity, health and other future crises. Like all government support and investment, COVID-19 stimulus programmes should therefore be geared towards climate-stabilizing long-term strategies and directed towards environmentally and socially forward-looking sectors for a fundamental transformation. Parallel to financial support measures, climate and environmental frameworks and standards should be strengthened rather than weakened (like in some G20 countries; Vivid Economics, 2021).

However, the consequences of the pandemic and the options for responding to it vary greatly around the world. The Human Development Index is expected to decline for the first time since its inception in 1990 (UNDP, 2020). A large proportion of those at additional risk of extreme poverty due to the COVID-19 crisis live in South Asia (60%) and sub-Saharan Africa (27%; Lakner et al., 2021). There is also a great disparity in the scale of the COVID-19 stimulus programmes that have been put in place. While high-income countries are injecting around 16% of their GDP, emerging economies are using about 4% and low-income countries only 1.6% (UN, 2021). Per-capita stimulus spending in high-income countries is about 580 times higher than in the least developed countries (UNDESA, 2021). Yet the 2030 Agenda aspires to "leave no one behind". This is also in the interest of all countries, since global challenges such as climate change, the biodiversity crisis or pandemics can only be overcome together. In order to counteract a further structural reinforcement of differences in the capabilities of national economies, high-income countries should therefore also make a disproportionate international contribution to overcoming COVID-19 and to restructuring. Existing multilateral instruments should be given a financial boost for this purpose.

The WBGU recommends:

- It is essential for climate stabilization to use COVID-19 stimulus programmes for an environmentally and socially sound, globally balanced transformation. Investments with structural and catalytic effects are needed in sectors such as energy, industry, transport, food, agriculture, forestry, fisheries and health. Long-term climate-policy strategies should point the way forward here.

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